OVERHEAD-AWARE DISTRIBUTED CSI SELECTION IN THE MIMO INTERFERENCE CHANNEL

Rami Mochaourab, Rasmus Brandt*, Hadi Ghauch**, Mats Bengtsson**

*Signal Processing Department, ACCESS Linnaeus Centre, KTH Royal Institute of Technology
**Communication Theory Department, KTH Royal Institute of Technology

ABSTRACT

We consider a MIMO interference channel in which the transmitters and receivers operate in frequency-division duplex mode. In this setting, interference management through coordinated transceiver design necessitates channel state information at the transmitters (CSI-T). The acquisition of CSI-T is done through feedback from the receivers, which entitles a loss in degrees of freedom, due to training and feedback. This loss increases with the amount of CSI-T. In this work, after formulating an overhead model for CSI acquisition at the transmitters, we propose a distributed mechanism to find for each transmitter a subset of the complete CSI, which is used to perform interference management. The mechanism is based on many-to-many stable matching. We prove the existence of a stable matching and exploit an algorithm to reach it. Simulation results show performance improvement compared to full and minimal CSI-T.

Index Terms— MIMO Interference Channel, Interference Management, Incomplete CSI, Stable Matching

1. INTRODUCTION

Ultra-dense networks have been identified as one of the key scenarios in 5G communication systems, characterized by a high number of nodes, located in close proximity, in both heterogeneous and homogeneous networks [1]. Evidently, *coordination among transmitters and receivers* is vital in such scenarios, where it is well-known that the sum-rate performance is limited by unsuppressed interference. *Forward-backward training* algorithms, such as [2–4], employ uplink and downlink pilots to estimate the required channel state information (CSI) quantities, and iteratively refine the precoding / decoding matrices in a cluster of cooperating nodes (requiring local CSI only).

It becomes clear at this stage that the overhead associated with such clusters is a major concern (especially in the aforementioned dense networks): this motivates the need for schemes that take into account the loss in performance incurred by coordination, training and possibly feedback. This problem was addressed in [5] where the authors proposed a training and analog feedback scheme that maximizes the *effective sum-rate* (the achievable sum-rate in the network accounting for the loss in degrees of freedom (DoF) due to overhead). Furthermore, the issue of *user partitioning* was tackled in [6] where the authors proposed several schemes for partitioning the users into orthogonal groups, based on several criteria.

We propose in this work an overhead-aware framework for distributed cooperation in frequency-division-duplex (FDD) systems: sets of potentially cooperating transmitters and receivers are formed using many-to-many stable matching, where the utilities at both transmitters and receivers are designed to take into account both performance of each link, and the associated overhead for channel estimation and feedback. We prove that the formulated model satisfies the conditions for the existence of a many-to-many stable matching. By utilizing an algorithm to reach a stable matching we provide a distributed mechanism to determine the amount of CSI present at each transmitter which is exploited for interference management. This being said, any algorithm for precoder / decoder optimization can now be employed to optimize any desired metric (interference leakage, sum-rate, MSE, etc...). Finally, our simulations clearly indicate that our proposed scheme offers significant gains in performance, over selected benchmark schemes.

Notations: Column vectors and matrices are given in lowercase and uppercase boldface letters, respectively. $\mathrm{tr}(\cdot)$, $\|\cdot\|_{\mathrm{F}}$, and $(\cdot)^\dagger$ denote respectively the trace, Frobenius norm, and Hermitian transpose. $\boldsymbol{I}$ is an identity matrix.

2. SYSTEM MODEL

We consider a set of transmitter-receiver pairs $\mathcal{K} = \{1, \ldots, K\}$ operating in the same spectral band. The transmitters and receiver are equipped with multiple antennas such that transmitter j uses M_j antennas and receiver k uses N_k antennas. The flat fading channel matrix from a transmitter j to a receiver k is $\boldsymbol{H}_{jk} \in \mathbb{C}^{N_k \times M_j}$.

