Joint Beamforming and Precoding in TD-SCDMA Downlink System

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Abstract: In this paper, beamforming and precoding is combined to improve the performance of TD-SCDMA downlink based on MIMO (Multiple-Input-Multiple-Output). We deduced beamforming vector and precoding matrix combined beamforming and precoding. And then, we compared beamforming scheme based signal-to-interference-plus-noise ratio (SINR) and based signal-to-leakage-plus-noise ratio (SLNR) in TD-SCDMA Downlink System. The performance of scheme with precoding based on SINR and SLNR outperform than the scheme without precoding. As the user number or the number of receive antenna increase, the beamforming scheme with precoding outperform the traditional beamforming still, and the beamforming precoding based on SLNR is superior gradually to the beamforming precoding based on SINR.

1. Introduction

In multi-user downlink communications, a base station communicates with several co-channel users in the same frequency and time slots. It is therefore necessary to rely on transmission schemes that are able to suppress inter symbol interference (ISI) and multiple access interference (MAI). In TD-SCDMA, it is combined smart antenna at BS with joint detection technology at MS to eliminate those interferences, but the mobile terminal (MT) is expensive inevitably for its high computation and implement complex. Precoding scheme [2-5] was proposed, which can observably reduce the computation and the complexity of mobile station, especially in TD-SCDMA downlink based MIMO[3].

Beamforming forms a signal that the best combined or distributed the base band signal under the system of performance indicator [1,6], thereby, raising carrier to interference ratio of the expectations of users and avoid interference to other users. However, the antenna arrays maintain light load, the optimal array collapses the signal from the interference direction. In limited circumstances, with the number of interference users has become much, arrays continue to beamforming for expected users, but the ability of the antenna array collapse the interference signal sharp decline. With the array overload, power of all interference signals out from array has been greatly increased. On the other hand, complexity and the number of antenna restrictions, making the width of the main beam often be 10 degrees or even greater , In such a coverage of the main beam, there are often multiple users, and lead to multi-user interference. Recently, we have found that joint beamforming and precoding technologies can not only overcome the above problems, but also can improve the reliability and channel capacity.

The paper is structured as follows. The multi-user MIMO downlink system model is introduced in section 2. Section 3 derives beamforming weighted vector based on SINR and SLNR algorithms. Precoded matrix based on combination of beamforming and precoding is deduced in section 4. Simulations the performance of this scheme in the TD-SCDMA downlink based on MIMO is given in Section 5.

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2. System Model

An array of K_B transmit antenna elements on BS is considered, and at each MT $\mu_k, k=1,...,K$, an array of K_M receive antenna elements are arranged, where K is the number of MTs (i.e. users). Figure 1 shows the multi-user MIMO downlink model.

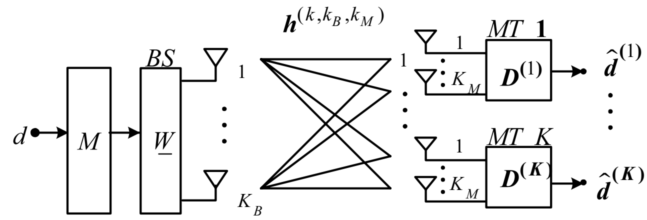

Figure 1. The multi-user MIMO downlink model

It is assumed that N data symbols have to be transmitted from BS to each MS μ_k , K data vectors for all the MS are put together to form the total data vector[4]:

$$\boldsymbol{d}^{(k)} = (\boldsymbol{d}_1^{(k)} \cdots \boldsymbol{d}_N^{(k)})^T \qquad k = 1,\cdots,K \tag{1}$$

Total data vector have to be transmitted to K MT

$$\boldsymbol{d} = (\boldsymbol{d}^{(1)^T} \cdots \boldsymbol{d}^{(K)^T})^T = (\boldsymbol{d}_1 \cdots \boldsymbol{d}_{KN})^T \tag{2}$$

The data vector d of length KN is linearly modulated and mapped into a $K_B S\times 1$ spatial spread signal t .

$$\boldsymbol{t} = (\boldsymbol{t}^{(1)^T} \cdots \boldsymbol{t}^{(K_B)^T}) = (\boldsymbol{t}_1 \cdots \boldsymbol{t}_{K_B S})^T = \boldsymbol{Md} \tag{3}$$

$S = NS_0$, S_0 is termed spread factor, and M is $K_B S \times KN$ modulation matrix. The $S\times 1$ spatial signal $\boldsymbol{t}^{(k_B)}$ is transmitted by the k_B transmit antenna.

