Cooperative diversity with multiple relays using opportunistic beamforming

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Abstract— **The performance of cooperative diversity with opportunistic beamforming is analyzed in rayleigh fading channels. Cooperative communication is viewed as a method for increasing diversity gain and reducing end to end path loss. The use of relays can create a virtual antenna array so that it allows users to exploit the advantages of multiple input multiple output (MIMO) techniques. In this paper we show that opportunistic beamforming is beneficial for cooperation transmission with multiple relays where the main goal is a very low bit error rate (BER)of the system. Simulation results confirm the effectiveness of opportunistic beamforming with cooperative diversity techniques.**

I. Introduction

In recent years, cooperative diversity is considered as a potential transmit strategy for wireless networks. The basic idea of cooperative transmission is to allow several transmit nodes in the network to help in order to create a virtual antenna array and exploit spatial diversity at the destination [4], [5], [6]. It has been shown in the literature [7], [9] that cooperative communication can avoid the difficulties of implementing actual antenna arrays and convert the single input single output (SISO) system into a virtual multiple input multiple output (MIMO) system. In this way, cooperation between users allows them to exploit the diversity gain and others advantages of MIMO system in a SISO wireless network. Several protocols have been proposed to achieve the gains promised by the use of node cooperation. Two main relay protocols are widely known: amplify and forward (AAF) and decode and forward (DAF). AAF means that the received signal is multiplied by an amplification gain and then retransmitted by the relay without performing any decoding. In contrast to this, the signal is decoded at the relay and re-encoded for retransmission in (DAF) strategy. Most current research on cooperative transmission focuses on protocol design and analysis, power control, relay selection and cross layer optimization. Examples of these works, in [8]the performance of AAF protocol and DAF protocol is analyzed in terms of outage probabilities. In [7], a simple novel scheme that selects the best relay between source and destination based on instantaneous channel measurements is proposed. In [3], the authors showed that full diversity can still be achieved with systems where only the best relay is selected. A study presented in [2] proposed performance metrics in a closed form to show how exploiting adaptively the diversity gain of the relay selection. A distributed game theoretical framework was proposed in [1] for multiuser cooperative communication systems to achieve optimal relay selection and power allocation. In [11], a theoretical analysis of probability of collision in Racian channel for cooperative diversity scheme is analyzed. Also, cooperation methods using distributed space time coding are widely being studied [12], [13].

In this paper, we consider a cooperative AAF communication system in Rayleigh fading channels using opportunistic beamforming (OBF) at the source. OBF is proposed in [10]. This technique induces random fading in a real system, where the environment has little scattering and or the fading is slow in order to implement multiuser diversity. In the proposed scheme multiple relays are available but a single relay among a set of N relays is selected. The received signals at the destination according to maximum ratio combining rule.

The remainder of this paper is organized as follows: while section II deals with a review of opportunistic beamforming (OBF), section III presents the cooperative OBF signal model with multiple relays and section IV derive the SNR analysis followed by section V with simulations results. The paper finally draws the conclusions in section VI.

II. OBF overview

We consider a downlink system where a base station is equipped with M_t transmit antennas communicates with K users. Each of K mobile terminals has one receive antenna. We note $h_{ik}(t)$ the complex channel gain from i antenna to the kth user in time slot t. In time slot t, the same block $x(t)$ of symbols is transmitted from all of the antennas except that it is multiplied by a complex number $w_i(t) = \sqrt{\alpha_i(t)}e^{j\theta_i(t)}$ at antenna i, for $i = 1, ..., M_t$, such that $\sum_{i=1}^{M_t} \alpha_i(t) = 1$, preserving the total transmit power. The received signal at user k is given by

$$y_k(t) = h_k^T w(t)x(t) + n_k(t) \quad (1)$$

where

$$h_k^T := [h_{1k}(t), h_{2k}(t), ..., h_{M_t k}(t)]$$

is the channel vector and

$$w(t) := [\sqrt{\alpha_1(t)}e^{j\theta_1(t)}, \sqrt{\alpha_2(t)}e^{j\theta_2(t)}, ..., \sqrt{\alpha_{M_t}(t)}e^{j\theta_{M_t}(t)}]^T$$

and $n_k(t) \sim N(0, \sigma^2)$ is the corresponding noise. The overall channel gain is $h_k^T(t)w(t)$. The signal-to-noise ratio(SNR)of

