

On the Performance of Coordinated AF Relaying Transmission Schemes

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Abstract—In this paper, we study various cooperative relaying transmission schemes of multiple amplify-and-forward (AF) relays system for various geometric environments in view of capacity. We consider joint encoding (JE) with channel matched filtering (CMF) and selective transmission (ST) as coordinated AF relay transmission schemes. Through relay channel model considering link SNRs, we find suitable cooperative relaying schemes that depend on the locations of two relay nodes. The extensive simulation results show that JE-CMF performs better than ST or non-cooperative transmission (NC) mostly in symmetric channel environment. On the contrary to the superior performance of JE-CMF in conventional network multi-input multi-output (MIMO) cellular system, ST outperforms JE-CMF as the asymmetry in links gets larger.

Keywords— Multiple relay, wireless routing, capacity maximization, cooperative relaying schemes, geometric environments

I. INTRODUCTION

Recently multi-hop communication has become an active field of research in wireless communication. In mobile communication system, relaying schemes provide promising technologies to transmit at higher data rate to destinations [1]. By using relays, we can extend coverage and boost link capacity in cellular networks. When there are multiple relays in the system, the performance of the system tends to depend heavily on transmission schemes. The relay channel, where relays are used to aid in sending data from a source to a destination, has been extensively studied [2]-[3]. However, most research considers a single relay system. Yet, search on various geometric environments of multiple relays is still in its early stage. Processing in relays is usually classified into amplify-and-forward (AF) and decode-and-forward (DF) relaying protocols [4]. When there are multiple relays in the system, the performance usually depends on the locations of the relays and the transmission schemes. [5] shows that cooperative transmission schemes for DF multiple relaying achieve higher transmission rate than serving different users in separate channels. There have been several papers on multiple AF relaying. In [6], the authors show that optimal selection and transmission of a single relay among a set of multiple AF relay candidate minimize the outage probability. This outage optimality demonstrates that cooperation benefits are

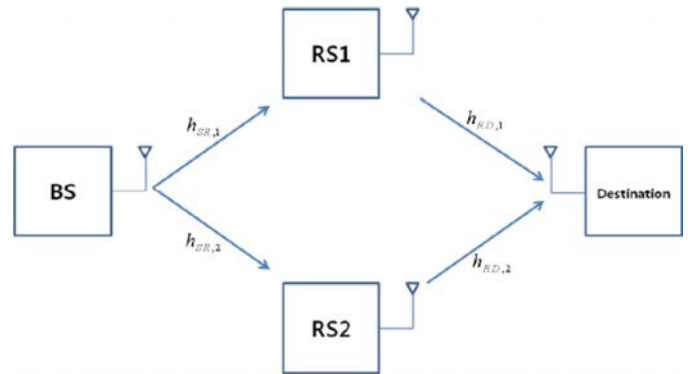


Figure 1. System model

maximized with intelligent scheduling among AF relays. Also in [7], the idea of beamforming in networks with parallel AF relays and a separate short-term power constraint on each node is proposed. However, to the best of author's knowledge, the performance of coordinated multiple AF relaying schemes relay with various geometric environments has not been fully studied.

In this paper, the communication between source-destination pairs is aided by multiple AF relays. We study the dependency of the cooperative AF relaying schemes on the locations of the relay in the system. We consider joint encoding (JE) with channel matched filtering (CMF) and selective transmission (ST) as cooperative transmission schemes while the base line performance is set to be that of non-cooperative transmission (NC). It is found that the JE-CMF performs better than others when the symmetry of channels is guaranteed. However, contrasted with the always better performance of JE-CMF in cooperative transmission of the base stations in cellular systems, ST shows better performance especially when the asymmetry of channels is very large.

The outline of this paper is as follows. In section II, the cooperative relay system model with multiple relays are introduced. We calculate the SNRs for JE-CMF, ST, and NCs in section III so that we can make some performance comparison. In section IV, we study the performance of the considered transmission schemes in various different environments so that we can characterize the performance of transmission schemes depending on the relative geometries of

the relays. In section V, we make some conclusions and suggest some future research directions.

