MULTI-USER MIMO DOWNLINK PRECODING FOR TIME-VARIANT CORRELATED CHANNELS

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ABSTRACT

Multi-user multiple-input multiple-output (MU-MIMO) systems provide a significantly increased capacity and spectral efficiency by exploiting the benefits of space division multiple access (SDMA). The channel state information (CSI) at the base station (BS) is used to precode the transmit signals and to simplify the processing at the users' terminals. If perfect CSI is available at the transmitter, the multi-user interference (MUI) can be effectively eliminated at the BS. If the channel varies too fast to obtain short-term CSI, long-term CSI can be used alternatively to improve the system performance. In this paper we propose a new approach to multi-user precoding based on long-term CSI, which can be applied to previously defined precoding techniques originally requiring perfect CSI at the BS. It is shown that a significant performance improvement is achieved by the new approach as compared to a state of the art approach [1] to multi-user precoding with long-term CSI, especially for the case when a user has a line of sight (LOS) channel.

1. INTRODUCTION

In a multi-user multiple-input multiple-output (MIMO) communication system, multiple antennas at both ends of the link offer us the benefit of using space division multiple access (SDMA) to simultaneously transmit multiple data streams to a group of users, which results in a significant improvement of the system capacity. Obviously, this benefit comes from the awareness of channel state information (CSI) at the transmitter.

Linear precoding, as a sub-optimal SDMA strategy, has attracted much attention due to its lower complexity compared to dirty paper coding (DPC) [2–5]. In [2], a linear precoding technique called block diagonalization (BD) is proposed. With perfect CSI at the transmitter, multi-user interference (MUI) can be completely eliminated by choosing the precoding matrix of each user such that it lies in the null space of all other users' channel matrices. The main disadvantages of BD are the performance loss especially in the low SNR regime due to the strict zero MUI constraint and the dimensionality limitation that the aggregate number of receive antennas has to be less than or equal to the number of transmit antennas.

In [3], the authors introduce a regularized block diagonalization (RBD) linear precoding technique, which relaxes the limitation on the aggregate number of receive antennas. The precoding matrix of each user does not only lie in the null space of all other users' channel matrices, but also lies in the signal space of all other users' channel matrices with a power that is inversely proportional to the singular values of all other users' channels. As a result, some MUI is allowed. With perfect CSI, this technique can provide a higher data rate than BD.

By exploiting perfect CSI at the transmitter, the capacity of a multi-user MIMO system with linear precoding can be significantly improved. If it is impossible to acquire perfect instantaneous CSI at the transmitter, the spatial channel correlation can alternatively be used to reduce the MUI and improve the system performance. In this paper we consider the multi-user MIMO downlink and assume that the channel is correlated and varies too rapidly to obtain short-term CSI. We propose a new approach to exploit the knowledge of the spatial correlation at the base station (BS) that allows us to use existing precoding techniques (e.g., BD and RBD) designed for perfect CSI at the BS.

In this paper, upper case and lower case boldface letters are used to denote matrices $\boldsymbol{A}$ and column vectors $\boldsymbol{a}$, respectively. We use $\boldsymbol{A}^{\mathrm{T}}$ and $\boldsymbol{A}^{\mathrm{H}}$ to indicate the transpose and Hermitian transpose of the matrix $\boldsymbol{A}$. Moreover, $\boldsymbol{A}(i,j)$ is the matrix element in the $i\mathrm{th}$ row and the $j\mathrm{th}$ column. $\boldsymbol{A}(:,j)$ represents the $j\mathrm{th}$ column vector of the matrix $\boldsymbol{A}$.

This paper is organized as follows: The system model is described in Section 2. A new approach called rank-one ap-

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proximated long-term CSI is introduced in Section 3, while the simulation results are presented in Section 4. A short conclusion follows in Section 5.

