Opportunistic Feedback Mechanisms for Decentralized Network MIMO systems

Sandeep Kottath †#, David Gesbert #, Eric Hardouin †

† *Orange Labs, Issy-les-Moulineaux, FRANCE*
Email: {sandeep.kottath,eric.hardouin}@orange.com
EURECOM, Mobile Communications Dept., FRANCE
Email: {kottath,gesbert}@eurecom.fr

***Abstract*—Dense interference-limited wireless networks can rely coordinated multipoint transmission (such as Network MIMO) as a way to improve on spectral efficiency. Unfortunately, Network MIMO requires global channel state information (CSI) at all transmitters, hence places stringent requirements on backhaul rate and even more on latency. As a solution, this paper investigates an emerging design philosophy for CSI that exploits the broadcast nature of wireless which is well suited to dense networks. In our design, feedback is broadcast from each terminal and decoded opportunistically by any overhearing base station which in turn must design opportunistic interference-cancelling precoders. The corresponding precoder design is shown to be equivalent to a decentralized decision problem whose general solution is challenging, yet for which heuristic schemes can be derived. The obtained algorithms are able to capitalize on the opportunistic feedback without the need for global CSI sharing.**

I. Introduction

The use of transmitter-based cooperation in interference-limited wireless networks promises substantial gains. In particular the joint design of MIMO precoders at various distant transmitters offers a powerful approach to interference avoidance, in the context of dense multicell/network MIMO [1], or interference coordination, e.g. using alignment strategies [2], [3]. In theory such methods can help restore a network sum rate behavior that scales indefinitely as we increase the transmitted power (i.e. the Degrees of Freedom are strictly more than zero). Nevertheless this ideal view is challenged by a number of practical considerations [4]. In particular, it is well known that the benefits of multiple antenna transmitter cooperation go at the expense of requiring channel state information (CSI) at *all* the transmitters. In practice current standardized systems operating in frequency division duplex FDD bands allow for a limited rate feedback channel to convey channel information from a given receiver back to its serving transmitter (Serving eNodeB in the 3GPP terminology) alone. In a second step, CSI is exchanged among the various transmitters over a backhaul signaling link, fixed or wireless (for e.g. using relaying) [5], [6]. Unfortunately, this approach has two main drawbacks. First, it is suitable for networks having a preexisting backhaul signaling infrastructure, less so for ad-hoc deployments (e.g HetNets etc.). Second, inter-transmitter information exchange is not easily scalable as the network grows ultra dense because exchanging CSI across many nodes over the (latency prone) backhaul is expected to cause substantial outdating to the CSI, making it close to obsolete in high mobility scenarios. As a solution to this problem, an new feedback design concept is emerging, which exploits the fundamental broadcast nature of wireless propagation. In a recent paper [7], this approach was investigated, under the name of *Broadcast Feedback*. Under the broadcast feedback, terminals estimate their downlink CSI (from possibly all surrounding base stations), quantizes it, then broadcasts it over the uplink. The CSI is then opportunistically decoded by the base stations. An interesting feature of this design lies in the fact it capitalizes on long-term fading reciprocity, through the fact that broadcast CSI tend to be successfully decoded primarily at the base stations that cause the highest average of interference to a given user, in other words at the base station where it matters the most without the need for a systematic exchange of global CSI over a backhaul. Saving signaling overhead for CSI sharing is especially beneficial when the backhaul is wireless and every resource needs to be carefully spent.

The penalty however caused by this approach is that, since not all transmitters will be able to successfully decode all the feedback data, the transmitter must make precoder design decision on the basis of partial, not fully global CSI, which can be recast as a challenging *distributed* signal processing problem[8]. Interestingly the challenge related to the distributedness of the problem can be alleviated by resorting to the well known notion of cooperation clusters, a concept used e.g. in 3GPP's Coordinated MultiPoint (CoMP) transmission. In our approach, a cooperation cluster is defined by considering a group of user terminals and base stations such that the broadcast feedback messages sent by all terminals in the cluster are successfully decoded by each of the member base stations of that cluster.