The received signal at a receiver k is

$$\boldsymbol{y}_k = \sum_{j=1}^{K} \sqrt{\gamma_{jk}} \boldsymbol{U}_k^\dagger \boldsymbol{H}_{jk} \boldsymbol{V}_j \boldsymbol{s}_j + \boldsymbol{z}_k, \qquad (1)$$

where $\boldsymbol{s}_j$ is the transmitted signal vector of dimension d_j,

$\boldsymbol{V}_j \in \mathbb{C}^{M_j \times d_j}$ is the transmit precoding matrix at transmitter j, $\boldsymbol{U}_k \in \mathbb{C}^{N_j \times d_j}$ is the receive decoding matrix at receiver k, γ_{jk} is the pathloss coefficient, and $\boldsymbol{z}_k \sim \mathcal{CN}(0, \sigma^2 \boldsymbol{I})$ is additive white Gaussian noise. The transmit precoding matrix $\boldsymbol{V}_j$ used at transmitter j is restricted to a power constraint such as $\mathrm{tr}\left(\boldsymbol{V}_j \boldsymbol{V}_j^\dagger\right) \leq P_j,\ j \in \mathcal{K}$.

Given a pre-log factor $\beta \in [0, 1]$, determined by the lost temporal degrees of freedom due to training and overhead [5, 6], the spectral efficiency of link k is given as

$$R_k = \beta \log_2 \left| \boldsymbol{I} + \gamma_{kk} \boldsymbol{Z}_k^{-1} \boldsymbol{U}_k^\dagger \boldsymbol{H}_{kk} \boldsymbol{V}_k \boldsymbol{V}_k^\dagger \boldsymbol{H}_{kk}^\dagger \boldsymbol{U}_k \right|, \quad (2)$$

where $\boldsymbol{Z}_k = \sigma^2 \boldsymbol{I} + \sum_{j \neq k} \gamma_{jk} \boldsymbol{U}_k^\dagger \boldsymbol{H}_{jk} \boldsymbol{V}_j \boldsymbol{V}_j^\dagger \boldsymbol{H}_{jk}^\dagger \boldsymbol{U}_k$ is the interference and noise covariance matrix.

2.1. CSI-T Sharing Set

The precoding and decoding matrices are designed based on the current network conditions, in the form of CSI. We are assuming an FDD system, meaning that CSI at the receivers (CSI-R) can be obtained by pilot-assisted channel training from the transmitters. In order to obtain CSI at the transmitters (CSI-T) however, due to the non-reciprocal nature of the channel, the receivers must feed back their CSI-R. Both the channel training and the CSI feedback lead to overhead, whose impact on the spectral efficiencies depend on the channel coherence time.

In our model, each receiver k has a non-zero channel from each transmitter j (cf. (1)). The corresponding links are indexed by the index set

$$\mathcal{J} = \{(j, k) \mid (j, k) \in \mathcal{K} \times \mathcal{K}\}. \quad (3)$$

Due to the path loss factor γ_{jk} in (1), it is clear that some of the cross-links will interfere more strongly than others. We thus define $\mathcal{I} \subseteq \mathcal{J}$, which will be called a *CSI-T sharing set*. This set specifies what CSI is fed back from the receivers to the transmitters, and should thus correlate with which cross-links are deemed important to treat in the precoder design. Clearly, $(k, k) \in \mathcal{I},\ \forall\, k \in \mathcal{K}$. The output of the stable matching algorithm in Sec. 3 will be such a CSI-T sharing set.

The CSI-T sharing set $\mathcal{I}$ describes how *incomplete* the CSI-T is. This can range from minimal CSI-T ($\mathcal{I} = \{(k, k) \mid k \in \mathcal{K}\}$), to complete CSI-T ($\mathcal{I} = \mathcal{J}$). In certain scenarios, it has been shown that the feasibility of interference alignment can be retained under some level of incomplete CSI-T [7]. Given a $\mathcal{I} \subseteq \mathcal{J}$, we now detail how the CSI acquisition will take place, and the corresponding overhead.

2.2. Overhead Model

The channel estimation is based on pilot-assisted training and the feedback is based on analog feedback [5]. We assume a block fading model, where the channel is constant for T symbol intervals. One such block of T symbol intervals is termed a *coherence block*, and the CSI must be estimated once per coherence block.

We propose a simple overhead model for the channel training and CSI feedback. For the channel training, we assume that minimal training is sufficient, i.e. that each channel coefficient can be identified using a single pilot symbol. For the analog feedback, we assume that the minimal number of symbol intervals for orthogonalizing the feedback between users is sufficient for acceptable performance. Admittedly, these assumptions might be coarse approximations of proper system design at low signal to noise ratio (SNR), but they allow us to clearly compare the overhead of training and CSI feedback. Similar approximations have been used, e.g. in [6]. Given these assumptions, we now simply count the number of symbol intervals that are needed for the different phases of the CSI acquisition to get a measure of the overhead.