2. SYSTEM MODEL

We model the multi-user MIMO downlink channel as a perfectly tuned OFDM channel without any inter subcarrier interference. There are K users in the system. The BS is equipped with M_T transmit antennas and the ith user has M_{R_i} receive antennas. The total number of receive antennas of all users is denoted by M_R (i.e., $M_\mathrm{R} = \sum_{i=1}^{K} M_{\mathrm{R}_i}$). We use $\boldsymbol{H}_i(N_f, N_t) \in \mathbb{C}^{M_{\mathrm{R}_i} \times M_\mathrm{T}}$ to denote the propagation channel between the BS and the user i at subcarrier N_f and OFDM symbol N_t. Then the combined MIMO channel matrix of all users can be defined as

$$\boldsymbol{H}(N_f, N_t) = \left[\boldsymbol{H}_1^\mathrm{T}(N_f, N_t)\ \boldsymbol{H}_2^\mathrm{T}(N_f, N_t) \ldots \boldsymbol{H}_K^\mathrm{T}(N_f, N_t)\right]^\mathrm{T} . \quad (1)$$

We assume that it is not possible to track fast variations of users' channels but the information about spatial correlations of the channels can be obtained.

The downlink input output data model with linear precoding matrix $\boldsymbol{F}$ and decoding matrix $\boldsymbol{D}$ can be expressed as

$$\boldsymbol{y} = \boldsymbol{D}\big(\boldsymbol{H}(N_f, N_t)\boldsymbol{F}\boldsymbol{x} + \boldsymbol{n}\big) , \quad (2)$$

where the vectors $\boldsymbol{x}$, $\boldsymbol{y}$, and $\boldsymbol{n}$ represent the vectors of transmitted symbols, received signals at all users, and additive noise at the receive antennas, respectively. $\boldsymbol{F} = [\boldsymbol{F}_1, \ldots, \boldsymbol{F}_K]$ denotes the joint precoding matrix which is used to mitigate MUI, and $\boldsymbol{D} \in \mathbb{C}^{r \times M_\mathrm{R}}$ is a block-diagonal decoding matrix containing each user's receive filter $\boldsymbol{D}_i \in \mathbb{C}^{r_i \times M_{\mathrm{R}_i}}$ which is designed to combine the signals of the user's antennas efficiently. The dimensions r and r_i denote the total number of data streams and the number of data streams at the ith user terminal, respectively.

We define a chunk as the basic resource element, which contains N_T consecutive OFDM symbols in the time direction and N_F subcarriers in the frequency direction. Therefore, the number of $N_\mathrm{chunk} = N_F \cdot N_T$ symbols are available within each chunk. Chunk-wise precoding and decoding are performed.

3. MULTI-USER LINEAR PRECODING

In a time division duplex (TDD) system, by taking into account the reciprocity principle it is possible to use the estimated uplink channel for downlink transmission. This information can be used as short-term CSI to perform precoding at the BS.

If we assume that the channel varies too rapidly to be trackable, only the information relative to the geometry of the propagation paths is captured by a spatial correlation matrix. In order to effectively perform precoding based on the available CSI at the BS, in this section we propose to exploit the knowledge of the spatial correlation with a new approach called rank-one approximated long-term CSI (ROLT-CSI).

Based on ROLT-CSI, any linear precoding technique, which is designed for perfect CSI at the BS, can be modified for long-term CSI. In this paper, we present this modification for BD and RBD precoding as instructive examples.

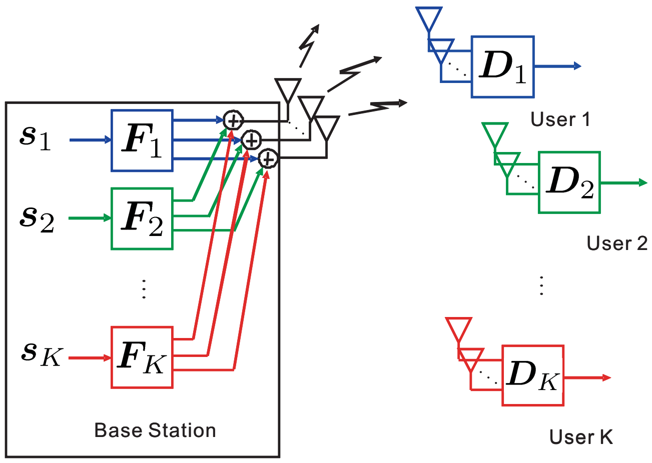

Fig. 1. Block diagram of a multi-user MIMO downlink system.