The formation of dynamic clusters based on the criterion above is shown to allow the recasting of the original decentralized precoding design problems into a centralized one for each cluster taken independently. A typical shortcoming of clustering in network MIMO [9], [10], [11] lies in the inter-cluster interference [12] [13] [14]. In this paper we show how opportunistic broadcast feedback can be exploited to alleviate this problem while keeping low the backhaul information sharing overhead [15], [16]. More specifically, our contributions are as follows:

- We propose a broadcast feedback design for use in network MIMO. We identify an interesting trade-off between the number of base stations that are capable of decoding the CSI feedback (cluster size) and the *quality* of the quantized CSI made available to such base stations.
- The problem of designing network MIMO precoders at base stations that do not share the same CSI is inherently distributed and challenging. We show how a clustering approach can help turn the problem into a tractable one.
- We propose a criterion for precoding design that exploits both CSI from within the cluster, as well as additional CSI originating from out-of-cluster terminals in an opportunistic manner, in view of mitigating inter-cluster interference.

II. Signal and System Model

We consider the downlink of an FDD wireless communication network consisting of a set of M base stations (BS) each equipped with J antennas, serving a set of K single antenna users (UE), with $K \leq JM$.

We assume that the downlink channel of each UE is affected by distance dependent pathloss and fast fading. The multi-cell downlink channel estimated by the k^{th} user is denoted as $\mathbf{h}_k \in \mathbb{C}^{MJ\times 1}$.

$$\mathbf{h}_k = [\mathbf{h}_{k1}^T \ \mathbf{h}_{k2}^T \ \dots \ \mathbf{h}_{kM}^T]^T \tag{1}$$

where, $\mathbf{h}_{km} \in \mathbb{C}^{J\times 1}$ is a column vector corresponding to the channel from m^{th} base station.

This work is focusing on the impact of limited feedback through imperfect uplink channels, and hence we assume perfect channel estimation at the user side.

III. Background and Problem Formulation

A. Broadcast Feedback

The concept of broadcast feedback was introduced in [7] and [9], but is briefly restated here for convenience. A *broadcast feedback* exploits the broadcast nature of the wireless channel in allowing every BS in the neighborhood to overhear the feedback sent by any terminal over the uplink. Classically, we assume that some orthogonality is maintained between the feedback messages sent by the multiple terminals, hence no interference is considered on the feedback channel itself.

We consider that each UE estimates and quantizes the aggregated downlink channels and quantizes over a B bit codebook then transmits it over β_{fb} channel uses. We assume random vector quantization (RVQ) for the ease of analysis.

The success of feedback message detection is modeled by comparison with an ideal capacity expression for the feedback channel between k^{th} user and m^{th} base station.

$$C_{mk} = \beta_{fb} \cdot log(1 + \frac{|\mathbf{h}_{mk}^U|^2 P}{\sigma_\eta^2}) \tag{2}$$

where $\mathbf{h}_{mk}^U \in \mathbb{C}^{J\times 1}$ is the uplink channel from k^{th} UE to m^{th} BS, P is the transmit power from UE. σ_n^2 is the thermal noise power at the base station, assumed to be equal to that at the UE for ease of notation.

The feedback decoding and subsequent downlink transmission rule is as follows:

- if $C_{mk} < B$ then m^{th} BS is not able to decode the feedback sent by k^{th} UE (no feedback) and will not attempt to serve it.
- if $C_{mk} \geq B$ then m^{th} BS decodes the feedback from k^{th} UE without error and hence BS utilize this channel state information to either serve the UE or to minimize interference to that UE.

It is important to remark that broadcast feedback leads to a distributed form of CSI among the base stations [8], in the sense that each base station obtains its own subset of the global channel state information matrix, hence giving rise to a distributed signal processing problem when designing the downlink precoders. This distributedness is the key challenge addressed by this paper.