2.2.1. Phases of CSI Acquisition

The CSI acquisition has the following phases, which are repeated in each coherence block.

- T1 **Downlink channel training.** This phase lets the receivers acquire CSI-R, which will be fed back to the transmitters during the *F* phase, as well as being used for formulating the receiver utilities in the *SM* phase. Given orthogonal pilot transmissions from the transmitters, the receivers estimate their local CSI-R. Due to the orthogonality constraint, this phase requires $\sum_{j=1}^{K} M_j$ symbol intervals.
- T2 **Uplink feedback channel training.** This phase lets the transmitters acquire CSI for the uplink feedback channel[1]. This CSI is used for decoding the feedback symbols received in the uplink during the *F* phase. For orthogonality reasons, this phase requires $\sum_{k=1}^{K} N_k$ symbol intervals.
- SM **Stable matching.** This phase determines the CSI-T sharing set $\mathcal{I}$ using the stable matching algorithm in Sec. 3. This phase requires L_{SM} symbol intervals of communication, which will be quantified in Sec. 3.
- F **Analog CSI feedback.** In this phase, the transmitters acquire CSI-T needed for the precoder design. Given a CSI-T sharing set $\mathcal{I} \subseteq \mathcal{J}$, receiver k feeds back the CSI for $j \in \{i \mid (i, k) \in \mathcal{I}\}$ to all transmitters $i \in \mathcal{K}$. With analog feedback this phase requires $\sum_{(j,k) \in \mathcal{I}} M_j$ symbol intervals for $N_k \leq M_j$, for all $j \in \mathcal{K}$ using a distributed processing strategy [5, Sec. III.A].
- T3 **Downlink effective channel training.** After the CSI-T has been acquired in the *F* phase, all transmitters optimize the precoders independently in parallel. The resulting *effective channels* (i.e. channel matrices multiplied by precoders) are trained based on pilot transmissions. This phase requires $\sum_{k=1}^{K} d_k$ symbol intervals.

[1] Recall that this is an FDD system, and the uplink and downlink channels are thus not reciprocal.

Summing up the number of symbol intervals needed for training and feedback, the CSI acquisition overhead is

$$L_{\text{CSI}} = \sum\nolimits_{k=1}^{K} (M_k + N_k + d_k) + \sum\nolimits_{(j,k)\in\mathcal{I}} M_j. \quad (4)$$

Note that the first term in the summation (accumulated training overhead) is linear in K, whereas the second term (feedback overhead) in the worst case becomes quadratic in K. Hence, in terms of overhead reduction, there are large gains to be anticipated by reducing the amount of feedback.

After the five phases of CSI acquisition, data transmission takes place during the remaining $L_{\text{data}} = T - L_{\text{CSI}} - L_{\text{SM}}$ symbol intervals. Then, the pre-log factor β in (2) is

$$\beta = L_{\text{data}}/T = 1 - (L_{\text{CSI}} + L_{\text{SM}})/T. \quad (5)$$

It is now clear that optimizing R_k in (2) becomes a tradeoff between better interference management (higher spectral efficiency factor) and lower overhead (higher pre-log factor). Next, we detail the stable matching procedure which will determine the CSI-T sharing set.

3. MANY-TO-MANY STABLE MATCHING

Many-to-many stable matching has been of interest for its application in the job matching problem [8]. There, a set of firms and a set of workers exist, where each firm has a set of vacant positions to offer to workers, and each worker can work at more than one firm. The interest of a firm is to hire the best workers and each worker's interest is to work at the most preferred combination of firms. The solution of the job matching problem is a many-to-many stable matching, which we will formally define later in this section.

The job matching problem relates to the problem in our setting in the following. First, we seek a matching between the set of transmitters (firms) and the receivers (workers) which dictates the CSI-T. Second, the distributed implementation of the mechanism is supported by the stability concept in many-to-many stable matching.

3.1. Stable Matching Model

In a stable matching problem, there exists two sets of agents. In our case, these correspond to the set of transmitters $\mathcal{T} = \{tx_1, \ldots, tx_K\}$ and the set of receivers $\mathcal{R} = \{rx_1, \ldots, rx_K\}$. A matching between the two sets is defined as follows.