3.1. Previous Long-term CSI Method

The authors in [1, 6] introduce a method to exploit the long-term CSI for multi-user precoding. They define the singular value decomposition (SVD) of the ith user's spatial correlation matrix estimate $\hat{\boldsymbol{R}}_i$ as

$$\hat{\boldsymbol{R}}_i = \boldsymbol{V}_i \boldsymbol{\Lambda}_i \boldsymbol{V}_i^\mathrm{H} \in \mathbb{C}^{M_\mathrm{T} \times M_\mathrm{T}} . \quad (3)$$

Then the equivalent channel of user i can be represented as

$$\hat{\boldsymbol{H}}_i = \boldsymbol{\Lambda}_i^{1/2} \boldsymbol{V}_i^\mathrm{H} . \quad (4)$$

The spatial correlation matrix estimate $\hat{\boldsymbol{R}}_{i,b}$ for user i and chunk b can be expressed as

$$\hat{\boldsymbol{R}}_{i,b} = \frac{1}{N_\mathrm{chunk}} \sum_{N_f=1}^{N_F} \sum_{N_t=1}^{N_T} \boldsymbol{H}_i^\mathrm{H}(N_f, N_t) \boldsymbol{H}_i(N_f, N_t) . \quad (5)$$

Its SVD is

$$\hat{\boldsymbol{R}}_{i,b} = \boldsymbol{V}_{i,b} \boldsymbol{\Lambda}_{i,b} \boldsymbol{V}_{i,b}^\mathrm{H} . \quad (6)$$

The multi-user MIMO precoding is now performed on the equivalent channel defined as follows

$$\hat{\boldsymbol{H}}_{i,b} = \boldsymbol{\Lambda}_{i,b}^{1/2} \boldsymbol{V}_{i,b}^\mathrm{H} . \quad (7)$$

3.2. ROLT-CSI

The ROLT-CSI approach is designed to effectively represent the channel by exploiting the knowledge of the estimated long-term channel spatial correlation.

For each receive antenna of user i, the spatial correlation matrix is represented as

$$\boldsymbol{R}_{i,l}(N_f, N_t) = \mathrm{E}\left\{\boldsymbol{h}_{i,l}(N_f, N_t)\boldsymbol{h}_{i,l}^{\mathrm{H}}(N_f, N_t)\right\} \in \mathbb{C}^{M_{\mathrm{T}}\times M_{\mathrm{T}}} \,. \tag{8}$$

Here $\boldsymbol{h}_{i,l}^{\mathrm{H}}(N_f, N_t)$ denotes the lth row of the channel matrix $\boldsymbol{H}_i(N_f, N_t) \in \mathbb{C}^{M_{\mathrm{R}_i}\times M_{\mathrm{T}}}$. The index l indicates the lth receive antenna of user i. In this paper we estimate the spatial correlation matrix of the lth receive antenna of user i by averaging over one chunk. Let $\hat{\boldsymbol{R}}_{i,b,l}$ denote the estimated spatial correlation matrix of user i, chunk b, and receive antenna l. Then we have

$$\hat{\boldsymbol{R}}_{i,b,l} = \frac{1}{N_{\mathrm{chunk}}} \sum_{N_f=1}^{N_F} \sum_{N_t=1}^{N_T} \boldsymbol{h}_{i,l}(N_f, N_t)\boldsymbol{h}_{i,l}^{\mathrm{H}}(N_f, N_t) \tag{9}$$

and its SVD as

$$\hat{\boldsymbol{R}}_{i,b,l} = \boldsymbol{V}_{i,b,l}\boldsymbol{\Lambda}_{i,b,l}\boldsymbol{V}_{i,b,l}^{\mathrm{H}} \,, l = 1, \ldots, M_{\mathrm{R}_i} \,. \tag{10}$$

According to [7], when only second-order channel statistics are available at the transmitter, the optimum strategy is to transmit along the dominant eigenmode of the matrix $\hat{\boldsymbol{R}}_{i,b,l}$. Therefore, we define the equivalent channel matrix of user i in chunk b as

$$\hat{\boldsymbol{H}}_{i,b} = \boldsymbol{A}_{i,b}\boldsymbol{B}_{i,b} \in \mathbb{C}^{M_{\mathrm{R}_i}\times M_{\mathrm{T}}} \,, \tag{11}$$

