An Optimal Transmission Scheme for Two-way Relaying Networks With Power Constraint

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***Abstract*—Cooperative communication is an efficient method to combat wireless channel fading and to increase system throughput in future board communication. Through physical layer networking coding(PNC)modulation, two-way relaying has been shown to improve the network capacity significantly. However for power-constraints application, the performance of two-way relaying is actually inferior to one-way relaying at low SNR environment. To solve the issue, the scenario of three nodes cooperative communication is considered in this paper.Assuming that perfect channel knowledge is available at the relay node, an optimal transmission scheme for two-way relaying communication is proposed. The transmission scheme, which is based on instantaneous channel link quality, is selected to offer maximum system capacity. The efficiency of the proposed solution is demonstrated by both analytical performance and simulations.**

I. Introduction

Due to the advantage of improving bandwidth efficiency, saving terminal power and enhancing system reliability, cooperative communication is an efficient method to combat wireless channel fading and to increase system throughput in future board communication [1, 2]. In cooperative relay communication, full-duplex relaying achieves higher spectral efficiency. However for the large difference in power levels of the receive and transmit signals, it makes full-duplex relay transmission difficult to implement. Thus, it spurs much plenty of research into half-duplex relay system.

In half-duplex relay systems, two main categories are discussed as: one-way relaying and two-way relaying. In conventional one-way relaying network, at least four phases should be required to exchange information between two terminals. i.e. it takes two phases to send information from one terminal to the other terminal and two phases for the reverse direction. However in two-way relaying network, through exploiting the knowledge of the broadcast nature of the wireless medium and terminals'own transmitted signals, only two phases are used to exchange information, which can improve the spectral efficiency efficiently. Due to its fundamental and practical importance, there has been an increasing interest in two-way relaying. In [3, 4], the sum rate of amplify-and-forward(AF)and decode-and-forward(DF) two-way relaying was investigated. In [5], performance bounds of DF bidirectional network was given. In [6], the capacity region at the broadcast phrase in two-phrase bidirectional relaying is proposed. The optimal resource allocation problem for two-way relaying OFDMA system was investigated in [7]. Thus, it is generally accepted that two-way half-duplex relaying achieve ahigher rate than its one-way counterpart.

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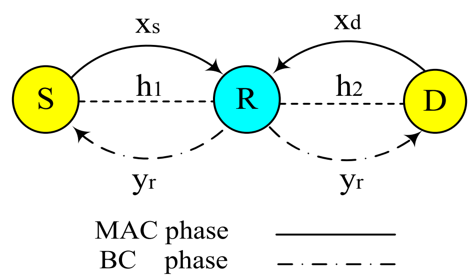

Fig. 1. two-way relaying network

However in [8], under the condition of the total power constraint and the low SNR region, it has been proved that the performance of one-way relaying actually outperforms that of two-way relaying. It indicated that at low SNR region, two-way relaying might not necessarily be a better choice over one-way relaying.

In this paper, the three-node cooperative communication scenario of half-duplex two-way AF relaying is considered due to its simplicity in practical implementation. To solve the issue of performance degradation at low SNR, an optimal transmission scheme is proposed, in which the choice of system transmission is based on instantaneous channel quality. The scheme aims to maximize the network system capacity. Performance analysis and simulations show that the proposed approach can achieve better performance of outage probability and symbol error rate.

The rest of this paper is organized as follows: Section II introduces the signal model for AF cooperative system firstly,

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followed by the optimal transmission solution in Section III. Subsequently, Section IV describes the performance analysis in detail, together with the simulation results and discussions given in Section V. Finally, the concluding remarks are provided in Section VI.

II. System Model and Protocol

In this section, three nodes cooperative communication is considered, where a half-duplex relay node R bidirectionally communicates between source node S and destination node D, which is shown in Figure 1. It is assumed that all the nodes are half-duplex nodes, i.e. nodes cannot receive and transmit simultaneously using the same channel. We also assumed that there is no direct path between the source node S and destination node D due to large path loss, and that the relay node helps their reliable communications using the two-way relaying protocol.

