Zero-Forcing Design of Precoders and Decoders in Multiuser CDMA Cooperative Networks

Chun-Ting Liu, Li-Chung Lo and Wan-Jen Huang
National Sun Yat-sen University, Kaohsiung, Taiwan
E-mail: {m983070018,d973070002}@student.nsysu.edu.tw, wjhuang@faculty.nsysu.edu.tw

***Abstract*—Consider a multiuser cooperative CDMA networks where multiple sources transmit signals toward their respective destinations with assistance of multiple relays. We propose joint designs of precoders at relays and decoders at the destinations to eliminate MAI and improve system performance. Specifically, two sub-optimal designs of precoders are developed to maximize SNR averaged over all users and to maximize SNR of the worst user respectively. It shows through computer simulations that the precoder maximizing average SNR favors the best user, while the precoder maximizing the minimal SNR balances radio usage of relays such that all users can achieve near-optimal diversity order.**

I. Introduction

Cooperative communications [1]–[3] attract significant attention in academia or industrial standards. By allowing relays to forward source user's information, alternative transmission paths are introduced and the set of relays forms a virtual antenna array to combat channel fading effectively. In existing work, cooperating strategies focused mostly on the case with single source/desination pair [3]. If multiple sources would like to leverage the spatial diversity of the cooperative networks, the resource provided by relays was usually allocated in an orthogonal manner over the time domain[4] or frequency domain. However, it takes twice time-slots or bandwidth to accomplish cooperative transmission of each source. To enhance the spectral efficiency, the cooperative strategy that allows relays to forward all sources' symbols over a common channel simultaneously was proposed in [5]. The precoders proposed in [5] is able to eliminate multiple access interference (MAI) among users completely, but it demands a large number of relays to satisfy zero-forcing (ZF) criterion.

In this work, we consider a multiuser cooperative code-division-multiple-access (CDMA) system where L relays assist transmissions of K sources toward respective destinations using a common spreading waveform. Due to imperfect orthogonality among spreading waveforms allocated to source users, signals forwarded by relays and received at the destination are contaminated by MAI. To eliminate MAI and enhance system performance, we proposed two sub-optimal designs of precoders at relays and decoder at destinations in terms of maximal average signal to noise ratio (SNR) of all users and maximal SNR of the worst user, respectively. The former design tends to allocate more radio resource to the users with better channel quality, while the later balances resource usage of relays such that each user has comparable performance. It shows through simulation results that the precoder maximizing average SNR favors the user with best channel quality in terms of diversity gain and coding gain. In precoding scheme maximizing the minimal SNR, all users achieve near-optimal diversity order with penalty of observable coding gain.

II. System Model

In this work, we consider a multiuser CDMA cooperative network where K source users transmit signals simultaneously to their respective destinations with assistant of L relays. For concise notation, we denote the k-th source-destination pair as (S_k, D_k), for $k = 1, 2, \cdots, K$, and denote the ℓ-th relay as R_ℓ, $(\ell = 1, 2, \cdots, L)$. The cooperative transmission is accomplished in two phases. During Phase I, each source, say S_k, transmits signal with power P_{S_k} using an user-specific spreading waveform $s_k(t)$ to its destination. The spreading waveforms $\{s_k(t)\}$ have unit energy and spreading factor N, and are assumed known at all relays and destinations. After receiving signals, destinations first passes the signal through a matched filter bank (MFB) corresponding to $s_1(t), s_2(t), \cdots, s_K(t)$. The MFB output vectors at destination D_i is given by

$$\mathbf{y}_{D_i}^{(1)} = \mathbf{R}\mathbf{H}_{SD_i}\mathbf{x} + \mathbf{n}_{D_i}^{(1)}, \quad (1)$$

where $\mathbf{x} = [x_1, x_2, \cdots, x_K]^T$ is a vector of all source symbols with $\mathrm{E}[\mathbf{x}\mathbf{x}^H] = \mathbf{I}$, $\mathbf{H}_{SD_i} = \mathrm{diag}(\sqrt{P_{S_1}}h_{S_1D_i}, \cdots, \sqrt{P_{S_K}}h_{S_KD_i})$, $h_{S_kD_i}$ is channel coefficient of the S_k-D_i link, $\mathbf{R}$ is correlation matrix of spreading waveforms, and $\mathbf{n}_{D_i}^{(1)}$ is a zero-mean Gaussian noise vector with covariance matrix $\sigma^2\mathbf{R}$. The (m, j)-th element of correlation matrix $\mathbf{R}$ is given by

