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Research Article

Power Optimized Single Relay Selection with an Improved Link-Adaptive-Regenerative Protocol

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To improve the reliability and efficiency in cooperative communications, a power optimized single relay selection scheme is proposed by increasing the diversity effort with an improved link-adaptive-regenerative (ILAR) protocol. The protocol determines the forwarding power of a relay node by comparing the signal-to-noise ratio (SNR) at both sides of the node; thus it improves the power efficiency. Moreover, it also proposes a single relay selection strategy to maximize the instantaneous SNR product, which ensures the approximate best channel link quality for good relay forwarding. And the system adjusts the forwarding power in real time and also selects the best relay node participated in the cooperative forwarding. In addition, the cooperation in the protocol is analyzed and the approximate expression of the bit-error-rate (BER) and the outage probability at high SNRs are also derived. Simulation results indicate that the BER and outage probability of the relay selection scheme by the ILAR protocol outperform other contrast schemes of current existing protocols. At BER of 10^{-2}, the proposed scheme with ILAR protocol outperforms those of the decoded-and-forward (DF), the selected DF (SDF), and the amplify-and-forward (AF) protocols by 3.5, 3.5 and 7 dB, respectively. Moreover, the outage probability of the relay system decreases with the growth of the relay number. Therefore, the proposed relay selection scheme with ILAR strategies can be properly used in cooperative communications for good reliability and high power efficiency.

1. Introduction

In wireless communications, multipath fading deteriorated the transmission rate and quality of the communications system and the diversity was one of the effective ways to combat it [1]. As a typical space diversity technology, the multiple-input multiple-output (MIMO) system was then proposed to improve the achievable rate and the BER performance [2]. However, modern mobile communications, especially for the handset mobile phones, etc., were strictly confined to the physical size, power, locations, etc., in practice, which limited the wide applications of the technique. So, cooperative communications were proposed to exploit nearby relay nodes to forward the messages to achieve cooperative diversity, which actually formed a virtual MIMO system [3–5]. Nowadays, with the rapid development of the next generation mobile communications, cooperative communications have become one of the research hot-spots in wireless cooperative communications.

The relay selection is one of the key issues in cooperative communications. For the relay selection in literature, there had been several schemes based on the decision of the outage probability, the SNR threshold, the BER performance and the channel status information (CSI), and so on. Two relay selection schemes for cooperative diversity were discussed in [6]. And a threshold-based adaptive relay selection was suggested to minimize the forwarding relay number given a fixed outage requirement. So the computation complexity was reduced and the probability of the outage events was prevented as much as possible. In addition, power selection cooperation can be used to obtain better performance than those of the maximum ratio combination (MRC) based protocol [7]. In [8], performance analysis of a single relay selection in Rayleigh fading was discussed and analyzed. And the closed-form expressions of the outage probability and the bit error probability (BEP) of an uncoded threshold-based opportunistic relaying (OR) and a selection cooperation (SC) were provided for the optimized forwarding. Finally, relay selection based on statistical CSI was proposed in [9]. And the closed-form expressions for the outage and BEP were derived with the DF relays at the Rayleigh fading channel. So the outage probability, the SNR threshold, the BER performance, and the channel status information (CSI) can be referenced for the improvement of a cooperative relay communication system.

The performances of the cooperative communications are mainly determined by the forwarding, and the combining schemes, etc. For the forwarding schemes, there were several existing relay forwarding protocols, as well as their improved version, such as the amplify-and-forward (AF), the decode and-forward (DF), the selective DF (SDF), the hybrid of the above three schemes, and so on [10, 11]. In the AF, the destination node can achieve available diversity with maximum ratio combining (MRC) [12]. Nevertheless, it may be less pragmatic, because it required the relay nodes to store these analog information waveforms, which required huge storage resources [13]. The DF protocol was then proposed with decoding and forwarding for better performance and thus more practical. But the full diversity gain cannot be easily acquired in a poor source-relay-destination link [14]. The SDF protocol with cyclic redundancy check (CRC) codes can detect errors at relay node and selectively forwarded the received messages to the destination [15]. It enabled diversity at the cost of some decoding delay and inefficiency spectrum utilization due to the CRC codes. But it cannot get full diversity gains due to the error propagation phenomena. Actually, the DF protocol only utilized the simple optimization of the combing information at destinations [16]. Then, the maximum likelihood (ML) combining was put forward to solving the diversity problem in the early years [4]. However, it was too complicated to be implemented. Recently, a cooperative MRC (C-MRC) algorithm was proposed and investigated in [14] for full diversity. With C-MRC measure at the destination, the relay system can achieve full diversity gains by the DF at the cost of rather large signal processing overhead. Subsequently, a link-adaptive-regenerative (LAR) protocol was proposed with a C-MRC to overcome the above deficiency [17]. By the DF strategy in a LAR scheme, the decoded messages at the relay were firstly scaled in power before being forwarded to the destination. For the LAR protocol, the scale was firstly adopted at the relay node, which was closely correlated with the signal-to-noise ratio (SNR) of the source-relay and destination-relay links. After that, the C-MRC was adopted at the destination to guarantee the maximum diversity gains [17]. Therefore, it gave a new approach to solve the diversity problems by the DF like strategies.

