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Low Complexity Precoders for Multicell Multiuser (MU) MIMO System

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Abstract: ***This paper deals with analysis and comparison of a Precoder design in a multicell multi user (MU) MIMO system on per cell basis in both competition and coordination mode. In competition mode base- station selfishly determines its precoding strategy based on the knowledge of inter-cell interference (ICI) at its connected mobile-stations (MS).In this mode a strategic non-cooperative game (SNG) is considered, therefore the existence and uniqueness of Nash equilibrium in SNG is analysed. Whereas in coordination mode, network weighted sum-rate (WSR) is maximized by jointly designing a Precoder for multiple base-stations (BSs). The main aim of the propose work is to analyze the block-diagonalization (BD) Precoding, BD-dirty paper coding (BD-DPC) Precoding and to compare these results with zero forcing (ZF) Precoding. Simulation result shows that by designing a Precoder jointly network sum-rate can be improved significantly, and ZF Precoding provides almost the same network sum rate with low complexity.***

Keywords: MIMO, ICI, Nash equilibrium, CoMP, BD Precoding, ZF Precoding

1. Introduction

The present age has seen a rapid increment in research and development of communication technologies, each of these technologies are differ from one another. In a multiple-input multiple-output (MIMO) framework, space division multiple access (SDMA) can be used at the base-station (BS) to simultaneously multiplex information streams for multiple mobile-stations (MS). With proper downlink Precoding techniques at the BS, SDMA can significantly enhance the system spectral efficiency [1]. The research on downlink precoding for a multiple-input multiple-output (MIMO) framework has been a dynamic zone for long time. Dirty paper coding (DPC) [2], [3] has been turned out to be the capacity achieving multi-user Precoding methodology. However, due to its high complexity implementation that involves random nonlinear encoding and decoding, DPC only remains as a theoretical benchmark. As a result, linear Precoding techniques, such as zero-forcing (ZF), block-diagonalization (BD) turns out to be great choices because of their simplicity and good performance. In BD Precoding, the transmitted information from the BS expected for a specific user is limited to be in the null space made by the downlink channels connected with the various users. Hence, all inter-user interference within the cell at the MSs can be fully suppressed [4]-[6].

All the conventional Precoding design deal with single-cell setting where the inter-cell interference (ICI) is treated as noise but now a day wireless network adopt universal frequency reuse, which leads to high level of ICI and hence it should not be ignored. A lot of research work is done for designing a Precoder for coordinated transmission/reception. (CoMP) in a multi-cell system [7]-[11]. The advantage of CoMP comes with cost high complexity i.e. by designing a joint Precoder and by providing ideal exchange of data and control information among the BSs [12]. In this propose work, Precoding is done on per cell basis so exchange of data among BSs is not required.

In the interference aware (IA) mode each IA MSs measure the level of ICI sends this information back to connected BS [13]. By knowing ICI each BS greedily alter its Precoding strategy to increase the sum rate of its connected MSs, thus multi-cell system said to be in competition mode as each BS is competing with other BS for radio resource. Naturally IA mode characterizes a SNG with BSs as rational player.

While in interference coordination (IC) mode precoders from all BSs are designed mutually to completely control the level of ICI [14].

BD and BD-DPC Precoding are implemented in both IC and IA mode. In BD-DPC, the data Signals Sent to the multiple users are encoded in sequence such that the receiver at any user does not see any intra-cell interference because of the utilization of BD and DPC at the BS [15]. Thus, BD-DPC can take Advantage of DPC to improve the Performance of BD Precoding. Further this work is extended for zero forcing (ZF) Precoder design. ZF Precoding avoids singular value decomposition (SVD) and hence complexity is further reduced compare to BD and BD-DPC Precoding [16].