II. SYSTEM MODEL

The system model is illustrated in Figure 1. We consider a relaying system downlink with one source, two AF relay stations (RS) and one destination. We assume there is no direct connection between BS and destination. Each node is equipped with a single antenna in this paper. The channel between source and relay i is denoted as $h_{SR,i} \in \mathbb{C}$, where $i = 1, 2$. The channel between relay i and destination is denoted as $h_{RD,i} \in \mathbb{C}$, where $i = 1, 2$. Each channel is assumed to experience independent flat Rayleigh block fading. It is also assumed that all channel state information (CSI) is known. We assume circularly symmetric zero mean complex additive white gaussian noise (AWGN) at the RSs and destination receivers, and their variances are denoted as $\sigma_{R,1}^2$, $\sigma_{R,2}^2$, and σ_D^2 respectively. Since each relay is required to process the received signal extensively in our system setup, considering processing time, we assume half-duplex relay system. The information symbol s is selected randomly from the codebook $\mathbf{S}$. The average transmit power at source is denoted as P_s .

With this system setup and assumptions, the received signal at the i th RS can be represented as

$$r_i = \sqrt{P_s} h_{SR,i} s + n_{R,i} \quad (1)$$

, where $i = 1, 2$, and $n_{R,i}$ is the AWGN at the i th relay.

In addition to process the received signal to improve the signal quality at the destination, relays also amplify the received signal. This amplification factor α_i can be calculated from relationship between input and output power, which can be written as

$$\alpha_i = \frac{\sqrt{P_{r,i}}}{\sqrt{P_s |h_{SR,i}|^2 + \sigma_{R,i}^2}} \quad (2)$$

The received signal at the destination from each RS is given by

$$y_{RD,i} = \alpha_i h_{RD,i} r_i + n_D \quad (3)$$

, where $i = 1, 2$. n_D is the AWGN at the destination.

In the following we define the transmitted SNRs, and received SNR from the source link and relay link. With the above expression, the received SNRs at each link can be expressed as

$$\gamma_{Tx-S,i} = \frac{P_s}{\sigma_{R,i}^2}, \quad \gamma_{Rx-R,i} = \frac{P_s |h_{SR,i}|^2}{\sigma_{R,i}^2} \quad (4)$$

$$\gamma_{Tx-R,i} = \frac{P_{r,i}}{\sigma_D^2}, \quad \gamma_{Rx-D,i} = \frac{P_{r,i} |h_{RD,i}|^2}{(P_s |h_{SR,i}|^2 + \sigma_{R,i}^2) \sigma_D^2} \quad (5)$$

, where $i = 1, 2$. We will discuss in detail with respect to each cooperative relay scheme in the following sections.

III. COOPERATIVE RELAYING SCHEMES

We consider JE-CMF and ST schemes. JE-CMF exploits diversity gain through identical information transmission from all multiple relays. There can be many encoding schemes which is applicable to multiple relay transmission. For simplicity, we consider channel matched filtering (CMF) at the relay. ST transmits information through the relay link with the best channel quality. As a baseline transmission scheme, we consider non-cooperative transmission (NC) in which allows the first relay to transmit the information to the destination always while the other one is off.

The beam coefficients for proposed JE, w_1, w_2 at each RS can be expressed as

$$w_i = \frac{h_{SR,i}^* h_{RD,i}^*}{\sqrt{|h_{SR,1}^* h_{RD,1}^*|^2 + |h_{SR,2}^* h_{RD,2}^*|^2}} \quad (6)$$

With this notation, the received signal with JE at the destination can be written as

$$y_{RD,i} = \alpha_i h_{RD,i} w_i r_i + n_D \quad (7)$$

From (1)-(7), The SNR equations for cooperative AF relaying transmission schemes are summarized in Table 1. We can calculate the capacity of each relaying scheme in the following way.

$$R_{mode} = 0.5 \{\log_2(1 + \eta_{mode})\} \quad (8)$$

, where 0.5 is in charge of half-duplex relay, and mode = JE, ST, and NC.