For the LAR like scheme, the performance of the multibranch relay system can be globally optimized by selecting the proper cooperative relay nodes. In a cooperative diversity system, all relays participate in sending the source signals to the destination. So the destination can combine all received signals from the source-relay-destination or the source-destination link with the MRC mechanism. In the best relay selection scheme, the destination node combines the best source-relay-destination link with the source-destination link only. The main advantages of the best relay selection can be evaluated by low complexity and high resource utilization [18]. So in this paper, based on the single relay system, the end-to-end performance of the relay system with LAR protocol is introduced and analyzed. And the main contribution of this paper is listed as follows:

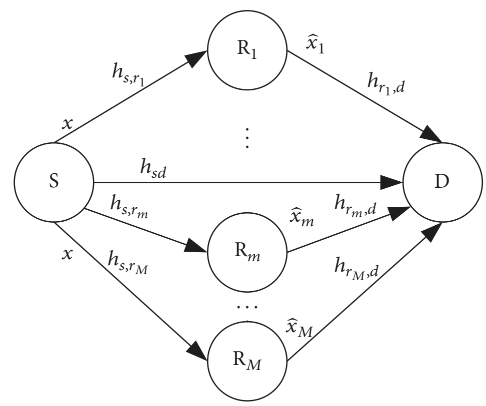

Figure 1: A multibranch cooperative system model.

(1) The ILAR protocol is introduced to solve the diversity gains problem by introducing a new channel scaling factor to match the channel status information properly in the DF like transmission schemes.

(2) Based on the above ILAR protocol, the best single relay selection scheme is proposed, where the relay node with the largest equivalent channel SNR is optimally chosen to forward the messages for best cooperative transmission. And the equivalent channel SNR is generated with the above channel scaling factor and the instantaneous and average SNRs, which is much more suitable for the relay channel status.

(3) The BER performance and outage probability of the relay selection system with ILAR protocol are analyzed and explained for the good performance brought by the suggested power optimized single relay selection scheme with the ILAR protocol.

The remainder of the paper is organized as follows. In Section 2, the cooperative system model is described and the ILAR protocol is briefly introduced. In Section 3, by the above proposed ILAR protocol, the best single relay selection in a multibranch relay system is accomplished and analyzed, including the closed-form analytic expression of the BER and the outage probability in the ILAR relay selection system. In Section 4, the numerical simulations and the corresponding result analyses are performed to verify the effectiveness of the proposed scheme. Finally, the conclusion is drawn in Section 5.

2. Cooperative System Model and ILAR Protocol

2.1. Cooperative System Model. As a typical multibranch cooperative relay system depicted in Figure 1, there are one source node (S), one destination node (D), and M relay nodes (R_m) with $m = 1, 2, \ldots, M$. In this model, besides the message transmission link from the source node S direct to the destination node D, messages are also transmitted from the node S to the node D via one of the mth relay R_m node. The relay node R_m have no own data to be transmitted and they just help transmit the messages from the source node S to the destination node D indirectly. Even if the nodes of S, R_m, and D are all equipped with the only one antenna, the messages can arrive at the destination node D from link S-R_m-D and link S-D, respectively, and can be tackled by the MRC criterion efficiently to merge the whole messages for high space diversity gains and optimal power efficiency. And the transmission can be performed by a time-division half-duplex mode.

Because the time-division scheme is widely exploited, this paper mainly concerns the half-duplex relay channel model. It is easily extended to much more relay models, such as multibranch relay, etc. Suppose that the symbols x from the source node S and $\widehat{x}_m$ from the relay node R_m are transmitted over the half-duplex relay channel by time-division mode. Each time period T is divided into two time slots for data transmission.

In the first time slot lT with $0 < l < 1$, the source node S broadcasts the symbol x with power P_s. Then the received information y_{sr_m} and y_{sd} at the relay and destination nodes of R_m and D are expressed, respectively, as

$$y_{sr_m} = \sqrt{P_s} h_{sr_m} x + z_{sr_m}, \tag{1}$$

$$y_{sd} = \sqrt{P_s} h_{sd} x + z_{sd}, \tag{2}$$

where h_{sr_m} and h_{sd} are the fading coefficients of the link S-R_m and the link S-D, respectively. z_{sr_m} and z_{sd} are the additive white Gaussian noise (AWGN) in the S-R_m and S-D links, respectively.