$$[\mathbf{R}]_{m,j} = \int s_m(t)s_j(t)dt,$$

and assume that the spreading waveforms are not perfectly orthogonal due to practical concerns. Due to broadcasting nature of wireless medium, relays can overhear all source signals. The MFB output vectors at each relay, say R_ℓ, is then given by

$$\mathbf{y}_{R_\ell} = \mathbf{R}\mathbf{H}_{SR_\ell}\mathbf{x} + \mathbf{n}_{R_\ell}, \quad (2)$$

where $\mathbf{H}_{SR_\ell} = \mathrm{diag}(\sqrt{P_{S_1}}h_{S_1R_\ell}, \cdots, \sqrt{P_{S_K}}h_{S_KR_\ell})$, $h_{S_kR_\ell}$ is channel coefficient of the S_k-R_ℓ link, and $\mathbf{n}_{R_\ell}$ is a noise vector with $\mathbf{n}_{R_\ell} \sim \mathcal{CN}(0, \sigma^2\mathbf{R})$.

During Phase II, the relays adopt amplify-forward relaying scheme to assist transmissions of K source-destination pairs. To eliminate MAI of forwarded symbols, relay R_ℓ passes the MFB output $\mathbf{y}_{R_\ell}$ through decorrelating multiuser detector followed by a linear precoder $\mathbf{b}_\ell = [b_{\ell,1},\ b_{\ell,2},\ \cdots,\ b_{\ell,K}]$. The precoded symbol at R_ℓ is given by

$$t_\ell \;=\; \mathbf{b}_\ell \mathbf{R}^{-1} \mathbf{y}_{R_\ell}.$$

During Phase II, each relay forwards the precoded symbol to the destinations using a common spreading waveform $s_r(t)$. After passing the received signal to a matched filter corresponding to $s_r(t)$, each destination, say D_i, obtains an output symbol given by

$$y_{D_i}^{(2)} = \sum_{\ell=1}^{L} h_{R_\ell D_i} t_\ell + n_{D_i}^{(2)}, \tag{3}$$

where $h_{R_\ell D_i}$ is channel coefficient of the R_ℓ-D_i link, and $n_{D_i}^{(2)}$ is zero-mean Gaussian noise with variance σ^2. The destination D_i the proceeds to demodulate source symbol of interest x_i based on received symbols in $\mathbf{y}_{D_i}^{(1)}$ and $y_{D_i}^{(2)}$. To eliminate MAI, the MFB output $\mathbf{y}_{D_i}^{(1)}$ is first multiplied by a decorrelating matrix $\mathbf{R}^{-1}$ before combining symbols received in both phases through a linear decoder. More specifically, decoder output at the i-th destination is given by

$$z_i = \mathbf{c}_i^{(1)} \mathbf{R}^{-1} \mathbf{y}_{D_i}^{(1)} + c_{i,K+1} y_{D_i}^{(2)}, \tag{4}$$

where $\mathbf{c}_i^{(1)} = [c_{i,1}, c_{i,2}, \ldots, c_{i,K}]$ and $c_{i,K+1}$ are coefficients of decoder at destination D_i. The destination D_i can demodulate source symbol x_i from z_i. In this work, we assume that global channel information is known, and the set of precoders at relays and decoders at destinations is optimized to eliminate MAI as well as to maximize SNR of z_i.