In the first multiple access phase, the two terminals(S and D)transmit their information to the relay simultaneity. For analytical simplifying, we will further presume that the channels are reciprocal. ie. the channel coefficient for S-R and R-S link is same as $h_{sr} = h_{rs} = h_1$ and $h_{dr} = h_{rd} = h_2$. Thus, the received signal at the relay node R is given by

$$y_r = h_1 x_s + h_2 x_d + z_r \tag{1}$$

where x_s and x_d is the transmitted signal from the two terminals. With transmission power control, it means that $\mathbb{E}\{|x_s|^2\} = P_s$, $\mathbb{E}\{|x_d|^2\} = P_d$. $z_r \sim \mathcal{CN}(0, \sigma^2)$ is the complex AWGN at the relay.

In the second broadcast phase, the relay node R scaled the received signal y_r with the signal power gain g with

$$g = \sqrt{\frac{P_r}{|h_1|^2 P_s + |h_2|^2 P_d + \sigma^2}} \tag{2}$$

in order to meet its average transmit power constraint, and then converts it to a PNC-modulated signal [9, 10], and then broadcasts it to both S and D terminal. Without requiring a decoding and re-encoding process at the relay node, the PNC-modulated signal y_r can be easily generated by simply applying a PNC mapping. We can write the signals received at S and D nodes as

$$\begin{aligned} y_s &= h_1 g y_r + z_s \\ &= |h_1|^2 g x_s + h_1 h_2 g x_d + h_1 g z_r + z_s \quad (3) \\ y_d &= h_2 g y_r + z_d \\ &= |h_2|^2 g x_d + h_1 h_2 g x_s + h_2 g z_r + z_d \quad (4) \end{aligned}$$

where z_s and z_d denotes the AWGN at the S and D nodes respectively. For analytical simplifying, it is assumed that the noise is a white Gaussian noise with zero-mean and unit-variance σ^2. ie. $z_s \sim \mathcal{CN}(0, \sigma^2)$, $z_d \sim \mathcal{CN}(0, \sigma^2)$.

Since nodes S and D know their own transmitted symbols x_s and x_d, they can subtract the back-propagating self-interference $|h_1|^2 g x_s$ in (3) and $|h_2|^2 g x_d$ in (4) respectively. Assuming perfect knowledge of the corresponding channel

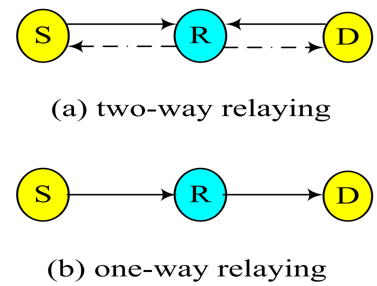

Fig. 2. two possible transmission schemes

coefficients, it can decode the sent information. Thus according to [3], the sum-rate of two-way relaying is then given by

$$R^{AF}_{two-way} = \frac{1}{2}\varepsilon\left\{log_2\Big(1 + \frac{P_s|h_1 h_2 g|^2}{(1+|h_2 g|^2)\sigma^2}\Big)\right\} + \frac{1}{2}\varepsilon\left\{log_2\Big(1 + \frac{P_d|h_1 h_2 g|^2}{(1+|h_2 g|^2)\sigma^2}\Big)\right\} \tag{5}$$

However in one-way relay, we should use four phases to complete the entire information exchanging between the node S and D. In first two phases, the source terminal S first transmits an information symbol to the relay node R. The relay amplifies the received symbol (including noise) according to its available average transmit power and forwards a scaled signal in the second time slot to the destination terminal D. The last two phases, the the reverse direction transmission from D to S node is the same as the first two phases.

III. Optimal transmission scheme

It has been generally accepted that the two-way relaying can efficiently improve the network performance. However for power-constraint application, since the noise is amplified heavily by the cooperation relay at low SNR, their performance has little improvement than conventional one-way relaying [8]. Hence different transmission scheme shall be chosen according to different channel link quality.

It can be seen that there are two possible transmission schemes in the scenario, which is depicted in Figure 2. In this paper, a fair power constraint is considered. ie. the total transmit power P_{total} is equal for both one-way and two-way relaying.

(a) two-way relaying case: Through exploiting the broadcast nature of the wireless medium using physical layer networking coding(PNC)modulation, only two phases are used to exchange information. With a fair power constraint, for completing one entire message transmission, three nodes should be used to transmit their symbols. ie. $P = P_{total}/3$.

(b) one-way relaying case: For one entire transmission, only two nodes is required to transmit their messages. ie. $P = P_{total}/2$.