where

$$\boldsymbol{A}_{i,b} = \begin{bmatrix} \sqrt{\boldsymbol{\Lambda}_{i,b,1}(1,1)} & \boldsymbol{0} & \cdots & \boldsymbol{0} \\ \boldsymbol{0} & \sqrt{\boldsymbol{\Lambda}_{i,b,2}(1,1)} & \cdots & \boldsymbol{0} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{0} & \boldsymbol{0} & \cdots & \sqrt{\boldsymbol{\Lambda}_{i,b,M_{\mathrm{R}_i}}(1,1)} \end{bmatrix}$$

and

$$\boldsymbol{B}_{i,b} = \begin{bmatrix} \boldsymbol{V}_{i,b,1}^{\mathrm{H}}(:,1) \\ \boldsymbol{V}_{i,b,2}^{\mathrm{H}}(:,1) \\ \vdots \\ \boldsymbol{V}_{i,b,M_{\mathrm{R}_i}}^{\mathrm{H}}(:,1) \end{bmatrix} .$$

Here $\boldsymbol{\Lambda}_{i,b,l}(1,1)$ indicates the largest eigenvalue of $\hat{\boldsymbol{R}}_{i,b,l}$ and $\boldsymbol{V}_{i,b,l}^{\mathrm{H}}(:,1)$ denotes the corresponding eigenvector of $\hat{\boldsymbol{R}}_{i,b,l}$.

The multi-user MIMO precoding can now be performed on the equivalent channel as defined in equation (11). Clearly, the rank-one approximation in equation (11) effectively represents the channel only if its spatial correlation matrix in equation (9) also has a low rank.

3.3. Block Diagonalization Precoding

We define $\boldsymbol{F}_i \in \mathbb{C}^{M_{\mathrm{T}}\times r_i}$ as the ith user's precoding matrix. In [2], the optimal $\boldsymbol{F}_i$ of BD precoding lies in the null space of the other users' channel matrices. Thereby, a multi-user MIMO downlink channel is decomposed into multiple parallel independent single-user MIMO channels.

Let us define $\widetilde{\boldsymbol{H}}_i$ as [1]

$$\widetilde{\boldsymbol{H}}_i = \begin{bmatrix} \boldsymbol{H}_1 \\ \vdots \\ \boldsymbol{H}_{i-1} \\ \boldsymbol{H}_{i+1} \\ \vdots \\ \boldsymbol{H}_K \end{bmatrix} \in \mathbb{C}^{(M_{\mathrm{R}}-M_{\mathrm{R}_i})\times M_{\mathrm{T}}} \,. \tag{12}$$

The zero MUI constraint forces the matrix $\boldsymbol{F}_i$ to lie in the null space of $\widetilde{\boldsymbol{H}}_i$. By using the singular value decomposition (SVD), $\widetilde{\boldsymbol{H}}_i$ is written as

$$\widetilde{\boldsymbol{H}}_i = \widetilde{\boldsymbol{U}}_i\widetilde{\boldsymbol{\Sigma}}_i \left[\widetilde{\boldsymbol{V}}_i^{(1)} \; \widetilde{\boldsymbol{V}}_i^{(0)}\right]^{\mathrm{H}} \tag{13}$$

where $\widetilde{\boldsymbol{V}}_i^{(1)}$ holds the first $\widetilde{L}_i$ right singular vectors, and $\widetilde{\boldsymbol{V}}_i^{(0)}$ holds the last $(M_{\mathrm{T}} - \widetilde{L}_i)$ right singular vectors. Here $\widetilde{L}_i$ indicates the rank of $\widetilde{\boldsymbol{H}}_i$. Thus, $\widetilde{\boldsymbol{V}}_i^{(0)}$ forms an orthogonal basis for the null space of $\widetilde{\boldsymbol{H}}_i$. The equivalent channel of user i after eliminating the MUI is represented as $\boldsymbol{H}_i\widetilde{\boldsymbol{V}}_i^{(0)} \in \mathbb{C}^{M_{\mathrm{R}_i}\times(M_{\mathrm{T}}-\widetilde{L}_i)}$ which is equivalent to a system with $M_{\mathrm{T}}-\widetilde{L}_i$ transmit antennas and M_{R_i} receive antennas. Each of these equivalent single-user MIMO channels has the same properties as a conventional single-user MIMO channel.