IV. SIMULATION RESULTS

In this chapter, we evaluate the performance of the proposed cooperative AF relay transmission schemes through simulation in various system environments. Unless otherwise stated, the simulation setup follows the assumptions and conditions in section II. Basically we compare the average transmission rates in the symmetric and asymmetric links. First, we consider symmetric link where SNRs over every source to relay links are the same and those over relay to destination link are the same too. Second, asymmetric channel environments are considered. For simplicity, we fix the location of the second relay while the changing SNRs associated with the first relay changes depending on the change of location of the first relay.

A. Symmetric Link

Figure 2 compares the performance of JE-CMF and ST as the SNR at source-relay link increases while the sum of $\gamma_{Tx-S,i}$ and $\gamma_{Tx-R,i}$ in dB scale is set to be 40dB. By adjusting transmit SNR, we can mimic the various locations of relays while locations of source and destination are fixed. It can be observed that when SNRs of source-relays and relays-destination link are more balanced, that is, as both relays are located at strictly middle point between source and destination, the performance of every relay transmission scheme is improved. It is also noted that the performances of JE-CMF and ST are almost the same when the S-R SNR is low. When SNR is low, JE-CMF is not very efficient due to unequal total

TABLE 1. SNR OF COOPERATIVE AF RELAYING SCHEMES

AF Relaying Schemes	SNR
JE	$\eta_{JE} = \frac{P_s \left(\alpha_1^2 h_{SR,1} ^2 h_{RD,1} ^2 + \alpha_2^2 h_{SR,2} ^2 h_{RD,2} ^2 \right)^2}{\left(\alpha_1^2 \sigma_{R,1}^2 h_{SR,1} ^2 h_{RD,1} ^4 + \alpha_2^2 \sigma_{R,2}^2 h_{SR,2} ^2 h_{RD,2} ^4 \right) + \sigma_D^2 \left(h_{SR,1}^* h_{RD,1}^* ^2 + h_{SR,2}^* h_{RD,2}^* ^2 \right)}$
ST	$\eta_{ST} = \max \left(\frac{\alpha_1^2 P_s h_{SR,1} ^2 h_{RD,1} ^2}{\alpha_1^2 \sigma_{R,1}^2 h_{RD,1} ^2 + \sigma_D^2}, \frac{\alpha_2^2 P_s h_{SR,2} ^2 h_{RD,2} ^2}{\alpha_2^2 \sigma_{R,2}^2 h_{RD,2} ^2 + \sigma_D^2} \right)$
NC	$\eta_{NC} = \frac{\alpha_1^2 P_s h_{SR,2} ^2 h_{RD,2} ^2}{\alpha_1^2 \sigma_{R,1}^2 h_{RD,1} ^2 + \sigma_D^2}$

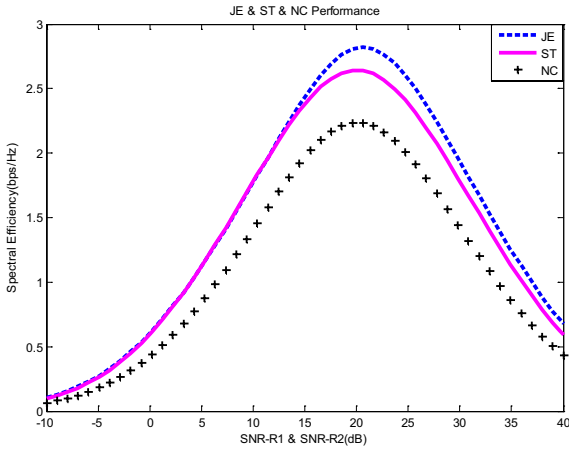


Figure 2. Performance of cooperative AF relaying schemes with different locations when channels are symmetric

