Performance Analysis of C-MRC Technique in DF Based Cooperative System with Co-Channel Interference

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Abstract

We have investigated the performance analysis of DF (Decode-And-Forward) based cooperative system using cooperative MRC (C-MRC) at the destination with co-channel interference in Rayleigh fading channels. The performance of C-MRC is compared with maximal-ratio combining (MRC) using the effective Signal to Interference plus Noise Ratio (SINR) of the system. It is seen that performance of C-MRC technique is much better than that of MRC. The Monte Carlo simulations are provided to illustrate the effect of interference on the performance where interference channels are independent and identically distributed.

1. Introduction

Multiple input multiple output (MIMO) system is a promising technology to increase the network capacity by employing multiple antennas at both transmitter and receiver sides [1, 2]. Although using multiple antennas can be feasible for the base stations, it is not appropriate for mobile stations due to the size and power limitations. Thus cooperative communication has emerged as an alternative technology which acquires the advantages of MIMO systems by apply single antenna at the transmiting relays and receiving stations [3-4].

Cooperative communications have attracted too much attention in research community due to its ability to extend the network coverage, low cost of deployment, increase of spectral efficiency and reliable transmission [3-5]. Cooperative diversity creates virtual antennas between participant terminals, which share resources. Two of the most well-known relaying techniques used in cooperative communication systems are amplify-and-forward (AF) and decode-and-forward (DF). The AF is the simplest cooperative protocol in which the relay amplifies the received signal from the source together with the noise and forwards to the destination without any alteration or filtration. Its disadvantage is the higher noise level at the receiver which is highly depending on the condition of channel between the source, relay and destination. The main advantages of this protocol are less transmission delay and low implementation complexity. In DF protocol, the relay attempts to decode the received signal in order to recover the original transmitted signal. After decoding, the data bits are then encoded and transmitted to the destination. The main advantage of this protocol is the elimination of the noise at the relay and its disadvantage is the decoding errors at the relay due to deep fading in the link which lead degradation in overall performance of the system.

Various detection techniques can be used in DF based cooperative communication systems in order to decrease the effect of error propagation at the relay terminal such as cooperative maximal ratio combining (C-MRC) [9], Maximal ratio combining [7], maximum likelihood (ML) detection [5] and the link-adaptive regeneration (LAR) [8]. In ML detection [5] and C-MRC [9] the destination combines signals transmitted from the relay and the source terminals taking the quality of the source-relay link into consideration. Cooperative-MRC (C-MRC) [9] achieved a performance that nearly maximum likelihood detection performance but lower complexity. On the other hand, in LAR based strategies [8] combating with the error propagation is accomplished by allowing soft power scaling at the intermediate terminals.

Nevertheless, co-channel interference is a major issue in cooperative communication systems. It is generally dominates AWGN in wireles networks because all terminals may using same frequency. The authors in [10] have deployed the performance analysis of a dual-hop relay network in presence of co-channel interference at relay and destination terminals where upper bound of the exact equivalent signal-to-interference-plus-noise ratio (SINR) at the destination is formulated. Also the authors in [10] derived the cumulative distribution function, probability density function and moment generating function of the upper bounded end-to-end SINR. In [11], the authors investigated the performance of DF base cooperative system in presence of co-channel interference over mixed fading channels between the source-destination and the source-relay-destination paths. The outage probability of DF cooperative relaying systems using MRC in the presence of co-channel interference is investigated in [12] and a closed-form expression for the outage probability is derived. Also optimization of cooperative diversity systems in generic noise and co-channel interference is studied in [13] and the authors have derived a unified mathematical framework for performance

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analysis. In [14], the author investigates a dual-hop DF relaying vehicular system in presence of co-channel interference, in which source, relay and destination terminals are composed vehicles and interferers are stationary.

In this paper, we have compared the performances of C-MRC and MRC tecniques in DF based cooperative system with co-channel interference over Rayleigh fading channels by using Monte-Carlo simuliation. The results show that, C-MRC technique gives higher diversity gains in the absence of co-channel interference with respect to the MRC technique. When there are multiple interferences, the performance of both techniques decrease drammatically but the C-MRC technique show better performance than the MRC technique in low SNR regime.

2. System Model

We have considered a DF based cooperative communication system (Fig.1), in which a source terminal S communicates with a destination terminal D with the help of a relay terminal R. All terminals operate in half-duplex mode and are equipped with a single pair of transmit and receive antennas. In this paper, the interferer links at destination are assumed to have Rayleigh fading.