B. Clustered Network MIMO

Let $\mathcal{V}_m \subseteq [1, K]$ be the set of users whose feedback was decoded by m^{th} base station. We assume that the information about $\mathcal{V}_m \forall m \in [1, M]$ is collected at a central node, where the clustering algorithm is applied to find *Joint CSIT clusters*.

Definition 1. A *Joint CSIT Cluster* denoted by $\{\mathcal{M}, \mathcal{K}\}$ is a distinct subset of users $\mathcal{K}$ and base stations $\mathcal{M}$ such that feedback from all users in the cluster has been successfully decoded by all the base stations in that cluster. We assume that the cluster results are known to all the BS. Finally the data symbols of each UE are shared among the base stations in its cluster but not outside. ■

One of the possible clustering algorithm for this particular broadcast feedback scheme is shown in [7] and is not reproduced here, any other clustering algorithm can also be modified for this purpose. We now consider one target cluster consisting of a set $\mathcal{M}$ of BSs and a set $\mathcal{K}$ of UEs.

Let N_b and N_u be the number of BSs and UEs in the target cluster $\{\mathcal{M}, \mathcal{K}\}$. Assume that the users in the target cluster are the users with indices $i_1, i_2, ..i_{N_u} \in [1, K]$ and the base stations in the same cluster are the BS with indices $j_1, j_2, ..j_{N_b} \in [1, M]$. We consider the design of the precoder at an arbitrary BS j_m within the target cluster.

C. Problem Formulation

We are interested at a design strategy of the precoder at BS j_m denoted as $\mathbf{w}_{j_m}$ that exploits the CSI information that is available at BS j_m. The CSI at BS j_m is two-fold: first the CSI related to users served by the cluster (which includes user i_k), and which by construction of the cluster is shared by the other BSs in the cluster, and secondly any additional CSI that BS j_m may have opportunistically decoded from out-of-cluster users, with indices $\mathcal{V}_{j_m} \setminus \mathcal{K}$. Note however that this extra CSI is *not* shared by all the other BS in the cluster.

The difficulty of this problem resides in the fact that the base stations are designing their precoders in a fully decentralized manner. Therefore an optimal design would fall in the category of classical yet very challenging decentralized control problems [17].

IV. Opportunistic Precoder Optimization

Although a precoding algorithm exploiting opportunistic CSI will be decentralized by nature and challenging to optimize, we propose a heuristic partially cooperative precoding method. More precisely, we propose an approach where the base station mitigates a combination of the interference it generates towards other cluster users (OCI) and within or intra-cluster users (ICI). In practice this can be done using the classical concept of virtual SINR or minimum leakage [18], [19].

Similar to our previous notations, the channel information vector containing coefficients from BS $j_1, ..j_{N_b}$ towards user i_k is represented as $\mathbf{h}_{i_k} \in \mathbb{C}^{N_b J \times 1}$.

$$\mathbf{h}_{i_k} = \left[\begin{array}{cccc} \mathbf{h}_{i_k,j_1}^T & \mathbf{h}_{i_k,j_2}^T & \cdots & \mathbf{h}_{i_k,j_{N_b}}^T \end{array} \right]^T \tag{3}$$

where $\mathbf{h}_{i_k,j_m} \in \mathbb{C}^{J \times 1}$ is the downlink channel from an arbitrary base station j_m to the UE i_k. The received signal at UE i_k belonging to this cluster can be expressed as a sum of the signal, interfering signals and noise as follows,

$$y_{i_k} = \sum_{m \in \mathcal{M}} \mathbf{h}_{i_k,m}^H \mathbf{w}_{m,i_k} s_{i_k} + \sum_{j \neq i_k} \sum_{m \in [1,M]} \mathbf{h}_{i_k,m}^H \mathbf{w}_{mj} s_j + \eta_{i_k} \tag{4}$$

where s_{i_k} is the symbol intended for the UE i_k and η_{i_k} is the thermal noise at the receiver of UE i_k modeled as i.i.d normalized Gaussian random variable $\mathcal{CN}(0, \sigma_\eta^2)$. $\mathbf{w}_{m,i_k} \in \mathbb{C}^{J \times 1}$ is the precoder implemented at BS m and used to serve UE i_k.