III. Zero-Forcing Design of Precoders and Decoders

A. Design of Zero-Forcing Decoders

Substituting (1) and (3) into (4), the decoder output z_i can be re-written by

$$\begin{aligned} z_i = {} & \sqrt{P_{S_i}} \left(c_{i,i} h_{S_i D_i} + c_{i,K+1} \sum_{\ell=1}^{L} \tilde{h}_{i\ell i} b_{\ell,i} \right) x_i \\ & + \sum_{\substack{k=1 \\ k \neq i}}^{K} \sqrt{P_{S_k}} \left(c_{i,k} h_{S_k D_i} + c_{i,K+1} \sum_{\ell=1}^{L} \tilde{h}_{k\ell i} b_{\ell,k} \right) x_k \\ & + c_{i,K+1} \sum_{\ell=1}^{L} \mathbf{b}_\ell \mathbf{R}^{-1} \mathbf{n}_{R_\ell} h_{R_\ell D_i} + \mathbf{c}_i^{(1)} \mathbf{R}^{-1} \mathbf{n}_{D_i}^{(1)} + c_{i,K+1} n_{D_i}^{(2)}, \end{aligned} \tag{5}$$

where $\tilde{h}_{k\ell i} \triangleq h_{S_k R_\ell} h_{R_\ell D_i}$ is the effective coefficient of the composite channel from source S_k to destination D_i through the relay R_ℓ. The first term in (5) is desired for destination D_i, the second term is composed of MAI, and the third term is additive Gaussian noise. To completely eliminate MAI, we introduce zero-forcing (ZF) criterion by forcing the second term to be zero, which can be achieved by setting

$$c_{i,k} = -\frac{\sum_{\ell=1}^{L} \tilde{h}_{k\ell i} b_{\ell,k}}{h_{S_k D_i}} c_{i,K+1},\ \forall k \neq i,\ \forall i. \tag{6}$$

After applying ZF criterion, design of $K+1$ decoder coefficients for destination D_i is now reduced to optimization of $c_{i,i}$ and $c_{i,K+1}$. The SNR at destination D_i is then given by

$$SNR_i = \frac{P_{S_i} \left| c_{i,i} h_{S_i D_i} + c_{i,K+1} \sum_{\ell=1}^{L} \tilde{h}_{i\ell i} b_{\ell,i} \right|^2}{\sigma^2 \left(|c_{i,i}|^2 a_{i,i} + |c_{i,K+1}|^2 \delta_i(\mathbf{b}) \right)}, \tag{7}$$

where $a_{i,j}$ is the (i,j)-th element of $\mathbf{R}^{-1}$, and $\delta_i(\mathbf{b})$ is a function of $\mathbf{b} \triangleq [\mathbf{b}_1, \mathbf{b}_2, \ldots, \mathbf{b}_L]$ given by

$$\begin{aligned} \delta_i(\mathbf{b}) = {} & 1 + \sum_{\ell=1}^{L} \sum_{k=1}^{K} \sum_{j=1}^{K} b_{\ell,k} a_{k,j} b_{\ell,j}^* \left| h_{R_\ell D_i} \right|^2 \\ & + \sum_{\substack{k=1 \\ k \neq i}}^{K} \sum_{\substack{j=1 \\ j \neq i}}^{K} \frac{a_{k,j}}{h_{S_k D_i} h_{S_j D_i}^*} \sum_{\ell=1}^{L} \tilde{h}_{k\ell i} b_{\ell,k} \sum_{\ell'=1}^{L} \tilde{h}_{j\ell' i}^* b_{\ell',j}^* \end{aligned}$$

Let $\bar{\mathbf{c}}_i \triangleq [c_{i,i}, c_{i,K+1}]$, the value of SNR in (7) can be further simplified by

$$SNR_i = \frac{P_{S_i}}{\sigma^2} \frac{|\mathbf{u}_i(\mathbf{b}) \bar{\mathbf{c}}_i|^2}{\bar{\mathbf{c}}_i^H \mathbf{N}_i(\mathbf{b}) \bar{\mathbf{c}}_i}, \tag{8}$$

where $\mathbf{u}_i(\mathbf{b}) = \left[h_{S_i D_i}, \sum_{\ell=1}^{L} \tilde{h}_{i\ell i} b_{\ell,i} \right]$ and $\mathbf{N}_i(\mathbf{b}) = \mathrm{diag}(1, \delta_i(\mathbf{b}))$ are functions of precoding vector $\mathbf{b}$.

