

Robust Transceiver with Switched Preprocessing for K -Pair MIMO Interference Channels

Yunlong Cai ^{#1}, Ming-Min Zhao ^{#2}, Benoit Champagne ^{*3} and Min-Jian Zhao ^{#4}

[#] Department of Information Science and Electronic Engineering, Zhejiang University, Hangzhou, China, 310027

^{*} Department of Electrical and Computer Engineering, McGill University, Montreal, QC, Canada, H3A 2A7

¹ ylcai@zju.edu.cn, ² zmmblack@zju.edu.cn, ³ benoit.champagne@mcgill.ca, ⁴ mjzhao@zju.edu.cn

Abstract—In this work, we propose a transceiver strategy with switched preprocessing (SP) for interference suppression in K -pair multiple-input multiple-output (MIMO) interference channels. Each transmitter is equipped with a codebook of permutation matrices. For the given MIMO interference channel, all the combinations of permutation matrices among the transmitters can create a number of parallel transceivers. Based on the given channel state information (CSI) and a block of transmit symbols, the optimum transceiver branch is chosen by a suitable selection criterion for transmission. For each branch, we introduce a robust transceiver design algorithm based on minimizing the mean square error (MSE) criterion. The selection criterion is designed to minimize the Euclidean distance between the true transmit symbol vector and the pre-estimated noiseless received vector. Simulation results show that the performance of the proposed technique is significantly better than prior art in the case of imperfect CSI.¹

Index Terms- Robust transceiver, MIMO interference channel, switched preprocessing, MMSE, interference alignment.

I. INTRODUCTION

Recently, K -Pair MIMO interference channel has attracted considerable attention in the research community, and many believe that it will be the next major innovation following point-to-point MIMO and MIMO broadcasting channels. Interference alignment (IA) for interference channels has been studied in [1] as a means to align the interfering signals at the transmitters, allowing the receivers to cancel more interferers. It is particularly well suited for applications to coordinated multi-point (CoMP) transmissions, as it can improve detection performance for a group of users at the cell edge by reducing inter-cell interference and thereby improving data rates. In [2], Gomadam *et al.* proposed distributed interference alignment algorithms to cancel the interference by iteratively minimizing leakage interference or maximizing signal-to-interference-plus-noise ratio (SINR). However, IA is considered as a sub-optimal approach since it aims at suppressing the interference and makes no attempt to increase the desired signal power.

Considering that the potential gains of IA are only attainable in the limit of very high signal-to-noise ratio (SNR), several researchers have recently turned their attention to the joint transmitter and receiver design by relaxing the perfect alignment constraint. Here, the aim is to achieve better capacity in the low to intermediate SNR regimes, which better represent the practical conditions of operation away from the base stations in cellular systems. In [3], the authors propose three generalizations of IA with full CSI for the MIMO interference channel, i.e. the minimum interference-plus-noise leakage (INL), the maximum SINR and the joint minimum MSE design

algorithms, which are simulated alongside existing methods in regimes previously not considered in the literature. A gradient descent method based on maximizing the weighted sum rate is investigated in [4], where the aim is to identify a local optimal solution iteratively. In [5], novel robust transceiver algorithms against channel errors for the MIMO interference channel are proposed based on the MSE criterion, especially by minimizing the Sum-MSE and the maximum per user MSE.

In this paper, we propose a robust switched preprocessing transceiver strategy for K -pair MIMO interference channels. We equip each transmitter with a codebook of permutation matrices. For the given MIMO interference channel, all the combinations of permutation matrices among the transmitters can generate different permuted channels, and then create a number of parallel transceivers. Based on the given CSI and a block of transmit symbols, the optimum transceiver branch used to send the data is chosen by a suitable selection criterion. For each branch, we introduce a robust transceiver design algorithm based on minimizing the Sum-MSE criterion. The selection criterion is designed to minimize the Euclidean distance between the true transmit symbol vector and the pre-estimated noiseless received vector. Simulation results show that the performance of the proposed techniques is significantly better than prior art in the presence of imperfect CSI.

II. PROPOSED TRANSMISSION SCHEME

We consider a MIMO interference channel with K multi-antenna transmitter-receiver pairs, as illustrated in Fig. 1. Furthermore, each transmitter is equipped with a codebook of permutation matrices². Suppose that the codebook size is B , then we have B^K possible combinations of permutation matrices among all the transmitters. Each combination of permutation matrices can create a permuted K -pair MIMO interference channel. According to all the permuted MIMO interference channels, we can design B^K parallel branches of transceivers (precoding and receiving matrices) for all the transmission pairs. The optimum branch is determined by the selection criterion and the data block is transmitted by following the selected branch. That is to say, at each transmitter, the data is transmitted by using the selected precoding matrix first, then the precoded vector is operated by the corresponding preprocessing matrix, i.e., the selected permutation matrix, before transmission. Finally, at the receiver, the corresponding receiving matrix is employed to decode the symbols. More detailed description will be given in the following sections.