Definition 1. *A matching $\mathcal{M}$ is a correspondence from the set $\mathcal{T} \cup \mathcal{R}$ to the set of all subsets of $\mathcal{T} \cup \mathcal{R}$ and satisfies the following properties for $j \in \mathcal{T}$ and $k \in \mathcal{R}$:*

1. *$\mathcal{M}(j) \in \mathcal{R} \cup \emptyset$, and $\mathcal{M}(k) \in \mathcal{T} \cup \emptyset$,*
2. *$k \in \mathcal{M}(j)$ if and only if $j \in \mathcal{M}(k)$.*

The matching $\mathcal{M}$ is a set valued function such that $\mathcal{M}(j)$ is the set of receivers matched to transmitter $j \in \mathcal{T}$ and $\mathcal{M}(k)$ is the set of transmitters matched to receiver $k \in \mathcal{R}$. If a transmitter j is unmatched, then $\mathcal{M}(j) = \emptyset$. Similarly, $\mathcal{M}(k) = \emptyset$ means that receiver k is unmatched. Condition 2. in Definition 1 ensures that whenever a transmitter j is matched to a receiver k then k would be also matched to transmitter j.

3.1.1. Receiver and Transmitter Preference Sets

Each receiver $k \in \mathcal{R}$ must have strict, transitive and complete preference relations over the set $2^{\mathcal{T}}$ containing all subsets of $\mathcal{T}$. For a given a set of transmitters $\mathcal{B} \subseteq \mathcal{T}$, a receiver k is able to select the most preferred subset of $\mathcal{B}$ by the following optimization problem:

$$\begin{aligned} \mathcal{C}_k^{rx}(\mathcal{B}) = \underset{\mathcal{S}\in\mathcal{B}}{\arg\max} & \sum\nolimits_{j\in\mathcal{S}} \phi_k^{rx}(j) \\ & s.t.\ \phi_k^{rx}(j) > \phi_k^{rx}(\emptyset), j \in \mathcal{S}, |\mathcal{S}| \le q_k^{rx}, \end{aligned} \quad (6)$$

where the functions $\phi_k^{rx}(j)$ are defined as

$$\phi_k^{rx}(j) = \gamma_{jk}\gamma_{kk} \|\boldsymbol{H}_{jk}^{\dagger}\boldsymbol{H}_{kk}\|_{\text{F}} / \|\boldsymbol{H}_{kk}\|_{\text{F}}^2, \quad j \in \mathcal{T}, \quad (7)$$

and $\phi_k^{rx}(\emptyset) = (1 + e^{\alpha\text{SNR}})^{-1} + \min_{j\in\mathcal{T}}\{\phi_k^{rx}(j)\}$. The function in (7) reflects a measure on how much the channel from transmitter j is aligned to the direct channel. This model shares similarities with the utility functions formulated in [9] in the context of cognitive radio. If this measure is large, then the corresponding transmitter j could potentially generate substantial amount of interference at receiver k, and hence an effort in terms of CSI feedback and precoding should be taken to manage it. The function $\phi_k^{rx}(\emptyset)$, corresponding to receiver k being unmatched, is novel. Its first summation term is the sigmoidal function which takes values in $[0, 1]$, while the second term limits the minimum value of $\phi_k^{rx}(\emptyset)$. The function $\phi_k^{rx}(\emptyset)$ is designed to decrease with SNR in dB at a rate adaptable by the design parameter α. As $\phi_k^{rx}(\emptyset)$ serves as a minimum requirement threshold in receiver k's preferences, it is desirable to decrease $\phi_k^{rx}(\emptyset)$ with SNR since this would lead to an increase in the number of transmitters preferred to the receiver. Consequently, more transmitters will be involved in interference management at high SNR.

In the optimization (6), a receiver k prefers to be matched with the transmitters which maximize the sum of the measures defined in (7), with the constraint that the performance is better than being unmatched and also that the total number of matched transmitters is not more than a design integer $q_k^{rx} \in \mathbb{N}$ called a matching quota. Observe, that Problem (6) can be solved with low complexity by a greedy method since the objective functions are additively separable [10].