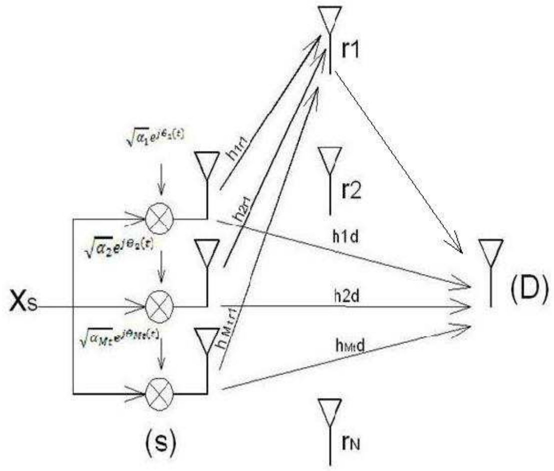

Fig. 1. A system model of the proposed cooperative relay network

user k is $SNR_k(t) = \frac{|h_k^T(t)w(t)|}{\sigma^2}$. We assume that the receivers can perfectly track the overall(SNR)or effectively the fading processes $h_k(t)_t$, then the maximum long-term average sum-capacity of the channel can be achieved by the transmission strategy which schedules at any one time the best user.

III. SYSTEM MODEL

We consider an amplify and forward (AAF) cooperative diversity system. We focus on the communication model depicted by 1, with one source denoted s, one destination denoted d, and one or more relays denoted $r = 1, 2, ..., N$. In this paper, we consider that the source is equipped with M_t transmit antennas and uses the opportunistic beamforming technique for transmission and we assume that each wireless channel between nodes has independent Rayleigh fading. The r-th relay has M_r antennas that are used for reception on the s-r link and transmission on the r-d link, and the destination has M_d receive antennas. We restrict ourselves to the case of $M_r = M_d = 1$ for simplicity. A single relay among a set of N relay nodes is selected, depending on which relay provides for the "best" end to end path between source. The source node transmits during the first phase and the relay node transmits during the second phase. The relay amplifies the received data before retransmitting it to the destination. The signals from the source node and from relay node are combined at the destination using maximal ratio combining rule (MRC). In the first phase, the source broadcast a pilot signals in order to estimate the instantaneous SNR of the N relays. The best relay r which has the maximum instantaneous SNR is selected for cooperative transmission. The selection of relay is done in quick fashion, well before the channel changes again. Then,the transmitted signal is received by relay and the destination. The source-relay r signal model y_{sr} is given by:

$$y_{sr} = h_r^T w x_s + n_{sr}, r = 1, 2, ..., N \tag{2}$$

where

$$h_r^T := [h_{1r}(t), h_{2r}(t), ..., h_{M_t r}(t)]$$

is the channel vector and

$$w(t) := [\sqrt{\alpha_1(t)}e^{j\theta_1(t)}, \sqrt{\alpha_2(t)}e^{j\theta_2(t)}, ..., \sqrt{\alpha_{M_t}(t)}e^{j\theta_{M_t}(t)}]^T$$

we note H_{sr}^{BF} the overall channel gain:

$$H_{sr}^{BF} = h_r^T w, r = 1, 2, ..., N \tag{3}$$

and the source-destination signal model y_{sd}

$$y_{sd} = h_d^T w x_s + n_{sd} \tag{4}$$

where

$$h_d^T := [h_{1d}(t), h_{2d}(t), ..., h_{M_t d}(t)]$$

is the channel vector and

$$w(t) := [\sqrt{\alpha_1(t)}e^{j\theta_1(t)}, \sqrt{\alpha_2(t)}e^{j\theta_2(t)}, ..., \sqrt{\alpha_{M_t}(t)}e^{j\theta_{M_t}(t)}]^T$$

is the beamforming vector.