¹This work was supported by the Fundamental Research Funds for the Central Universities, the National Science Foundation of China (NSFC) under Grant 61101103, the Scientific Research Project of Zhejiang Provincial Education Department under Grant Y201122655, and the Huawei Innovation Research Program.

²A permutation matrix is a square binary matrix that has exactly one entry 1 in each row and each column and 0s elsewhere. It aims at allocating the elements of the vector provided by the precoder on different transmit antennas in a certain order.

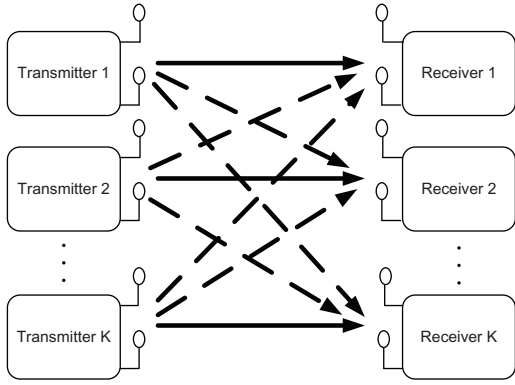


Fig. 1. The K -pair MIMO interference channel. The solid lines denote the desired transmission links and the dashed lines denote the links of interference.

A. Proposed System Model

The k -th transmitter equipped with M_k antennas aims to send symbols to its paired receiver, where $k \in \{1, \dots, K\}$. The k -th receiver equipped with N_k antennas aims to decode the symbols from its corresponding transmitter, and treats the symbols from the other transmitters as interference. Here, the acronyms MUI refer to multi-user interference. The transmitters and receivers' antennas are linked by multiple wireless channels, which we assume to undergo frequency flat (e.g. Rayleigh), slow fading.

Focusing on the k -th transmit-receive pair, the receive data vector $\mathbf{r}_k \in \mathbb{C}^{N_k \times 1}$ can be expressed in the following form:

$$\begin{aligned} \mathbf{r}_k &= \sum_{l=1}^K \mathbf{H}_{k,l} \mathbf{T}_{n,l} \mathbf{P}_{n,l} \mathbf{b}_l + \mathbf{n}_k \\ &= \mathbf{H}_{k,k} \mathbf{T}_{n,k} \mathbf{P}_{n,k} \mathbf{b}_k + \overbrace{\sum_{l \neq k} \mathbf{H}_{k,l} \mathbf{T}_{n,l} \mathbf{P}_{n,l} \mathbf{b}_l}^{\text{MUI}} + \mathbf{n}_k, \end{aligned} \quad (1)$$

where $\mathbf{b}_l \in \mathbb{C}^{D_l \times 1}$ is the symbol vector emitted by the l -th transmitter, D_l denotes the number of data streams of the l -th pair and $\mathbf{P}_{n,l} \in \mathbb{C}^{M_l \times D_l}$ denotes the precoding matrix corresponding to the n -th branch of transceivers applied to the transmitted symbol vector \mathbf{b}_l , where $n \in \{1, \dots, B^K\}$. $\mathbf{T}_{n,l}$ denotes the permutation matrix corresponding to the n -th branch for the l -th transmitter while $\mathbf{H}_{k,l} \in \mathbb{C}^{N_k \times M_l}$ denotes the MIMO channel matrix between the l -th transmitter and the k -th receiver, whose elements are independent and identically distributed (i.i.d.) complex Gaussian variables with zero mean and unit variance. In this respect, the set of matrices $\{\mathbf{H}_{k,l} \mathbf{T}_{n,l}\}$ represents the collection of permuted MIMO channel matrices corresponding to the n -th branch. The term $\mathbf{n}_k \in \mathbb{C}^{N_k \times 1}$ is an additive noise vector, which is assumed to be temporally white, independent over the receiver index k , with zero-mean and covariance matrices $E[\mathbf{n}_k \mathbf{n}_k^H] = \sigma_n^2 \mathbf{I}$. The transmitted symbols are independent of the noise vector \mathbf{n}_k at any receiver.

At each receiver, we let $\mathbf{W}_{n,k} \in \mathbb{C}^{D_k \times N_k}$ denote the receiving matrix of the n -th branch, which is applied to \mathbf{r}_k to form the linear estimate of \mathbf{b}_k , which is given by

$$\hat{\mathbf{b}}_k = \mathcal{Q}\{\mathbf{W}_{n,k} \mathbf{r}_k\}. \quad (2)$$

where $\mathcal{Q}\{\cdot\}$ represents the quantization operation. The main problem of transceiver design for the above MIMO interfer-

ence channel is to derive the precoding matrices $\{\mathbf{P}_{n,l}\}$ and receiving weight matrices $\{\mathbf{W}_{n,l}\}$ corresponding to all the branches of transceivers that optimize a predefined performance criterion. In this work, we consider the time-division duplexing (TDD) mode and therefore, the transmit CSI can be obtained by using channel estimation algorithms due to the reciprocal property.