For the two possible transmission schemes, an adaptive scheme is proposed to determine the preferable path chosen at different channel link state in this paper. The instantaneous network capacity is calculated as the selection criterion. In order to obtain this strategy, the sum network capacity for every possible transmission strategy is required.

For one-way relaying, the relay node R amplifies the received symbol from the terminal S or R, and then forwards a scaled signal to the destination terminal with the scale power gain g_1

$$g_1 = \sqrt{\frac{P_{total}/2}{|h_1 h_2|^2 P_{total}/2 + \sigma^2}}$$

in order to meet the total transmit power constraint.

Hence the end-to-end SNR from S to D is easy to be calculated as

$$\gamma = \frac{|g_1 h_1 h_2|^2 P_{total}/2}{(|g_1 h_2|^2 + 1)\sigma^2} \tag{6}$$

and the instantaneous capacity for the one-way relaying case is given as

$$R_1^{AF} = \frac{1}{2}\log_2(1+\gamma) \tag{7}$$

For two-way relaying, due to the total power constraint, the scaled gain in equation (2) can be re-written as

$$g_2 = \sqrt{\frac{P_{total}/3}{(|h_1|^2 + |h_2|^2) P_{total}/3 + \sigma^2}}$$

For the simplicity of the notions, let $\beta = |g_2 h_1 h_2|^2$, $\gamma_1 = |g_2 h_2|^2$, $\gamma_2 = |g_2 h_1|^2$. Thus according to the equation (5), the instantaneous sum network capacity for the two-way relaying case can be deduced as:

$$R_2^{AF} = \frac{1}{2}\log_2\left(1 + \frac{\beta P_{total}/3}{(\gamma_1+1)\sigma^2}\right)\left(1 + \frac{\beta P_{total}/3}{(\gamma_2+1)\sigma^2}\right) \tag{8}$$

Hence our optimal transmission scheme is to select the one offering the maximum instantaneous network capacity. i.e.

$$\arg\max\{R_1^{AF}, R_2^{AF}\} \tag{9}$$

From our selection criterion, assuming the perfect channel state information available at the relay node, it can be seen that the sum system rate of our proposed transmission scheme is the largest among the possible transmission scheme. Thus our proposed strategy always choose an optimal transmission path to transmit the terminal message, which can increase system throughput efficiently.

According to the above lists, our proposed algorithm is given as

(1) calculate the sum rate of the two possible transmission schemes according to the equation (7) and (5).

(2) select the actually transmission strategy using the criterion in (9).

In this proposed scheme, the relay node R is supposed to decide the transmission strategy chosen at different channel link quality. From the select criterion, it can be seen that the relay node R must know perfect channel state information(CSI). And it can be gotten by channel estimation and channel feedback. The instantaneous channel information of S-R link can be gotten by channel estimation at the relay node. The channel information of R-D link can be achieved by channel feedback at the relay.

IV. Performance analysis

In this section, the performance of our proposed scheme is evaluated from two aspects: symbol error rate (SER) and outage probability .

A. Symbol Error Rate

It has been known that the SER of a system always monotonically increase with received SNR η for any memoryless modulation network. e.g. the SER of BPSK data modulation format is given by $Q\sqrt{2\eta}$. Hence it means that maximizing the received SNR is equivalent to minimizing SER. Moreover,the network capacity is strictly increasing function of the received SNR in general, so we can deduced that maximizing the network capacity is equivalent to minimizing SER. In our proposed scheme, the optimal transmission scheme is chosen based on maximum instantaneous network capacity. Thus, we can confirm that the our proposed strategy can achieve lower SER than other transmission schemes.

B. Outage probability

In the same way, we argue that our proposed scheme can minimize outage probability as well. The system performance of outage probability is defined as

$$P_{out} = P\{C < R\}$$

where R denotes the spectral efficiency in bits per channel use. From our proposed scheme, the transmission strategy is selected to maximize the instantaneous network capacity at different channel link quality. So the instantaneous network capacity of our proposed scheme is larger than other cases. As a result, the adaptive scheme is in outage if one-way relaying and two-way relaying are all in outage. i.e.

$$P_{out}^{optimal} < P_{out}^{one-way} \, and \, P_{out}^{optimal} < P_{out}^{two-way}$$

Hence it is shown that the outage probability of our propose scheme is lower than other transmission schemes.

