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A COORDINATED MULTI-POINT PRECODING ALGORITHM BASED ON MSLNR-MMSE

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Abstract. *This paper proposes a new linear precoding algorithm suitable for coordinated multi-point (CoMP) transmission system of joint processing mode. Under the premise of considering the leakage signals and noise at the output of receive filter, the proposed algorithm obtains maximum precoding matrix of modified signal-to-leakage-and-noise ratio (mSLNR) algorithm to better suppress inter-user and noise interference. Besides, the suppression of users' intra-user interference is achieved by minimum mean square error (MMSE) precoding of equivalent channel matrix. Therefore, the proposed algorithm can suppress inter-user, noise and intra-user interference, and can reduce system bit error rate (BER) and improve system capacity. Simulation results show that the proposed algorithm has certain advantages in bit error rate and system capacity compared with other precoding algorithms.*
Keywords: Coordinated multi-point (CoMP), Precoding algorithm, Leakage signals, Minimum mean square error (MMSE), Intra-user interference

1. **Introduction.** In long term evolution-advanced (LTE-A) system, CoMP communication technology is used to suppress inter-cell interference through mutual cooperation between multiple base stations, so that the original interference limited system becomes a wireless cooperative system [1].

Coordinated multi-point precoding algorithm is a typical signal preprocessing technology at the transmitting end. When the transmitting end obtains complete channel state information, the signal is preprocessed at the transmitting end; therefore the interference caused by transmitting signal going through wireless channel can be eliminated in advance so as to reach the purpose of ensuring communication reliability and improving system performance [2,3]. MMSE precoding algorithm can suppress user's own internal interference, but it cannot suppress the interference among users [4,5]. Signal-to-leakage-and-noise ratio (SLNR) precoding algorithm can suppress inter-user and noise interference, but can not suppress intra-user interference [6-8]. mSLNR precoding algorithm incorporates the receive filter into the calculation of leakage and noise powers. Although it can suppress inter-user and noise interference better than SLNR precoding algorithm, there is still a problem that mSLNR precoding algorithm cannot suppress intra-user interference [9]. Aiming at the problem of mSLNR precoding algorithm, this paper proposes a precoding algorithm based on mSLNR-MMSE. The proposed algorithm introduces MMSE precoding algorithm into mSLNR precoding algorithm so as to suppress inter-user and noise interference and intra-user interference at the same time.

This paper is organized as follows. The system model is given in Section 2. A brief review of the mSLNR precoding algorithm is presented in Section 3. The proposed mSLNR-MMSE precoding algorithm is described in detail in Section 4. Simulation results and conclusions are displayed in Section 5 and Section 6, respectively.

2. **System Model.** Figure 1 [10] is a single-cell downlink multi-user CoMP system model. After precoding, user data is sent from transmit antennas at the base station to the receive antennas at the user equipment, and then superimposes channel noise. And ultimately user's receiving signal can be formed. The system has N transmit antennas at the base station (BS) and M_k receive antennas at the user equipment (UE) k, denoted as UE$_k$. It is assumed that there are K users in the system. $\mathbf{W} = [\mathbf{W}_1, \mathbf{W}_2, \ldots, \mathbf{W}_K]$ is the transmit precoding matrix, where $\mathbf{W}_k \in C^{N\times S_k}$. S_k data streams are transmitted to the user k. x_k denotes the user k's data, where $x_k \in C^{S_k\times 1}$ $(k = 1, 2, \ldots, K)$. P_k is normalized transmit power for the user k. The receiving signal for the user k can be expressed as

$$y_k = \mathbf{H}_k\mathbf{W}_k\sqrt{P_k}x_k + \mathbf{H}_k\sum_{i\neq k}\mathbf{W}_i\sqrt{P_i}x_i + n_k \tag{1}$$

where y_k denotes the user k's receiving signal. The user k's channel matrix, denoted as $\mathbf{H}_k \in C^{M_k\times N}$, is assumed to be known at the BS. n_k is the user k's additive Gauss noise with zero mean and σ_k^2 variance.