The frequency selective channel impulse responses between k_B transmit antennas at the BS and k_M receive antennas of k MTs μ_k .

$$\boldsymbol{h}^{(k,k_B,k_M)} = (\boldsymbol{h}_1^{(k,k_B,k_M)} \cdots \boldsymbol{h}_W^{(k,k_B,k_M)})^T \tag{4}$$

Therefore we can obtain a channel convolution matrix by $(S+W-1)\times S$

$$\boldsymbol{H}^{(k,k_B,k_M)} = (\boldsymbol{H}_{i,j}^{k,k_B,k_M}) \qquad i = 1,\cdots S+W-1;\ \ j = 1,\cdots,S \tag{5}$$

$$H_{i,j}^{(k,k_B,k_M)} = \begin{cases} h_{i-j+1}^{(k,k_B,k_M)} & , \quad 1 \le i-j+1 \le W \\ 0 & , \quad \text{else} \end{cases} \tag{6}$$

$k = 1,\cdots K;\ k_B = 1,\cdots,K_B;\ k_M = 1,\cdots,K_M$

Then, in the case of absence of disturbing noise at the receiver inputs, the K user received signals $\boldsymbol{r}^{(k)}$ (k=1, … , K) weighted by beamforming vector of each user are to form the total received signal of dimension $KK_M(S+W-1)\times 1$

$$\boldsymbol{r} = (\boldsymbol{r}^{(1)^{\mathrm{T}}} \cdots \boldsymbol{r}^{(K)^{\mathrm{T}}})^{\mathrm{T}} = \boldsymbol{H}\underline{\boldsymbol{W}}\boldsymbol{t} \tag{7}$$

We assume no noise at the receiver inputs, at each MT μ_k the corresponding received signal $\boldsymbol{r}^{(k)}$ is demodulated with the goal to obtain the corresponding data vector $\boldsymbol{d}^{(k)}$. In the case of a linear demodulator the demodulation process at MT μ_k can be described by a demodulator matrix $\boldsymbol{D}^{(k)}$

$$\boldsymbol{d}^{(k)} = \boldsymbol{D}^{(k)}\boldsymbol{r}^{(k)}, k = 1,\cdots,K \tag{8}$$

The data vector $\boldsymbol{d}^{(k)}$ of (1) intended for MT μ_k is detected without ISI and MAI.

We assume $\boldsymbol{D}^{(k)} = \boldsymbol{C}^{(k)^H}$, $\boldsymbol{C}^{(k)}$ is termed spread code matrix, which is composed of user μ_k CDMA spread code

$$\boldsymbol{c}^{(k)} = (\boldsymbol{c}_1^{(k)} \cdots \boldsymbol{c}_{S_0}^{(k)})^T \tag{9}$$

$$\boldsymbol{C}^{(k)} = [\boldsymbol{C}^{(k,1)^{\boldsymbol{H}}} \cdots \boldsymbol{C}^{(k,K_M)^{\boldsymbol{H}}}]^{\boldsymbol{H}} \tag{10}$$

Here, $\boldsymbol{C}^{(k,k_M)}$ is correspond to the sub spread code matrix of use μ_k k_M $(k_M = 1,\cdots,K_M)$ receive antenna and is equal with each other. The total spread code matrices of K user is

$$\boldsymbol{C} = blockdiag[\boldsymbol{C}^{(1)} \cdots \boldsymbol{C}^{(K)}] \tag{11}$$

So we obtain the total demodulator matrices

$$\boldsymbol{D} = \boldsymbol{C}^{\boldsymbol{H}}, \boldsymbol{D} = blockdiag[\boldsymbol{D}^{(1)} \cdots \boldsymbol{D}^{(K)}] \tag{12}$$

With (12) we can stack the K equations of (8) and obtain under consideration of (7) the single equation

$$\boldsymbol{d} = \boldsymbol{Dr} = \boldsymbol{DHt} \tag{13}$$

If we assume $\boldsymbol{B} = \boldsymbol{DH}$, we will obtain the data vector

$$\boldsymbol{d} = \boldsymbol{Bt} = \boldsymbol{C}^H\boldsymbol{Ht} = \boldsymbol{C}^H\boldsymbol{H}\underline{\boldsymbol{W}}\boldsymbol{Md} \tag{14}$$

Taking noise into account, the received signal $\boldsymbol{r}$ will be disturbed by additive noise $\boldsymbol{n}$ of dimension $KK_M(S+W-1)\times 1$

$$\boldsymbol{n} = (\boldsymbol{n}_1 \cdots \boldsymbol{n}_{KK_M(S+W-1)})^{\boldsymbol{T}} \tag{15}$$