In the second time slot $(1-l)T$, the information received by the relay nodes R_m is detected and forwarded to the destination node D with power $\sqrt{P_{R_m}\alpha_m}$. So the received information $y_{r_m d}$ at the destination node D is

$$y_{r_m d} = h_{r_m d} \sqrt{P_{R_m}\alpha_m} \widehat{x}_m + z_{r_m d}, \tag{3}$$

where $h_{r_m d}$ and $z_{r_m d}$ are the fading coefficients and the AWGN parameter in the link R_m-D. P_{R_m} is transmit power at R_m and α_m represents a power control coefficient.

2.2. ILAR Protocol. Based on the above model, the ILAR protocol can be operated on the following three conditions.

Firstly, assume that the wireless channels are Rayleigh fading channels and the fading coefficients are subject to the complex Gaussian random distribution, i.e., $h_{sr_m} \sim CN(0, \sigma^2_{sr_m})$, $h_{sd} \sim CN(0, \sigma^2_{sd})$, and $h_{r_m d} \sim CN(0, \sigma^2_{r_m d})$, with $\sigma^2_{sr_m} = E\{|h^2_{sr_m}|\}$, $\sigma^2_{sd} = E\{|h^2_{sd}|\}$, $\sigma^2_{r_m d} = E\{|h^2_{r_m d}|\}$, and z_{sr_m}, z_{sd}, and $z_{r_m d} \sim \mathrm{CN}(0, \mathrm{N}_0)$. $\mathrm{CN}(0, \sigma^2)$ is defined as the circular symmetric complex Gaussian distribution with zero mean and variance σ^2. Hence, the corresponding instantaneous and average SNR sets $(\gamma_{sr_m}, \gamma_{r_m d}, \gamma_{sd})$ and $(\overline{\gamma}_{sr_m}, \overline{\gamma}_{r_m d}, \overline{\gamma}_{sd})$ of S-R_m, R_m-D, and S-D links are expressed, respectively, as follows:

$$\begin{aligned} \gamma_{sr_m} &= \left|h_{sr_m}\right|^2 \overline{\gamma}, \\ \gamma_{r_m d} &= \left|h_{r_m d}\right|^2 \overline{\gamma}, \\ \gamma_{sd} &= \left|h_{sd}\right|^2 \overline{\gamma}, \end{aligned} \tag{4}$$

$$\begin{aligned} \overline{\gamma}_{sr_m} &= \sigma^2_{sr_m} \overline{\gamma}, \\ \overline{\gamma}_{r_m d} &= \sigma^2_{r_m d} \overline{\gamma}, \\ \overline{\gamma}_{sd} &= \sigma^2_{sd} \overline{\gamma}, \end{aligned} \tag{5}$$

where $\overline{\gamma} = P_S/N_0$ and P_S denotes the average transmit power at the source node S. And the transmission power at each relay node is supposed to be the same as that in the source node, i.e., $P_{R_m} = P_S$.

Secondly, symbols flows from the source node S are detected at the relay nodes R_m with maximum likelihood (ML) demodulation as follows:

$$\widehat{x}_m = \arg\min_{x \in A_x} \left| y_{sr_m} - h_{sr_m} x \right|^2, \tag{6}$$

where $|\mathrm{A}x| = \theta$ is defined as the size of the θ-ary constellation. Then the detected symbol $\widehat{x}_m$ is remodulated and forwarded to the destination node D, with power control coefficient of

$$\alpha_m^{inst} = \frac{\min\left(\gamma_{sr_m}, \gamma_{r_m d}\right)}{\gamma_{r_m d}} = \begin{cases} \dfrac{\gamma_{\mathrm{sr}_m}}{\gamma_{r_m d}}, & \gamma_{\mathrm{sr}_m} < \gamma_{r_m d} \\ 1, & \gamma_{\mathrm{sr}_m} \geq \gamma_{r_m d}. \end{cases} \tag{7}$$

The instantaneous SNR of each link is difficult to be achieved. So γ_{sr_m} and $\gamma_{r_m d}$ are always used instead in practice, where $\overline{\gamma}_{r_m d}$ is the average SNR of link S-R_m. Then (7) is rewritten as

$$\alpha_m = \frac{\min\left(\gamma_{sr_m}, \overline{\gamma}_{r_m d}\right)}{\overline{\gamma}_{r_m d}} = \begin{cases} \dfrac{\gamma_{sr_m}}{\overline{\gamma}_{r_m d}}, & \gamma_{sr_m} < \overline{\gamma}_{r_m d} \\ 1, & \gamma_{sr_m} \geq \overline{\gamma}_{r_m d}. \end{cases} \tag{8}$$

In (7), $\gamma_{r_m d}$ is hard to be obtained. So α_m is clearly practical even on a fast Rayleigh fading channel, because $\overline{\gamma}_{r_m d}$ can be easily estimated under the given stationary channel.