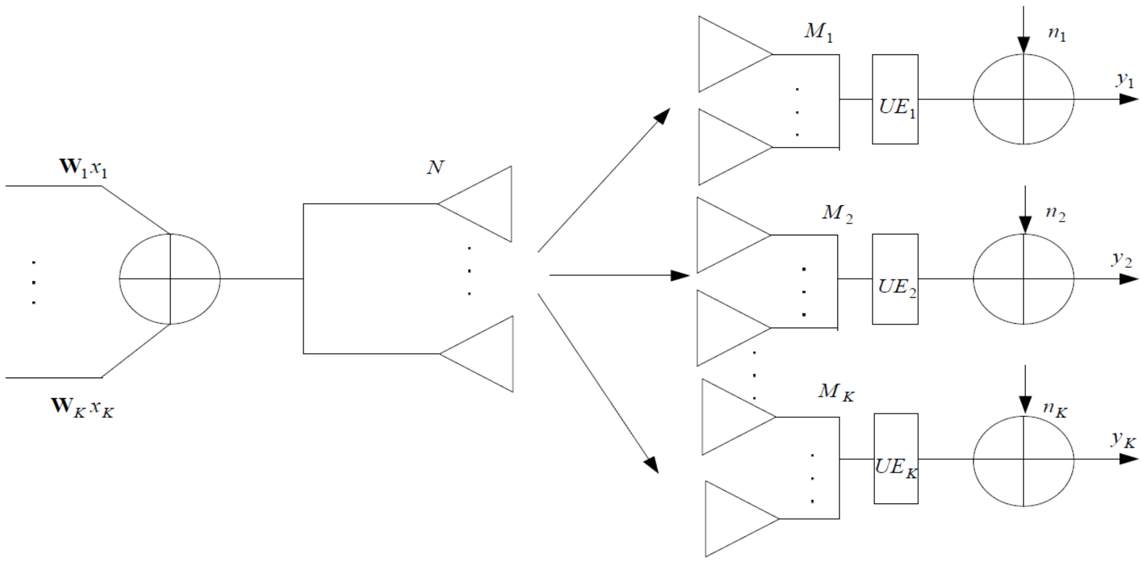

FIGURE 1. Multi-user CoMP system model

3. **Considering Receive Filter Output Precoding Algorithm.** The definition of SLNR is the ratio between the signal power transmitted to the target user and the sum of the leakage plus noise powers leaked to the outputs of the other users' receive antennas. The design idea of SLNR precoding algorithm is to maximize the target user's signal-to-leakage-and-noise ratio, so as to increase the signal power of the target user and reduce the power leaked to other users and noise power. Since the leakage signals and noise at the receive antenna outputs are processed by the decoding matrix, parts of these leakage signals and noise after receive filter may be filtered out, which makes the leakage and noise powers at the receive filter output smaller. So considering the leakage and noise powers at the receive filter output is more in line with the design requirements of SLNR algorithm [9]. So the user k's mSLNR can be expressed as

$$mSLNR_k = \frac{tr\left(\mathbf{W}_k^H\mathbf{H}_k^H\mathbf{H}_k\mathbf{W}_k\right)}{tr\left(\mathbf{W}_k^H\left(\sum_{i\neq k}\overline{\mathbf{H}}_i^H\overline{\mathbf{H}}_i + \sigma_k^2\mathbf{I}\right)\mathbf{W}_k\right)} \tag{2}$$

where $tr(.)$ denotes the trace of a matrix. $\mathbf{I}$ denotes unit matrix of size $N \times N$. Hermitian transpose of matrix is described by $(.)^H$. The equivalent leakage channel matrix for the user i is defined as

$$\overline{\mathbf{H}}_i = \overline{\mathbf{G}}_i \mathbf{H}_i \tag{3}$$

where $\overline{\mathbf{G}}$ denotes receive filter.

The mSLNR precoding problem is to find the precoding matrix $\mathbf{W}_{mSLNR-k}$ that maximizes mSLNR, so mSLNR precoding problem for the user k can be given by

$$\begin{aligned} &\mathbf{W}_{mSLNR-k} = \arg\max mSLNR_k \\ &\text{s.t. } tr\left(\mathbf{W}_{mSLNR-k}^H \mathbf{W}_{mSLNR-k}\right) = S_k,\ k = 1, 2, \ldots, K \end{aligned} \tag{4}$$

Through derivation, mSLNR precoding matrix for the user k can be expressed as

$$\mathbf{W}_{mSLNR-k} = \max eigenvector \left(\left(\sum_{i \neq k} \bar{\mathbf{H}}_i^H \bar{\mathbf{H}}_i + \sigma_k^2 \mathbf{I} \right)^{-1} \mathbf{H}_k^H \mathbf{H}_k \right) \tag{5}$$

4. **Precoding Algorithm Based on mSLNR-MMSE.** mSLNR precoding algorithm makes improvements in taking the leakage signals and noise at the receive filter output into account based on SLNR precoding algorithm. Compared with SLNR precoding algorithm, mSLNR precoding algorithm can suppress inter-user and noise interference better, but it cannot suppress user's internal interference. In order to suppress inter-user, noise and intra-user interference at the same time, MMSE precoding algorithm is introduced into mSLNR algorithm to further optimize system performance. In theory, the proposed algorithm can suppress inter-user, noise and intra-user interference at the same time, and can reduce system bit error rate and improve system capacity compared with mSLNR, MMSE and SLNR-MMSE precoding algorithms. mSLNR-MMSE precoding algorithm steps are as follows.