V. Simulation Results

In this section, we present simulation results to show the performance of the proposed optimal transmission scheme. In our simulation,the wireless channel is modeled as Clarke's flat fading model. The power spectral density of AWGN is defined as -80dBW/Hz.

Figure 3 shows the system throughput for three different transmission strategy including 1) our proposed optimal transmission solution; 2) one-way relaying transmission; 3) two-way transmission scheme. From the figure, it can be seen that the our proposed scheme improves the system throughput by about 1 dB at low SNR region. Moreover the two-way relaying scheme has inferior performance than one-way relaying due to the affect of the noise amplification at low SNR. And the curve of optimal scheme matches together with two-way relaying

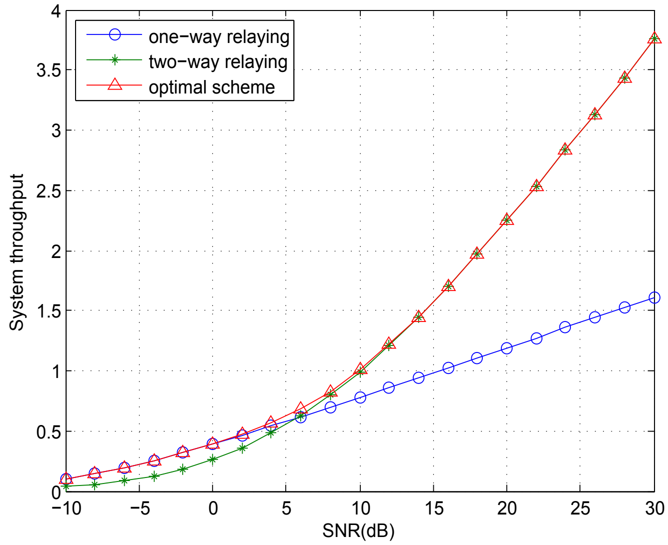

Fig. 3. system throughput

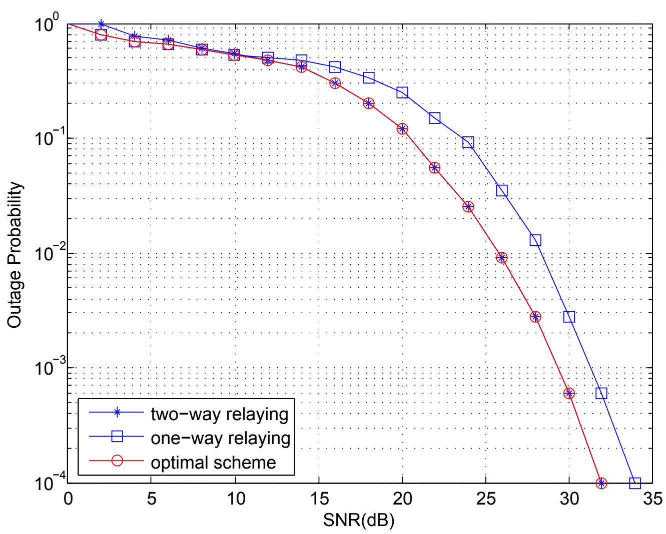

Fig. 4. outage probability

case at high SNR. In addition, under the condition of high SNR region, the sum system throughput of two-way relaying can actually outperform than that of conventional one-way relaying.

Figure 4 shows the outage probability of these above three transmission schemes. For the expression of the outage probability, Monte Carlo simulation was used to achieve the curve. And we set the defined spectral efficiency R as 1. In the same way, the cure of our proposed optimal scheme is under the of two-way relaying and one-way relaying scheme, which coincide with the anylsis result. In addition, the performance of optimal transmission scheme has archived a gain of 1dB than one-way relaying scheme.

VI. Conclusion

Cooperative relay transmission is an efficient solution to combat wireless channel fading and to increase system throughput in future board communication. Through exploiting the broadcast nature of the wireless medium using physical layer networking coding(PNC)modulation, two-way relaying has been proved to improve the network capacity significantly. However for some power-constraints application, the performance of two-way relaying does not actually outperform the one-way relaying at low SNR region. In this paper, the scenario of three nodes cooperative communication is considered. Assuming that perfect channel knowledge is available at the relay node, an optimal transmission scheme for two-way relaying communication is proposed. The transmission scheme, which is based on instantaneous channel link quality, is selected to offer maximum system capacity. The efficiency of the proposed solution is demonstrated by both analytical performance and simulations.

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