Compared with other protocols, the main difference of the ILAR protocol is that the relay transmission power is related to the R_m-D link. For the DF protocol, α=1 and the transmit power at relay is independent with the channel status information. According to (8), $\alpha \in [0,1]$ is proper for the ILAR protocol. When the link S-R_m is more reliable than the link R_m-D, the relay node transmits information with full power, i.e., α=1. Otherwise, the transmit power is scaled with the coefficient of $\alpha \in (0,1]$. When α=0, it means that the relay node is idle in the subslot and the source node S performs the retransmission.

Finally, the demodulation at the destination node D is analyzed. For the weight coefficients $w_{sd} = h^*_{sd}$ and

$w_{r_m d} = h^*_{r_m d}\sqrt{\alpha_m}$, the MRC processing result at the destination node D is expressed as

$$x_d^{MRC} = \arg\min_{x\in A_x} \Big| w_{sd} y_{sd} + w_{r_m d} y_{r_m d} - \left(w_{sd} h_{sd} + w_{r_m d} h_{r_m d}\sqrt{\alpha_m}\right) x \Big|^2 . \quad (9)$$

To solve (9), h_{sd} and $h_{r_m d}\sqrt{\alpha_m}$ are supposed to be available in the destination node D and both of them can be gotten by the channel training of a trained sequence for good channel estimation.

3. Relay Selection Scheme and Performance Analysis

3.1. Relay Selection Scheme. Based on the ILAR protocol described above, the single relay selection scheme is discussed in this relay selection scheme.

In the selection cooperation (SC) of the relay selection model, all relay nodes listen to the source node S in the first time slot and only those relay nodes of $\gamma_{sr_m} > A$ demodulate the received signal, where A is the threshold of SNR of link S-R_m. Therefore, the candidate relay node set is shown as

$$\Omega_m = \left\{ R_m : \gamma_{sr_m} \geq A \right\}. \quad (10)$$

In the second time slot, there are two situations to be discussed.

Situation I. When the set is empty, it means that the relay node does not transmit at all. It corresponds to the situation where the power scaling coefficient α is zero.

Situation II. When the relay nodes have demodulated the information correctly, then only the relay nodes of the highest $\gamma'_{r_m d}$ transmit signals to the destination node D. Assume that the ith relay node is the best choice; there is

$$\gamma'_{r_i d} = \max\left\{ \gamma'_{r_1 d}, \gamma'_{r_2 d}, \dots, \gamma'_{r_M d} \right\}, \quad (11)$$

where $\gamma'_{r_i d} = \alpha_i \gamma_{r_i d}$ is the instantaneous SNR of the received signal from the ith relay node. AS α_i is the power scaling coefficient of the ith relay node for normalization and it has been derived in (8). Under the above circumstances, it is expressed as

$$\alpha_i = \frac{\min\left(\gamma_{sr_i}, \overline{\gamma}_{r_i d}\right)}{\overline{\gamma}_{r_i d}}. \quad (12)$$

3.2. Performance Analysis

3.2.1. BER Analysis. Take a special case for instance, e.g., binary phase shift keying (BPSK) modulation; the signal x is transmitted from the source node S and it can only carry a message either $x = \sqrt{P_x}$ or $x = -\sqrt{P_x}$. Correspondingly, the detected $\widehat{x}$ at the relay node R_i can only be $\widehat{x} = x$, or $\widehat{x} = -x$. In each case, the received information y_D at the destination node D is represented as

$$y_D = w_{rd} y_{rd} + w_{sd} y_{sd} = \begin{cases} w_{sd} h_{sd} + w_{rd} h_{rd}\sqrt{\alpha} x + w_{rd} z_{rd} + w_{sd} z_{sd}, & \widehat{x} = x \\ w_{sd} h_{sd} - w_{rd} h_{rd}\sqrt{\alpha} x + w_{rd} z_{rd} + w_{sd} z_{sd}, & \widehat{x} = -x. \end{cases} \quad (13)$$