We define the SVD of

$$\boldsymbol{H}_i\widetilde{\boldsymbol{V}}_i^{(0)} = \boldsymbol{U}_i\boldsymbol{\Sigma}_i \left[\boldsymbol{V}_i^{(1)} \; \boldsymbol{V}_i^{(0)}\right]^{\mathrm{H}} \tag{14}$$

and denote the rank of the ith user's equivalent channel matrix as L_i. Now the BD precoding matrix of user i can be defined as the product of the first L_i singular vectors $\boldsymbol{V}_i^{(1)}$ and $\widetilde{\boldsymbol{V}}_i^{(0)}$ with proper power loading.

If there is only long-term CSI available at the BS, we use the equivalent channel (11) from the ROLT-CSI approach instead of the exact channel $\boldsymbol{H}_i$ in equations (12) and (14).

3.4. Regularized Block Diagonalization Precoding

RBD precoding is designed to relax the limitation on the aggregate number of receive antennas and has a significantly improved data rate and diversity order compared to BD precoding [3]. The RBD precoding design is performed in two steps. In the first step, we balance the MUI suppression

[1]In subsections 3.3 and 3.4, we use $\boldsymbol{H}_i$ instead of $\boldsymbol{H}_i(N_f, N_t)$ in order to simplify the introduction to BD and RBD precoding.

which is achieved by reducing the overlap of the row spaces spanned by the effective channel matrices of different users and any MIMO processing gain which requires that the users use as much as possible the available subspace. In the second step, we optimize the system performance assuming parallel single-user MIMO channels.

Let us define the joint precoding matrix as

$$\boldsymbol{F} = [\boldsymbol{F}_1 \quad \boldsymbol{F}_2 \quad \ldots \quad \boldsymbol{F}_K] \in \mathbb{C}^{M_{\mathrm{T}} \times r} , \tag{15}$$

where $\boldsymbol{F}_i \in \mathbb{C}^{M_{\mathrm{T}} \times r_i}$ is the ith user's precoding matrix.

In [3], the matrix $\boldsymbol{F}$ of RBD precoding is proposed as

$$\boldsymbol{F} = \beta \boldsymbol{F}_a \cdot \boldsymbol{F}_b , \tag{16}$$

where

$$\boldsymbol{F}_a = [\boldsymbol{F}_{a_1} \, \boldsymbol{F}_{a_2} \ldots \boldsymbol{F}_{a_K}] \in \mathbb{C}^{M_{\mathrm{T}} \times r} ,$$

and

$$\boldsymbol{F}_b = \begin{bmatrix} \boldsymbol{F}_{b_1} & \boldsymbol{0} & \cdots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{F}_{b_2} & \cdots & \boldsymbol{0} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{0} & \boldsymbol{0} & \cdots & \boldsymbol{F}_{b_K} \end{bmatrix} \in \mathbb{C}^{r \times r} .$$

The matrix $\boldsymbol{F}_a$ is used to suppress MUI while balancing it with noise enhancement first, and then the matrix $\boldsymbol{F}_b$ is used to further optimize the system performance by optimal power loading. Finally, the parameter β is chosen to set the total transmit power to the power constraint.

The equivalent combined channel matrix of all users after precoding is equal to

$$\boldsymbol{H}\boldsymbol{F}_a = \begin{bmatrix} \boldsymbol{H}_1\boldsymbol{F}_{a_1} & \boldsymbol{H}_1\boldsymbol{F}_{a_2} & \cdots & \boldsymbol{H}_1\boldsymbol{F}_{a_K} \\ \boldsymbol{H}_2\boldsymbol{F}_{a_1} & \boldsymbol{H}_2\boldsymbol{F}_{a_2} & \cdots & \boldsymbol{H}_2\boldsymbol{F}_{a_K} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{H}_K\boldsymbol{F}_{a_1} & \boldsymbol{H}_K\boldsymbol{F}_{a_2} & \cdots & \boldsymbol{H}_K\boldsymbol{F}_{a_K} \end{bmatrix} , \tag{17}$$

where $\boldsymbol{H} \in \mathbb{C}^{M_{\mathrm{R}} \times M_{\mathrm{T}}}$ represents the combined channel matrix of all users. The ith user's effective channel is given by $\boldsymbol{H}_i\boldsymbol{F}_{a_i}$ and the interference generated to the other users is determined by $\widetilde{\boldsymbol{H}}_i\boldsymbol{F}_{a_i}$, where $\widetilde{\boldsymbol{H}}_i$ is defined in equation (12).

