Multicell Interference Coordination Strategy Based on Hybrid Channel Information

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***Abstract*—Inter-cell interference (ICI) limits the throughput of multicell massive MIMO systems. Considering the large-scale array at base stations, high array gain can be obtained by analog beamforming based on statistical channel information. In this paper, we propose an interference coordination strategy based on both statistical and instantaneous channel information to mitigate ICI in multicell massive MIMO systems. We propose an enhanced Joint Spatial Division and Multiplexing (JSDM) precoding to mitigate ICI by cooperative beamforming implemented by the two-stage precoding based on channel covariance matrices and global effective channel state information (CSI). We also present the way to implement the precoding in practical systems without perfect effective CSI. Simulation results show that the proposed precoding can effectively mitigate ICI, thus provide remarkable gain in the downlink throughput and improve the fairness among users over the traditional one.**

***Index Terms*—Inter-cell interference, interference coordination, two-stage precoding**

I. Introduction

By deploying a large number of antennas at a base station (BS), massive multiple-input multiple-output (MIMO) can provide spatial multiplexing gain and array gain, and hence boost system throughput [1] [2].

In dense cellular networks, inter-cell interference (ICI) is a key factor of limiting the system throughput [3]. Therefore, significant research efforts have been made to circumvent the ICI problem. Coordinated multi-point (CoMP), such as coordinated beamforming and scheduling (CS/CB), is one kind of the methods [4]. In [5], interference-aware regularized zero forcing (RZF) precoding was proposed to use imperfect channel state information (CSI) of interference channel for precoding, which can avoid ICI and obtain data rate gain without complex BS cooperation. With CoMP joint transmission [6], multiple BSs are connected via backhaul links so that they act as a single huge MIMO system to eliminate ICI and enhance the desired signal [7] [8].

Traditional CoMP systems employs instantaneous channel information, i.e., CSI, to mitigate ICI. For example, with CS/CB, the BSs share the CSI of the scheduled users and compute their own precoding matrix to avoid ICI according to the scheduling results of neighbour cells. However, CoMP based on CSI is sensitive to the backhaul delay [9]. The scheduling result communicated via backhaul links may be outdated and thus the beamforming according to the scheduling result may no longer avoid ICI as expected. One possible way to cope with this issue is to employ statistical channel information, which varies much slower than CSI. Since the array of traditional MIMO system is small and the beam formed by the statistical channel information is wide, interference coordination based on the statistical channel information does not perform well. In massive MIMO system, analog precoding based on statistical channel information can achieve high array gain, which provides a new method of interference coordination.

In this paper, we propose an interference coordination strategy based on hybrid (both statistical and instantaneous) channel information to mitigate ICI in multicell massive MIMO system. To solve the problem of the outdated instantaneous scheduling result, we partition the users into groups according to the similarity of their channel covariance matrices, which can be approximately replaced by the positions of the users, since the users that are close to each other are likely to experience the similar scattering environments. The users are scheduled in groups for a longer time period than the coherent time of channel fading, which is robust to backhaul delay. In [10], a Joint Spatial Division and Multiplexing (JSDM) precoding was proposed to mitigate inter-group interference in a single-cell massive MIMO system, which employs the method based on the eigenspace obtained from the channel covariance matrices. However, the JSDM precoding can not mitigate ICI effectively in multicell systems. We extend the JSDM preoding to multicell systems based on the eigenspace obtained from the channel covariance matrices and global effective CSI. We also present a way to implement the precoding in practical systems without perfect effective CSI. Finally, simulations are provided to evaluate the performance gain of the proposed precoding.

II. System Model

Considering the overhead to obtain CSI, time-division duplex (TDD) is widely recognized as a preferred mode for massive MIMO systems, where the downlink CSI can be obtained through uplink training by exploiting the channel reciprocity. Hence, we consider TDD mode. Consider the downlink transmission of a TDD massive MIMO network with N cells. In each cell, a BS equipped with M antennas serves K single-antenna users that are divided into G groups. The

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number of users in the i-th cell is $K_i = \sum_{g=1}^{G} K_{i,g}$, where $K_{i,g}$ is the number of the users of the g-th group in the i-th cell. Denote $\mathbf{h}_{ig_{j,mk}} \in \mathbb{C}^M$ as the channel vector between the i-th BS and the k-th user of the m-th group in the j-th cell.