The global precoder matrix at BS j_m is represented as $\mathbf{W}^{(j_m)} \in \mathbb{C}^{N_u \times N_b J}$

$$\mathbf{W}^{(j_m)} = \left[\begin{array}{cccc} \mathbf{w}_{i_1} & \mathbf{w}_{i_2} & \cdots & \mathbf{w}_{i_{N_u}} \end{array} \right] \tag{5}$$

where $\mathbf{w}_{i_k} \in \mathbb{C}^{1 \times J}$ is the cluster precoder for serving UE i_k. We can expand $\mathbf{W}^{(j_m)}$ as,

$$\mathbf{W}^{(j_m)} = \left[\begin{array}{cccc} \mathbf{w}_{j_1,i_1} & \mathbf{w}_{j_1,i_2} & \cdots & \mathbf{w}_{j_1,i_{N_u}} \\ \mathbf{w}_{j_2,i_1} & \mathbf{w}_{j_2,i_2} & \cdots & \mathbf{w}_{j_2,i_{N_u}} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{w}_{j_{N_b},i_1} & \mathbf{w}_{j_{N_b},i_2} & \cdots & \mathbf{w}_{j_{N_b},i_{N_u}} \end{array} \right] \tag{6}$$

The part of this global precoder that correspond to the BS j_m are given by

$$\mathbf{W}_{j_m} = \left[\begin{array}{cccc} \mathbf{w}_{j_m,i_1} & \mathbf{w}_{j_m,i_2} & \cdots & \mathbf{w}_{j_m,i_{N_u}} \end{array} \right] \tag{7}$$

Assume that BS j_m has opportunistically decoded the feedback messages of a set $\mathcal{V}_m \setminus \mathcal{K}$ of additional users outside its cluster. This extra CSI is collected in vectors $\mathbf{h}_{p,j_m} \forall p \in \mathcal{V}_{j_m} \setminus \mathcal{K}$.

The design of the precoder at BS j_m is aimed at striking a compromise between mitigating the interference inside the cluster and generated interference towards users $\mathcal{V}_{j_m}$. However the interference within the cluster is tackled in a cooperative manner among BSs $\mathcal{M}$, hence BS j_m must take into account the precoders implemented by all the base stations $j_1, j_2, ..j_{N_b}$. This can be done by optimizing the whole cluster precoder matrix $\mathbf{W}^{(j_m)}$ and then discarding all precoders that are not directly exploited at BS j_m.

For ease of exposition, we are considering a scenario with sum power constraint for each cluster rather than a distributed power constraint. Note that, this assumption is justified in statistically symmetric settings where the sum peak power constraint will fulfill some individual average power constraint at each base station. The generalization of this work to more practical per antenna per transmitter power constraint is subject to ongoing work.

A. Distributed Precoder Optimization

We are interested in designing the precoder at each base station in the cluster $\mathcal{M}$. We first derive the precoder optimization procedure at an arbitrary BS j_m such that the ratio of useful transmitted energy within the cluster by BS j_m over the sum of generated interference by this base station within and outside the cluster (i.e. to the user outside the cluster that were opportunistically overheard) is maximized. We then explain the whole algorithm based on this derivation.