Since BPSK symbols are real value, the real part $y = \mathrm{Re}\{y_D\}$ can be employed in demodulation. It is a real Gaussian random variable with zero mean and variance $\sigma^2 = (|w_{sd}|^2 + |w_{r_i d}|^2) N_0/2$. With the weight coefficients $w_{sd} = h^*_{sd}$ and $w_{r_i d} = h^*_{r_i d}\sqrt{\alpha_i}$, the instantaneous BER at the destination node D can be expressed as

$$P^b = \left\{1 - Q\left[\sqrt{2\gamma_{sr_i}}\right]\right\} Q\left[\sqrt{2\left(\gamma_{sd} + \gamma'_{r_i d}\right)}\right] + Q\left[\sqrt{2\gamma_{sr_i}}\right] Q\left[\frac{\sqrt{2}\left(\gamma_{sd} - \gamma'_{r_i d}\right)}{\sqrt{\gamma_{sd} + \gamma'_{r_i d}}}\right], \quad (14)$$

where

$$\gamma'_{r_i d} = \frac{\alpha \left|h_{r_i d}\right|^2 P_x}{N_0} = \alpha_i \gamma_{r_i d}, \quad (15)$$

$$Q(x) = \frac{1}{\sqrt{2\pi}\int_x^{\infty} \exp\left(-t^2/2\right) dt}. \quad (16)$$

Taking expectation over the instantaneous SNR, the average BEP $E[P^b]$ is obtained, and it follows from the inequality $0 \leq Q(x) \leq 1$ as

$$P^b \leq Q\left[\sqrt{2\left(\gamma_{sd} + \gamma'_{r_i d}\right)}\right] + Q\left[\sqrt{2\gamma_{sr_i}}\right] Q\left[\frac{\sqrt{2}\left(\gamma_{sd} - \gamma'_{r_i d}\right)}{\sqrt{\gamma_{sd} + \gamma'_{r_i d}}}\right]. \quad (17)$$

3.2.2. Outage Probability. When the transmission rate is larger than the mutual information of the relay system, the system will be interrupted. According to the above relay selection scheme, the relay system will be interrupted in the following two situations. The first one is retransmission situation, i.e., the above Situation I. The second one is the cooperation situation, i.e., the above Situation II. Therefore, the outage probability of the relay system can be written as

$$p^{out} = P_1^{out} + P_2^{out}, \quad (18)$$

where P_1^{out} is the outage probability of retransmission Situation I and P_2^{out} is the outage probability of the cooperation Situation II.

For Situation I, when the candidate relay node set is empty, i.e., all these relay nodes cannot demodulate correctly ($\gamma_{sr_m} >$ A), and the source node S retransmits all signals.

When the mutual information I_1 is less than transmission rate R, i.e., $I_1 < R$, the relay system is interrupted and there is the result as

$$I_1 = \frac{1}{2} \cdot lb\left(1 + 2\gamma_{sd}\right) < R. \tag{19}$$

According to (19), there is the conclusion of $\gamma_{sd} < A/2$. Combining the retransmission in Situation I, the outage probability P_1^{out} of Situation I is deduced as

$$\begin{aligned} P_1^{out} &= \Pr\left(\Omega_m = \varnothing\right\} \cdot \Pr\left(\gamma_{sd} < \frac{A}{2}\right) \\ &= \prod_{m=1}^{M} \Pr\left(\gamma_{sr_m} < A\right) \Pr\left(\gamma_{sd} < \frac{A}{2}\right) \\ &= \left[1 - \exp\left(-\frac{A}{\overline{\gamma}_{sr}}\right)\right]^M \left\{1 - \exp\left[-\frac{A}{\left(2\gamma_{sd}\right)}\right]\right\}, \end{aligned} \tag{20}$$

where $\overline{\gamma}_{sr} = E(\gamma_{sr_m}) = 1/(SNR \cdot \delta_{sr_m}^2)$. At the high SNR, i.e., $\overline{\gamma}_{sr}$ and γ_{sd} approach infinity, (19) can be approximately rewritten as

$$P_1^{out} = \left(\frac{A}{\overline{\gamma}_{sr}}\right)^M \left[\frac{A}{\left(2\gamma_{sd}\right)}\right]. \tag{21}$$