The received signal of the users is expressed in groups, since one group of users share the same analog precoder in the following section. The received signal of the users of the n-th group in the i-th cell can be expressed as

$$\begin{aligned}\mathbf{y}_{i,n} =&\mathbf{H}_{ig_{i,n}}^H \mathbf{V}_{i,n}\mathbf{d}_{i,n} + \sum\nolimits_{m\neq n} \mathbf{H}_{ig_{i,n}}^H \mathbf{V}_{i,m}\mathbf{d}_{i,m} \\ &+ \sum\nolimits_{j\neq i}\sum_{m=1}^{G} \mathbf{H}_{jg_{i,n}}^H \mathbf{V}_{j,m}\mathbf{d}_{j,m} + \mathbf{w}_{i,n},\end{aligned} \tag{1}$$

where the second item is the inter-group interference and the third item is the ICI, $\mathbf{H}^H{}_{jg_{i,n}} = [\mathbf{h}_{jg_{i,n1}}, \ldots, \mathbf{h}_{jg_{i,nK_{i,n}}}]^H$ is the $K_{i,n} \times M$ channel matrix between the j-th BS and the n-th group of the i-th cell, $\mathbf{V}_{i,n} \in \mathbb{C}^{M\times K_{i,n}}$ is the precoding matrix of the n-th group in the i-th cell, $\mathbf{d}_{i,n} \in \mathbb{C}^{K_{i,n}}$ is the transmit signal of the n-th group in the i-th cell and $\mathbf{w}_{i,n} \in \mathbb{C}^{K_{i,n}}$ is the additive Gaussian noise.

III. Two-stage Precoding

JSDM precoding is proposed in single-cell massive MIMO system. The main idea is first dividing the users into groups with approximately the same channel eigenspace, and then splitting the downlink beamforming into two stages. In this section, we propose an enhanced JSDM precoding to mitigate ICI in multicell massive MIMO system, which is first presented with hybrid channel information. Then, we provide a method to implement it in practical systems.

A. The Proposed Enhanced JSDM Precoding

If directly applied to multicell networks, JSDM precoding can mitigate ICI at the first-stage precoding but cannot perform well, since only covariance matrices are used. We further mitigate ICI using the instantaneous effective channels at the second-stage precoding. The CSI between each BS and the scheduled users at both the local cell and the neighbour cells is processed with the first-stage precoding matrix and the corresponding effective channel can be obtained. Then, the effective channel can be employed to implement RZF precoding as a coordinated beamforming.

The precoding matrix of the n-th group in the i-th cell is composed of two parts that can be expressed as

$$\mathbf{V}_{i,n} = \mathbf{B}_{i,n}\mathbf{P}_{i,n}, \tag{2}$$

where $\mathbf{B}_{i,n}$ is the first-stage precoding matrix based on the statistical channel information, $\mathbf{P}_{i,n}$ is the second-stage precoding matrix based on the instantaneous effective channels.

The precoding matrices of all users in the ith cell can be expressed in compact form as

$$\mathbf{V}_i = [\mathbf{V}_{i,1}, \ldots, \mathbf{V}_{i,G}]. \tag{3}$$

The following presentation focuses on the n-th group in the i-th cell for the precoding matrix design.

1) The First-Stage Precoding: When the BS designs the precoding matrix, the user groups in the neighbour cells can be equivalently regarded as the user groups in the local cell, where ICI is actually the intergroup interference. Then, the ICI can be mitigated by using the method of mitigating inter-group interference in JSDM precoding.

The aim of the first-stage precoding is to force to zero the received signal power at any user group in each cell corresponding to the signals transmitted from the neighbour BSs in a statistical way. Let $\mathbf{R}_{ig_{j,m}} = \frac{1}{K_{j,m}}\sum_{k=1}^{K_{j,m}} \mathbf{R}_{ig_{j,mk}}$ denote the mean covariance matrix of the channels between the i-th BS and the m-th user group of the j-th cell, where $\mathbf{R}_{ig_{j,mk}}$ is the covariance matrix of $\mathbf{h}_{ig_{j,mk}}$. $\mathbf{U}_{ig_{j,m}}$ is obtained from the eigenvectors of $\mathbf{R}_{ig_{j,m}}$ corresponding to the r dominant eigenvalues. We use the channel covariance matrices to design $\mathbf{B}_{i,n}$, satisfying

$$\begin{aligned}\mathbf{U}_{ig_{i,m}}^H \mathbf{B}_{i,n} = 0 \quad (m\neq n)\\ \mathbf{U}_{ig_{j,m}}^H \mathbf{B}_{i,n} = 0 \quad (j\neq i).\end{aligned} \tag{4}$$