After demodulation, we can obtain the estimated data

$$\hat{\boldsymbol{d}} = \boldsymbol{D}[\boldsymbol{r}+\boldsymbol{n}] = \boldsymbol{D}[\boldsymbol{H}\underline{\boldsymbol{W}}\boldsymbol{Md}+\boldsymbol{n}] = \boldsymbol{d} + \boldsymbol{Dn} \tag{16}$$

If the dimension K_BS of $\boldsymbol{t}$ is chosen larger than the dimension KN of $\boldsymbol{d}$ and if $\boldsymbol{B}$ has maximum rank, i.e. if $rank\boldsymbol{B} = KN < K_BS$ holds, then transmit signal $\boldsymbol{t}$ will exist a lot of solutions.

3. Beamforming Vector

The beamforming technique for MIMO systems simultaneously obtains downlink multi-user diversity gain and array gain. In this paper, we discuss two eigen beamforming techniques based on SINR and SLNR respectively.

3.1 Beamforming vector based SINR

It is assumed that each channel matrix $\boldsymbol{H}_k$ is available at the base station and at the corresponding user, but is not required to be known by the other users. We add noise at the receiver inputs, we rewrite (7) as

$$\boldsymbol{r}_k = \boldsymbol{H}_k\boldsymbol{w}_k\boldsymbol{t}_k + \sum_{i=1,i\neq k}^{K} \boldsymbol{H}_k\boldsymbol{w}_i\boldsymbol{t}_i + \boldsymbol{n} \tag{17}$$

where the second term is the CCI caused by the multi-user nature of the system.

The signal-to-interference-plus-noise ratio (SINR) at the input of the receiver is defined as [1], [6]

$$\mathrm{SINR}_k = \frac{\|\boldsymbol{H}_k\boldsymbol{w}_k\|}{K_M\sigma_K^2 + \sum_{i=1,i\neq k}^{K}\boldsymbol{H}_k\boldsymbol{w}_i} \tag{18}$$

Using the SINR expression as an optimization criterion

$$\boldsymbol{w}_k = \arg\max_{\boldsymbol{w}_k} \frac{\|\boldsymbol{H}_k\boldsymbol{w}_k\|}{K_M\sigma_K^2 + \sum_{i=1,i\neq k}^{K}\boldsymbol{H}_k\boldsymbol{w}_i} \tag{19}$$

Thus, the beamforming vectors is given by[6]

$$\boldsymbol{w}_k \propto \text{max eigenvector}(\boldsymbol{H}^{\mathrm{H}}\boldsymbol{H}) \tag{20}$$

3.2 Beamforming vector based SLNR

The following is a summary of the leakage-based solution from [7], [8].Start from (20) and note that the power of the desired signal component for user *k* is given by$\|\boldsymbol{H}_k\boldsymbol{w}_k\|^2$. At the same time, the power of the interference that is caused by user *k* on the signal received by some other user *i* is given by $\|\boldsymbol{H}_i\boldsymbol{w}_k\|^2$. We thus define a quantity, called leakage for user *i*, as the total power leaked from this user to all other users

$$\sum_{i=1,i\neq k}^{K}\boldsymbol{H}_i\boldsymbol{w}_k$$

The signal-to-leakage-plus-noise ratio (SLNR) at the input of the receiver is given by[7]

$$\mathrm{SLNR}_k = \frac{\|\boldsymbol{H}_k\boldsymbol{w}_k\|}{K_M\sigma_K^2 + \sum_{i=1,i\neq k}^{K}\boldsymbol{H}_i\boldsymbol{w}_k} \tag{21}$$

Using this concept of leakage, we have formulated in [8] the following decoupled optimization problem:

$$\boldsymbol{w}_k = \arg\max_{\boldsymbol{w}_k} \frac{\|\boldsymbol{H}_k\boldsymbol{w}_k\|}{K_M\sigma_K^2 + \sum_{i=1,i\neq k}^{K}\boldsymbol{H}_i\boldsymbol{w}_k} \tag{22}$$

It was shown in [8] that the solution is given by

$$\boldsymbol{w}_k \propto \text{max eigenvector}((K_M\sigma_k\boldsymbol{I} + \tilde{\boldsymbol{H}}_k^H\tilde{\boldsymbol{H}}_k)^{-1}(\boldsymbol{H}^H\boldsymbol{H}))$$

(23)

where

$$\tilde{\boldsymbol{H}}_k = [\tilde{\boldsymbol{H}}^H \cdots \tilde{\boldsymbol{H}}_{k-1}^H\tilde{\boldsymbol{H}}_{k+1}^H \cdots \tilde{\boldsymbol{H}}_k^H]^H \tag{24}$$

is an extended channel matrix that excludes $\boldsymbol{H}_k$ only.