For Situation II, the best relay is selected. When the mutual information I_2 is less than transmission rate R, i.e., $I_2 < R$, the relay system is interrupted, and there is

$$I_2 = \frac{1}{2} \cdot lb\left(1 + \gamma_{sd} + \sqrt{\alpha_i}\gamma_{r_i d}\right) < R, \tag{22}$$

where the ith relay is the best relay. According to (22), there is a conclusion of $\gamma_{sd} + \sqrt{\alpha_i}\gamma_{r_i d} < A$. Combining the cooperation Situation II, the outage probability P_2^{out} of Situation II is derived as

$$\begin{aligned} P_2^{out} &= \Pr\left(\Omega_k\right\} \cdot \Pr\left(\gamma_{sd} + \sqrt{\alpha_i}\gamma_{r_i d} < A\right) \\ &= C_M^k \exp\left(-\frac{k\gamma_{sd}}{\overline{\gamma}_{sr}}\right)\left[1 - \exp\left(-\frac{A}{\overline{\gamma}_{sr}}\right)\right]^{M-k} \\ &\quad \times \left\{1 - \exp\left[-\frac{\left(A - \sqrt{\alpha_i}\gamma_{r_i d}\right)}{\gamma_{sd}}\right]\right\}, \end{aligned} \tag{23}$$

where k is the number of relay nodes with correct demodulation and $C_M^k = M!/[k!(M-k)!]$ is the combination expression in mathematics. At high SNRs, (23) can be rewritten as

$$P_2^{out} = C_M^k \left(\frac{A}{\overline{\gamma}_{sr}}\right)^{M-k} \left[\frac{\left(A - \sqrt{\alpha_i}\gamma_{r_i d}\right)}{\gamma_{sd}}\right]. \tag{24}$$

Finally, according to (18), (21), and (24), at high SNR, the outage probability of the relay system can be deduced as

$$\begin{aligned} P^{out} &= \left(\frac{A}{\overline{\gamma}_{sr}}\right)^M \left(\frac{A}{2\gamma_{sd}}\right) \\ &\quad + C_M^k \left(\frac{A}{\overline{\gamma}_{sr}}\right)^{M-k} \left(\frac{A - \sqrt{\alpha_i}\gamma_{r_i d}}{\gamma_{sd}}\right) \end{aligned} \tag{25}$$

3.3. Computational Complexity Analysis. To evaluate the complexity of the proposed ILAR scheme, we compare it with the contrast scheme of the AF, DF, and SDF protocol. The entire relay transmission system is supposed to be made up of a source node, a destination node, and N relay nodes. And the comparison of computational complexity can be analyzed and summarized as follows,

In the AF scheme, N relay nodes all forward the messages from the source node to the destination node by multiplying a specific factor to amplify both the signals and noises. And then there is joint detection of the messages from all source-relay-destination links and the direct source-destination link. So there will be a calculation of the optimally joint maximum ratio combination (MRC) detection with $N + 1$ received user messages. So the additional computations other than the MRC detection are the N times of the multiplication in the amplifying procedure in the relays.

In the DF scheme, N relay nodes all decode with a channel code and then forward the decoded messages from all relay nodes to the destination node. Here the channel code is decided by the channel status and the practical hardware resources available in the source node and relay nodes. And then there is also the joint detection of the messages from all joint source-relay-destination links and the direct source-destination link. So there will be a calculation of the optimally joint MRC detection with $N + 1$ received user messages form the relay nodes. So the additional computations other than the MRC detection are one time of encoding of channel code at the source, N times of decoding of channel code at the relay nodes, respectively.

In the SDF scheme, the relay nodes decode and then forward the decoded source message only if the decoded messages are free of errors. But with half-duplex transmissions, the SDF scheme suffers from a multiplexing loss. And the unsuccessful source messages are supposed to be retransmitted at the next time slot. Given a successful decoding rate of a, the additional computations other than the MRC detection are one time of encoding at the source and an average of N/a time of channel decoding at the relay nodes, respectively.

In the proposed ILAR scheme, there are some negligible calculations about the exchangeable average SNR threshold by (8). Other than these computations, the symbols flows from the source node S are detected at the relay nodes R_m with maximum likelihood (ML) demodulation as in (6). So the additional computations other than the MRC detection are N times of ML demodulation at the relay nodes.

Finally, the computational complexity of the proposed ILAR scheme is concluded at Table 1, as well as those of the contrast AF, DF, and SDF schemes. Generally, the complexity

Table 1: Complexity of the proposed ILAR scheme and the contrast schemes.

Forwarding scheme	Pre-process at source node	Decoding/demodulation or transmission at Relay node	Combination at the destination
AF	No	N Multiplications	MRC detection
DF	1 Channel encoding	N Channel decoding	MRC detection
SDF	1 Channel encoding	N Channel decoding	MRC detection
Proposed ILAR	No	N ML-demodulation	MRC detection

of channel decoding is larger than that of the ML demodulation. So from Table 1, we can get the natural order of the computational complexity of the schemes as SDF > DF > ILAR > AF. In addition, the SDF and the ILAR schemes need another time slot to finish the forwarding, which requires much longer time. So the processing delay of the proposed ILAR scheme is still large and it needs to be considered in practice.