Define a $M \times ((NG-1)r)$ matrix

$$\mathbf{Z}_{i,n} = \left[\mathbf{U}_{ig_{1,1}}, \cdots, \mathbf{U}_{ig_{i,n-1}}, \mathbf{U}_{ig_{i,n+1}}, \cdots, \mathbf{U}_{ig_{N,G}}\right] \tag{5}$$

with rank $(NG-1)r$. Let $\left[\ \mathbf{E}_{i,n}^{(1)}, \mathbf{E}_{i,n}^{(0)}\ \right]$ denote the left singular vectors of $\mathbf{Z}_{i,n}$ obtained from the singular value decomposition (SVD) of $\mathbf{Z}_{i,n}$, such that the columns of the $M\times(M-(NG-1)r)$ matrix $\mathbf{E}_{i,n}{}^{(0)}$ forms a unitary basis for the orthogonal complement of Span($\mathbf{Z}_{i,n}$), i.e., Span($\mathbf{E}_{i,n}^{(0)}$) $=$ Span$^{\perp}(\{\mathbf{U}_{ig_{i,m}} : m\neq n, \mathbf{U}_{ig_{j,m}} : j\neq i\})$.

$\mathbf{B}_{i,n}$ can be obtained by concatenating the projection onto Span($\mathbf{E}_{i,n}^{(0)}$) with eigen-beamforming along the eigenmodes of the channel covariance matrix of the n-th group in the i-th cell. The effective covariance matrix of the channels between the i-th BS and the n-th user group of the i-th cell is given by

$$\hat{\mathbf{R}}_{ig_{i,n}} = \left(\mathbf{E}_{i,n}^{(0)}\right)^H \mathbf{R}_{ig_{i,n}} \mathbf{E}_{i,n}^{(0)} = \mathbf{G}_{i,n}\Phi_{i,n}\mathbf{G}_{i,n}^H, \tag{6}$$

where the expression on the right hand side of (6) is the eigenvalue decomposition of $\hat{\mathbf{R}}_{ig_{i,n}}$. Let $\mathbf{G}_{i,n} = \left[\mathbf{G}_{i,n}^{(1)}, \mathbf{G}_{i,n}^{(0)}\right]$, where $\mathbf{G}_{i,n}^{(1)}$ contains the eigenvectors corresponding to the $b(NK \leq b \leq M-(NG-1)r)$ dominant eigenvalues of $\hat{\mathbf{R}}_{ig_{i,n}}$. Then, the first-stage precoding matrix of the n-th group in the i-th cell can be expressed as

$$\mathbf{B}_{i,n} = \mathbf{E}_{i,n}^{(0)}\mathbf{G}_{i,n}^{(1)}. \tag{7}$$

2) The Second-Stage Precoding: The original JSDM precoding cannot avoid ICI thoroughly due to the use of statistical channel information. Moreover, for the common case where Span($\mathbf{R}_{ig_{j,m}}$) is of large dimension, to reduce computational complexity only part of the eigenspace of $\mathbf{R}_{ig_{j,m}}$ ($\mathbf{U}_{ig_{j,m}}$) is used at the first-stage precoding which also causes remaining interference. Thus, we further avoid the ICI at the second-stage precoding based on effective CSI. Particularly, we employ the RZF precoding based on the effective CSI of all user groups after the first-stage precoding to mitigate the remaining interference.

