Journal of ELECTRICAL ENGINEERING, VOL 69 (2018), NO4, 300–304

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Cooperative relay beamforming in IDMA communication networks

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In this paper, a new combination of Interleave division multiple access (IDMA) and spatial diversity offered by cooperative relay aided distributed beam forming is proposed. In the offered scheme communication strategy consists two steps. All users broadcast their message to relays in the first step and then relays amplifies and forward the information to the desired destination. IDMA, which is popular non-orthogonal multiple access (NOMA) technique is used to combat the effect of multiple access interference (MAI) at relay as well as destination nodes. Each relay processed the signal to maintain the QoS of destination. The goal of this work is to find the appropriate beam forming weights by minimising the transmit power and without compromising the QoS in terms of SINR. However power minimization is not the convex problem, so semi-definite relaxation is used to modify the problem in to semi-definite programming (SDP) problem and the conventional SDP problem solver CVX is used for solution. The numerical explanation and simulation experiment of the proposed scheme shows the performance improvements in terms of bit error rate.

K e y w o r d s: IDMA, QoS, cooperative relay beamforming, semidefinite programming

1 Introduction

Interference and signal fading are two major impairments in wireless communication system that can have severe destructive effect on the quality and reliability of wireless transmission. To achieve robustness against fading, diversity is the popular solution. Among many schemes, spatial diversity is prominently used in wireless transmission which used multiple antennas to enhance the link reliability, throughput and spectral efficiency of the system. However, in some wireless networks; such as in mobile communication (IDMA), the use of multiple antennas are not feasible due to the size of devices. The concept of cooperative communication can be the feasible solution of this problem. In cooperative communication, each device transmits their own information and also acts as a helping agent *ie* relay for other users. The relay nodes desires to cooperate to establish the link between all the sources and destination and this network can be named as ‘cooperative relay networks’ [1–2]. This relaying network is popular in dealing with multipath fading scenario because of its simplicity and acceptable performance as well as range extension which is achieved by multi-hoping [3–4].

Relay network presents the nodes architecture utilizing the transmit and receive beamformer to transmit the power of each signal source to its destination node. The basic node architecture of cooperative relay network is presented in Fig. 1. Several relay protocols have been proposed on the basis of their relaying functionality such as Decode and forward (DF), amplify and forward (AF), compress and forward and cooperative cooperation. However large number of signal sources or relay nodes can lead to increase in multiple access interference (MAI), which can degrade the network performance [3–8]. Also the channel access schemes in relay networks are generally orthogonal which produce excess rate loss in the case of large number of users or relaying nodes as well as orthogonal schemes are having insufficient usage of time and frequency resources.

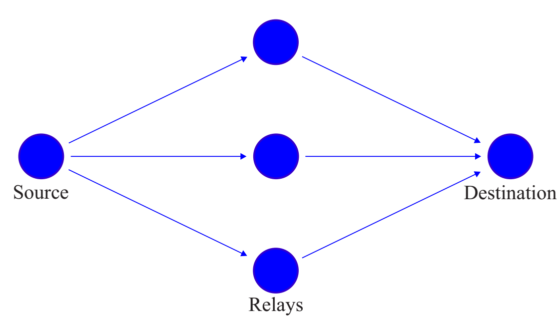

Fig. 1. Basic architecture of cooperative relay networks

On the other hand, interleave division multiple access (IDMA) which is modified version of CDMA scheme, efficiently utilize the time and frequency resources and also suggested as popular code domain non-orthogonal multiple access (NOMA) scheme for 5G communication. Cooperation in CDMA scheme has been prominently studied in literature. In [10], asynchronous cooperative CDMA is presented and the performance is studied in terms of outage probability. The MIMO cooperative CDMA has

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DOI: 10.2478/jee-2018–0042, Print (till 2015) ISSN 1335-3632, On-line ISSN 1339-309X