The matrix $\boldsymbol{F}_a$ is chosen such that the off-diagonal block matrices of equation (17) converge to zero as the SNR increases. Then we have

$$\boldsymbol{F}_{a_i} = \widetilde{\boldsymbol{V}}_i \big(\widetilde{\boldsymbol{\Sigma}}_i^{\mathrm{T}} \widetilde{\boldsymbol{\Sigma}}_i + \mu \boldsymbol{I}_{M_{\mathrm{T}}} \big)^{-1/2} , \tag{18}$$

where the SVD of $\widetilde{\boldsymbol{H}}_i$ is given by

$$\widetilde{\boldsymbol{H}}_i = \widetilde{\boldsymbol{U}}_i \widetilde{\boldsymbol{\Sigma}}_i \widetilde{\boldsymbol{V}}_i^{\mathrm{H}} . \tag{19}$$

After suppressing MUI by $\boldsymbol{F}_a$, we optimize the system performance by setting $\boldsymbol{F}_{b_i}$ as

$$\boldsymbol{F}_{b_i} = \boldsymbol{V}_i \boldsymbol{M}_{b_i} \tag{20}$$

where $\boldsymbol{V}_i$ is obtained from the SVD of the ith user's equivalent channel

$$\boldsymbol{H}_i \boldsymbol{F}_{a_i} = \boldsymbol{U}_i \boldsymbol{\Sigma}_i \boldsymbol{V}_i^{\mathrm{H}} . \tag{21}$$

The choice of the power loading matrix $\boldsymbol{M}_{b_i}$ depends on the optimization criteria. In this work we assume that $\boldsymbol{M}_{b_i}$ is unitary.

If there is only long-term CSI available at the BS, we use the equivalent channel (11) from the ROLT-CSI approach instead of the exact channel $\boldsymbol{H}_i$ in equations (12), (17) and (21).

4. SIMULATION RESULTS

In this section we evaluate the throughput performance of the BD and RBD precoding techniques, when only long-term CSI is available. We consider a 3 users MIMO downlink system. The simulation scenario is illustrated in Figure 2. The channels between each user and the BS are generated by a geometry-based channel model called *IlmProp*, which has been developed at Ilmenau University of Technology [8] and is capable of dealing with time variant frequency selective scenarios.

There are 8 transmit antennas at the BS and each user is equipped with 2 receive antennas. We simultaneously transmit two data streams to each user. User 1 and user 2 always have non-line of sight (NLOS) channels and user 3 alway has a line of sight (LOS) channel. The velocities of the three users are 10 km/h. In Table 1, the important OFDM parameters are listed.

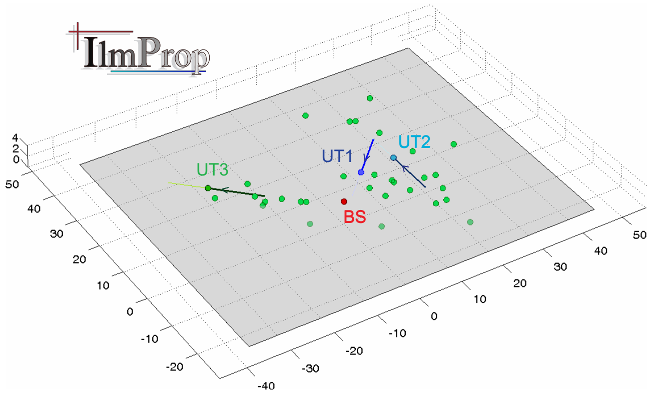

Fig. 2. The geometrical representation of the simulation scenario. Each green point represents a fixed scatter. The channel impulse responses (CIR) are generated as a sum of propagation rays. The channel is computed from the superposition of the LOS component and a number of rays which represent the multi-path components. User 1 and user 2 always have NLOS channels and user 3 alway has a LOS channel.

We use *uplink dedicated pilots* to estimate the channel between the user terminal and all BS antennas. For each chunk, there are several pilots available. We compute one channel estimate per pilot and then interpolate between these estimates

Table 1. OFDM Parameters

Parameters	**Values**
Carrier Frequency	5 GHz
Subcarrier Spacing	0.50196 MHz
Useful Symbol Duration	1.9922 μs
System Bandwidth	128.5 MHz
Used Subcarriers	$[-128:+128]$, 0 not used
Chunk Size	8 subcarriers, 15 OFDM symbols
Duplexing Mode	TDD

for every symbol in the chunk. Then we calculate the equivalent channel of the chunk with equation (11) for the ROLT-CSI approach and with equation (7) for the long-term CSI method of [1], respectively. Then the BS can compute the precoding matrix $\boldsymbol{F}$ for each chunk. The linear precoding schemes used in the simulation are BD precoding and RBD precoding.