In this subsection, we assume that each BS has perfect effective CSI to all the users in N cells. The effective channel matrix of the users of the m-th group in the j-th cell after the first-stage precoding can be expressed as

$$\bar{\mathbf{H}}_{i,ng_{j,m}}^{H} = \mathbf{H}_{ig_{j,m}}^{H}\mathbf{B}_{i,n}. \quad (8)$$

Define $\bar{\mathbf{H}}_{i,n} = [\bar{\mathbf{H}}_{i,ng_{1,1}}, \cdots, \bar{\mathbf{H}}_{i,ng_{1,G}}, \bar{\mathbf{H}}_{i,ng_{2,1}}, \cdots, \bar{\mathbf{H}}_{i,ng_{2,G}}, \cdots, \bar{\mathbf{H}}_{i,ng_{N,1}}, \cdots, \bar{\mathbf{H}}_{i,ng_{N,G}}]$. The second-stage precoding matrix of the enhanced JSDM precoding is given by

$$\mathbf{P}_{i,n} = \bar{\xi}_{i,n}\bar{\mathbf{K}}_{i,n}\bar{\mathbf{H}}_{i,ng_{i,n}}, \quad (9)$$

where $\bar{\mathbf{K}}_{i,n} = \left[\bar{\mathbf{H}}_{i,n}\bar{\mathbf{H}}_{i,n}^{H} + \bar{\alpha}\mathbf{I}_b\right]^{-1}$ with $\bar{\alpha} = \frac{NK}{b\rho}$ being the regularization factor, ρ is the signal-to-noise ratio, $\mathbf{I}_b \in \mathbb{C}^{b\times b}$ is the identity matrix and $\bar{\xi}_{i,n}$ is the power normalization factor given by

$$\bar{\xi}_{i,n}^2 = \frac{K_{i,n}}{tr((\mathbf{B}_{i,n}\bar{\mathbf{K}}_{i,n}\bar{\mathbf{H}}_{i,ng_{i,n}})^H(\mathbf{B}_{i,n}\bar{\mathbf{K}}_{i,n}\bar{\mathbf{H}}_{i,ng_{i,n}}))}. \quad (10)$$

B. The Enhanced JSDM Precoding in Practical Systems

The practical issue to implement the enhanced JSDM precoding is that it is quite difficult for each BS to estimate the CSI between the BS and the users of the neighbor cells (we call it "cross-link" CSI). In this subsection, we present the implementation of the enhanced JSDM precoding in *practical systems* considering that each BS does not know the perfect CSI of the local link (we call it "local-link" CSI) and cross-link CSI. However, the BS knows the perfect covariance matrices of local- and cross-link channels.

Using the channel reciprocity of TDD systems, we can obtain the downlink CSI from uplink transmission. The coherent time of the uplink transmission consists of T_t training symbols and T_d data symbols. First, each BS obtains the local-link CSI through uplink channel estimation. We assume that the BSs and the UEs are perfectly synchronized and operate according to a pilot-based protocol [11]. Particularly, K orthogonal unit-norm pilot sequences are reused across N cells during the uplink training period. The pilot of the k-th user in each cell is denoted by $\mathbf{x}_k \in \mathbb{C}^K$. Let $\mathbf{h}_{ink} \in \mathbb{C}^M$ be the channel between the i-th BS and the k-th user in the n-th cell. The minimum mean square error (MMSE) estimation of $\mathbf{h}_{iik}$ is given by

$$\hat{\mathbf{h}}_{iik} = \mathbf{R}_{iik}\mathbf{Q}_{ik}{}^{-1}\mathbf{y}_{ik}^{p}, \quad (11)$$

where

$$\mathbf{y}_{ik}^{p} = \mathbf{h}_{iik} + \sum_{n=1, n\neq i}^{N}\mathbf{h}_{ink} + \mathbf{N}_i\mathbf{x}_k^H. \quad (12)$$

$\mathbf{R}_{iik}$ is the covariance matrix of $\mathbf{h}_{iik}$ and $\mathbf{Q}_{ik}$ is the sum of the covariance matrices of the channels between the i-th BS and the k-th users of all the cells given by

$$\mathbf{Q}_{ik} = \sum_{n=1}^{N}\mathbf{R}_{ink}. \quad (13)$$

For RZF precoding, instead of the CSI, we only need to know the aggregation of the instantaneous cross-link channel covariance matrices of the i-th cell, i.e.,

$$\mathbf{C}_i = \sum_{n\neq i}\mathbf{h}_{in}\mathbf{h}_{in}^{H}, \quad (14)$$

where $\mathbf{h}_{in} = [\mathbf{h}_{in1}, ..., \mathbf{h}_{ink}, ..., \mathbf{h}_{inK}] \in \mathbb{C}^{M\times K}$. To estimate $\mathbf{C}_i$ in (14), we use the Almost Blank Subframes (ABSF) technique in LTE [12]. The main idea of ABSF is that all users within each cell do not transmit during some symbols in the uplink data transmission phase, which are determined by the BS these users are associated with. Blank symbols of each cell are randomly and independently placed within each coherent time.