It is worthwhile noting that the received SNR at destination D_i depends on the joint precoding vector $\mathbf{b}$ and respective decoding coefficients in $\bar{\mathbf{c}}_i$, rather than decoding coefficients regarding other destinations $\bar{\mathbf{c}}_j$, $j \neq i$. To maximize received SNR at each destination, the first step is to determine optimum solution of $\bar{\mathbf{c}}_i$ $(i = 1, 2, \cdots, K)$, which can be written as

$$\begin{aligned} \bar{\mathbf{c}}_i^{\text{opt}} &= \arg\max_{\bar{\mathbf{c}}_i} \frac{|\mathbf{u}_i(\mathbf{b}) \bar{\mathbf{c}}_i|^2}{\bar{\mathbf{c}}_i^H \mathbf{N}_i(\mathbf{b}) \bar{\mathbf{c}}_i} \\ &= \alpha_i \mathbf{N}_i^{-1}(\mathbf{b}) \mathbf{u}_i^H(\mathbf{b}), \end{aligned} \tag{9}$$

where α_i is arbitrary nonzero constant. The resulting maximal received SNR at destination D_i is now given by

$$\begin{aligned} SNR_i &= \frac{P_{S_i}}{\sigma^2} \mathbf{u}_i^H(\mathbf{b}) \mathbf{N}_i^{-1} \mathbf{u}_i(\mathbf{b}) \\ &= \frac{P_{S_i} |h_{S_i D_i}|^2}{\sigma^2} + \frac{P_{S_i}}{\sigma^2 \delta_i(\mathbf{b})} \left| \sum_{\ell=1}^{L} \tilde{h}_{i\ell i} b_{\ell,i} \right|^2. \end{aligned} \tag{10}$$

The first term in (10) is contributed by direct link between source S_i and Destination D_i, while the second term is resulted from relays' assistance and depends on the precoder $\mathbf{b}$. In the remaining part of this section, we will investigate two precoder designs to maximize average SNR of all users and maximize SNR of the worst user respectively.

B. Precoder Design to Maximize Average SNR

In this section, we will develop sub-optimal design to maximize average SNR of all users subject to satisfying aggregate power constraint at all relays. The optimum precoder maximizing SNR is can be written by

$$\begin{aligned}\mathbf{b}_{\text{opt}} &= \arg\max_{\mathbf{b}} \frac{1}{N}\sum_{i=1}^{K} SNR_i \\ &= \arg\max_{\mathbf{b}} \sum_{i=1}^{K} \frac{P_{S_i}}{\delta_i(\mathbf{b})}\left|\sum_{\ell=1}^{L}\tilde{h}_{i\ell i} b_{\ell,i}\right|^2, \end{aligned} \tag{11}$$

where the value of $\mathbf{b}$ must satisfy power constraint given by

$$\sum_{\ell=1}^{L}\mathbf{E}\left[|t_\ell|^2\right] = \mathbf{b}\mathbf{R}_y\mathbf{b}^H \le P_{R,T}, \tag{12}$$

where $\mathbf{R}_y = \text{diag}(\mathbf{R}_{y,1}, \mathbf{R}_{y,2}, \cdots, \mathbf{R}_{y,L})$ is a $LK \times LK$ block diagonal matrix and $\mathbf{R}_{y,\ell} = \mathbf{H}_{SR_\ell}\mathbf{H}_{SR_\ell}^H + \sigma^2\mathbf{R}^{-1}$ is correlation matrix of $\mathbf{R}^{-1}\mathbf{y}_{R_\ell}$. However, the optimal solution in (11) is intractable since the denominator terms $\delta_i(\mathbf{b})$ are different for all i. In this work, we adopt an alternative criterion to maximize the ratio of desired signal power summed over all users to the power of noises at all destination. The suboptimal precoder can be written by

$$\begin{aligned}\mathbf{b}_{\text{subopt}} &= \arg\max_{\mathbf{b}} \frac{\sum_{i=1}^{K} P_{S_i}\left|\sum_{\ell=1}^{L}\tilde{h}_{i\ell i} b_{\ell,i}\right|^2}{\sum_{i=1}^{K}\delta_i(\mathbf{b})} \\ &= \arg\max_{\mathbf{b}} \frac{\mathbf{b}\mathbf{Z}\mathbf{b}^H}{K + \mathbf{b}\mathbf{Q}\mathbf{b}^H + \mathbf{b}\mathbf{U}\mathbf{b}^H},, \end{aligned} \tag{13}$$