The sum of desired signal powers at the UEs of our target cluster is expressed as,

$$P_d = \sum_{k \in \mathcal{K}} \mathbf{w}_k^H \mathbf{h}_k \mathbf{h}_k^H \mathbf{w}_k \tag{8}$$

We denote $R_d^{(k)} = \mathbf{h}_k \mathbf{h}_k^H \forall k \in \mathcal{K}$. Now we aim to find the total generated (to users for which it has decoded feedback) interference plus noise power for the BS j_m.

$$P_I = \sum_{\forall k \in \mathcal{K}} \sum_{j \neq k} \mathbf{w}_k^H \mathbf{h}_j^H \mathbf{h}_j \mathbf{w}_k + \sum_{\forall p \in \mathcal{V}_m \setminus \mathcal{K}} \mathbf{w}_{mk}^H \mathbf{h}_{pm} \mathbf{h}_{pm}^H \mathbf{w}_{mk} + \sigma_\eta^2 \tag{9}$$

Rearranging the above quadratic forms depending on the terms depending on user index (k in the above equation), so that the final expression can be written as a single block diagonal quadratic form,

$$P_I = \sum_{\forall k \in \mathcal{K}} \mathbf{w}_k^H \mathbf{R}_{int}^{(k)} \mathbf{w}_k + \mathbf{w}_k^H \mathbf{R}_o^{(m)} \mathbf{w}_k + \mathbf{w}_k^H \left(\frac{\sigma_\eta^2}{N_b P} I \right) \mathbf{w}_k \tag{10}$$

where,

$$\mathbf{R}_{int}^{(k)} = \sum_{j \neq k} \mathbf{h}_j \mathbf{h}_j^H$$

correspond to intra-cluster interference experienced by any UE $k \in \mathcal{K}$, I is the identity matrix and

$$\mathbf{R}_o^{(j_m)} = blkdiag\left(\mathbf{\Theta}_1, \mathbf{\Theta}_2 \ \ldots \mathbf{\Theta}_i \ldots \ \mathbf{\Theta}_{N_b}\right)$$

is related to the other-cluster interference power that can be opportunistically minimized by BS j_m since it has decoded the corresponding extra CSI, where *blkdiag*(.) is the block-diagonal matrix formed by the matrices in the argument.

where $\mathbf{\Theta}_i \in \mathbb{C}^{J \times J}$ is,

$$\mathbf{\Theta}_i = \begin{cases} \mathbf{0} & \text{if } i \neq j_m \\ \sum_{\forall p \in \mathcal{V}_{j_m} \setminus \mathcal{K}} \mathbf{h}_{p,j_m} \mathbf{h}_{p,j_m}^H & \text{if } i = j_m \end{cases}$$

We denote the central matrix in the quadratic form in Eq.10 corresponding to each user $k \in \mathcal{K}$ as ,

$$\mathbf{R}_I^{(k)} = \mathbf{R}_{int}^{(k)} + \mathbf{R}_o^{(j_m)} + \frac{\sigma_\eta^2}{N_b P} \tag{11}$$

and the aggregated block diagonal matrix as $\mathbf{R}_I$, with each block $\mathbf{R}_I^{(k)}$ corresponding to each UE $k \in \mathcal{K}$ in the cluster.

Hence our precoder optimization problem can be formulated as follows,

$$\mathbf{vec}(\mathbf{W}^{(j_m)}) = arg\ max_{||\mathbf{w}_{j_m}||^2 = N_b P} \ \frac{P_d}{P_I} \tag{12}$$

where $\mathbf{vec}(\cdot)$ is the *vectorization* operator of a matrix which converts the matrix into a column vector, obtained by stacking the columns of the matrix on top of one another. (12) is a classical Rayleigh-Ritz ratio, whose maximization is obtained by the maximum eigen vector of the generalized eigen equation,

$$\mathbf{R}_d \ vec(\mathbf{W}^{(j_m)}) = \lambda \ \mathbf{R}_I \ vec(\mathbf{W}^{(j_m)}) \tag{13}$$

Since R_d and R_I are both in block diagonal form, it can also be solved by maximum generalized eigen vector (λ_{max}) of each block corresponding to each UE in the cluster.