B. Channel Error Model

As indicated by the literature, it is impractical or too expensive to have perfect CSI at both the transmitter and the receiver sides. Therefore, CSI is usually not accurate. To model the channel matrix distribution, the well-known Kronecker model is adopted for the covariance of the CSI mismatch [6]. We have the following expressions

$$\mathbf{H}_{k,l} = \hat{\mathbf{H}}_{k,l} + \Delta \mathbf{H}_{k,l}, \quad (3)$$

where $\hat{\mathbf{H}}_{k,l}$ is the estimated channel matrix, while $\Delta \mathbf{H}_{k,l}$ is the corresponding channel estimation error matrices, $\Delta \mathbf{H}_{k,l}$ can be written as $\Delta \mathbf{H}_{k,l} = \Sigma_{k,l}^{\frac{1}{2}} \tilde{\mathbf{H}}_{k,l} \Psi_{k,l}^{\frac{1}{2}}$, where the elements of $\tilde{\mathbf{H}}_{k,l}$ are i.i.d. Gaussian random variables with zero mean and unit variance, and $\Psi_{k,l}$ and $\Sigma_{k,l}$ denote the covariance matrices of the channel seen from the transmitter and receiver, respectively. Furthermore, the matrix $\Delta \mathbf{H}_{k,l}$ has the matrix-variate complex Gaussian distribution, which can be expressed as $\Delta \mathbf{H}_{k,l} \sim \mathcal{CN}_{N_k, M_l}(\mathbf{0}_{N_k, M_l}, \Sigma_{k,l} \otimes \Psi_{k,l}^T)$ [6], [7], where the factor \otimes denotes the operation of the Kronecker product. By using the estimation algorithm in [8], we have $\Psi_{k,l} = \mathbf{R}_T$ and $\Sigma_{k,l} = \sigma_e^2 \mathbf{R}_R$. The matrices \mathbf{R}_T and \mathbf{R}_R are the transmit and receive antennas correlation matrices at the transmitter and the receiver, respectively, and σ_e^2 is the channel estimation error variance. A reasonable assumption that we can make is that $\Psi_{k,l}$ and $\Sigma_{k,l}$ are slowly varying and can be known a priori by estimating long term channel statistics. It is important to note that the analysis to be presented in this paper can be applied in exactly the same way without assuming any specific form of the channel estimation error covariance matrix as long as it is symmetric and full-rank [8]-[10].

III. PROPOSED SP-BASED ROBUST TRANSCEIVER

From the aforementioned description, we know that the proposed SP-based transceiver scheme contains B^K parallel branches of permutation matrices, precoding matrices and receiving matrices, and the optimum branch should be selected based on a certain criterion before transmission. In this section, we firstly introduce a Sum-MSE minimization algorithm to design the n -th branch robust transceivers based on a set of permuted MIMO channel matrices $\{\mathbf{H}_{k,l} \mathbf{T}_{n,l}\}$ generated by the n -th combination of permutation matrices among the transmitters. Secondly, the selection criterion, which is based on the Euclidean distance between the true transmit symbol vector and the noiseless pre-estimated symbol vector, is introduced to choose the optimum branch.

A. Robust Transceiver Design

We propose to employ Sum-MSE minimization to design the robust transceivers for each branch in the presence of channel estimation errors. The Sum-MSE based algorithm was originally proposed in [5]; here we extend it to our proposed SP-based scheme using the channel error model with

transmitter and receiver covariance matrices. Let us consider the following criterion