Let β denote the temporal fraction of the blank symbols within each coherent time. During a blank symbol in a cell, the local users do not transmit. Then, the received signal of the local BS is the aggregate of the signals from the other cells. The received signal vector of the i-th BS is given by

$$\mathbf{y}_i = \sum_{n\neq i}a_n\mathbf{h}_{in}\mathbf{d}_n + \mathbf{n}, \quad (15)$$

where $a_n = 0$ with probability β and $a_n = 1$ with probability $1-\beta$, $\mathbf{d}_n \in \mathbb{C}^K$ is the uplink data symbols of the users in the n-th cell and $\mathbf{n} \in \mathbb{C}^M$ is the noise. The covariance matrix of the received signal vector of the i-th BS can be obtained as

$$\begin{aligned}
&\mathbf{C}_{\mathbf{y}_i} = \mathrm{E}\{\mathbf{y}_i{\mathbf{y}_i}^H\} \\
&= \sum_{n_1\neq i}\sum_{n_2\neq i}\mathrm{E}\{a_{n_1}a_{n_2}\}\mathbf{h}_{in_1}\mathrm{E}\{\mathbf{d}_{n_1}{\mathbf{d}_{n_2}}^H\}{\mathbf{h}_{in_2}}^H + \frac{P}{\rho}\mathbf{I}_M \\
&= \sum_{n_1\neq i}\sum_{n_2\neq i}\mathrm{E}\{a_{n_1}a_{n_2}\}\mathbf{h}_{in_1}{\mathbf{h}_{in_2}}^H P\delta_{n_1n_2} + \frac{P}{\rho}\mathbf{I}_M \\
&=(1-\beta)P\sum_{n\neq i}\mathbf{h}_{in}{\mathbf{h}_{in}}^H + \frac{P}{\rho}\mathbf{I}_M \\
&=(1-\beta)P\mathbf{C}_i + \frac{P}{\rho}\mathbf{I}_M,
\end{aligned}$$

where P is the average transmit power of each user, $\delta_{n_1n_2} = 1$ if $n_1 = n_2$ and $\delta_{n_1n_2} = 0$ otherwise. Then, $\mathbf{C}_i$ can be rewritten as

$$\mathbf{C}_i = \frac{1}{(1-\beta)P}(\mathbf{C}_{\mathbf{y}_i} - \frac{P}{\rho}\mathbf{I}_M). \quad (16)$$

Denoting T the set of the symbol periods during the blank symbols, the estimation of $\mathbf{C}_i$ can be obtained from the sample-covariance of $\mathbf{y}_i$ as follows:

$$\hat{\mathbf{C}}_i = \frac{1}{(1-\beta)P}\Big(\frac{1}{\beta T_d}\sum_{m\in T}\mathbf{y}_i(m)\mathbf{y}_i(m)^H - \frac{P}{\rho}\mathbf{I}_M\Big). \quad (17)$$

Then, the estimation of the aggregate instantaneous cross-link effective channel covariance matrix is given by

$$\hat{\mathbf{A}}_i = \mathbf{B}_{i,n}^{H}\hat{\mathbf{C}}_i\mathbf{B}_{i,n}. \quad (18)$$

The estimation of effective channel matrix for the users of the m-th group in the i-th cell after the first-stage precoding can

TABLE I
PARAMETER LIST

Number of cells	3
Number of BS antennas	128
Number of groups in each cell	3
Number of users in each group	3
Channel model	3GPP spatial correlation channel
Angle spread	15 degree
Transmit power of BS	46 dBm
Radius of cell	200 m

be obtained as

$$\hat{\mathbf{H}}_{i,ng_{i,m}}^H = \hat{\mathbf{H}}_{ig_{i,m}}^H \mathbf{B}_{i,n}, \tag{19}$$

where $\hat{\mathbf{H}}_{ig_{i,m}}$ is obtained in (11). Let $\hat{\mathbf{H}}_{i,ng_i} = [\hat{\mathbf{H}}_{i,ng_{i,1}}, \cdots, \hat{\mathbf{H}}_{i,ng_{i,G}}]$. The second-stage precoding matrix of the enhanced JSDM precoding can be obtained as

$$\hat{\mathbf{P}}_{i,n} = \hat{\xi}_{i,n} \hat{\mathbf{K}}_{i,n} \hat{\mathbf{H}}_{i,ng_{i,n}}, \tag{20}$$

where $\hat{\mathbf{K}}_{i,n} = \left[\hat{\mathbf{A}}_i + \hat{\mathbf{H}}_{i,ng_i} \hat{\mathbf{H}}_{i,ng_i}^H + \bar{\alpha}\mathbf{I}_b\right]^{-1}$.