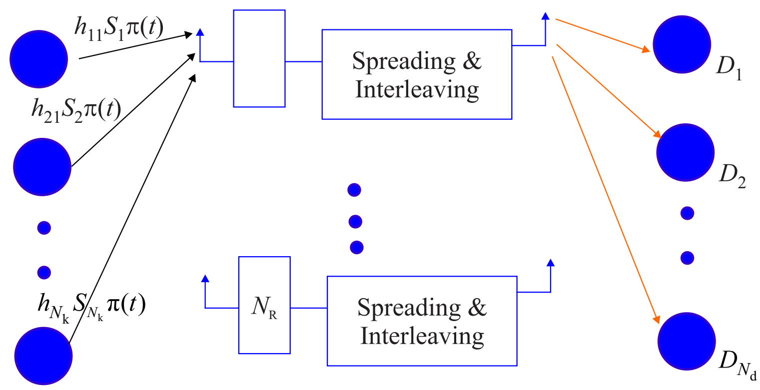

Fig. 2. Cooperative relay communication using IDMA networks

also been presented in [xx]. However, this is already verified in literature that IDMA outperforms CDMA and an important NOMA scheme. So in this paper benefits of IDMA and cooperation of relays are utilised to enhance the system performance [9–12].

Contributions of the presented work are briefly stated as follows:

- We extend the work of cooperative relaying through AF relays in the place DF relay (as in [10]) to avoid the huge computational complexity.
- IDMA technique is adopted along with cooperative beam forming to enhance the system performance in contrast to other orthogonal and CDMA scheme.

2 System model

Assume a wireless relay network with N_k sources, N_l relays and N_d destinations nodes. Each node consist a single antenna at sources and destination and communicating to each other without direct link due to path loss and deep shadowing between source and destination node. The relays used in network are AF relays and act as intermediate stage between source and destination so firstly the source sent their data to relays after spreading and interleaving operation and then in second stage the AF relays amplify and forward the data to the desired destination node [4, 5] and [13–16] In a synchronous transmission, the received signal at the l^{th} relay can be expressed as

$$X_l(t) = \sum_{k=1}^{N_k} h_{k,l} S_k \Pi_k(t) + \eta_l(t) \tag{1}$$

where S_k is the source signal with is transmit power $pow_k = E\{|S_k|^2\}$, $h_{k,l}$ is the complex channel coefficient from k^{th} source to l^{th} relay, $\eta_l(t)$ is the AWGN (Additive white gaussian noise) at the l^{th} relay and $\Pi_k(t) = \pi_k^l(t) + \pi_l^Q(t)$ is the function of combined complex spreading and interleaving operation assigned to k^{th} user. If λ_c is the spreading factor and user specific random interleaver is used at the source, the $\Pi_k(t)$ can be expressed as [9, 13, 18–20]

$$\Pi_k(t) = \pi\Big(\sum_{i=1}^{\lambda_c} c_k[\lambda] S(t - iT_c)\Big) \tag{2}$$

where $k = 1, 2, \dots, N_K$, $c_k[\lambda]$ is the λ^{th} element of spreading sequence and $S(t)$ is the normalized and unit energy chip of duration $T_c = T_0/\lambda_c$. To perform cooperative relay Beamforming the complex weight vector is used at AF relay, which can be given as $W = [w_1, w_2, \dots, w_k]^\top$. The cooperative communication using IDMA network has shown in Fig. 2.

The output signal at the relay from IDMA transmitter can be expressed as $T_x = W^H X_l$. So the received signal at the desired destination node can be given as

$$\begin{aligned} Z_k &= \widetilde{h}^\top T_x + \xi_k = \widetilde{h}^\top W^H X_i + \xi_k \\ &= \widetilde{h}_k^\top W^H \Big(\sum_{k=1}^{N_k} h_{k,l} S_k \Pi_k(t) + \eta_l(t)\Big) + \xi_k. \end{aligned} \tag{3}$$