where $\mathbf{Z}$ is a $LK \times LK$ block matrix with the (ℓ, ℓ')-th block $(\ell, \ell' = 1, 2, \cdots, L)$ being $\mathbf{Z}_{\ell\ell'} = \text{diag}(P_{S_1}\tilde{h}_{1\ell 1}\tilde{h}^*_{1\ell' 1}, P_{S_2}\tilde{h}_{2\ell 2}\tilde{h}^*_{2\ell' 2}, \cdots, P_{S_K}\tilde{h}_{K\ell K}\tilde{h}^*_{K\ell' K})$, $\mathbf{Q}$ is a $LK\times LK$ block diagonal matrix with the (i,j)-th element $(i, j = 1, 2, \cdots, K)$ of the ℓ-th diagonal block$(\ell = 1, 2, \cdots, L)$ being $[\mathbf{Q}_{\ell,\ell}]_{i,j} = a_{ij}\sum_{k=1}^{K}|h_{R_\ell D_k}|^2$, and $\mathbf{U}$ is a $LK\times LK$ block matrix where the (i, j)-th element of the (ℓ, ℓ')-th block is

$$[\mathbf{U}_{\ell\ell'}]_{ij} = \sum_{\substack{k=1\\k\neq i,j}}^{K} \frac{\tilde{h}_{i\ell k}\tilde{h}^*_{j\ell' k} a_{ij}}{h_{S_i D_k} h^*_{S_j D_k}}.$$

After manipulation, the suboptimal solution of precoder equals

$$\mathbf{b}_{\text{subopt}} = \sqrt{\frac{P_{RT}}{\mathbf{v}_{\max}^H\mathbf{P}^{-\frac{1}{2}}\mathbf{R}_y\mathbf{P}^{-\frac{H}{2}}\mathbf{v}_{\max}}} \cdot \mathbf{v}_{\max}^H\mathbf{P}^{-\frac{1}{2}}, \tag{14}$$

where $\mathbf{P} = \frac{K}{P_{RT}}\mathbf{R}_y + \mathbf{Q} + \mathbf{U}$, $\mathbf{v}_{\max}$ is the eigenvector of $\mathbf{P}^{-\frac{1}{2}}\mathbf{Z}\mathbf{P}^{-\frac{H}{2}}$ corresponding to the maximum eigenvalue.

C. Precoder Design to Maximize SNR of the Worst User

The precoder in (14) is designed to maximize the average SNR, which tends to allocate more power to the user pair with better channel quality. If fairness is a major concern of the cooperative system, the precoding vector can be designed to maximize received SNR for the worst user, i.e.,

$$\begin{aligned}\mathbf{b}_{\text{opt}} &= \arg\max_{\mathbf{b}}\min_{i} SNR_i \\ &= \arg\max_{\mathbf{b}}\min_{i} \frac{P_{S_i}}{\delta_i(\mathbf{b})}\left|\sum_{\ell=1}^{L}\tilde{h}_{i\ell i} b_{\ell,i}\right|^2. \end{aligned} \tag{15}$$

The optimization problem can be expressed as follows

$$\begin{aligned} &\max_{\mathbf{b},t}\, t \\ &\text{s.t. } \frac{P_{S_i}}{\delta_i(\mathbf{b})}\left|\sum_{\ell=1}^{L}\tilde{h}_{i\ell i} b_{\ell,i}\right|^2 \ge t,\ \forall i, \\ &\quad \mathbf{b}\mathbf{R}_y\mathbf{b} \le P_{RT}. \end{aligned} \tag{16}$$