IV. Simulation Results

In this section, we evaluate the performance of the proposed interference coordination strategy via simulations. We consider a network of three cells, where each cell consists of one BS to serve 9 single-antenna users which are divided into 3 groups. The users of each group are uniformly distributed in a circle area. The radius of the circle is 30 m, and the angles of arrival of the three groups are respectively 20°, 60° and 100°. The distance from the center of the circle to the BS is random. Table 1 shows the parameters used in the simulation.

A. Average Downlink Throughput

Fig. 1 shows the average downlink throughput of one cell with perfect CSI. We show the performance without interference coordination (with legend "Baseline") as a benchmark and the performance of single cell with RZF precoding based on the local-link CSI but without ICI (with legend "no ICI") as an upper bound. We also show the performance of the original JSDM precoding (with legend "JSDM") and the proposed interference coordination strategy with the enhanced JSDM precoding (with legend "Proposed"). The performance of CoMP coordinated beamforming (CoMP-CB) with RZF precoding based on perfect backhaul as well as perfect local- and cross-link CSI (with legend "CB") is shown to compare with the proposed strategy. The results show that the proposed interference coordination strategy based on hybrid channel information is far better than the original JSDM precoding, especially in high SNR regime. Moreover, the proposed policy is close to CoMP-CB and the upper bound with no ICI. In addition, the proposed precoding reduces the computational complexity of precoding at the BSs with respect to the RZF precoding, since it reduces the dimension of the matrix at inversion.

We also evaluate the performance of the proposed strategy in practical systems without perfect effective CSI using the

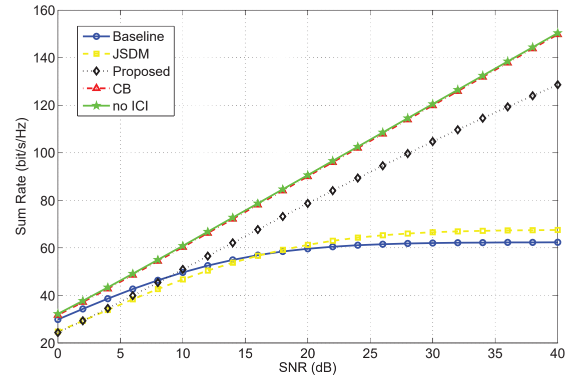

Fig. 1. Downlink throughput with perfect CSI

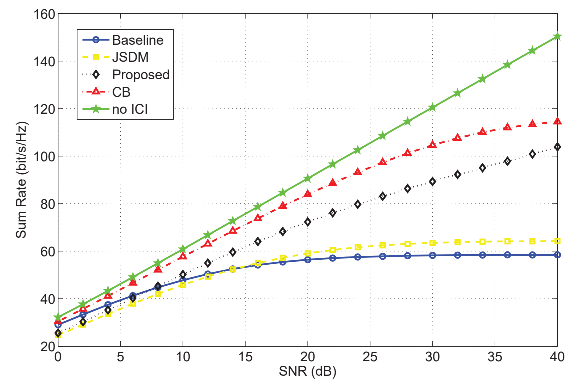

Fig. 2. Downlink throughput in practical systems

method presented in Section III-B. Fig. 2 shows the average downlink throughput of one cell with $\beta = 0.02$ and $T_d = 1000$ symbols corresponding to Fig. 1. From Fig. 2, we can get the same conclusion as that from Fig. 1. The results show that the proposed strategy can be implemented in practical systems and perform well.