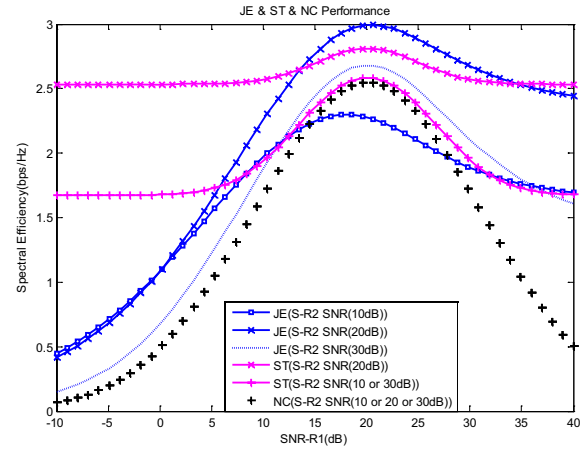


Figure 3. Performance of cooperative AF relaying schemes with different locations when channels are asymmetric over relays

noise variance at the destination. Simulation results show that JE-CMF can exploit the beamforming gain when SNR is high enough to be close to optimal joint encoding. It is also noted that proposed JE-CMF and ST provides noticeable gain over NC regardless of SNR conditions in symmetric link, which results from diversity gain for ST or power gain JE-CMF.

B. Asymmetric Link

Figure 3 compares the performances of JE-CMF and ST over the asymmetric links. To simulate the asymmetric link, we vary S-R1 SNR while S-R2 SNR is fixed. Thus, since NC using baseline performance uses only relay 1, its performance is kept the same regardless of location of relay 2. To characterize the impact of the asymmetric geometric environment, we considered three different locations of relay 2. We plots the simulation results in figure 3 where the S-R2 SNR of 10 dB represents the case that relay 2 is fixed at location closer to the destination and S-R2 SNR of 30dB does the case that it is fixed at location closer to the source. As previously stated, it can be observed that the performance of all transmission schemes appears best when the S-R1 and S-R2 SNRs and R1-D and R2-D SNRs are same as 20dB

respectively. This can be attributed to the fact that the performance of JE-CMF is limited by SNR of the worst link. With similar reason, it can be seen that the performance is relatively high when the S-R1 SNR and S-R2 SNR are similar to each other. Thus, one can improve the performance of JE-CMF by locating the relays such that their SNRs are almost same.

While the performances of JE-CMF differ when S-R2 SNR is 10dB or 30dB, those of ST is almost the same for this case. As stated, the performance of relay system is dominated by worst case SNR. Thus, when S-R2 SNR is 10dB, received SNR at the destination is limited by this S-R2 SNR, while it is by R2-D SNR when S-R2 SNR is 30dB. With similar reason, ST shows the almost the same performance when SNR-R1 is low or high. In this case, ST selects the relay 2, since total link SNR over relay 1 is likely to be bad for the most of times.

When S-R1 SNR is low, the total link SNR of JE-CMF is limited by S-R1 SNR. Thus, in this case, ST shows the better performance than JE-CMF. JE-CMF shows the better performance than ST only when S-R1 and S-R2 is high enough to exploit the power gain from beamforming. When S-R1 is too high, the R1-D SNR is very low since we fix the

total SNR to be 40dB. Thus, the total SNR over the relay 1 link will acts as source of noise, in which ST shows the better performance.

V. CONCLUSIONS

In this paper, we study the performance of the cooperative AF relaying schemes for various system environments. It is found out that the performance of cooperative multiple AF relay systems depends on the transmission scheme and geometry of the system, which mandate the careful design of the cooperative relay transmission scheme in various operating environment, On the contrary to the common belief in the superior performance of JE-CMF, JE-CMF performs worse than ST in some cases even though it performs better in most cases. It is noted that this is particularly case when there is a link with bad quality which dominates the performance at the destination. Even though we focused on single antenna case to characterize the performance of cooperative relay schemes more simply, it can be extended to all MIMO network which allows various transmission schemes. This is likely to be nontrivial in the sense that in addition to the link unbalance, partitioning degree of freedom (DoF) between the signal dimension and interference dimension is likely to be another key parameters which will be left for future research.

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