$$\sum_{k=1}^K \zeta_{n,k}, \quad (4)$$

where

$$\begin{aligned} \zeta_{n,k} &= E[\|\mathbf{b}_k - \mathbf{W}_{n,k} \mathbf{r}_k\|^2] \\ &= E \left[\text{Tr} \left\{ (\mathbf{W}_{n,k} \left(\sum_{l=1}^K (\hat{\mathbf{H}}_{k,l} + \Delta \mathbf{H}_{k,l}) \mathbf{T}_{n,l} \mathbf{P}_{n,l} \mathbf{b}_l + \mathbf{n}_k \right) - \mathbf{b}_k) \right. \right. \\ &\quad \left. \left. \times (\mathbf{W}_{n,k} \left(\sum_{l=1}^K (\hat{\mathbf{H}}_{k,l} + \Delta \mathbf{H}_{k,l}) \mathbf{T}_{n,l} \mathbf{P}_{n,l} \mathbf{b}_l + \mathbf{n}_k \right) - \mathbf{b}_k)^H \right\} \right] \\ &= \text{Tr} \left\{ \mathbf{W}_{n,k} \sum_{l=1}^K \hat{\mathbf{H}}_{k,l} \mathbf{T}_{n,l} \mathbf{P}_{n,l} \mathbf{P}_{n,l}^H \mathbf{T}_{n,l}^H \hat{\mathbf{H}}_{k,l}^H \mathbf{W}_{n,k}^H \right\} \\ &\quad + \sum_{l=1}^K \text{Tr} \{ \mathbf{W}_{n,k}^H \mathbf{W}_{n,k} \boldsymbol{\Sigma}_{k,l} \} \text{Tr} \{ \mathbf{T}_{n,l} \mathbf{P}_{n,l} \mathbf{P}_{n,l}^H \mathbf{T}_{n,l}^H \boldsymbol{\Psi}_{k,l} \} \\ &\quad - \text{Tr} \{ \mathbf{W}_{n,k} \hat{\mathbf{H}}_{k,k} \mathbf{T}_{n,k} \mathbf{P}_{n,k} \} - \text{Tr} \{ \mathbf{P}_{n,k}^H \mathbf{T}_{n,k}^H \hat{\mathbf{H}}_{k,k}^H \mathbf{W}_{n,k}^H \} \\ &\quad + \text{Tr} \{ \mathbf{I} + \sigma_n^2 \mathbf{W}_{n,k} \mathbf{W}_{n,k}^H \}. \end{aligned} \quad (5)$$

Note that the expectation is taken over all distributions of \mathbf{b}_l , \mathbf{n}_k , $\Delta \mathbf{H}_{k,l}$. We aim to design the precoding matrices $\mathbf{P}_{n,k}$ and the receiving matrices $\mathbf{W}_{n,k}$ for the n -th branch, which minimize the Sum-MSE under the transmit power constraints. The optimization problem is given by:

$$\min_{\mathbf{P}_{n,k}, \mathbf{W}_{n,k}} \sum_{k=1}^K \zeta_{n,k} \quad (6)$$

$$\text{s.t.} \quad \text{Tr} \{ \mathbf{P}_{n,k}^H \mathbf{P}_{n,k} \} \leq P_k, k = 1, 2, \dots, K. \quad (7)$$

Furthermore, we formulate the Lagrange objective function as follows,

$$J(\mathbf{P}_{n,k}, \mathbf{W}_{n,k}, \lambda_{n,k}) = \sum_{k=1}^K \zeta_{n,k} + \sum_{k=1}^K \lambda_{n,k} (\text{Tr} \{ \mathbf{P}_{n,k}^H \mathbf{P}_{n,k} \} - P_k), \quad (8)$$

where $\lambda_{n,k}$ denotes the Lagrange multiplier. By following the Karush-Kuhn-Tucker (KKT) conditions and the derivation in [5], we obtain the robust precoding and receiving expressions corresponding to the n -th branch as follows,

$$\begin{aligned} \mathbf{P}_{n,k} &= \left(\sum_{l=1}^K \mathbf{T}_{n,k}^H \hat{\mathbf{H}}_{l,k}^H \mathbf{W}_{n,l}^H \mathbf{W}_{n,l} \hat{\mathbf{H}}_{l,k} \mathbf{T}_{n,k} \right. \\ &\quad \left. + \sum_{l=1}^K \text{Tr} \{ \mathbf{W}_{n,l}^H \mathbf{W}_{n,l} \boldsymbol{\Sigma}_{l,k} \} \mathbf{T}_{n,k}^H \boldsymbol{\Psi}_{l,k} \mathbf{T}_{n,k} + \lambda_{n,k} \mathbf{I} \right)^{-1} \\ &\quad \times \mathbf{T}_{n,k}^H \hat{\mathbf{H}}_{k,k}^H \mathbf{W}_{n,k}^H, \quad k = 1, 2, \dots, K. \end{aligned} \quad (9)$$

$$\begin{aligned} \mathbf{W}_{n,k} &= \mathbf{P}_{n,k}^H \mathbf{T}_{n,k}^H \hat{\mathbf{H}}_{k,k}^H \left(\sum_{l=1}^K \hat{\mathbf{H}}_{k,l} \mathbf{T}_{n,l} \mathbf{P}_{n,l} \mathbf{P}_{n,l}^H \mathbf{T}_{n,l}^H \hat{\mathbf{H}}_{k,l}^H \right. \\ &\quad \left. + \sum_{l=1}^K \boldsymbol{\Sigma}_{k,l} \text{Tr} \{ \mathbf{T}_{n,l} \mathbf{P}_{n,l} \mathbf{P}_{n,l}^H \mathbf{T}_{n,l}^H \boldsymbol{\Psi}_{k,l} \} + \sigma_n^2 \mathbf{I} \right)^{-1} \quad (10) \\ &\quad k = 1, 2, \dots, K. \end{aligned}$$