In vector form the signal can be rewritten as

$$\begin{aligned} Z_k &= \\ &\widetilde{h}_k^\top W^H \sum_{k=1}^{N_k} h_{k,l} S_k \Pi_k + \widetilde{h}^\top W^H \eta_l + \xi_k = \widetilde{h}_p^\top W^H h_{p,l} S_p \Pi_p \\ &+ \widetilde{h}_k^\top W^H \sum_{k=1,\, k\neq p}^{N_k} h_{k,l} S_k \Pi_k + \big(\widetilde{h}_k^\top W^H \eta_l + \xi_k\big) \end{aligned} \tag{4}$$

where $\widetilde{h}_{l,k}$ is the channel coefficient between l^{th} relay and k^{th} destination and ξ_k is the noise vector between dedicated relay and destination node. Above equation (4) gives the desired received signal having three main components *ie* signal, interference and total noise. Assume P_{RT} is the total transmitting relay's power, ϕ^{th} as SINR (signal to interference noise ratio) threshold and SINR at the desired k^{th} destination is Γ_k. Further $P_{k,X}$, $P_{k,I}$ and $P_{k,n}$ are the signal, interference and noise power respectively at the destination [21–24].

3 Relay beamforming optimization

In this section, the purpose is to design an optimal beamforming vector $\omega_r|_{r=1}^{N_r}$ on the basis of relay power constraints *ie* to design a relay precoding matrix by minimizing the transmitted power from relays in IDMA network [4] and [18–25], while the SINR indicating towards QoS should be maintained above a certain predefined threshold value. Hence the optimization problem can be described as

$$\min P_{RT} \quad st \quad \Gamma_k \geq \varphi^{\text{th}}. \tag{5}$$

Here P_{RT} is the total transmitted power and ϕ^{th} is predefined SINR threshold. Further the value of SINR can be written as $SINR = P_{kX}/P_{kI} + P_{kn}$. Here $P_{k,X}$, $P_{k,I}$ and $P_{k,n}$ are the required signal, interference and noise power. The total transmit relay power can be expressed as

$$\begin{aligned} P_{\text{tot}} = E\{T_x T_x^H\} &= E\{X^H W W^H X\} \\ &= \operatorname{tr}\big(W^H E\{XX^H\}W\big) = W^H \mathbb{C} W. \end{aligned} \tag{6}$$

With reference to equation (6) the noise power can be calculated as

$$\begin{aligned} P_{k,n} &= E\{\eta_l^H W \widetilde{h}_k^* \widetilde{h}_k^\top W^H \eta_l\} + \sigma_n^2 \\ &= \operatorname{tr}\big(W^H E\{\eta_l^H \eta_l\} W E\{\widetilde{h}_k^* \widetilde{h}_k^\top\}\big) + \sigma_n^2 \\ &= \sigma_\eta^2 \operatorname{tr}\big(W^H R_h^k W\big) + \sigma_n^2 \end{aligned} \tag{7}$$

where R_h^k is the correlation matrix, which can be written as $R_h^k = E\{\widetilde{h}_k^* \widetilde{h}_k^\top\}$. Now the noise power in the matrix form can be rewritten as follows

$$\sigma_\eta^2 \sum_{r=1}^{N_R} \|W_r|^2 [R_h^k]_{r\times r} + \sigma_n^2 = W^H \mathbb{Z}_k W + \sigma_n^2 \tag{8}$$

where $\mathbb{Z}_k = \sigma_\eta^2 \operatorname{diag}\{[R_h^k]_{11}, [R_h^k]_{22}, \ldots, [R_h^k]_{rr}\}$.