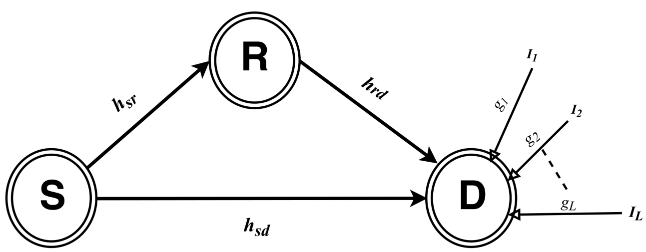

Fig. 1. System model.

Let us assume that the communication between the source and destination terminal is performed in two phase. In the first phase, the source transmits the data symbol $x \in$ {-1,1} to relay and destination. The destination terminal receives noisy signal and a number of co-channel interfering signal. Therefore, the received signal by relay and destination can be written as

$$y_{sr} = \sqrt{E_S} h_{sr} x + n_{sr}, \tag{1}$$

$$y_{sd} = \sqrt{E_S} h_{sd} x + n_{sd} + \sum_{i=1}^{L} \sqrt{E_i} g_i s_i, \tag{2}$$

respectively where x is the transmitted symbol by source terminal, s_i is the *i*th co-channel interferer's symbol, E_s is the energy of desired symbol, E_i is the energy of *i*th co-channel interferer, h_{ij} (i, j $\in$ {S, R, D}) is the complex fading coefficient between terminals i and j modelled as zero-mean complex Gaussian random variables with $\sigma_{ij}^2/2$ variance per dimension ($CN(0, \sigma_{ij}^2)$), g_i denotes the complex Gaussian random variable of *i*th co-channel interferer, modelled as $g_i \sim CN(0, \sigma_i^2)$, n_{sr} and n_{sd} denote AWGN with zero mean and variance of N_0 and modelled as $n_{sr} \sim CN(0, N_0)$, $n_{sd} \sim CN(0, N_0)$.

In the second phase, the relay estimates the data symbol of source terminal and then transmits re-encoded signal to the destination terminal. The estimated symbol $\tilde{x}$ is given as

$$\tilde{x} = arg \min_{x \in \{-1,1\}} \mid y_{sr} - \sqrt{E_s} x h_{sr} \mid^2 \tag{3}$$

Therefore the received signal by the destination in the second phase can be written as

$$y_{rd} = \sqrt{E_r} h_{rd} \tilde{x} + n_{rd} + \sum_{i=1}^{L} \sqrt{E_i} g_i s_i \tag{4}$$

where E_r is the energy of the relay terminal and n_{rd} denotes AWGN modelled as $n_{rd} \sim CN(0, N_0)$

3. Decision Rules

The decision rules used at the destination for MRC and C-MRC techniques are explained in the following subsections.

3.1. Maximal Ratio Combining

The MRC weight vector and the output signal are given as [1]

$$\begin{aligned} w_x &= h_x \\ y &= w_x^H r \end{aligned} \tag{5}$$

where y is the output of combiner and r is the received signal. Therefore under optimal condition, the output signal can be written as

$$y = w_{sd}^H y_{sd} + w_{rd}^H y_{rd} \tag{6}$$

where w_{sd} and w_{rd} are optimal weight vector and depend on h_{sd} and h_{rd} respectively. Subtituting $w_{sd}^H = h_{sd}^*$ and $w_{rd}^H = h_{rd}^*$ into (6), the output signal can be written as

$$y = \frac{h_{sd}^* y_{sd}}{N_0} + \frac{h_{rd}^* y_{rd}}{N_0} \tag{7}$$

where (.)* denotes the complex conjugate operator. Decision rule of MRC can be written as

$$x_D = \mathbb{R}\{y\} \underset{0}{\overset{1}{\gtrless}} 0 \tag{8}$$

where $\mathbb{R}\{y\}$ denotes real part of $\{y\}$.