Nevertheless, it is difficult to find a solution of optimization problem in (16). Since the precoder design is to maximize the minimum SNR value of all users, we propose a sub-optimal solution composed of vectors which are optimal respectively to user pairs. More specifically, let

$$\mathbf{b} = \sum_{k=1}^{K}\omega_k\mathbf{b}_{\text{opt},k}, \tag{17}$$

where

$$\begin{aligned}\mathbf{b}_{\text{opt},k} &= \arg\max_{\mathbf{b}} \frac{P_{S_k}}{\delta_k(\mathbf{b})}\left|\sum_{\ell=1}^{L}\tilde{h}_{k\ell k} b_{\ell,k}\right|^2 \\ &= \arg\max_{\mathbf{b}} \frac{\mathbf{b}\mathbf{Z}_k\mathbf{b}^H}{1 + \mathbf{b}\mathbf{Q}_k\mathbf{b}^H + \mathbf{b}\mathbf{U}_k\mathbf{b}^H} \end{aligned} \tag{18}$$

is the optimal precoder maximizing SNR of user i, $\mathbf{Z}_k$ is a $LK \times LK$ block matrix with the (ℓ, ℓ')-th block being $\mathbf{Z}_{\ell\ell'} = \text{diag}(0, 0, \cdots, P_{S_k}\tilde{h}_{k\ell k}\tilde{h}^*_{k\ell' k}, \cdots, 0)$, $\mathbf{Q}_k$ is a $LK\times LK$ block diagonal matrix with the ℓ-th diagonal block being $|h_{R_\ell D_k}|^2\mathbf{R}^{-1}$, $\mathbf{U}_k$ is a $LK\times LK$ block matrix where the (i, j)-th element of the (ℓ, ℓ')-th block is $\frac{\tilde{h}_{i\ell k}\tilde{h}^*_{j\ell' k}a_{ij}}{h_{S_i D_k}h^*_{S_j D_k}}$, if $i \neq j$ and 0 if $i = j$. After algebraic manipulation, solution of $\mathbf{b}_{\text{opt},k}$ equals

$$\mathbf{b}_{\text{opt},k} = \beta_k\mathbf{v}_{\max,k}^H\mathbf{P}_k^{-\frac{1}{2}}, \tag{19}$$

where $\mathbf{P}_k = \frac{1}{P_{RT}}\mathbf{R}_y + \mathbf{Q}_k + \mathbf{U}_k$, $\mathbf{v}_{\max,k}$ is the eigenvector of $\mathbf{P}_k^{-\frac{1}{2}}\mathbf{Z}_k\mathbf{P}_k^{-\frac{H}{2}}$ corresponding to the maximum eigenvalue, β_k is a constant. Without loss of generality, we set $\beta_k = 1$. The suboptimal design of precoding vector can be rewritten by

$$\begin{aligned} &\max_{\{\omega_k\},t}\, t \\ &\text{s.t. } \mathbf{b} = \sum_{k=1}^{K}\omega_k\mathbf{b}_{opt,k}, \\ &\quad \frac{P_{S_i}}{\delta_i(\mathbf{b})}\left|\sum_{\ell=1}^{L}\tilde{h}_{i\ell i} b_{\ell,i}\right|^2 \ge t,\ \forall i \\ &\quad \mathbf{b}\mathbf{R}_y\mathbf{b} \le P_{RT}. \end{aligned} \tag{20}$$

The optimal values of $\{\omega_k\}$ can be obtained numerically.