2. System Model

A multiuser multicell downlink framework with Q separate cells operating on the same frequency channel is considered. At a particular cell, say cell $-$ q, a multiple-antenna BS is simultaneously sending independent data streams to K_q remote MSs, each outfitted with multiple receive antennas. Let M_q and N_{qi} be the numbers of antennas of the BS and the ith MS at cell-q, respectively. Denote $x_q \in C^{M_q \times 1}$ as the transmitted signal vector from BS-q. Assuming linear Precoding at the BS x_q can be represented as $x_q = \sum_{i=1}^{K_q} W_{qi} s_{qi}$, where $W_{qi} \in C^{M_q \times L_{qi}}$ is the precoding matrix and $s_{qi} \in C^{L_{qi} \times 1}$ is the data symbol vector intended for MS-i with L_{qi} being the number of transmitted symbols. If loss is zero, expectation of $s_{qi} * s_{qi}^H$ is assumed to be one, i.e. $\mathbb{E}\left[s_{qi} s_{qi}^H \right] = I, \forall i, \forall q$.

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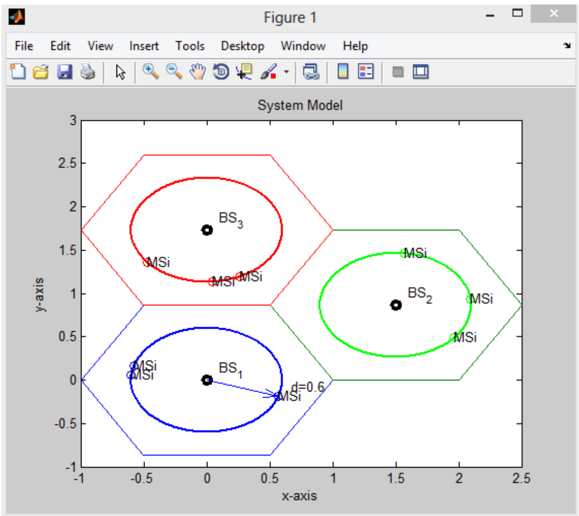

Figure 1: A multicell system configuration with 3 cells, 3 users per cell.

Let $H_{rqi} \in C^{N_{qi} \times M_r}$ is the model for channel coefficients from BS-r to MS-i of cell-q, and z_{qi} is the model for zero-mean complex additive Gaussian noise vector with an arbitrary covariance matrix Z_{qi} . The transmission to MS-i at cell-q can be modelled as

$$y_{qi} = \sum_{r=1}^{Q} H_{rqi} x_r + z_{qi} =$$

$$H_{qqi} W_{qi} s_{qi} + H_{qqi} \sum_{j \neq i}^{K_q} W_{qj} s_{qj} + \sum_{r \neq q}^{Q} H_{rqi} \sum_{j=1}^{K_r} W_{rj} s_{rj} + z_{qi}$$
.... (1)

It is cleared from equation (1) that received signal at MS-i of cell-q will have 4 components:

The useful information signal $H_{qqi} W_{qi} s_{qi}$, the intra-cell interference $H_{qq_i} \sum_{j \neq i}^{k_q} W_{q_j} s_{q_j}$,the inter-cell interference

$\sum_{r \neq q}^{Q} H_{rqi} \sum_{j=1}^{K_r} W_{rj} s_{rj}$, and the Gaussian noise z_{qi}.

In order to implement BD Precoding on per cell basis total number of receive antennas at MSs should be less than or equal to the total number of transmit antennas, at their connected BSs. If not then, BSs will select a subset of MSs for providing the service [17].

Let $Q_{qi} = W_{qi} W_{qi}^H$ be the transmit covariance matrix proposed for MS-i of cell-q, and $Q_q = \{Q_{qi}\}_{i=1}^{K_q}$ be the Precoding profile for K_q MSs of cell-q. Similarly, let $Q_{-q} = \{Q_1, \dots, Q_{q-1}, Q_{q+1}, \dots, Q_Q\}$ denote the precoding profile of all cells except cell-q. Denote $R_{qi}(Q_{-q})$ as the covariance matrix of the interference and noise (IPN) power (with no intra-cell interference) at the MS-i of cell-q, which is defined as

$$R_{qi}(Q_{-q}) = \sum_{r \neq q}^{Q} H_{rqi} \left(\sum_{j=1}^{K_r} Q_{rj}\right) H_{rqi}^H + Z_{qi} \text{ .... (2)}$$

With Precoding applied on a per-cell basis at BS-q, the achievable data rate R_{qi} to MS-i is then given by [5]

$$R_{qi}(Q_q, Q_{-q}) = \log|I + H_{qqi}^H R_{qi}^{-1}(Q_{-q}) H_{qqi} Q_{qi}| \text{ .... (3)}$$