Similarly, each transmitter j must have a strict, transitive and complete preference relation over the set $2^{\mathcal{R}}$ of all subsets of $\mathcal{R}$. Given a set of receivers $\mathcal{B} \subseteq \mathcal{R}$, we define the subset of $\mathcal{B}$ which transmitter j prefers the most as

$$\begin{aligned} \mathcal{C}_j^{tx}(\mathcal{B}) = \underset{\mathcal{S}\in\mathcal{B}}{\arg\max} & \sum\nolimits_{k\in\mathcal{S}} \phi_j^{tx}(k) \\ & s.t.\ \phi_j^{tx}(k) > \phi_j^{tx}(\emptyset), k \in \mathcal{S}, |\mathcal{S}| \le q_j^{tx}, \end{aligned} \quad (8)$$

where

$$\phi_j^{tx}(k) = \gamma_{jk} P_j \|\boldsymbol{H}_{jk}\|_{\mathrm{F}}^2 / (M_j N_j), \quad k \in \mathcal{R}, \tag{9}$$

and $\phi_j^{tx}(\emptyset) = (1 + e^{\alpha \mathrm{SNR}})^{-1} + \min_{k \in \mathcal{R}} \{\phi_j^{tx}(k)\}$. The function in (9) for a transmitter j is increasing in the strength of the channel to a receiver k and decreasing with the number of antennas. Since the number of antennas is proportional to the channel feedback overhead for CSI-T acquisition, the ratio in (9) reflects the amount of interference relative to overhead. If this measure is high indicating either high interference or/and low overhead, then a matching between transmitter j and receiver k is desirable. This is formulated in the constraint in (8). The choice of $\phi_j^{tx}(\emptyset)$ associated to unmatched transmitter j has similar motivation as the one for the receivers.

3.1.2. Many-to-many Stable Matching

The first of two requirements for stability is the following.

Definition 2. *Matching $\mathcal{M}$ is individually rational if*

1. *no transmitter $j \in \mathcal{T}$ exists with $\mathcal{M}(j) \neq \mathcal{C}_j^{tx}(\mathcal{M}(j))$,*
2. *no receiver $k \in \mathcal{R}$ exists with $\mathcal{M}(k) \neq \mathcal{C}_k^{rx}(\mathcal{M}(k))$.*

Condition 1. says that a matching $\mathcal{M}$ is not individually rational for a transmitter j if the set of receivers matched to transmitter j $\mathcal{M}(j)$ are not all within the solution of the optimization in (8) with $\mathcal{M}(j)$ as input. Analogously condition 2. for a receiver k.

Definition 3. *Matching $\mathcal{M}$ is pairwise stable if there does not exist a pair $(k, j) \in \mathcal{R} \times \mathcal{T}$ such that*

1. *$k \neq \mathcal{M}(j)$*
2. *$k \in \mathcal{C}_j^{tx}(\mathcal{M}(j) \cup \{k\})$ and $j \in \mathcal{C}_k^{rx}(\mathcal{M}(k) \cup \{j\})$*

Pairwise stability requires that there exist no receiver k and no transmitter j which are not matched to each other but prefer a matching between themselves. The two conditions in the second requirement mean, respectively, that transmitter j is in the solution set of receiver k's optimization problem in (6) given the set $\mathcal{M}(k) \cup \{j\}$ as input, and receiver k would be in the solution set of the optimization problem of transmitter j in (8) with $\mathcal{M}(j) \cup \{k\}$ as input.

Definition 4. *A matching $\mathcal{M}$ is* stable *if it is individually rational (Definition 2) and pairwise stable (Definition 3).*

Unlike in one-to-one or many-to-one stable matching, a many-to-many stable matching does not always exist. The next result answers the existence question positively.

Theorem 1. *A stable matching in our setting exists.*

Proof. A sufficient condition for the existence of a stable matching (Definition 4) is when the preferences of the transmitters and receivers satisfy the gross substitute property [8]. Our formulation of the utility functions satisfy this property according to [11, Section 2] since (6) and (8) correspond to the q-satiation of the performance. ☐

Algorithm 1 Stable matching algorithm [8].