3.2. Cooperative Maximal Ratio Combining

Unlike the MRC technique where only the SNR of the R-D link is taken into account, i then C-MRC approach, equivalent SNR of the S-R-D link is utilized in determining the weight vectors. The C-MRC weight vectors w_{sd} and w_{rd} are given as [9]

$$\begin{aligned} w_{sd} &= h_{sd}^*, \\ w_{rd} &= \frac{\gamma_{eq}}{\gamma_{rd}} h_{rd}^*. \end{aligned} \tag{9}$$

Here γ_{rd} can be expressed as $\gamma_{rd} = \dfrac{E_r}{N_0} \mid h_{rd} \mid^2$. Since co-channel interference is used at destination, we can use the effective SINR of $R-D$ link as $\gamma_{rd}^{eff} = \gamma_{rd}/(1 + \sum_{i=1}^{L} \gamma_{g_i})$. Thus, the expression w_{rd} in (9) can be rewitten as :

$$w_{rd} = \frac{\gamma_{eq}}{\gamma_{rd}^{eff}} h_{rd}^* \quad (10)$$

where γ_{g_i} is the total interference to noise ratio at destination and can be written as $\gamma_{g_i} = \frac{E_i}{N_0} \mid g_i \mid^2$. In accordance of γ_{rd}^{eff} end-to-end equivalent SNR of S-R-D link, γ_{eq} can given as [9]

$$\gamma_{eq} = \frac{1}{\alpha}\{Q^{-1}[P_{eq}^b(\gamma_{sr}, \gamma_{rd}^{eff})]\}^2 \quad (11)$$

where $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty \exp\left(-\frac{u^2}{2}\right) du$, and α is a constant that depends on the underlying constellation. ($\alpha = 2$ for BPSK). Errors at the destination occur either when $S-R$ transmission is received correctly and the $R-D$ transmission is received error or vice versa. So, P_{eq}^b is the bit error probability of $S-R-D$ transmission link and can be written as [9] :

$$\begin{aligned} P_{\text{eq}}^b(\gamma_{SR}, \gamma_{RD}) = {} & [1 - P_{SR}^b(\gamma_{SR})]P_{RD}^b(\gamma_{RD}) \\ & + [1 - P_{RD}^b(\gamma_{RD})]P_{SR}^b(\gamma_{SR}) \end{aligned} \quad (12)$$

The decision rule of C-MRC can be written as

$$\begin{aligned} x_D = {} & \arg\min_{x \in \mathcal{A}_x} |w_{SD} y_{SD} + w_{RD} y_{RD} \\ & (w_{SD} h_{SD} + w_{RD} h_{RD}) x|^2. \end{aligned} \quad (13)$$

4. Numeric Results

In this section, we provide the Monte Carlo simulation results for the MRC and the C-MRC techniques in DF based cooperative communication systems with co-channel interference at the destination over Rayleigh fading channels. BPSK modulation is used and the energies of the source and the relay terminals are taken on unity as $E_s = 1$ and $E_r = 1$ respectively. The Signal-to-Interference-Ratio (SIR) for considered system can be given as [10] $\Lambda = \frac{\bar{\gamma_{rd}}}{\bar{\gamma_{g_i}}}$ where $\bar{\gamma_{rd}} = E_r/N_0$ and $\bar{\gamma_{g_i}} = E_i/N_0$ and is assumed to be 20 dB. The BER comparisions are done at a BER of 10^{-4}.

Fig.2 shows the average BER of the MRC and the C-MRC techniques when there is no co-channel interference at the destination. It is shown that a significant increase exists in BER curves with respect to the direct transmission for both the MRC and the C-MRC techniques. Also it can be seen that the BER performance of the C-MRC is better than the MRC technique in absence of co-channel interference. The SNR gain between the C-MRC and the MRC is nearly 12 dB.

In Fig.3 and Fig.4 we consider only one co-channel inteferer and five co-channel interferers at the destination interrupting the system respectively. It is seen that when the considered system has multiple interferences, the BER performance of considered system decreasing drammaticaly. It can be observed clearly from figures that the BER performance of the proposed system with the C-MRC technique is better than the MRC technique. The SNR gains between the BER performance of the C-MRC and the MRC techniques are approximately 10 dB and 6 dB.

5. Conclusions

In this paper, we compared the C-MRC and the MRC tecniques in DF based cooperative system with co-channel interference at the destination over Rayleigh fading channels. We can see from figures that the performance of considered system is decreasing when there are multiple co-channel interferences at the destination terminal. It is also seen that C-MRC technique provides best performance in the presence of co-channel interference.