$$\mathbf{w}_k \propto \lambda_{max}\left(\mathbf{R}_d^{(k)}, \mathbf{R}_I^{(k)}\right) \ \ \forall \ k \ \in \ \mathcal{K} \tag{14}$$

The BS j_m finds the global precoder weights of the target cluster $\mathbf{W}^{(j_m)}$ using (12). Then the precoder norm is scaled with μ to apply the cluster transmit power constraint.

$$\mu = N_b P \cdot \frac{1}{||\mathbf{W}^{(j_m)}||} \tag{15}$$

The row of precoder weights corresponding to the antennas of the BS j_m is utilized and the rest is discarded. This process is done simultaneously at each of the base stations and the effective global CoMP precoder is found by concatenating rows corresponding to precoder weights at each BS. We illustrate this opportunistic precoder design using a small example in the following section.

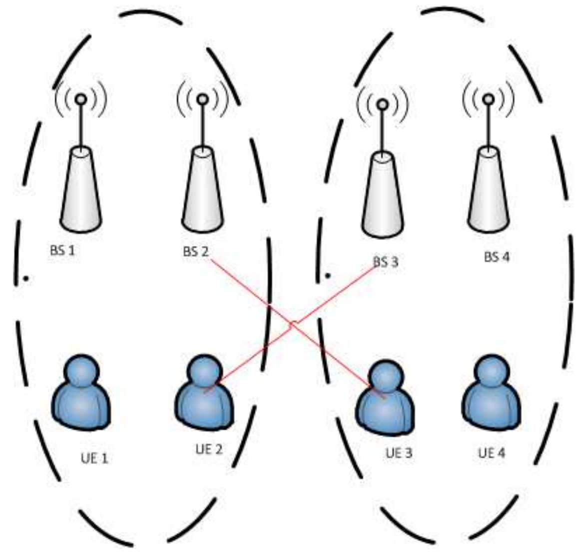

Fig. 1: A toy example illustrating the network of interest, with 4 Base Stations (M=4) each with two antennas (J=2) serving 4 UEs (K=4).

B. A Toy Example Illustration

Fig.1 illustrates an example of the problem of our interest. In this example, four BS are used and two clusters are formed which include BS 1 and 2 in the first cluster and BS 3 and 4 in the second cluster. We assume BS2 acquires the feedback of user 3 opportunistically, in addition to the feedback of user 1 and 2 in its own cluster. We will focus just on the precoder design at BS 2 to illustrate the main idea in this paper.

In this case since we are focusing at BS 2 which is part of the cluster $\mathcal{K}$, our mathematical notations becomes,

$$\mathcal{V}_m = \left[\begin{array}{ccc} 1 & 2 & 3 \end{array}\right]$$
$$\mathcal{K} = \left[\begin{array}{cc} 1 & 2 \end{array}\right]$$
$$\mathcal{M} = \left[\begin{array}{cc} 1 & 2 \end{array}\right]$$

$$\mathbf{w}_1 = \left[\begin{array}{c} \mathbf{w}_{11} \\ \mathbf{w}_{21} \end{array}\right] = \lambda_{max}\left(R_d^{(1)}, R_I^{(1)}\right)$$
$$\mathbf{w}_2 = \left[\begin{array}{c} \mathbf{w}_{12} \\ \mathbf{w}_{22} \end{array}\right] = \lambda_{max}\left(R_d^{(2)}, R_I^{(2)}\right)$$

where,

$$R_d^{(1)} = \left[\begin{array}{c} \mathbf{h}_{11} \\ \mathbf{h}_{12} \end{array}\right] \left[\begin{array}{c} \mathbf{h}_{11} \\ \mathbf{h}_{12} \end{array}\right]^H$$
$$R_d^{(2)} = \left[\begin{array}{c} \mathbf{h}_{21} \\ \mathbf{h}_{22} \end{array}\right] \left[\begin{array}{c} \mathbf{h}_{21} \\ \mathbf{h}_{22} \end{array}\right]^H$$