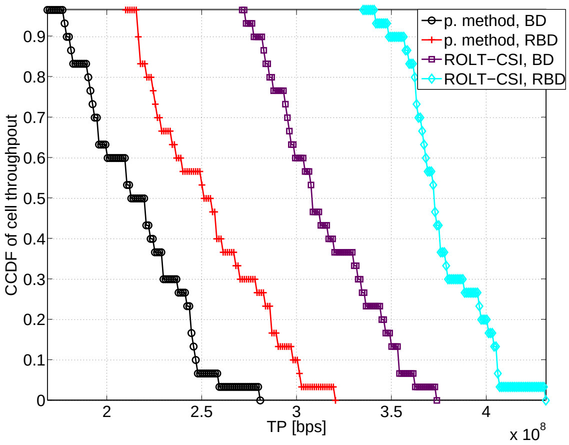

Fig. 3. CCDF of the sum rates with BD and RBD precoding based on long-term CSI at the transmitter, respectively. p. method indicates the previous long-term CSI method.

In Figures 3, 4, and 5 we assume that the channel estimate per pilot of each chunk is perfectly performed. In Figure 3, we compare the throughput of the system with precoding based on ROLT-CSI proposed in this paper to the throughput based on the state of the art long-term CSI method in [1]. We can see that RBD precoding can achieve a higher data rate than BD precoding. When linear precoding is performed based on long-term CSI, a significant performance gain can be achieved by our new approach relative to the previous long-term CSI method.

In Figures 4 and 5 the individual user throughputs based on ROLT-CSI and the previous long-term CSI approach are compared. It is shown that the ROLT-CSI approach is particularly efficient for the user who has the LOS channel. Even for the users who only have NLOS channels, which means

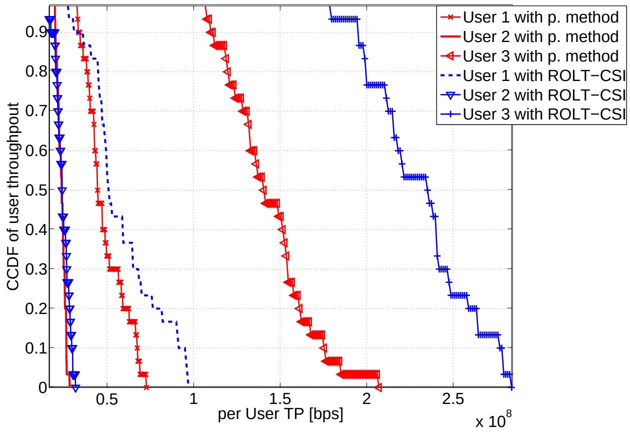

Fig. 4. CCDF of the individual user throughput with BD precoding based on long-term CSI at the transmitter, p. method indicates the previous long-term CSI method.

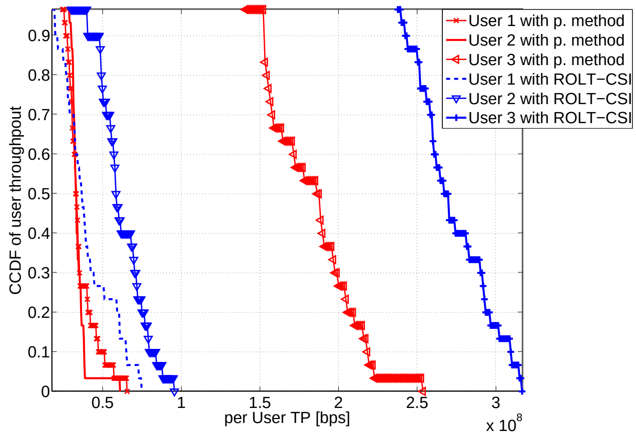

Fig. 5. CCDF of the individual user throughput with RBD precoding based on long-term CSI at the transmitter, p. method indicates the previous long-term CSI method.

that the spatial correlation matrix of these user channels have a high rank, relative to the previous long-term CSI method there are still some performance gains available for the presented ROLT-CSI approach.