Further, with the help of (4) the required signal power component can be further illustrated. First consider that matched filter receiver is used at a destination node [26–29]. So, to receive complete information, the de-spreading and de-interleaving operating is being processed and for this the received signal component has been multiplied by a combined de-spreading and de-interleaving function denoted as $\pi_k^*(T_0 - t)$. So the estimated signal component can be written as

$$\widetilde{h}_k^\top W^H h_{p,l} S_p \pi_p \times \pi_p^*(T_0 - t) = H_K W^H \widehat{S}_p. \tag{9}$$

The desired signal power can be written as

$$\begin{aligned} E\{H_K^\top W^H \widehat{S}_p H_K W \widehat{S}_p^*\} &= \operatorname{tr}(W^H E\{H_K^\top H_K\} W) E\{|S|^2\} \\ &= P_s \operatorname{tr}(W^H R_H^k W) = W^H R_H^k W. \end{aligned} \tag{10}$$

Further the interference power can be simplified as

$$P_{\text{int}} = W^H Q_k W \tag{11}$$

where $Q_k = E\{\sum P_p h^p (h^p)^H\} P_p$ is the power of p^{th} source, h^p is the channel coefficient between p^{th} source and the desired destination. Further, the SINR can be written as

$$SINR = \frac{P_{\text{sig}}}{P_{\text{int}} + P_{\text{noise}}}. \tag{12}$$

With the help of above relationships, the optimization problem can reiterate as

$$\min W^H \mathbb{C} W \qquad \text{such that:} \tag{13}$$

$$\begin{aligned} &\frac{W^H R_h^k W}{W^H Q_k W + W^H \mathbb{Z}_k} W + \sigma^2 \geq \tau\,, \\ &\frac{W^H R_h^k W}{W^H (Q_k + \mathbb{Z}_k) W + \sigma^2} \geq \tau\,. \end{aligned} \tag{14}$$

Although, the above said optimization problem is not convex optimization problem. So here semidefinite relaxation can be used to solve the optimization problem. For this, we can assume $\mathbb{N} = WW^H$. Then the optimization can be further modified as

$$\min \operatorname{tr}(\mathbb{N}C) \qquad \text{such that:} \qquad \operatorname{tr}(\mathbb{Z}\mathbb{N}) \geq \gamma\sigma^2\,. \tag{15}$$

and rank of $\mathbb{C}$ is 1 for all $\mathbb{C} \geq 0$. The rank is also not convex. Hence using semidefinite relaxation above problem can be rewritten as

$$\min \operatorname{tr}(\mathbb{N}C) \quad \text{s.t. } \operatorname{tr}(\mathbb{Z}\mathbb{N}) \geq \gamma\sigma^2 \text{ and } \operatorname{rank}(\mathbb{N}) > 0\,. \tag{16}$$

Now the above optimization problem is a convex and so it can be solved using software such as cvx or SeDuMi. If the solution obtained is of rank one, then this is the optimal solution, otherwise some alternative technique such as randomization can be used [28–31].

4 Simulation results

Here the numerical examples are given to illustrate the performance of proposed system. For the experiments, the noise power at relay and destination node has been considered as 0 dB W. Similarly the threshold SINR at each node is taken as $\gamma_k = \gamma$, $\forall k = 1, 2, 3\ldots$ more specifically, the noise power at relays and destinations node is considered same. *ie* σ^2. In the first simulation experiment, the channel coefficients are known at the relays and destination nodes. The spreading factor $S_L = 4$ and random interleaving scheme is used for IDMA network. Figure 3 shows the simulation result for $N = 4, 5$ (number of relays) and depicts the minimum relay power versus required SINR threshold. This is clear from the simulation experiment that for higher number of sources the

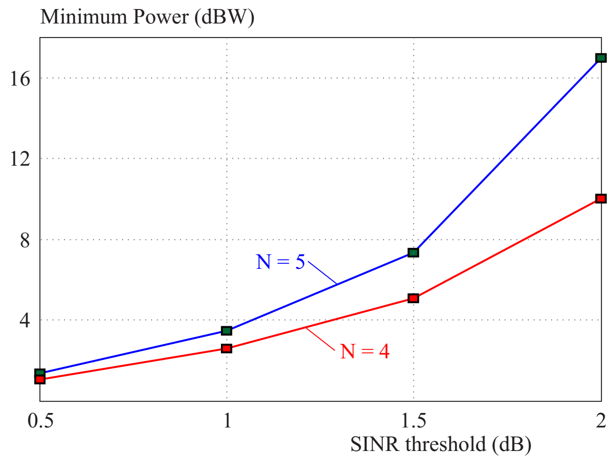

Fig. 3. Normalized average minimum relay transmit power versus SINR threshold γ, for different values of n, $\sigma^2 = 10$ dB