we note H_{sd}^{BF} the overall channel gain:

$$H_{sd}^{BF} = h_d^T w \tag{5}$$

where h_r^T is the channel gain matrix of source-relay r path and h_d^T is the channel gain matrix of source-destination path, x_s is the modulated transmitted symbol, and n_{sr} and n_{sd} are the respective channel noise drawn from an ensemble of i.i.d complex Gaussian random variables with zero mean and variance σ_{sr}^2 and σ_{sd}^2. During the second phase the selected relay r amplifies the message by a gain β_r and retransmits it to the destination.

$$x_r = \beta_r y_{sr} \tag{6}$$

and

$$\beta_r = \sqrt{\frac{\xi_r}{|H_{sr}^{BF}|^2 \xi_s + 2\sigma_{sr}^2}}, r = 1, 2, ..., N \tag{7}$$

where $\xi_s = E[|x_s|^2]$ denotes the energy of the transmitted power.

The r-th relay-destination y_{sr} signal model is given as:

$$y_{rd} = h_{rd} x_r + n_{rd}, r = 1, 2, ..., N \tag{8}$$

where h_{rd} is the channel gain vector of relay r-destination path and n_{rd} is the channel noise with variance σ_{rd}^2 .

IV. SNR ANALYSIS

The instantaneous signal to noise ratio (SNR) of the combiner output is:

$$\gamma_{MRC} = \gamma_s + \gamma_r \tag{9}$$

where γ_s is the instantaneous channel received Signal-to-Noise Ratio (SNR) over the direct link and it is defined as:

$$\gamma_s = \frac{|h_d^T|^2 \xi_s}{2\sigma_{sd}^2} \tag{10}$$

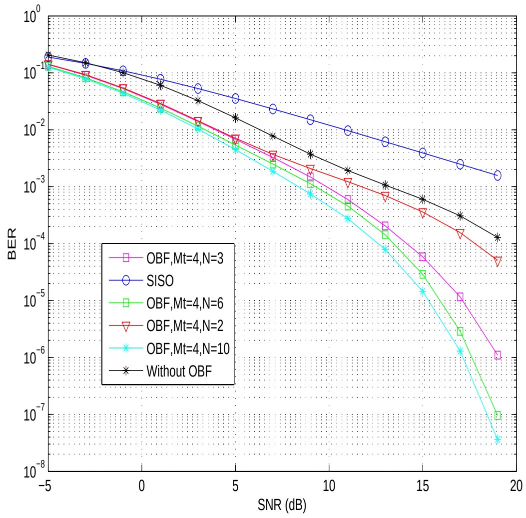

Fig. 2. BER performance of cooperative AAF system using OBF with different number of relays.

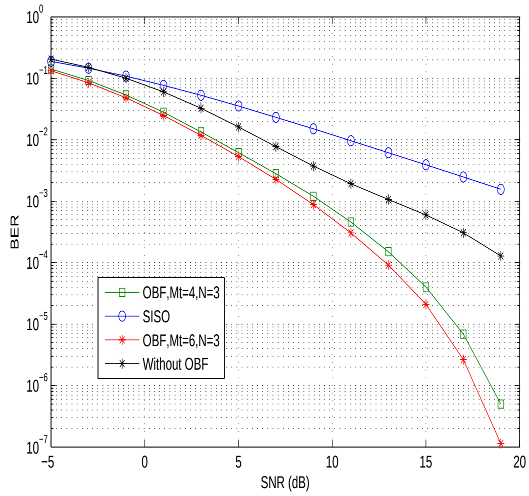

Fig. 3. BER performance of cooperative AAF system using OBF with different number of transmit antennas.

and γ_r is the instantaneous Signal-to-Noise Ratio (SNR) observed at the destination over the multi-hop link:

$$\gamma_r = \frac{\beta^2 |H_{sr}^{BF}|^2 |h_{rd}|^2 \xi_s}{\beta^2 |h_{rd}|^2 2\sigma_{sr}^2 + 2\sigma_{rd}^2} \tag{11}$$

For a QPSK modulated signal this will change to:

$$BER = Q(\sqrt{2\gamma_{MRC}}) \tag{12}$$

V. Simulation Results

In this section, we evaluate the performance of our scheme in terms of end-to-end BER at the destination as function of SNR for slow fading Rayleigh environments. The simulation is conducted for $M_t = 4, 6$ transmit antennas at the source and $M_r = M_d = 1$ antennas at the relay and the destination.