4. Precoding Combined Beamforming

We start from the received signal (7) and combine $\boldsymbol{H}_k$ and $\boldsymbol{w}_k$ into $\tilde{\boldsymbol{H}}_k$ for computation simplicity as follow:

$$\begin{aligned} \boldsymbol{r} &= \boldsymbol{H}\underline{\boldsymbol{W}}\boldsymbol{t} + \boldsymbol{n} \\ &= \sum_{k=1}^{K}\boldsymbol{H}^{(k)}\underline{\boldsymbol{W}}^{(k)}\boldsymbol{t}^{(k)} + \boldsymbol{n} \\ &= \sum_{k=1}^{K}\sum_{\mathrm{kb}=1}^{K_B}\boldsymbol{H}^{(k,\mathrm{kb})}\underline{\boldsymbol{W}}^{(k,\mathrm{kb})}\boldsymbol{t}^{(k,\mathrm{kb})} + \boldsymbol{n} \\ &= \sum_{k=1}^{K}\sum_{\mathrm{kb}=1}^{K_B}\tilde{\boldsymbol{H}}^{(k,\mathrm{kb})}\boldsymbol{t}^{(k,\mathrm{kb})} + \boldsymbol{n} \\ &= \tilde{\boldsymbol{H}}\boldsymbol{t} + \boldsymbol{n} \end{aligned} \tag{25}$$

And then, the data after demodulation (16) can be rewrite as

$$\hat{\boldsymbol{d}} = \boldsymbol{D}(\tilde{\boldsymbol{H}}\boldsymbol{Md} + \boldsymbol{n}) \tag{26}$$

Thus, we can get the precoding matrices used $\tilde{H}$ and D which have been known at transmitter.

$$\boldsymbol{M} = f(\boldsymbol{D},\tilde{\boldsymbol{H}}) \tag{27}$$

For simplicity, we construct precoding matrix based zero-forcing criterion and power constraint. To consider the gain β of the transmit filter we have to modify MSE[3]:

$$\varepsilon(\boldsymbol{M},\beta)=E\left[\|\boldsymbol{d}-\beta^{-1}\hat{\boldsymbol{d}}\|_2^2\right]$$
$$s.t.\boldsymbol{D}^H\tilde{\boldsymbol{H}}\boldsymbol{M}=\beta\boldsymbol{I}\ \ and\ \ \mathrm{E}\left[\|\boldsymbol{Md}\|_2^2\right]=E_t \quad (28)$$

The first constraint is the zero-forcing criterion to suppress interference and the second constraint defined the transmit power E_t.

Thus, the solution of the optimize equation (28) is TxZF precoding matrix

$$\boldsymbol{M}_{\mathrm{ZF}}=\beta(\boldsymbol{D}\tilde{\boldsymbol{H}})^H\left[\boldsymbol{D}\tilde{\boldsymbol{H}}(\boldsymbol{D}\tilde{\boldsymbol{H}})^H\right]^{-1} \quad (29)$$

where

$$\beta=\sqrt{\frac{E_{\mathrm{t}}}{\mathrm{tr}((\boldsymbol{D}^H\tilde{\boldsymbol{H}}\tilde{\boldsymbol{H}}^H\boldsymbol{D}^{-1})\boldsymbol{R}_d)}}\ .$$

5. Simulation

This paper simulates the schemes in TD-SCDMA based on MIMO system. According to 3GPP protocol, it is simulated with chip rate 1.28Mchip/s, and spreading factor S_0=16. Channel model employ parameters of multiple path fading case 3 of TD-SCDMA in 3GPP, velocity 120km/h , relative time delay[0 781 1563 2344]ns, average power [0 -3 -6 -9]dB, the length of channel impulse response W=4**,** BS use maximum likelihood to estimate channel impulse response and as channel matrix transmitted in downlink.