$$R_I^{(1)} = \begin{bmatrix} \mathbf{h}_{21} \\ \mathbf{h}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{h}_{21} \\ \mathbf{h}_{22} \end{bmatrix}^H + \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{h}_{32}\mathbf{h}_{32}^H \end{bmatrix} + \frac{\sigma_\eta^2}{2P} I$$

$$R_I^{(2)} = \begin{bmatrix} \mathbf{h}_{11} \\ \mathbf{h}_{12} \end{bmatrix} \begin{bmatrix} \mathbf{h}_{11} \\ \mathbf{h}_{12} \end{bmatrix}^H + \begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{h}_{32}\mathbf{h}_{32}^H \end{bmatrix} + \frac{\sigma_\eta^2}{2P} I$$

Based on the precoder design described before, the distributed precoding algorithm is summarized below. It has to be noted that, this algorithm is only describing the steps for finding the precoder for one particular joint-CSIT cluster. These steps has to be repeated for each of the joint-CSIT cluster in the network.

Algorithm Distributed Precoding Algorithm

Inputs:
  $\mathcal{K}, \mathcal{M}$
  $\mathcal{V}_m \forall m \in \mathcal{M}$
Initialize:
  $\mathbf{W}^{(m)} \leftarrow \mathbf{0} \; \forall m \in \mathcal{M}$
for $m \in \mathcal{M}$ **do**
  for $k \in \mathcal{K}$ **do**
    $\mathbf{w}_k = \mu \cdot \lambda_{max}\left(\mathbf{R}_d^{(k)}, \mathbf{R}_I^{(k)}\right)$
  Find the global precoding matrix at BS m,
    $\mathbf{W}^{(m)} = [\mathbf{w}_1 \; \mathbf{w}_2 \; \ldots \mathbf{w}_{N_u}]$
  Scale the norm of the precoder to satisfy the power constraint,
    $\mathbf{W}^{(m)} = \frac{N_b P}{||\mathbf{W}^{(m)}||_F} \mathbf{W}^{(m)}$
  Use (6) and (7) to find $\mathbf{W}_m$, the part of the global precoder to be implemented at BS m

Next section presents simulation results of the discussed algorithm to substantiate our claims and show that utilizing extra CSIT at each base station improves the performance of the network (average throughput).

V. Numerical Results

A. Simulation Methodology

We consider a 7-cell hexagonal network (and hence number of BSs, $M = 7$) where BSs are at the center of the hexagon of radius 200 meters. We assume that each BS has single active UE at a random location within the cell. Each BS is assumed to have two transmit antennas (J=2), and the UEs are assumed to have single antenna receivers. The downlink channels of UEs are affected by distant dependent pathloss and fast fading. The clustering and precoder design is done every time when there is a CSI feedback from the UE (it can depend on how fast CSI changes).

We find the sum rate (in bits/s/Hz) achieved by users for the downlink transmission by monte-carlo simulations. We compare the performance of the network with a precoder utilizing extra CSI available at each base station (opportunistic precoder) and a precoder which does not utilize the extra CSI available (conventional precoder).

B. Ergodic Achievable Rate

If γ_k is the SINR experienced by k^{th} UE belonging to an arbitrary cluster $\{\mathcal{M}, \mathcal{K}\}$, the average rate achieved per user with the proposed scheme can be written as,

$$R_k = \mathbb{E}_h[\log_2(1 + \gamma_k)] \tag{16}$$

where,

$$\gamma_k = \frac{|\sum_{m \in \mathcal{M}} \mathbf{h}_{km}^H \mathbf{w}_{mk}|^2}{\sum_{i \neq k} \left(|\sum_{m \in \mathcal{M}} \mathbf{h}_{km}^H \mathbf{w}_{mj} + \sum_{m \notin \mathcal{M}} \mathbf{h}_{km}^H \mathbf{w}_{mj}|^2\right) + \sigma_\eta^2} \tag{17}$$

$\sum_{m \in \mathcal{M}} \mathbf{h}_{km}^H \mathbf{w}_{mj}$ correspond to the intra-cluster interference (ICI) and $\sum_{m \notin \mathcal{M}} \mathbf{h}_{km}^H \mathbf{w}_{mj}$ correspond to the other-cluster interference (OCI).