In order to compute the Lagrange multiplier, we need to substitute (9) into the expression $\lambda_{n,k} (\text{Tr} \{ \mathbf{P}_{n,k}^H \mathbf{P}_{n,k} \} - P_k) = 0$

corresponding to the power constraint per transmitter in the KKT conditions [5]. With the aid of singular value decomposition (SVD), we can obtain the following polynomial equation of $\lambda_{n,k}$ [5],

$$\sum_{i=1}^{M_k} \frac{\mathbf{D}_{n,k}[i, i]}{(\lambda_{n,k} + \Lambda_{n,k}[i, i])^2} = P_k, \quad (11)$$

where the operation $[i, i]$ denotes taking the element in the i -th row and the i -th column of a given matrix, $\mathbf{D}_{n,k} = \mathbf{U}_{n,k}^H \mathbf{T}_{n,k}^H \hat{\mathbf{H}}_{k,k}^H \mathbf{W}_{n,k}^H \mathbf{W}_{n,k} \hat{\mathbf{H}}_{k,k} \mathbf{T}_{n,k} \mathbf{U}_{n,k}$, and the matrices $\Lambda_{n,k}$ and $\mathbf{U}_{n,k}$ are obtained by performing SVD on $\mathbf{L}_{n,k}$, i.e., $\mathbf{L}_{n,k} = \mathbf{U}_{n,k} \Lambda_{n,k} \mathbf{U}_{n,k}^H$, where

$$\begin{aligned} \mathbf{L}_{n,k} &= \sum_{l=1}^K \mathbf{T}_{n,k}^H \hat{\mathbf{H}}_{l,k}^H \mathbf{W}_{n,l}^H \mathbf{W}_{n,l} \hat{\mathbf{H}}_{l,k} \mathbf{T}_{n,k} \\ &\quad + \sum_{l=1}^K \text{Tr} \{ \mathbf{W}_{n,l}^H \mathbf{W}_{n,l} \boldsymbol{\Sigma}_{l,k} \} \mathbf{T}_{n,k}^H \boldsymbol{\Psi}_{l,k} \mathbf{T}_{n,k}. \end{aligned} \quad (12)$$

The Lagrange multiplier $\lambda_{n,k}$ is obtained by solving the polynomial equation (11) based on the root search method [11]. In the case where no positive $\lambda_{n,k} \in \mathbb{R}$ is found, we set $\lambda_{n,k}$ to 0. The solutions for $\mathbf{P}_{n,k}$ and $\mathbf{W}_{n,k}$ can be obtained by implementing (9), (10) and (11) iteratively with an initial value of $\mathbf{P}_{n,k}$. The iterative optimization algorithm is summarized in Table I for the proposed SP-based transmission scheme.

TABLE I
ROBUST SUM-MSE MINIMIZATION ALGORITHM FOR THE SP-BASED SCHEME

1	for the n -th branch.
2	Initialization: $\mathbf{P}_{n,k}, k \in \{1, \dots, K\}$.
3	for the i -th iteration.
4	for the k -th user.
5	Compute the receiving matrix $\mathbf{W}_{n,k}$ using (10).
6	Compute the Lagrange multiplier $\lambda_{n,k}$ by solving (11).
7	Compute the robust precoding matrix using (9).
8	end
9	Repeat step 4-8 until the algorithm converges.
10	Repeat step 2-9 until all the branches of transceivers are obtained.

B. Selection Criterion

We have experimented with a number of different criteria, and the squared Euclidean distance is the result to devise a simple and yet effective selection mechanism. Ideally, the optimum branch can be chosen to minimize the accumulated squared Euclidean distance between the true transmit symbol and the received soft information in one transmission block. However, since the selection criterion of the proposed scheme is applied at the transmitter side, we cannot employ the exact signal from the receiver side in this criterion. Therefore, we employ noiseless information to estimate the received signal in this work. The simulation results in Section IV show that the proposed scheme achieves a better performance compared to the conventional algorithms, which verifies the effectiveness of the approximation. By accumulating the values of the squared Euclidean distance in one transmission block, we have the following selection rule

$$n_{opt} = \arg \min_{1 \leq n \leq B^K} \left\{ \|\mathbf{s}_j - \mathbf{u}_{n,j}\|^2 \right\}, \quad (13)$$