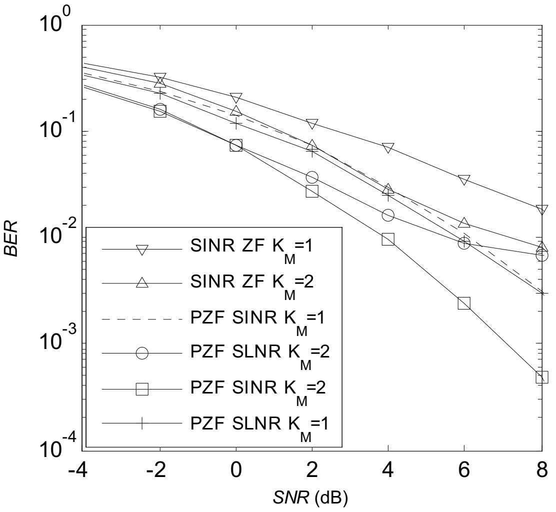

Figure 2. BER results assuming K_B=4 transmit antenna and K=4 user, each user has different receive antenna

Figure 2 shows the BER result of beamforming precoding based on SINR (the SINR-based scheme) and beamforming precoding based on SLNR (the SLNR-based scheme) assuming K_B=4 transmit antenna and K=4 user, each user has different receive antenna. When the receiver configured by single antenna, beamforming precoding based on SINR and SLNR have no significant differences, they are superior to the traditional beamforming method by 3.5 dB gain at BER=10^{-2}. When the receiver configured by multiple antennas, and the number of users is K=4, the SINR-based scheme is better than traditional beamforming method by 2-2.6dB gain at BER=10^{-2}-10^{-3}, and the SLNR-based scheme is better than traditional beamforming method about 2dB gain in the low SNR and worse than traditional beamforming method in the high SNR, and even worse than the receiver with single antenna beamforming precoding method with SNR increase.

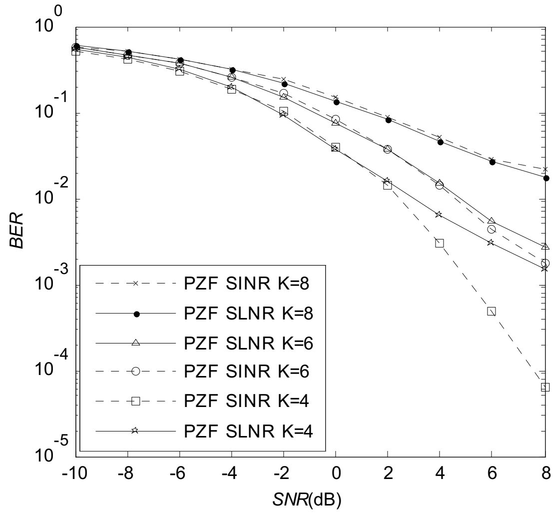

Figure 3. BER results assuming K_B=8 transmit antenna and different user number, each user has K_M=4 receive antenna

Figures 3 shows the BER result of the SINR-based scheme and the SLNR-based scheme assuming K_B=8 transmit antenna and different user number, each user has K_M=4 receive antenna. With the increase of the user number, the performance of the SLNR-based scheme is superior gradually to the SINR-based scheme, but has no significant advantage.

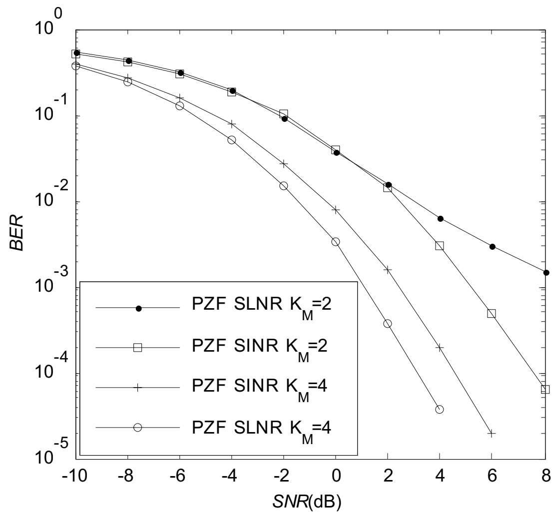

Figure 4. BER of the schemes assuming K_B=4 transmit antenna and K=4 user ,each user has different receive antenna

Figures 4 shows the BER result of the SINR-based scheme and the SLNR-based scheme assuming K_B=4 transmit antenna and K=4 user, each user has different receive antennas. With the increase of the number of receive antennas, the performance of the SLNR-based scheme is superior gradually to the SINR-based scheme. As the number of receive antennas is K_M=2, the performance curve of the SINR-based scheme bends upwards and is not better than the SLNR-based scheme in the high SNR. As the number of receive antennas is K_M=4, the SLNR-based scheme is better than the scheme based on SINR about 1.5 dB gain at BER=10^{-3}-10^{-4}.

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