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Two-Codebook-Based Cooperative Precoding for TDD-CoMP in 5G Ultra-Dense Networks

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Abstract

In ultra-dense networks (UDN), the local precoding scheme for time-division duplex coordinated multiple point transmission (TDD-CoMP) can have a good performance with no feedback by using reciprocity between uplink and downlink. However, if channel is time-varying, the channel difference would cause codeword mismatch between transmitter and receiver, which leads to performance degradation. In this paper, a linear interpolation method is proposed for TDD-CoMP system to estimate the uplink channel at the receiver, which would reduce the channel difference caused by time delay and decrease the probability of codeword mismatch between both sides. Moreover, to mitigate severe inter-cell interference and increase the coverage and throughput of cell-edge users in UDN, a two-codebook scheme is used to strengthen cooperation between base stations (BSs), which can outperform the global precoding scheme with less overhead. Simulations show that the proposed scheme can significantly improve the link performance compared to the global precoding scheme.

Keywords

ultra-dense networks; coordinated multiple point transmission; time-division duplex; two codebooks; cooperative precoding

1 Introduction

In order to meet the significant traffic demands in 5G system, ultra-dense networks (UDN) have been proposed as a promising approach by getting access nodes as close as possible to user equipment (UE) [1]. In UDN, coordinated multi-point (CoMP) operation should be especially considered for it improves coverage and increases cell-edge throughput [2]. However, CoMP requires significant feedback overhead. In fact, overhead could be decreased in time-division duplex (TDD) system by making use of reciprocity between uplink and downlink. Therefore, channel reciprocity will play an important role in TDD-CoMP.

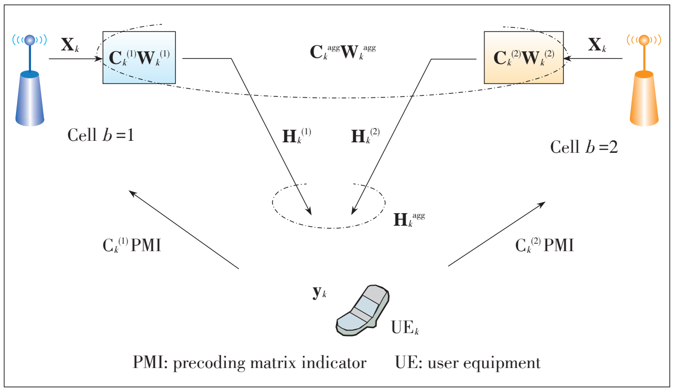
However, little difference between uplink and downlink could result in mismatch between precoding matrix and decoding matrix, which would seriously degrade the system performance [3]–[4]. So, in [5]–[6], Wiener filter was proposed to predict the channel state information (CSI) in next downlink transmission. In [7], a multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) downlink channel prediction technique based on Kalman filter was proposed for IEEE 802.16e systems. Although prediction could reduce performance loss caused by codeword mismatch, it leads to high computational complexity for transmitter and its benefit is limited. In this paper, a linear interpolation method is proposed for TDD-CoMP system to estimate the uplink channel at the receiver, which would reduce the channel difference caused by time delay and decrease the probability of codeword mismatch between both sides.

Therefore, by using reciprocity between uplink and downlink, local precoding scheme could have a good performance with no feedback [8]. However the performance of local precoding scheme was inferior to global precoding scheme owing to lack of cooperation between base stations (BSs). Hence, in this paper two codebooks known at both sides are constructed for strengthening cooperation between BSs.

Motivated by this, a precoding scheme based on two codebooks and linear interpolation is proposed for TDD-CoMP systems, where the transmitter and receiver can choose optimal codeword from codebooks according to the estimated channel by using linear interpolation.