where the quantity \mathbf{s}_j denotes a $(\sum_{l=1}^K D_l) \times 1$ vector corresponding to the j -th transmission data block, which is given by $\mathbf{s}_j = [\mathbf{d}_{(j-1)S+1}^T, \dots, \mathbf{d}_{jS}^T]^T$, where $j \in \{1, 2, \dots\}$, and S is the block length, the $\sum_{l=1}^K D_l \times 1$ vector $\mathbf{d}_{(j-1)S+m} = [\mathbf{b}_1^{T((j-1)S+m)}, \mathbf{b}_2^{T((j-1)S+m)}, \dots, \mathbf{b}_K^{T((j-1)S+m)}]^T$ denotes the m -th transmit vector of the j -th block among all the transmitters, $m \in \{1, \dots, S\}$, the $(\sum_{l=1}^K D_l) \times 1$ pre-estimated vector $\mathbf{u}_{n,j}$ is given by $\mathbf{u}_{n,j} = [\hat{\mathbf{y}}_{n,(j-1)S+1}^T, \dots, \hat{\mathbf{y}}_{n,jS}^T]^T$, where $\hat{\mathbf{y}}_{n,(j-1)S+m} = [\tilde{\mathbf{b}}_{n,1}^{T((j-1)S+m)}, \tilde{\mathbf{b}}_{n,2}^{T((j-1)S+m)}, \dots, \tilde{\mathbf{b}}_{n,K}^{T((j-1)S+m)}]^T$ denotes the $\sum_{l=1}^K D_l \times 1$ pre-estimated received vector based on the n -th branch for the m -th transmit vector of the j -th block, and the noiseless estimated vector $\tilde{\mathbf{b}}_{n,k}^{((j-1)S+m)}$ is given by

$$\tilde{\mathbf{b}}_{n,k}^{((j-1)S+m)} = \mathbf{W}_{n,k} \left(\sum_{l=1}^K \hat{\mathbf{H}}_{k,l} \mathbf{T}_{n,l} \mathbf{P}_{n,l} \mathbf{b}_l^{((j-1)S+m)} \right). \quad (14)$$

The optimum branch is chosen by minimizing the summation of the squared Euclidean distance values in one transmission data block. The selected optimum branch is updated once per block.

C. Computational Complexity

In this part, we focus on the computational complexity of the proposed SP-based transceiver scheme. We note that the complexity of the matrix inversion for the analyzed algorithm is cubic in the number of transmit or receive antennas [12], and the complexity to determine $\lambda_{n,k}$ is $O(8M_k^3)$ [11]. Thus, the proposed robust transceiver algorithm for the k -th pair corresponding to the n -th branch and the selection mechanism require the complexity in $O[\sum_{k'=1}^K (2M_{k'} D_{k'} N_{k'} + M_{k'}^2 N_{k'} + D_{k'} M_{k'}^2 + 2N_{k'}^2 D_{k'} + N_{k'}^3 + M_{k'}^3 + N_{k'}^2 + M_{k'}^2) + 9M_k^3 + N_k^3 + M_k^2 D_k + D_k N_k^2]$ and $O[S \sum_{k'=1}^K (N_{k'} M_{k'} + M_{k'}^2 + M_{k'} D_{k'} + D_{k'} N_{k'})]$, respectively. The overall complexity of the proposed algorithm includes the complexity of the selection mechanism and the complexity of the robust transceiver per branch multiplied by the codebook size B^K . In the simulation section, we will show that with the limitedly increased complexity the performance of the proposed transceiver algorithm outperforms the performance of the conventional precoding algorithms significantly. In practice, the codebook size should be chosen to meet the performance and the complexity requirements for implementation based on a given channel environment.

IV. SIMULATIONS

In this section, we evaluate the performance of the proposed SP-based robust transceiver scheme and compare it with the existing transceiver algorithms for K -pair MIMO interference channels. We assume that the MIMO channels are quasi-static flat fading channels with Rayleigh distribution. The simulation results shown below are the averages over 10000 independent trials. The MIMO channels are time-varying and updated at the beginning of each data block, where the latter contains $S = 128$ symbols. We assume that the system has $K = 3$ transmission pairs. Each transmitter is equipped with 4 antennas ($M_1 = M_2 = M_3 = 4$) and each receiver has 4 antennas ($N_1 = N_2 = N_3 = 4$). Each transmitter sends 2 data streams ($D_1 = D_2 = D_3 = 2$). By using the exponential

model [8], the channel estimation error covariance matrices can be expressed as

$$\Psi_{k,l} = \begin{bmatrix} 1 & \alpha & \alpha^2 & \alpha^3 \\ \alpha & 1 & \alpha & \alpha^2 \\ \alpha^2 & \alpha & 1 & \alpha \\ \alpha^3 & \alpha^2 & \alpha & 1 \end{bmatrix} \quad (15)$$

$$\Sigma_{k,l} = \sigma_e^2 \begin{bmatrix} 1 & \beta & \beta^2 & \beta^3 \\ \beta & 1 & \beta & \beta^2 \\ \beta^2 & \beta & 1 & \beta \\ \beta^3 & \beta^2 & \beta & 1 \end{bmatrix}, \quad (16)$$