Initialize: $i = 0, \mathcal{T}_k^0 = \mathcal{T}$, for all $k \in \mathcal{R}$, $L_{SM} = 0$

1: **repeat**
2: **for** $k \in \mathcal{R}$ **do**
3: Receiver k applies to $\mathcal{C}_k^{rx}(\mathcal{T}_k^i)$ with no transmitter in $\mathcal{T}_k$ has rejected him before.
4: $L_{SM} = L_{SM} + \left|\mathcal{C}_k^{rx}(\mathcal{T}_k^i)\right|$;
5: **for** $j \in \mathcal{T}$ **do**
6: Transmitter j accepts $\mathcal{C}_k^{tx}(\mathcal{P}_j^i)$ with no receiver in

$$\mathcal{P}_j^i = \{\mathcal{S} \subseteq \mathcal{R} \mid j \in \mathcal{C}_k^{rx}(\mathcal{T}_k^i), \ \forall k \in \mathcal{S}\}. \tag{10}$$

it rejected before.

7: Transmitter j rejects $\mathcal{P}_j^i \setminus \mathcal{C}_k^{tx}(\mathcal{P}_j^i)$.
8: $L_{SM} = L_{SM} + 1$;
9: $i = i + 1$;
10: **until** no receiver is rejected

The algorithm to reach a many-to-many stable matching is stated in Algorithm 1 and is based on the algorithm in [8]. In Step 1, each receiver "applies" to its most preferred transmitters by sending a message to each of them. This message includes the norm of the interference channel from the transmitter to the applying receiver. This is needed for the transmitter's optimization problem in (8). We assume that the message from a receiver k to a transmitter j requires a single symbol interval. Therefore the overhead L_{SM} is incremented as in Step 4. Each transmitter receives the applications from the receivers and decides on a subset of them. Then, the binary decisions of "accept" or "reject" is communicated to the applying receivers. We assume that this K bit (binary decision) message requires a single symbol interval (Step 8).

In each Step i of the algorithm, the receivers apply to the transmitters which they prefer the most and which have not rejected them before. The transmitters, upon obtaining the application messages from the receivers, choose the ones they prefer most and which they have not rejected before. The convergence of Algorithm 1 to a stable matching is guaranteed according to [8, Proposition 5]. One property of the stable matching algorithm is that each receiver applies at most once to a transmitter [8, Proposition 3]. Accordingly, an upper bound on the overhead is $L_{SM} \leq 2K^2$ based on the worst case scenario in which in each iteration each receiver applies to a single transmitter only.

4. NUMERICAL RESULTS

We consider 25 transmitter-receiver pairs. The transmitters are uniformly distributed in a 250×250 m^2 region, and each receiver is randomly located at a distance of 50 m from its transmitter. We set the number of antennas at each system to $N_k = M_j = 5$ for all j, k, and the number of data streams

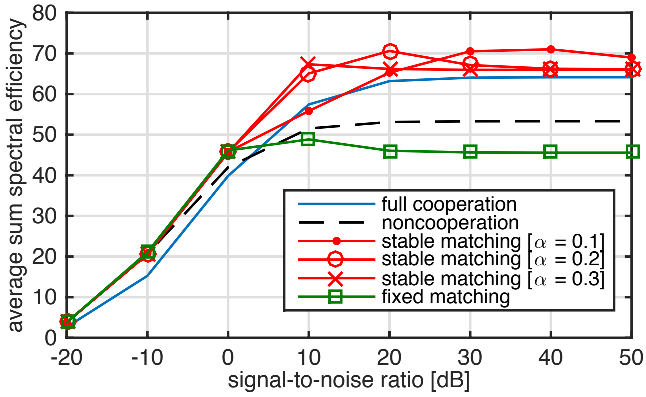

Fig. 1. Average sum rate of three different matching schemes.

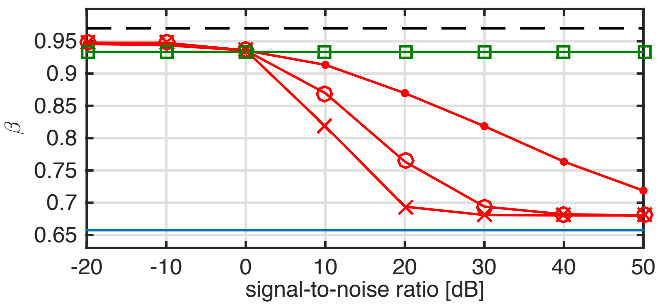

Fig. 2. Corresponding average data transmission time β.

per user is two. We assume Rayleigh fading such that $\boldsymbol{H}_{jk} \sim \mathcal{CN}(0, \boldsymbol{I})$ for all $j, k \in \mathcal{K}$. Let the distance between transmitter j and receiver k be a_{jk}. The pathloss coefficient is modeled as $\gamma_{jk} = a_{jk}^{-\delta}$, and we set the pathloss exponent $\delta = 3$. Define $\text{SNR} = (a_{kk}^{-\delta})/\sigma^2$.