Taking into account realistic channel propagation conditions, for Figure 6 and 7 we assume that the channel estimate per pilot of each chunk is imperfectly performed. We consider a channel estimation error, a channel interpolation error, and the delay resulting from the fact that the available CSI of chunk k will be used to optimize the transmission over the channel realization of chunk $(k+n)$. One chunk and three chunks delay are considered separately in the simulation. According to Table 1, the duration of one chunk is equal to the duration of 15 OFDM symbols.

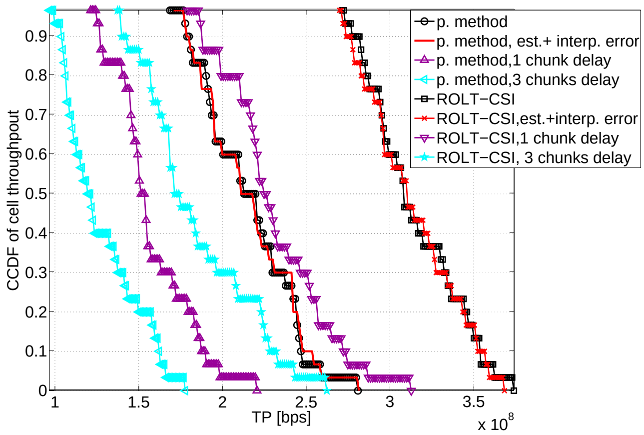

Fig. 6. CCDF of the sum rates with BD precoding based on long-term CSI at the transmitter, p. method indicates the previous long-term CSI method.

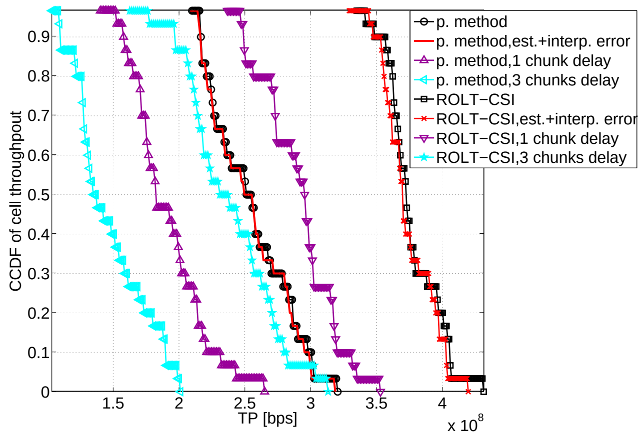

Fig. 7. CCDF of the sum rates with RBD precoding based on long-term CSI at the transmitter, p. method the indicates previous long-term CSI method.

For the CSI imperfection, the channel estimation error and interpolation error are modeled according to [9], but we increase the interpolation error variance to -20 dB. It is found that the delay is still the predominant cause of a performance degradation in a precoded multi-user MIMO system with long-term CSI.

5. CONCLUSIONS

In this paper we propose a new precoding approach that allows the use of previously defined linear precoding techniques originally requiring perfect CSI at the transmitter in cases when only long-term CSI is available. The new approach to exploit the long-term CSI is called rank-one approximated long-term CSI (ROLT-CSI). Using ROLT-CSI we evaluate the throughput performance of the two multi-user MIMO precoding techniques BD and RBD. RBD precoding permits some MUI and has no restrictions considering the number of antennas at the user. In contrast, BD has zero MUI and the aggregate number of receive antennas has to be less than or equal to the number of transmit antennas. Furthermore, we compare the throughput of the system with precoding based on ROLT-CSI to the system throughput based on the state of the art long-term CSI method in [1]. A significant performance gain can be achieved by our new approach. From the individual user throughput comparison we can see that our new approach is particularly efficient when the user's spatial correlation matrix has a low rank. If the user's spatial correlation matrix has a high rank, our new approach still works well.

To take into account realistic channel propagation conditions, we also consider in the simulations a channel estimation error, a channel interpolation error, and the delay resulting from the fact that the available CSI of chunk k will be used to optimize the transmission over the channel realization of chunk $(k + n)$. It is found that the delay is still the predominant cause of a performance degradation in a precoded multi-user MIMO system with long-term CSI.

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