2 System Model

As illustrated in **Fig. 1**, suppose the total number of CoMP cells is B. The baseband channel matrix between CoMP cell b with N_T antennas ($b=1,2,\cdots,B$) and UE_k (with N_R receive antennas) is denoted as $\mathbf{H}_k^{(b)}$ ($N_R \times N_T$). Let $\mathbf{W}_k^{(b)}$ be



PMI: precoding matrix indicator UE: user equipment

▲**Figure 1. The precoding scheme ($B=2$ CoMP cells).**

the precoding matrix of cell b with size $N_T \times N_S$, where N_S is the number of transmission layers for UE_k. Let $\mathrm{C}_k^{(b)}$ be the synchronization codeword matrix with size $N_T \times N_T$. For simplicity, let $B=2$. The received symbols can be expressed as

$$y_k = \sqrt{P}\,\mathbf{H}_k^{agg}\mathbf{C}_k^{agg}\mathbf{W}_k^{agg}\mathbf{x}_k + \mathbf{n}_k, \tag{1}$$

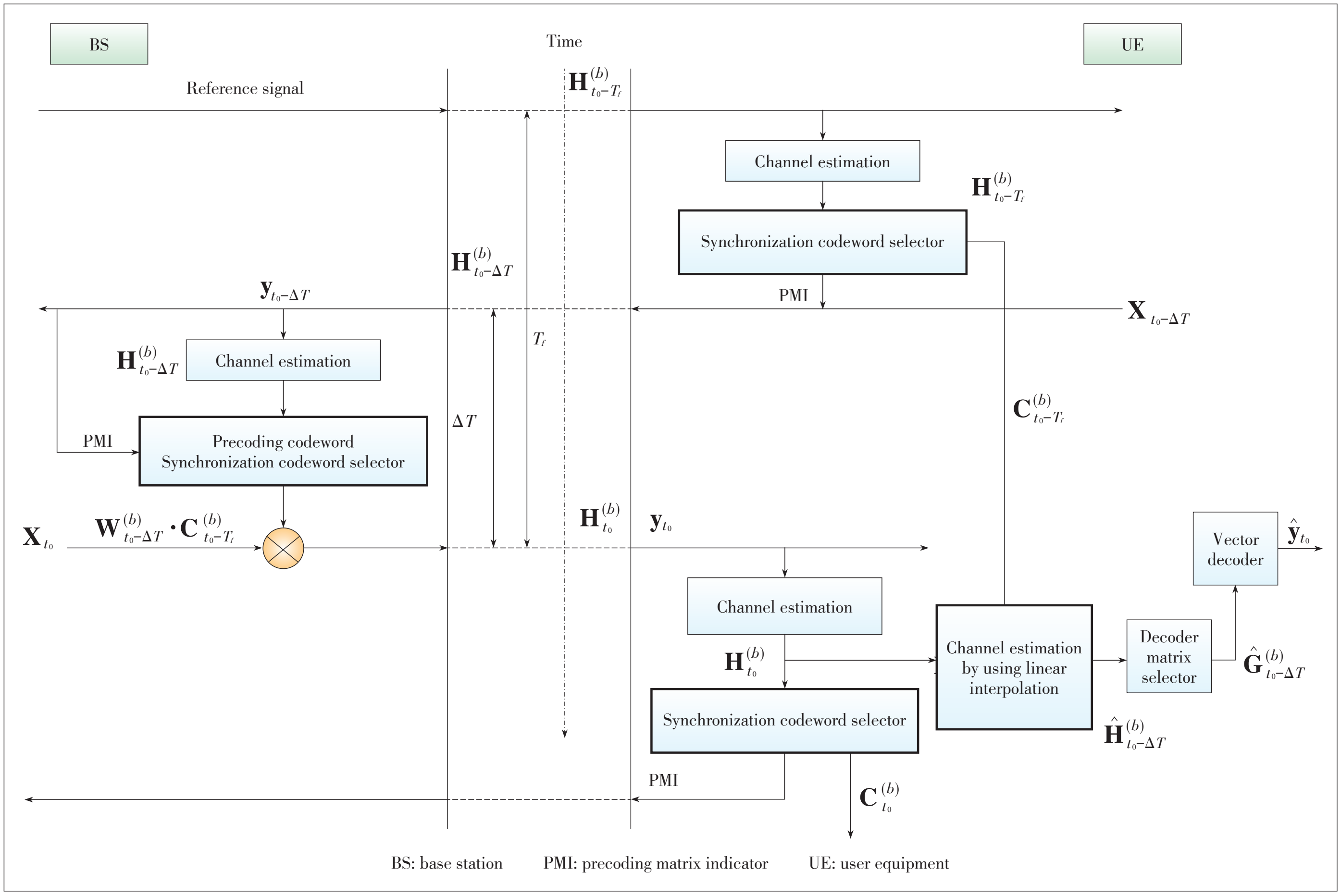
where $\mathbf{x}_k$ ($N_S \times 1$) is the transmission data with N_S layers, $\sqrt{P}$ is the total power on each layer from B CoMP cells, and $\mathbf{n}_k$ is the additive white Gaussian noise (AWGN) vector with covariance matrix $E\left[\mathbf{n}_k\mathbf{n}_k^H\right]=N_0\mathbf{I}_{N_R}$ with the operator $()^H$ representing a matrix conjugate transpose and $\mathbf{I}_{N_R}$ being the identity matrix of order N_R. For notational convenience, denote the aggregated channel matrix as $\mathbf{H}_k^{agg}=\left[\mathbf{H}_k^{(1)}\ \mathbf{H}_k^{(2)}\ \dots\ \mathbf{H}_k^{(B)}\right]$ ($N_R \times BN_T$) and $\mathbf{W}_k^{agg}=\begin{bmatrix}\mathbf{W}_k^{(1)}\\ \mathbf{W}_k^{(2)}\\ \vdots\\ \mathbf{W}_k^{(B)}\end{bmatrix}$, $\mathbf{C}_k^{agg}=\begin{bmatrix}\mathbf{C}_k^{(1)} & 0 & 0 & 0\\ 0 & \mathbf{C}_k^{(2)} & 0 & 0\\ 0 & 0 & \ddots & 0\\ 0 & 0 & 0 & \mathbf{C}_k^{(B)}\end{bmatrix}$.