Step 1: First, multi-user CoMP channel matrix composed of K users is decomposed. After decomposition, the channel is K independent and parallel single-user CoMP channel matrix $\mathbf{H}_k$ $(1 \leq k \leq K)$.

Step 2: The above K independent user channel matrix $\mathbf{H}_k$ multiplied by mSLNR precoding matrix $\mathbf{W}_{mSLNR-k}$ can obtain corresponding equivalent channel matrix $\mathbf{H}_{mSLNR-k}$. The formula of the matrix is as follows

$$\mathbf{H}_{mSLNR-k} = \mathbf{H}_k \times \mathbf{W}_{mSLNR-k},\ 1 \leq k \leq K \tag{6}$$

Step 3: MMSE precoding for K equivalent channel matrix can get new precoding matrix, which can be expressed as

$$\begin{aligned} \mathbf{W}_{mSLNR\text{-}MMSE-k} &= \mathbf{H}_{mSLNR-k}^H \left(\mathbf{H}_{mSLNR-k} \mathbf{H}_{mSLNR-k}^H + \sigma_k^2 \mathbf{I} \right)^{-1} \\ &= \mathbf{W}_{mSLNR-k}^H \mathbf{H}_k^H \left(\mathbf{H}_k \mathbf{W}_{mSLNR-k} \mathbf{W}_{mSLNR-k}^H \mathbf{H}_k^H + \sigma_k^2 \mathbf{I} \right)^{-1} \end{aligned} \tag{7}$$

Step 4: mSLNR-MMSE precoding matrix is given by

$$\begin{aligned} &\mathbf{W}_{mSLNR\text{-}MMSE} \\ &= \left[\mathbf{W}_{mSLNR\text{-}MMSE-1}, \ldots, \mathbf{W}_{mSLNR\text{-}MMSE-k}, \ldots, \mathbf{W}_{mSLNR\text{-}MMSE-K} \right] \end{aligned} \tag{8}$$

Thus, after mSLNR-MMSE precoding, the user k's receiving signal can be expressed as

$$y_k' = \mathbf{H}_k \mathbf{W}_{mSLNR\text{-}MMSE-k} \sqrt{P_k} x_k + \mathbf{H}_k \sum_{i \neq k} \mathbf{W}_{mSLNR\text{-}MMSE-i} \sqrt{P_i} x_i + n_k \tag{9}$$

From the above, we can see that mSLNR-MMSE precoding algorithm can suppress inter-user and noise interference and intra-user interference at the same time so as to reduce system bit error rate and improve system capacity.

5. **Algorithm Simulation.** This experiment is carried out in the MATLAB simulation environment and simulation parameters are derived from 3GPP TR36.814 [11]. Assuming that cell number of multi-user CoMP model is 3, and that per base station transmit antennas number is 2, so the total number of transmit antennas at the base stations is 6. User number is 3, and each user's receive antennas number is 2; therefore the total number of receive antennas at the user equipments is 6. Be sure to make the total number of transmit antennas at the base stations equal the total number of receive antennas at the user equipments. Base station transmit power is normalized ($1W$) to simplify calculation Modulation mode adopts quadrature phase shift keying (QPSK). The channel model employs flat Rayleigh channel, and Rayleigh distribution is a zero mean and σ_k^2 variance stationary narrowband Gauss process. The simulation parameters are shown in Table 1.

TABLE 1. Simulation parameters table

Simulation parameters	*value*
Cell number	*3*
Per BS transmit antennas number	*2*
User number	*3*
Each user's receive antennas number	*2*
Base station transmit power	*1W*
Mean signal-to-noise ratio	*0-30dB*
Modulation mode	*QPSK*
Channel model	*flat Rayleigh*

Precoding algorithm is analyzed in terms of bit error rate (BER) and system capacity. BER and system capacity are used for performance analysis.

$$BER = 1 - \left[1 - \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{2N_0}}\right)\right] \tag{10}$$

where E_b is the average bit energy, and N_0 is the noise power spectral density. C denotes system capacity, expressed as

$$C = \sum_{k=1}^{K} \log_2 \left(1 + \frac{\|\mathbf{H}_k \mathbf{W}_k\|^2}{\sum\limits_{i \neq k} \|\mathbf{H}_k \mathbf{W}_i\|^2 + \sigma_k^2}\right) \tag{11}$$

where K is the number of users. The simulation results are shown from Figure 2 to Figure 3.