B. Effect of the Temporal Fraction of Blank Symbols

The temporal fraction of blank symbols β can not be too large in order to avoid loss of the uplink throughput. We evaluate the performance of the proposed precoding with different values of β and the results are shown in Fig. 3. The

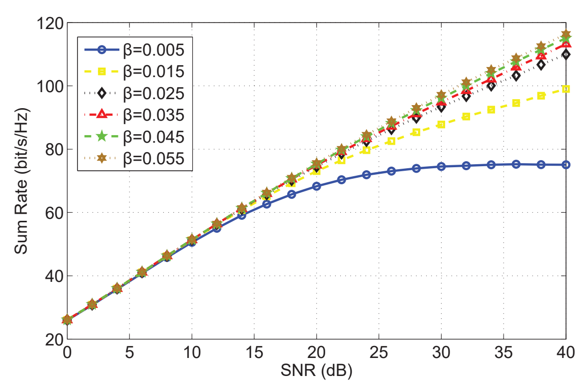

Fig. 3. Downlink throughput with different β

results show that the proposed precoding performs well for $\beta = 0.025$ or larger. Moreover, the performance improvement will be marginal when β continues to increase. We conclude that the proposed precoding can improve the average downlink throughput dramatically without much loss of the uplink throughput.

C. Effect of Imperfect Channel Covariance Matrices

In this subsection, we consider that the channel covariance matrices are estimated from the received training signal samples. The estimation can be more accurate but the overhead will grow as the number of samples increases. In Fig. 4, we evaluate the performance of the proposed precoding with different number of received training signal samples with $\beta = 0.02$ and $T_d = 1000$ symbols. The "Nsample" in the legend represents the number of the received training signal samples used to estimate the channel covariance matrix of each user. The results show that the performance of the proposed precoding is improved as the number of samples increases and the proposed precoding performs well without too many received training signal samples such as 50.

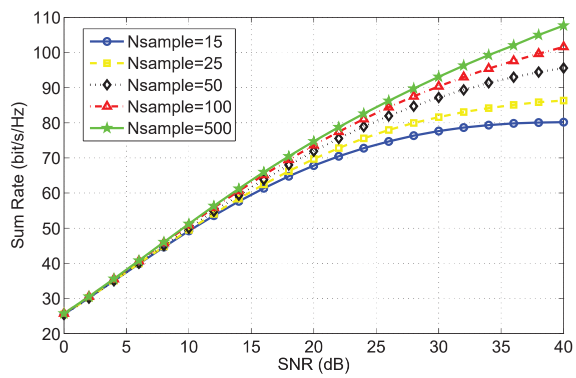

Fig. 4. Downlink throughput with different number of received signal samples

D. User Data Rate

Except for improving the system throughput, we also expect to improve the data rates of the users at the cell edge.

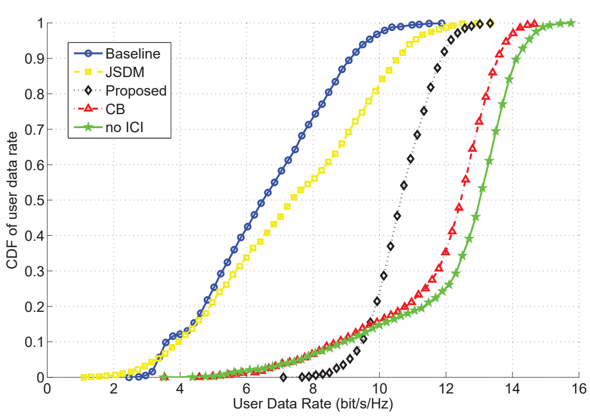

Fig. 5. CDF of the user data rate

Fig. 5 shows the cumulative distribution function (CDF) of the user data rate in one cell with $\mathrm{SNR} = 30\,\mathrm{dB}$, $\beta = 0.02$ and $T_d = 1000$ symbols. The results show that the distribution of the user data rate achieved by the proposed precoding is more centralized than that achieved by CoMP-CB and no ICI, which means that the data rate of most users is high including the users at the cell edge. As for the distribution of the user data rate of CoMP-CB and no ICI, almost 10% of the users have low date rate. Thus the proposed precoding can improve the quality of service at the cell edge and also the fairness among users.

V. Conclusions

In this paper, we have proposed an interference coordination strategy based on hybrid channel information for multicell massive MIMO systems. To avoid ICI, an enhanced JSDM precoding scheme has been introduced based on channel covariance as well as local- and cross-link effective CSI. We have also provided a method to implement the scheme in practical systems without perfect effective CSI. Simulation results showed that the enhanced JSDM precoding can improve the downlink throughput and also the fairness among users compared with the original JSDM precoding.

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