2.1 Problem Formulation: Competitive Design

By knowing the strategy profile Q_{-q} from other BSs, BS-q selfishly maximizes its payoff function by solving the following optimization problem

$$\underset{Q_{q1}, \dots, Q_{qK_q}}{\text{maximize}} \; R_q(Q_q, Q_{-q})$$
$$\text{subject to } H_{qqi} Q_{qi} H_{qqi}^H = 0, \forall j \neq i$$
$$Q_{qi} \geq 0, \forall i$$
$$\sum_{i=1}^{K_q} Tr\{Q_{qi}\} \leq P_q \text{ ... ... (4)}$$

Where P_q is the power budget at BS-q. To achieve the maximum sum data-rate at cell-q, it is assumed that the IPN matrix $R_{qi}(Q_{-q})$ is perfectly measured at the corresponding MS-i and reported back to its connected BS. In BD Precoder SVD of $\widehat{H}_{qi}$ is calculated which is used for formulating Q_{qi} matrix.

2.2 Coordinated Design

By means of the coordination between the BSs network sum-rate improvement can be obtained by jointly designing all the precoders at the same time. In any case, this favourable position come with the cost of message passing between the BSs, the coordinated multicell BD Precoding design is investigated in order to jointly maximize the network weighted sum-rate (WSR) through the following optimization

$$\underset{Q_1, \dots, Q_Q}{\underline{maximize}} \sum_{q=1}^{Q} \alpha_q \sum_{i=1}^{K_q} log|I + H_{qqi}^H R_{qi}^{-1}(Q_{qi}) H_{qqi} Q_{qi}|$$

$$subject\ to\ H_{qqi} Q_{qi} H_{qqj}^H = 0, \forall j \neq i, \forall q$$

$$Q_{qi} >= 0, \forall q$$

$$\sum_{i=1}^{K_q} Tr\{Q_{qi}\} \leq P_q, \forall q \text{....... (5)}$$

Where $\alpha_q \geq 0$ denotes the nonnegative weight associated with BS-q.

3. Nash Game Theory and Nash Equilibrium

Game theory studies interactive choice making, where the result for every member or "player" relies on upon the activities of all.

'Nash Equilibrium' can be characterized as a idea of game theory where the optimal result of a game is one where no player has an motivation to deviate from his or her picked methodology after considering an opponent's choice. An individual can get no incremental advantage from evolving activities. Expecting different players stay consistent in their methodologies.

Let (S, f) be a game with n players, where S_i is the technique set for player i, $S = S_1 X S_2 X \dots X S_n$ is the set of procedure profiles and $f = (f_1(x), \dots, f_n(x))$ is the payoff function for $x \in S$. Let x_i be a procedure profile of player i and x_{-i} be a procedure profile of all players with the exception of player i. At the point when every player $i \in \{1, \ldots, n\}$ picks strategy x_i resulting in procedure profile $x = (x_1, \ldots, x_n)$ then player i acquires payoff $f_i(x)$, which depends upon the strategy picked by player i as well as the strategies picked by all other players. A procedure profile $x^* \in S$ is Nash equilibrium (NE) if no one-sided deviation in strategy by any single player is beneficial for that player.

This means,

$$\forall i, x_i \in S_i : f_i(x_i^*, x_{-i}^*) \geq f_i(x_i, x_{-i}^*).$$

If the inequality in above equation holds entirely (with > rather than ≥) for all players then the harmony is named as a strict Nash equilibrium.

3.1 Characterization of the BD Precoding Game's Nash Equilibrium

In this segment, the two most major inquiries in investigating a SNG are examined: the presence and uniqueness of the game's NE. The NE portrayal permits us to foresee a stable result of the non- cooperative BD Precoding plan in game G. Keeping in mind the end goal to study the uniqueness of a NE in game G, we first explore the best reaction methodology at every player The best reaction procedure of player-q must be in the form $Q_{qi} = \hat{V}_{qi} D_{qi} \hat{V}_{qi}^H, \forall i. Let\ Dq \triangleq blk\{D_{qi}\}, D = \{D_q\}q \in \Omega$. At that point, the best response strategy D_q at BS-q can be acquired from the following optimization problem