In Fig. 1, the average sum rate is plotted for three matching schemes, where the averaging is done over 10^3 random system deployments. The corresponding overhead in CSI training is shown in Fig. 2. In the noncooperative scheme, the transmitters only have CSI-T regarding the direct channels. Precoding matrices are then calculated according to the eigenvectors of the direct channel. In the full cooperation scheme, full CSI-T is present at all transmitters. This scheme requires the highest amount of overhead in the F phase (Sec. 2.2.1) as is shown in Fig. 2. For calculating the transceivers, we use the alternating optimization algorithm in [4] in which we fix the maximum number of iterations to five. In the stable matching scheme, CSI-T at each transmitter is determined by the stable matching algorithm. We include the performance of a fixed matching scheme in which a receiver k is matched to a transmitter j if $\phi_k^{rx}(j) \geq 0.5$. After the F phase, the algorithm from [4] is applied at the transmitters using the incomplete CSI-T determined by the matching.

In Fig. 1, it can be seen that the performance of the noncooperative scheme is relatively high at low SNR while at high SNR interference management is necessary although a high overhead in CSI-T acquisition is needed. The performance of the stable matching scheme is shown to generally outperform the other two schemes depending on the choice of α, which is a design parameter in the function $\phi_k^{rx}(\emptyset)$ and $\phi_j^{tx}(\emptyset)$. This parameter influences the number of matchings in the system for different SNR levels and should be adapted accordingly. From Fig. 1, a low value of α gives higher performance at high SNR while larger α leads to gains at lower SNR values. It is shown that the fixed matching scheme performs poorly at SNR values above 0 dB.

REFERENCES

[1] METIS D6.2, "Initial report on horizontal topics, first results and 5G system concept," March 2014.

[2] K. Gomadam, V.R. Cadambe, and S.A. Jafar, "A distributed numerical approach to interference alignment and applications to wireless interference networks," *IEEE Trans Inf. Theory*, vol. 57, no. 6, pp. 3309–3322, June 2011.

[3] S. W. Peters and R. W. Heath, Jr., "Cooperative algorithms for MIMO interference channels," *IEEE Trans. Veh. Tech.*, vol. 60, no. 1, pp. 2006–218, Jan. 2011.

[4] Q. Shi, M. Razaviyayn, Z.-Q. Luo, and C. He, "An iteratively weighted MMSE approach to distributed sum-utility maximization for a MIMO interfering broadcast channel," *IEEE Trans. Signal Process.*, vol. 59, no. 9, pp. 4331–4340, Sep. 2011.

[5] O.E. Ayach and R.W. Heath, "Interference alignment with analog channel state feedback," *IEEE Trans. Wireless Commun.*, vol. 11, no. 2, pp. 626–636, Feb. 2012.

[6] S.W. Peters and R.W. Heath, "User partitioning for less overhead in MIMO interference channels," *IEEE Trans. Wireless Commun.*, vol. 11, no. 2, pp. 592–603, 2012.

[7] P. de Kerret and D. Gesbert, "Interference alignment with incomplete CSIT sharing," *IEEE Trans. Wireless Commun.*, vol. 13, no. 5, pp. 2563–2573, May 2014.

[8] A. E. Roth, "Stability and polarization of interests in job matching," *Econometrica*, vol. 52, no. 1, pp. 47–58, 1984.

[9] E. Jorswieck and P. Cao, "Matching and exchange market based resource allocation in MIMO cognitive radio networks," in *Proc. EUSIPCO*, 2013.

[10] A. Federgruen and H. Groenevelt, "The greedy procedure for resource allocation problems: Necessary and sufficient conditions for optimality," *Oper. Res.*, vol. 34, no. 6, pp. 909–918, 1986.

[11] F. Gul and E. Stacchetti, "Walrasian equilibrium with gross substitutes," *J. Econ. Theory*, vol. 87, no. 1, pp. 95–124, 1999.