3 Proposed Scheme

As illustrated in **Fig. 2**, the proposed scheme is composed of two key modules (that is, channel estimation by using linear interpolation and codeword selection based on codebook), where the design of codebooks is presented in Subsection 3.2.3.

3.1 Channel Estimation Based on Linear Interpolation

In traditional TDD precoding system, UE can obtain decod-



BS: base station PMI: precoding matrix indicator UE: user equipment

▲**Figure 2. The proposed precoding scheme in TDD system.**

ing matrix $\hat{\mathbf{G}}_{t_0}^{(b)}$ according to channel estimation $\mathbf{H}_{t_0}^{(b)}$, then the transmitted data vector is determined by using soft decision:

$$\mathbf{y}'_{t_0} = \mathrm{deci}\left(\hat{\mathbf{G}}_{t_0}^{(b)} \mathbf{y}_{t_0}\right), \tag{2}$$

where

$$\mathbf{y}_{t_0} = \mathbf{H}_{t_0}^{(b)} \mathbf{C}_{t_0 - T_f}^{(b)} \mathbf{W}_{t_0 - \Delta T}^{(b)} \mathbf{x}_{t_0} + \mathbf{n}_{t_0}, \tag{3}$$

where t_0 denotes time index of system, ΔT represents the time delay between uplink and downlink transmission, and T_f is the frame duration.