where α and β denote the correlation coefficients, and σ_e^2 is the estimation error variance. The estimated channel matrix, $\hat{\mathbf{H}}_{k,l}$, is generated by the distributions as follows:

$$\hat{\mathbf{H}}_{k,l} \sim \mathcal{CN}_{N_k, M_l} \left(\mathbf{0}_{N_k, M_l}, \frac{(1 - \sigma_e^2)}{\sigma_e^2} \Sigma_{k,l} \otimes \Psi_{k,l} \right) \quad (17)$$

such that channel realizations have unit variance. We assume that each transmitter has the same transmit power constraint, i.e., $P_1 = P_2 = P_3 = P_t$. The signal-to-noise ratio (SNR) is defined as $\frac{P_t}{\sigma_n^2}$. The quadrature phase-shift keying (QPSK) modulation is considered in the simulation. Among the proposed techniques, we consider:

- 1) SMSE minimization: the conventional robust Sum-MSE minimization algorithm [5].
- 2) SMSE with SP: the proposed robust SP-based transceiver scheme with the Sum-MSE minimization algorithm.

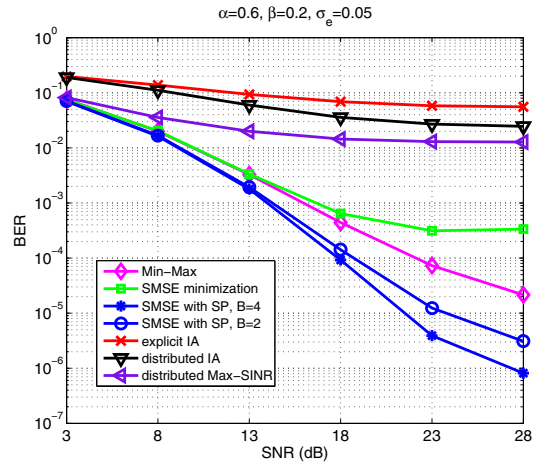


Fig. 2. Average BER performance versus SNR for the proposed SP-based robust transceiver scheme and the existing transceiver algorithms. $\alpha = 0.6$, $\beta = 0.2$, $\sigma_e = 0.05$.

Fig. 2 shows the average BER performance versus input SNR for comparing the proposed SP-based robust transceiver scheme with the existing transceiver algorithms, namely, the explicit IA algorithm proposed in [1], the distributed IA algorithm [2], the distributed Max-SINR algorithm [2], the robust Sum-MSE minimization algorithm [5] and the robust Min-Max algorithm [5]. The channel error standard variance is given by $\sigma_e = 0.05$, and the correlation coefficients are given by $\alpha = 0.6$ and $\beta = 0.2$. All the iterative algorithms employ 20 iterations. The right singular matrices are used for

the initialization values. From the results, we can see that the performance of the proposed SP-based robust scheme is much better than the others. In particular, the proposed SP-based robust transceiver scheme with the 4-entry codebook³ can lead to 5dB gain in SNR in comparison with the robust Min-Max algorithm, at the average BER level of 1×10^{-4} . Moreover, it shows that the performance of the proposed scheme increases with the increase of the codebook size. The results show the ability of the proposed SP-based algorithm to deal with channel uncertainties and multiuser interference.

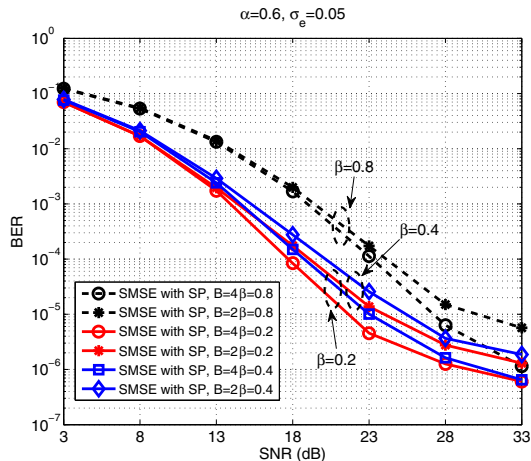


Fig. 3. Average BER performance versus SNR for the proposed robust SP-based transceiver scheme with the Sum-MSE minimization algorithm for different values of β . $\alpha = 0.6$, $\sigma_e = 0.05$.

Fig. 3 and Fig. 4 show the average BER performance versus the SNR for the proposed SP-based transceiver scheme with different values of β and α . The algorithm parameters are selected as in the previous simulation. In Fig. 3, we let $\alpha = 0.6$, $\sigma_e = 0.05$ and β is varied. In Fig. 4, we set $\beta = 0.2$ and $\sigma_e = 0.05$, and try different values for α . It can be seen that smaller correlation coefficients lead to a better performance. The proposed SP-based scheme with the 4-entry codebook outperforms that with the 2-entry codebook. In particular, Fig. 4 illustrates that the proposed algorithm with the 4-entry codebook can save up to almost 3 dB in comparison with the proposed algorithm with the 2-entry codebook, at the BER level of 1×10^{-5} in the case with $\alpha = 0.6$. It shows the ability of the proposed algorithm to deal with the channel correlation.