Figure 2 shows BER performance of mSLNR-MMSE, MMSE, SLNR, mSLNR, SLNR-MMSE precoding algorithm in multi-user CoMP system. From Figure 2, it can be seen that in the range of 0∼30dB, with the increase of signal-to-noise ratio (SNR), the bit error rate of each precoding algorithm is decreased. In the range of 0∼30dB, bit error rate of mSLNR-MMSE precoding algorithm is significantly lower than that of MMSE, mSLNR, SLNR. And the bit error rate of mSLNR-MMSE precoding algorithm is similar to SLNR-MMSE precoding algorithm in high SNR (20∼30dB). The bit error rate of mSLNR-MMSE precoding algorithm is obviously lower than SLNR-MMSE precoding algorithm in low SNR (0∼20dB), because mSLNR can suppress inter-user and noise better than SLNR.

Figure 3 illustrates system capacity performance of mSLNR-MMSE, MMSE, SLNR, mSLNR, and SLNR-MMSE precoding algorithm in multi-user CoMP system. Simulation results show that in the range of 0∼30dB, system capacity of each precoding algorithm is increased with the increase of SNR. In the range of 0∼30dB, system capacity of mSLNR-MMSE precoding algorithm is significantly higher than that of MMSE, mSLNR, SLNR, and the system capacity is similar to that of SLNR-MMSE precoding algorithm.

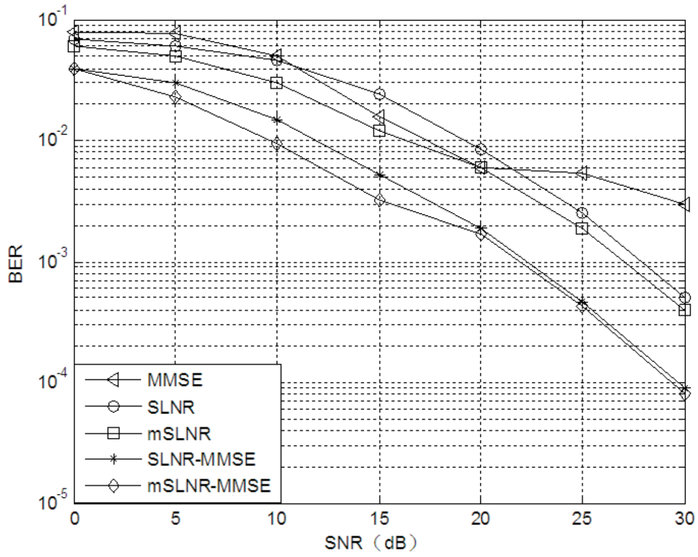

Figure 2. BER of different precoding algorithms

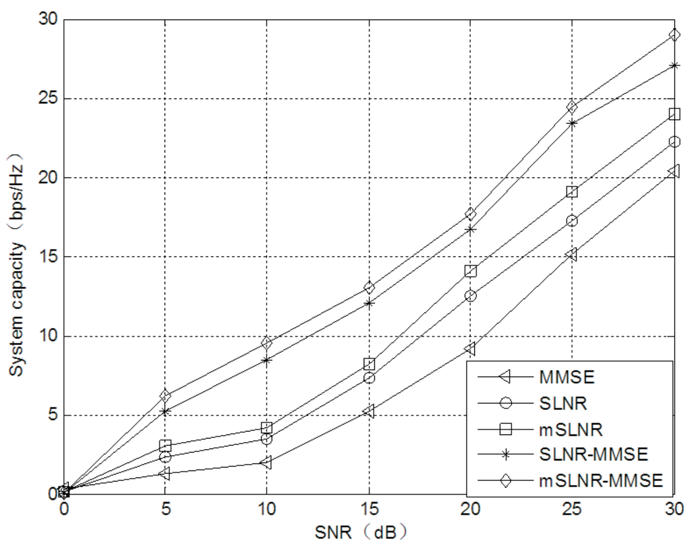

Figure 3. System capacity of different precoding algorithms

6. **Conclusions.** In this paper, we propose a precoding algorithm of multi-user coordinated multi-point communication system based on mSLNR-MMSE. The proposed precoding algorithm incorporates the receive filter into the calculation of leakage and noise powers so that it can better suppress inter-user and noise interference. And MMSE precoding algorithm is introduced into mSLNR algorithm to suppress intra-user interference. As a result, inter-user noise and intra-user interference can be suppressed at the same time. Simulation results show that mSLNR-MMSE precoding algorithm has certain advantages in bit error rate and system capacity compared with other precoding algorithms.

In LTE-A system, precoding in CoMP scene has many solutions. This paper describes a part of linear precoding in CoMP application. Further research could focus on better linear and nonlinear precoding algorithms, obtaining more outstanding performance.

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