4. Numerical Simulations and Result Analyses

Based on the parameter α in (8), the performance of the ILAR scheme is firstly analyzed. Diversity gain G_d is defined as the negative exponent in the average BER, when $\overline{\gamma} \longrightarrow \infty$ [17], i.e., SNR set are sufficiently high. So the relationship among $E[P^b]$, G_c, and $\overline{\gamma}$ is founded as

$$E\left[P^b\right] \approx \left(G_c\overline{\gamma}\right)^{-G_d}, \tag{26}$$

where G_c denotes the coding gain. For symbol-by-symbol demodulation of uncoded transmissions, G_c mainly depends on the modulation order and the transmit power. According to the expression of BER in (14) and (17), the BER performance of ILAR scheme is simulated and demonstrated. Suppose that the BPSK and Rayleigh fading channel are applied. The horizontal axis SNR(dB) = $\overline{\gamma}(1 + E[\alpha])$, where $E[\alpha]$ is the average value of α. Simultaneously, the BER performance of other popular protocols, such as the AF, the DF, and the SDF, are also figured out too, which gives a clear comparison among them.

Figure 2 indicates that the relay cooperation of the ILAR protocol has better BER performance than those of other protocols. At BER of 10^{-3}, the proposed scheme of the ILAR protocol has about 7 dB, 3.5 dB, and 3.5 dB gains than those of the AF, the DF, and the SDF protocols, respectively. The scheme of the AF protocol can get full diversity gains, but it does not outperform ILAR, because it cannot utilize the power efficiently due to the noise amplification effect at the relay node. When the channel status of the links connected to the relay nodes is poor, the AF scheme may be even worse than that of the direct link. The scheme of the DF protocol can obtain good performance at high SNRs since it can regenerate message by decoding and at the relay node and then forward to the destination node. But, the DF scheme exhibits worse BER performance at low SNRs due to the error propagation problem at low SNRs. The SDF protocol can be the combination of the AF and DF protocols. By an optimal design, the SDF scheme can even achieve the good performance of the AF scheme at low SNRs and the DF

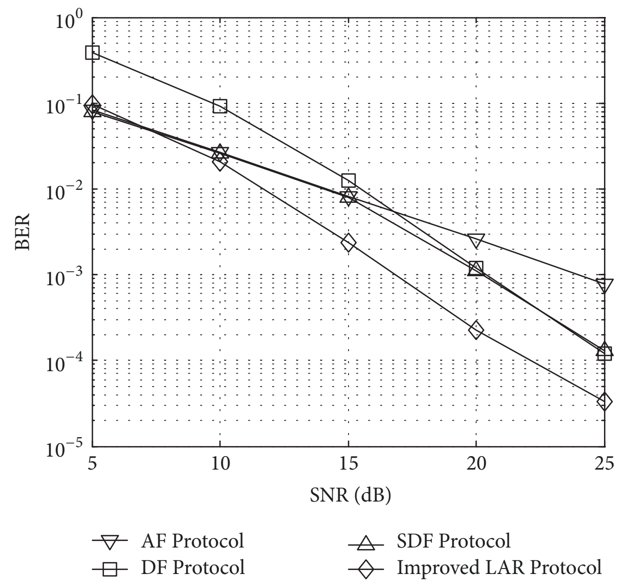

Figure 2: The BER performance of the scheme with an ILAR.

scheme at high SNRs. When it comes to adaptive regenerative protocols, the proposed ILAR scheme also outperforms the SDF scheme.

At low SNRs, the SNRs in all relay links are all poor for the proposed ILAR scheme and the contrast schemes, because large noises are in charge of the poor performance rather than the intersymbol interference (ISI) by Rayleigh fading at high SNRs. And the performance of the DF scheme is surely much worse due to the aforementioned error propagation effect by unsuccessful decoding and then encoding. However, compared with the contrast schemes other than the DF scheme, the performance of the proposed ILAR scheme is not improved much and the reasons are discussed as follows: although optimal relay link can be properly chosen by the proposed scheme with (11), the detection performance is still poor due to the similar large noises of the optimal relay link at low SNRs. So the proposed scheme cannot obtain more performance gain than the compared schemes other than the DF one at low SNRs. In other words, the performances are all predominated by the noises rather than the ISI by fading channels. And this phenomenon is also well presented reasonably by the simulations in Figure 2. Therefore, our ILAR scheme is mainly practical at rather high SNRs, e.g., larger than 10 dB under the above simulation parameters from our simulations.