V. CONCLUSION

In this paper, we have proposed a robust transceiver scheme based on switched preprocessing for K -pair MIMO interference channels. For each branch, we have developed a robust

³In the simulation, the 2-entry codebook consists of $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ and

$\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$, and the 4-entry codebook consists of $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$, $\begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$, $\begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$.

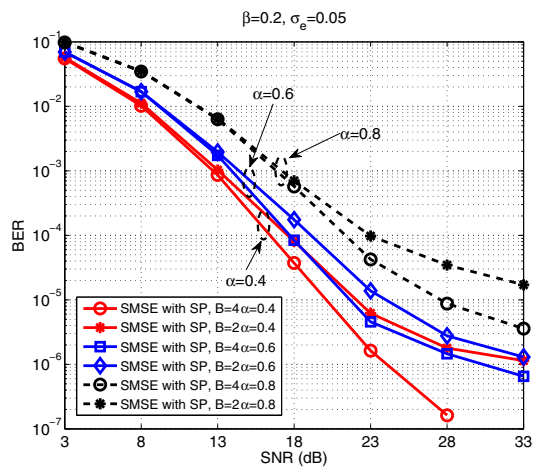


Fig. 4. Average BER performance versus SNR for the proposed robust SP-based transceiver scheme with the Sum-MSE minimization algorithm for different values of α . $\beta = 0.2$, $\sigma_e = 0.05$.

transceiver design algorithm based on minimizing the Sum-MSE criterion. We also designed the selection criterion to choose the optimum branch based on minimizing the Euclidean distance between the true transmit symbol vector and the pre-estimated noiseless received vector. The results have shown that the proposed SP-based transceiver scheme significantly outperforms the existing robust transceiver algorithms, in the presence of imperfect CSI.

REFERENCES

- [1] V. R. Cadambe and S. A. Jafar, "Interference alignment and the degrees of freedom for the K user interference channel," *IEEE Trans. Inf. Theory*, vol. IT-54, no. 8, pp. 3425-3441, Aug. 2008.
- [2] K. S. Gomadam, V. R. Cadambe, and S. A. Jafar, "Approaching the capacity of wireless networks through distributed interference alignment," in *Proc. IEEE GLOBECOM 2008*, Nov. 2008.
- [3] S. W. Peters and R. W. Heath, Jr., "Cooperative algorithms for MIMO interference channels," in *IEEE Trans. Veh. Tech.*, vol. 60, no. 1, pp. 206-218, Jan. 2011.
- [4] H. Sung, S. Park, K. Lee, and I. Lee, "Linear precoder designs for K -user interference channels," in *IEEE Trans. Wireless Comm.*, vol. 9, no. 1, Jan. 2010.
- [5] H. Shen, B. Li, M. Tao and X. Wang, "MSE-based transceiver Designs for the MIMO interference channel," in *IEEE Trans. Wireless Commun.*, vol. 9, no. 11, Nov. 2010, pp. 3480-3489.
- [6] C. Xing, S. Ma and Y. Wu, "Robust joint design of linear relay precoder and destination equalizer for dual-hop amplify-and-forward MIMO relay systems," *IEEE Trans. Signal Process.* vol. 58, no. 4, pp. 2273-2283, Apr. 2010.
- [7] A. T. James, "Distributions of matrix variates and latent roots derived from normal samples," *Ann. Math. Stat.*, vol. 35, pp. 475-501, 1964.
- [8] L. Musavian, M. Nakhai, M. Dohler, and A. Aghvami, "Effect of channel uncertainty on the mutual information of MIMO fading channels," *IEEE Trans. Veh. Technol.*, vol. 56, no. 5, pp. 2798-2806, Sep. 2007.
- [9] M. Ding and S. Blostein, "MIMO minimum total MSE transceiver design with imperfect CSI at both ends," *IEEE Trans. Signal Process.*, vol. 57, no. 3, pp. 1141-1150, Mar. 2009.
- [10] T. Yoo, E. Yoon, and A. Goldsmith, "MIMO capacity with channel uncertainty: Does feedback help?" in *Proc. IEEE GLOBECOM 2004*, vol. 1, Nov. 2004, pp. 96-100.
- [11] A. Edelman and H. Murakami, "Polynomial roots from companion matrix eigenvalues," *Math. Comput.*, vol. 64, pp. 763-776, 1995.
- [12] R. A. Horn and C. R. Johnson, *Matrix Analysis*. Cambridge, U.K.: Cambridge Univ. Press, 1985.