In the first part, the number of the relays is varied to see the effect on the performance of the system. For all the simulations one relay is selected for cooperative transmission and at the destination the received signals are combined according to MRC rule. Figure 2 shows the average bit error rate (BER) versus SNR for different number of the relays, $N = 2, 4, 6, 10$. The simulation is conducted for $M_t = 4$ antennas at the source. The best relay which has the maximum instantaneous SNR is selected. We can clearly see that the BER decrease when the number of relays increases. This is due to the fact that the performance of opportunistic beamforming (OBF) increase when there is a large number of users (relays) in the systems. This is because an additive relay augment the probability that there is a relay whose instantaneous channel vector matches the beamforming vector and can thus benefit from the array gain to minimize the end to end BER. We also note the superior performance in terms of BER compared to non cooperative system which is represented in this figure by SISO curve. In the same figure, we can see the improvement of the proposed schemes compared to the conventional cooperative system without OBF technique.

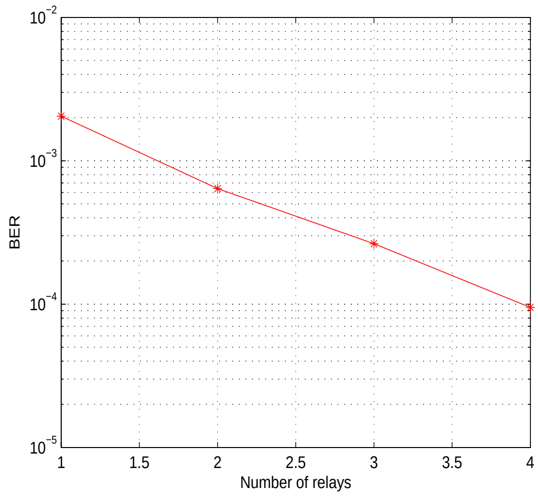

Fig. 4. BER performance as function of number of relays in the system at 10 dB SNR

Figure 3 displays the average bit error rate (BER) versus SNR for different number of antennas at source $M_t = 4, 6$. The number of relays is fixed at $N = 3$. Adding an antenna at source which uses opportunistic beamforming technique increase the diversity order of the system. For example, the value of BER from simulation for $M_t = 4$ and $N = 3$ at SNR=15dB equals 4×10^{-5}, while for $M_t = 6$ and $N = 3$ is 2×10^{-5}. We note also that the performance in terms of BER of the proposed schemes is superior compared to non cooperative system and conventional cooperative system. Figure 4 shows the average bit error rate (BER) versus number of relays at SNR=10 dB. Only one relay which has the highest SNR is used for transmission. Similar observations about cooperative diversity gain can also be made. Diversity benefits of cooperative transmission appear as faster decrease the BER with number of relays present in the system. For instance, increasing the number of relays (N), from 1 to 4, reduce the BER from 2×10^{-3} to 9×10^{-5} without any additional channel resources.

VI. Conclusion

In this work, we studied the performance of a cooperative AAF communication system using opportunistic beamforming (OBF) technique at the source and multiple relays and operating over Rayleigh fading channels. The best relay which has the maximum instantaneous SNR is selected for transmission. It should be emphasized that the best relay selection scheme has a strong advantage in saving the channel resources compared to cooperative diversity with multiple relays. Simulations results showed that the performance of the proposed scheme is superior to that of non cooperative system and conventional cooperative system and the improvement by opportunistic beamforming becomes larger as the number of relays increases and/or the number of transmit antennas increases. This is because an additive relay augment the probability that there is a relay whose instantaneous channel vector matches the beamforming vector and can thus benefit from the array gain to improve the system performance.

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