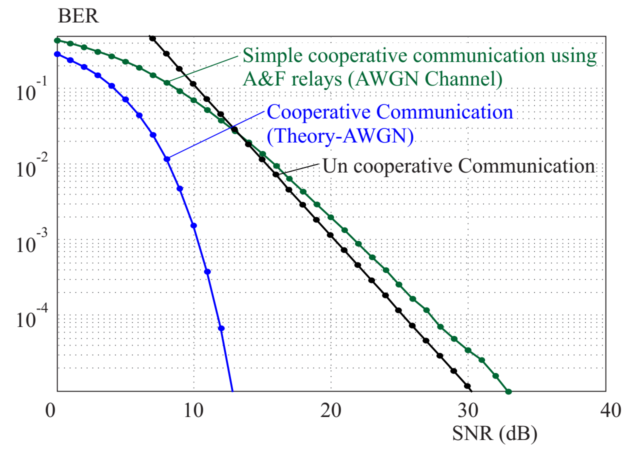

Fig. 4. BER versus SINR (db)for cooperative and uncooperative communication scheme with noise power $\sigma^2 = 10$ dB

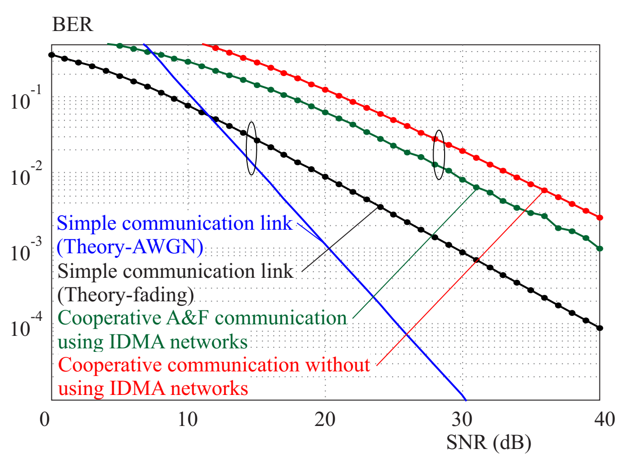

Fig. 5. BER versus $SINR$ (dB) for amplify & forward IDMA relay network for noise power $\sigma^2 = 10$ dB

minimum power requirement is also high and further increment in number of sources or destinations decreases the rank one solution.

In the next simulation experiment, the comparison between cooperative and uncooperative communication scheme has been presented as shown in Fig. 4. The data length 10^5 is taken as well as the AWGN channel is considered and results verify that the BER performance of the system using cooperative communication is somewhat better or near to the theoretical performance of uncooperative scheme.

In the subsequent simulation experiment symbol error rate performance of proposed scheme is presented in Fig. 5. The QPSK modulation is used, data length 10^5 is taken and it can be concluded that as SINR increased, the BER is decreased for a given minimum relay transmit power. The noise power in uplink channel (from source to relay) as well as in down link channel (from relay to destination) is considered same *ie* $\sigma^2 = 10$ dB.

5 Conclusion

A new scheme of peer to peer communication and beamforming weights is obtained using IDMA network. Further the power minimization problem has been formulated for relays as a convex optimization problem. The obtained minimum power is used to transmit the information from relay to destination node. Simulation results in terms of bit error rate has been clearly confirmed the superioriority of proposed scheme in terms of symbol error rate. In this work all relays including source and destination nodes consists single antenna frame work. However MIMO frame work and achievable rate analysis of the proposed scheme can be taken as future work.

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Received 28 May 2018