Taking into account of the tradeoff between the redundancy and the detection error probability of the CRC code, although full diversity is achieved, the SDF scheme does not lead to as good BER performance as that of the ILAR scheme over the range of the practical SNRs. This can be explained as follows. Compared with the DF or SDF protocol, the main difference from the ILAR protocol is that the power of the transmitted signals at the relay nodes is exactly matched for the CSI of the link S-R_m and R_m-D. For the DF/SDF protocol, the power scaling coefficient α_i in (12) is just set as a constant number of 1, and the transmitted power at any relay node has nothing to do with the CSI of the channels. Then the channel cannot be properly matched for high power efficiency and good transmission performance. But in the ILAR scheme, just as in (12), the power scaling coefficient α_i is in the range of $[0, 1]$. When the link S-R_m is much more reliable than the link R_m-D, the relay node can transmit the signals with full power, i.e., $\alpha_i = 1$, because the channel status of the first part of the link, i.e., the link S-R_m, is good enough for the message forwarding at the relay nodes. Otherwise, the transmitted power at the relay node is adjusted by the power scaling coefficient α_i, which falls into the range of (0,1). Also, for the left extreme condition, i.e., $\alpha_i = 0$, the relay node is stood at the idle mode at the second time slot. It means that the relay nodes are not participated in the cooperative transmission. Finally, by the cooperative MRC detection at the destination node D in (9), the proposed ILAR scheme can match the CSI in all of the channels and thus obtain better performance over the traditional schemes of the AF, the DF, and the SDF protocols under the premise of Rayleigh fading channel with the independent and identically distributed (*i.i.d.*) AWGN parameters.

For the relay selection scheme of the ILAR protocol, the channel parameters are set as follows: the transmission rate $R = 1$ bit/s and $\delta_{sd} = \delta_{sr_i} = \delta_{r_i d} = 1$. The transmit power at the relay node and the source node are both 0.5 W. The channels are *i.i.d.* Rayleigh channels, with equal AWGN parameters in each branch, are based on the uncoded channels. And the simulations are performed with binary phase shift keying (BPSK) modulation. In Figure 3, the outage probability of the relay selection scheme with the ILAR protocol at different relay number condition is presented.

Figure 3 indicates that the outage probability of the relay system decreases with the relay number M. The reason is that larger number of the relay nodes gives more chance to be chosen, and thus the probability of correct demodulation at each relay node is much higher. Because the channels connected to the relay nodes are *i.i.d.* Rayleigh channels with equal AWGN parameters in each branch, the performances of the cooperative systems with relay node growth increase gradually. And they almost approach the same performance bound shown in Figure 3, when the number of the relay nodes is larger than or equal to 4. Simultaneously, with the growth of the SNR, the outage probability decreases correspondingly. When the SNR increases, the received SNR at the destination node is much bigger. And just as the theoretical analysis around (22), the relay system with higher SNRs has much lower outage probability.

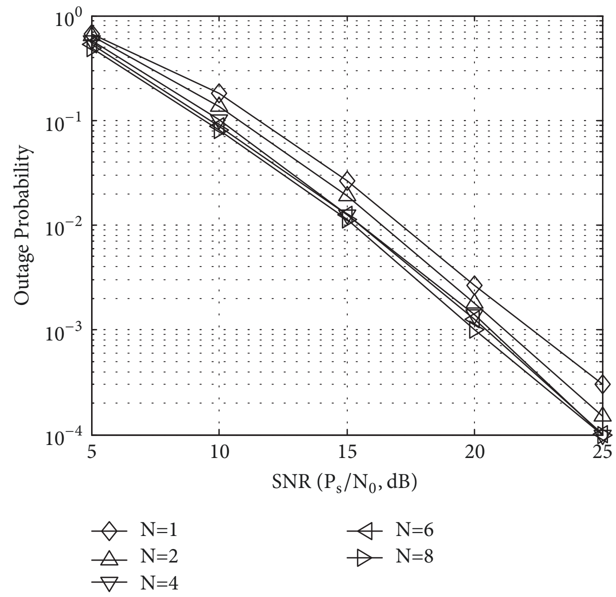

FIGURE 3: The outage probability of the ILAR scheme.

5. Conclusions

In this paper, we present and analyze a power optimized single relay selection scheme with an ILAR protocol. Firstly, in a cooperative communication system, the ILAR protocol is introduced. Then the best relay selection scheme with the proposed ILAR protocol is proposed and analyzed. By the protocol, the BER and outage probability expression are both derived for quantitative analysis. The simulation results preferably show that the scheme of an ILAR protocol has better BER performance than those of other current protocols, such as the AF, the DF, and the SDF protocols. The overall outage probability performance increases with the growth of relay number, but it also indefinitely approaches a performance bound, when the number of the relay nodes is large or equal to 4. Therefore, the proposed scheme can be applied in the optimization of relay selection and forwarding for efficient transmission power.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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