The sum rate of all the UEs is obtained by summing the ergodic rate achieved by all the UEs in the network.

C. Performance Evaluation

We compare the performance of the new opportunistic precoding algorithm with conventional precoding approach in Fig.2 for various amounts of feedback quantization bits B assuming an average SNR of 20dB. As can be seen , when the number of bits gets large, base stations receive a more accurate feedback but fewer base station are able to actually decode it, which leads to performance decrease. Conversely, when the number of quantization bits B becomes too small, most BS can decode the feedback, leading to wider cooperation clusters, albeit with poor CSI quality.

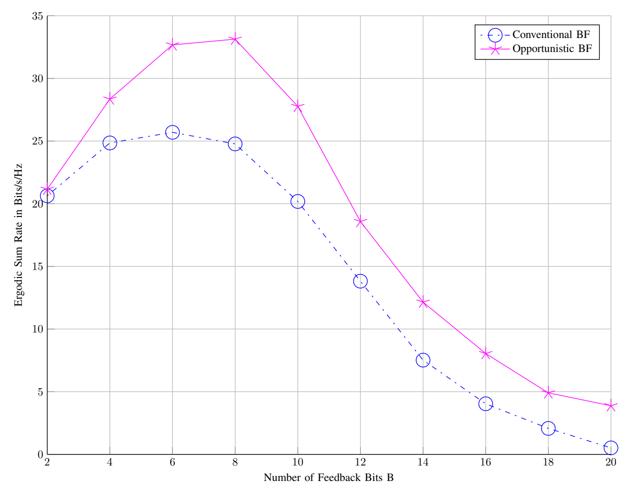

Fig. 2: Variation of sum rate with number of feedback bits B for a network with average SNR of 20dB.

Now we evaluate the performance of the opportunistic precoder and compare with the conventional approach. As seen in Fig.3, the performance of the new opportunistic precoder outperforms the classical precoder at all SNR values, and the performance improvement is higher at higher SNR values because the out-of-cluster interference becomes limiting at high SNR and any opportunistic CSI helps with system performance.

VI. Conclusions

We proposed a decentralized precoding method which is capable of exploiting additional opportunistic out-of-cluster

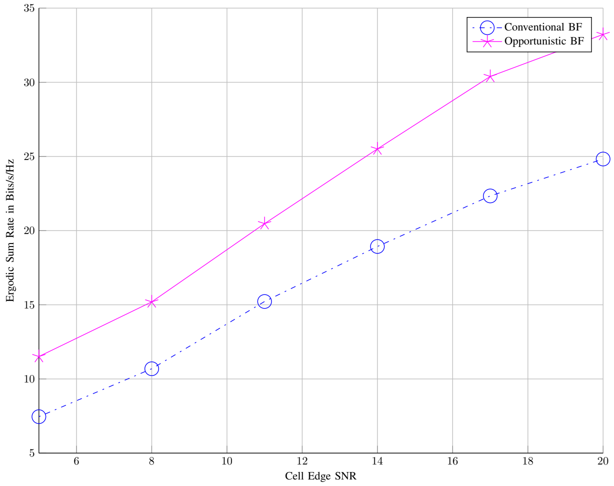

Fig. 3: Comparison of the sum rate of opportunistic precoder with conventional precoder for different average cell edge SNR for a B = 8.

broadcast feedback in Network MIMO. The method shows clear gain over a conventional network MIMO setup which exploits CSI limited to its own cluster.

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