The interpolation based channel estimation method aims to estimate the uplink channel in last frame. When the CSI at t_0 is available at UE, the estimated uplink channel $\hat{\mathbf{H}}_{t_0 - \Delta T}^{(b)}$ could be given by

$$\hat{\mathbf{H}}_{t_0 - \Delta T}^{(b)} = \mathbf{H}_{t_0}^{(b)} - \Delta T * \Delta \mathbf{H}^{(b)},\ \Delta \mathbf{H}^{(b)} = \frac{\mathbf{H}_{t_0}^{(b)} - \mathbf{H}_{t_0 - T_f}^{(b)}}{T_f}. \tag{4}$$

Thus $\hat{\mathbf{G}}_{t_0 - \Delta T}^{(b)}$ can be derived from $\hat{\mathbf{H}}_{t_0 - \Delta T}^{(b)}$, (2) turns out to be:

$$\hat{\mathbf{y}}_{t_0} = \mathrm{deci}\left(\hat{\mathbf{G}}_{t_0 - \Delta T}^{(b)} \mathbf{y}_{t_0}\right). \tag{5}$$

Considering the complexity of maximum likelihood (ML) receiver, the proposed scheme adopts a sub-optimal linear receiver.

In (1), receiver obtains estimated value of $\mathbf{y}_k$ by using $N_R \times N_T$ matrix $\mathbf{G}_k^{(b)}$:

$$\hat{\mathbf{y}}_k = \mathrm{deci}\left(\mathbf{G}_k^{(b)} \mathbf{y}_k\right). \tag{6}$$

When zero-forcing (ZF) receiver is used in system:

$$\mathbf{G}_k^{(b)} = \left(\mathbf{H}_k^{(b)} \mathbf{W}_k^{(b)}\right)^{-1}. \tag{7}$$

3.2 Codeword Selection Based on Codebook

The scheme of codeword selection based on codebook is composed of two parts.

3.2.1 Precoding Codeword Selection

UE$_k$ can know the channel matrix $\mathbf{H}_k^{(b)}$ according to downlink reference signals, then the optimal precoding codeword which maximums the capacity of equivalent channel is chosen from the first codebook. The criterion can be expressed as

$$\mathbf{W}_k^{(b)} = \underset{\mathbf{W}_{i,k}^{(b)} \in \mathbf{W}}{\arg\max} \left(C\left(\mathbf{W}_{i,k}^{(b)}\right)\right), \tag{8}$$

$$C\left(\mathbf{W}_{i,k}^{(b)}\right) = \log_2\left(\det\left[\mathbf{I}_{N_s} + \frac{P}{N_S N_0} \mathbf{W}_{i,k}^{(b)H} \mathbf{H}_k^{(b)H} \mathbf{H}_k^{(b)} \mathbf{W}_{i,k}^{(b)}\right]\right), \tag{9}$$

where $b = 1,2$ denotes the coordinated BSs.

3.2.2 Synchronization Codeword Selection

With the aggregated matrix, the optimal synchronization codeword which maximums the capacity of equivalent channel can be chosen from the second codebook. The criterion can be expressed as

$$\mathbf{C}_k^{agg} = \underset{\mathbf{C}_{i,k}^{agg} \in \mathbf{C}}{\arg\max} \left(\mathbf{C}\left(\mathbf{C}_{i,k}^{agg}\right)\right), \tag{10}$$

$$\mathbf{C}\left(\mathbf{C}_{i,k}^{agg}\right) = \log_2\left(\det\left[\mathbf{I}_{N_s} + \frac{P}{N_S N_0} (\mathbf{C}_{i,k}^{agg} \cdot \mathbf{W}_k^{agg})^H \mathbf{H}_k^{agg\,H} \mathbf{H}_k^{agg} (\mathbf{C}_{i,k}^{agg} \cdot \mathbf{W}_k^{agg})\right]\right). \tag{11}$$

3.2.3 Codebook Design

Two codebooks are used in our scheme. The first codebook design can be found in TS36.211, and the second codebook is constructed as follows.