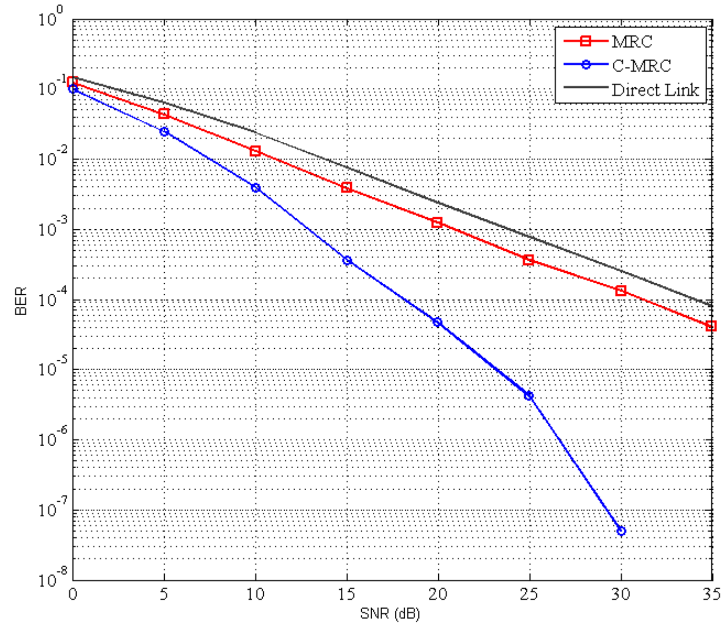

Fig. 2. Comparasion of C-MRC and MRC techniques in absence of co-channel interference.

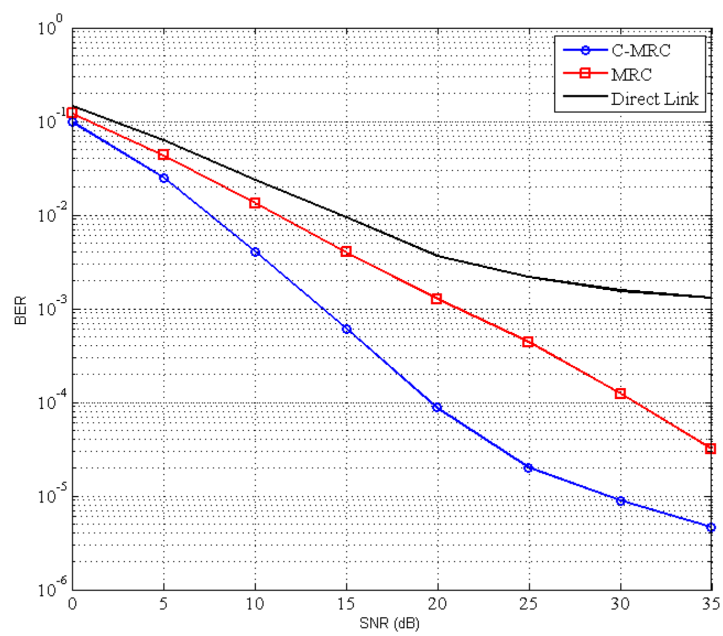

Fig. 3. Comparasion of C-MRC and MRC techniques in presence of one co-channel interference.

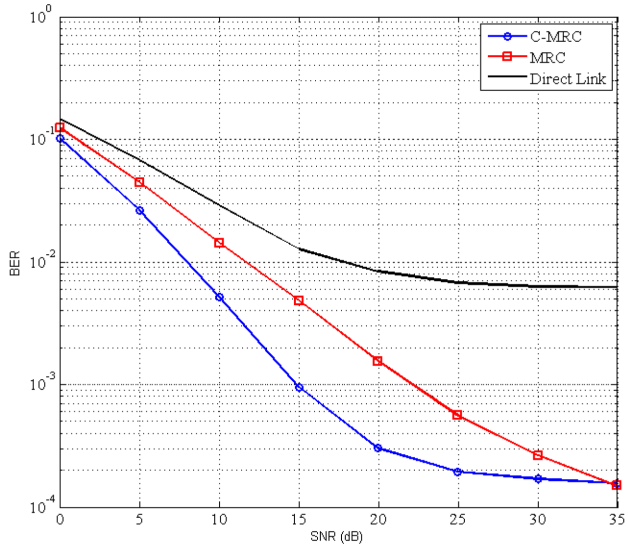

Fig. 4. Comparasion of C-MRC and MRC techniques in presence of five co-channel interferences.

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