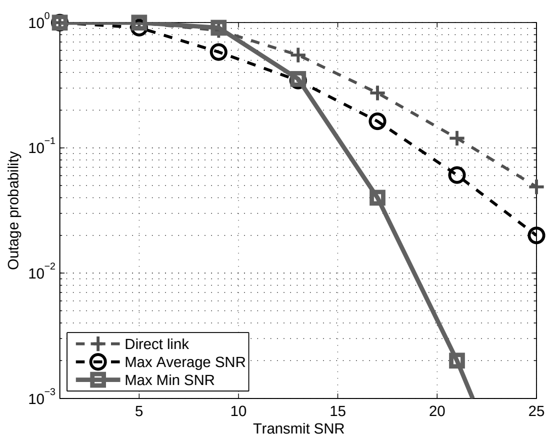

Fig. 1. Comparison of average outage performances for $K = 2$ and $L = 2$

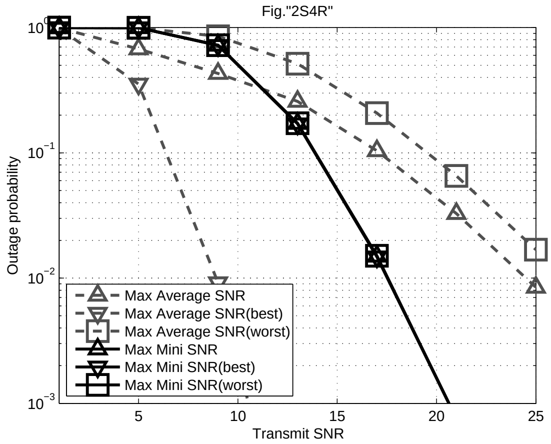

Fig. 2. Comparison of outage probabilities for $K = 2$ and $L = 4$

IV. Computer Simulations

In this section, outage performance of proposed scheme is demonstrated through Monte Carlo simulations. In the following simulations, assume that the transmission rate of each source user is set as $R = 1$, and all channels are Rayleigh fading with unit gain. Transmission power of each source is set as $P_{S_k} = P/K$, and total transmission power of relays is $P_{RT=}P$. In Fig.1, average outage performance of the proposed schemes in terms of $\mathtt{SNR} = P/\sigma^2$ is compared with direct transmission scheme for cooperative systems with $K = 2$ users and $L = 2$ relays. In direct transmission scheme, transmission power of eah source is $2P/K$ for fariness. The outage probability of the i-th user using direct transmission is

$$P_{out,i} = \Pr\{\log_2(1 + SNR_i) < R\},$$

where SNR_i is the received SNR at destination D_i over direct transmission channel. In our proposed schemes, $K+1$ spreading waveforms is ultilized to serve K user pairs, thus, outage probability of the proposed scheme can be written as

$$P_{out,i} = \Pr\left\{\frac{K}{K+1}\log_2(1 + SNR_i) < R\right\}.$$

It shows that the precoder maximizing SNR of the worst user outperforms and achieve higher diversity order in average. The average outage performance of the precoder maximizing average SNR is dominated by the worst user pair at high SNR since most radio resource is allocated to the user pair with better channel quality. Nevertheless, it still outperforms direct transmission by 3 dB. To gain more insight on resource allocation among two user-pairs, Fig.2 demonstrates outage probabilities of the best user and the worst user and average outage probability for $K = 2$ users and $L = 4$ relays. In precoding scheme that maximizes average SNR, the best user attains the best outage performance with penalty of diversity gain attained by the other user. It also shows that both users is able to achieve diversity gain with precoders maximizing the minimum SNR.

V. Conclusions

We proposed joint designs of precoders at relays and decoders at destinations to eliminate MAI and enhance system performance in multiuser cooperative CDMA networks. Simulation shows that the precoder maximizing average SNR allocates most radio resource to the best user, while precoder that maximizes the minimal SNR allows all users to have comparable performances.

Acknowledgment

This research was supported in part by the National Science Council, Taiwan, under grant NSC-100-2221-E-110-062.

References

[1] A. Sendonaris, E. Erkip, and B. Aazhang, "User cooperation diversity – Part I: System description," *IEEE Trans. Commun.*, vol. 51, no. 11, pp. 1927–1938, Nov. 2003.

[2] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, "Cooperative diversity in wireless networks: efficient protocols and outage behavior," *IEEE Trans. Inform. Theory*, vol. 50, no.12, Dec. 2004.

[3] Y.-W. Hong, W.-J. Huang, F.-H. Chiu, and C.-C. J. Kuo, "Cooperative communications in resource-constrained wireless networks," *IEEE Signal Processing Mag.*, vol. 24, no. 3, pp. 47–57, May 2007.

[4] I. Hammerstrom, M. Kuhn and A. Wittneben, "Channel adaptive scheduling for cooperative relay networks," in *Proc. of IEEE Veh. Tech. Conf. (VTC Fall)*, Sep. 2004

[5] C. Esli, S. Berger and A. Wittneben, "Optimizing zero-forcing based gain allocation for wireless multiuser networks," in *Proc. of IEEE Intl. Conf. on Communications (ICC)*, Jun. 2007

[6] C.-P. Zhao, W.-J. Huang and T.-Y. Wang, "Optimal zero-forcing design of precoders and decoders for multiuser cooperative networks," in *Proc. of IEEE Intl. Symp. on Broadband Multimedia Systems and Broadcasting (BMSB)*, Mar. 2010