For transmission on 2-Tx antennas in TS36.211, the precoding matrix $\mathbf{W}$ can be denoted as

$$\mathbf{W} = \begin{bmatrix} a \\ b \end{bmatrix}. \tag{12}$$

With partial CSI at the transmitter (CSIT), the precoding matrix $\mathbf{W}$ tries to approximately match its eigen-beams to the channel eigen-directions (the eigenvectors of $\mathbf{H}^H \mathbf{H}$) and therefore reduces the interference among signals sent on these beams [3]. Now $\mathbf{W}$ is used to match the eigen-beams from B BSs in the aggregated channel eigen-directions and reduce the interference among signals sent from B BSs. For transmission on $B = 2$ BSs, the new codeword $\mathbf{C}_k^{(b)}$ based on $\mathbf{W}$ can be described by

$$\mathbf{C}_k^{(1)} = \begin{pmatrix} a & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & a \end{pmatrix},\quad \mathbf{C}_k^{(2)} = \begin{pmatrix} b & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & b \end{pmatrix}. \tag{13}$$

The synchronization codeword $C_k^{(1)}$, $C_k^{(2)}$ ($N_T \times N_T$) should be normalized as

$$\mathbf{C}_k^{(1)} = \mathbf{C}_k^{(1)} / \mathrm{norm}(\mathbf{C}_k^{(1)}),\ \mathbf{C}_k^{(2)} = \mathbf{C}_k^{(2)} / \mathrm{norm}(\mathbf{C}_k^{(2)}), \tag{14}$$

and the aggregated synchronization codeword matrix is defined by

$$\mathbf{C}_k^{agg} = \begin{bmatrix} \mathbf{C}_k^{(1)} & 0 \\ 0 & \mathbf{C}_k^{(2)} \end{bmatrix}. \tag{15}$$

Also, note that the second codebook size is equal to the 2-Tx codebook size in TS36.211.

4 Simulation Results

To show the superiority of the proposed scheme, two sets of bit error ratio (BER) lower bounds are evaluated by the Monte Carlo method. An example of TDD frame structure in **Fig. 3** would give a clear illustration.

The CSI estimation delay is modeled by setting $\Delta T = 3.5T_S$. Assume that the mean square error (MSE) of time-varying channel is α^2, then the channel of different time can be modeled as

$$\mathbf{H}^{(b)}_{t_0-\Delta T} = \alpha \mathbf{H}^{(b)}_{t_0-T_f} + \sqrt{(1-\alpha^2)}\,\mathbf{I}, \tag{16}$$

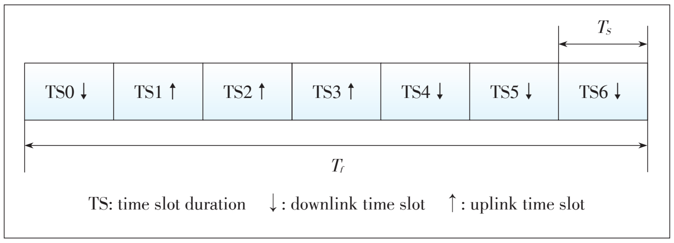
$$\mathbf{H}^{(b)}_{t_0} = \alpha \mathbf{H}^{(b)}_{t_0-\Delta T} + \sqrt{(1-\alpha^2)}\,\mathbf{I}. \tag{17}$$

Fig. 4 presents the BER performance versus transmitted signal to noise ratio (SNR) for ideal TDD system. The results show that our proposed scheme outperforms the global codebook scheme with less overhead because the proposed scheme makes full use of reciprocity between uplink and downlink in the ideal TDD system. It is also shown that the singular value decomposition (SVD) scheme outperforms the local codebook scheme without channel estimation by using linear interpolation.

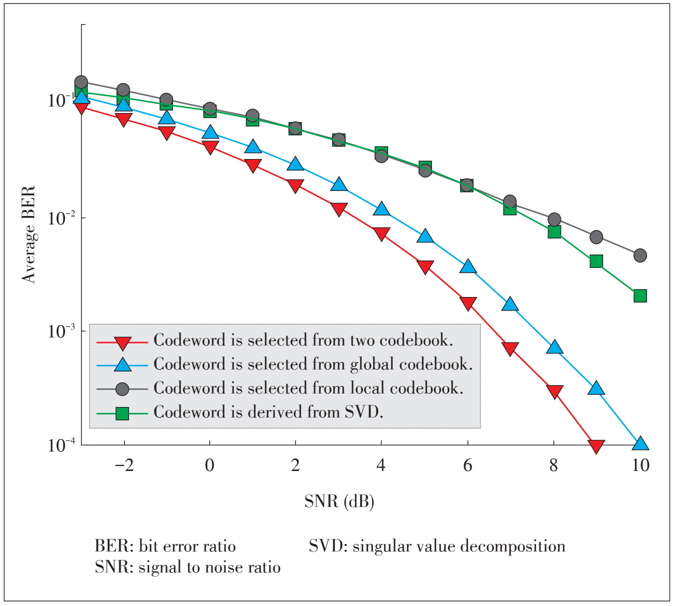
Fig. 5 presents the BER performance versus transmitted SNR for the practical TDD system. As shown in the figure, the proposed technique is superior to the local codebook scheme owing to synchronization codeword overhead. Besides, the proposed technique is always superior to the two codebooks scheme, which is due to the fact that the channel estimation by using linear interpolation reduces the probability of mismatch between precoding matrix and decoding matrix. Fig. 5 also shows that the precoding scheme based on codebook is superior to the SVD scheme in practical system.

5 Conclusions

In UDN, a novel precoding technique for TDD-CoMP system is proposed, which aims at reducing the probability of codeword mismatch and improving the cell-edge throughput. To reduce the CSI difference between both sides caused by time delay, a linear interpolation method is utilized at UE to estimate the CSI achieved at BS. Furthermore, the proposed scheme selects the codeword from two codebooks defined previously at both sides, in order to benefit from cooperation between BSs. As illustrated in simulation results, the proposed scheme could improve link performance of TDD-CoMP system and reduce feedback remarkably, compared to the global codebook scheme.

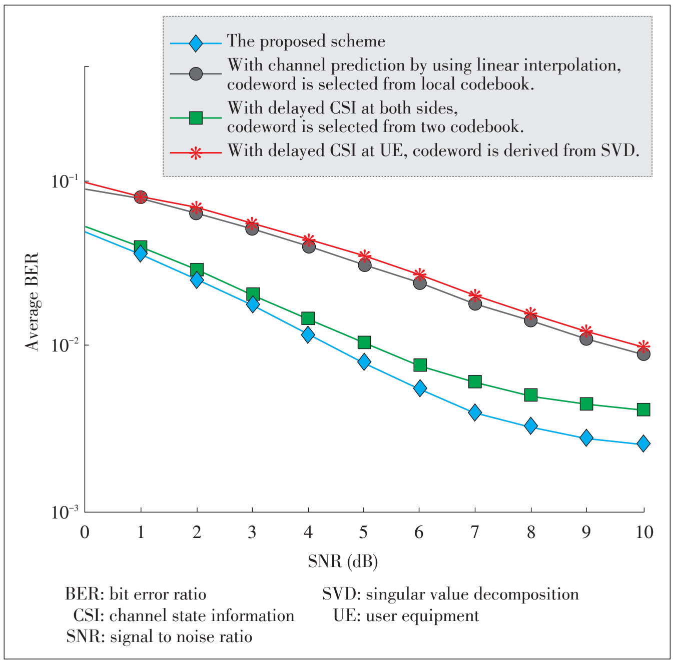


▲Figure 3. Example of TDD frame structure.



BER: bit error ratio
SNR: signal to noise ratio
SVD: singular value decomposition

▲Figure 4. BER performance comparison in ideal TDD system.



BER: bit error ratio
CSI: channel state information
SNR: signal to noise ratio
SVD: singular value decomposition
UE: user equipment

▲Figure 5. BER performance comparison in practical TDD system.

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