$$\underset{D_{q1} \ldots \ldots D_{k_q}}{maximize} \sum_{i=1}^{k_q} log\,|\,I + \hat{V}_{qi}^H H_{qq_i}^H \hat{R}_{q_i}^{-1}(D_{-q}) H_{qq_i} \hat{}V_{q_i} D_{q_i}\,|$$

$$subjected\ to\ D_{q_i} \geq 0\ \forall\ i,$$

$$\sum_{i=1}^{k_q} Tr\{D_{q_i}\} \leq P_q \ldots\ldots\ldots\ldots\ldots (6)$$

Where $\hat{}R_{q_i}(D_{-q})$ is defined as

$$\hat{R}_{q_i}^{-1}(D_{-q}) = \hat{R}_{q_i}(Q_{-q})$$

$$= \sum_{r \neq q}^{Q} H_{rq_i} \left(\sum_{j=1}^{k_r} \hat{V}_{r_j} D_{r_j} \hat{V}_{r_j}^H\right) H_{rq_i}^H + Z_{q_i}$$

From Eigen-decomposing $\hat{V}_{qi}^H H_{qqi}^H \hat{R}_{qi}^{-1}(D_q) H_{qqi} \hat{V}_{qi} = \hat{U}_{qi} \Lambda_{qi} \hat{U}_{qi}^H$, the optimal solution to problem (6) can be obtained from the WF method.

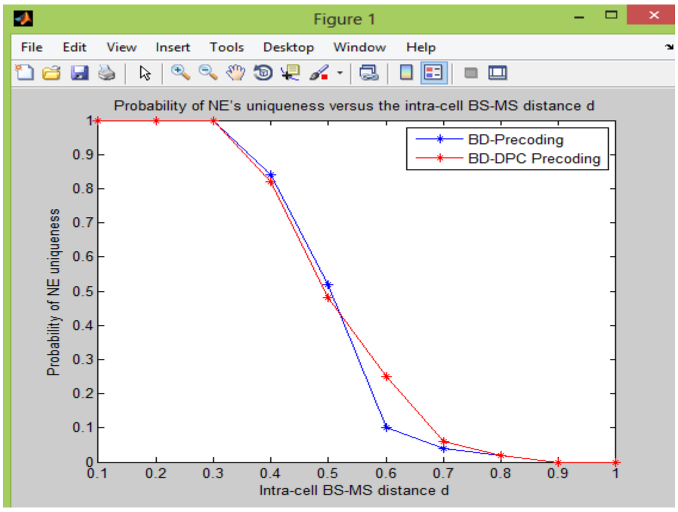

Figure 2: probability NE's uniqueness VS intra-cell BS-MS distance d

4. Optimization Problem

The above optimization problem in equation (6) is equivalent to:

$$\underset{D_{q1} \ldots \ldots D_{k_q}}{minimize} \sum_{i=1}^{k_q} \left\| D_{q_i} + \left(\hat{V}_{q_i}^H H_{qq_i}^H R_{q_i}^{-1}(D_{-q}) H_{qq_i} \hat{V}_{q_i}\right)^{\#} + c_q P_{\mathcal{N}(\boldsymbol{H_{qqi}} \hat{V}_{qi})} \right\|_F^2 \ldots\ldots\ldots\ldots\ldots (7)$$

$$subjected\ to\ \sum_{i=1}^{k_q} Tr\{D_{q_i}\} \leq P_q, D_{q_i} \geq 0,$$

Where $P_{\mathcal{N}(\boldsymbol{H_{qqi}} \hat{V}_{qi})}$ the orthogonal projection onto the null is space of $H_{qqi} \hat{V}_{q_i}$, and c_q is an arbitrarily constant satisfying $c_q \geq P_q + max_{\forall i, \forall k} [\Lambda_{qi}]_{kk}^{-1}$.

The figure shows the convergence of multi-cell Precoding game G and G'. BSs perform sequential Precoder updates and both games converge very quickly in a few iteration. In the figure solid line is used for BD Precoding where as dashed-dot lines are for BD-DPC Precoding. First figure is for IA mode and second represents IC mode.

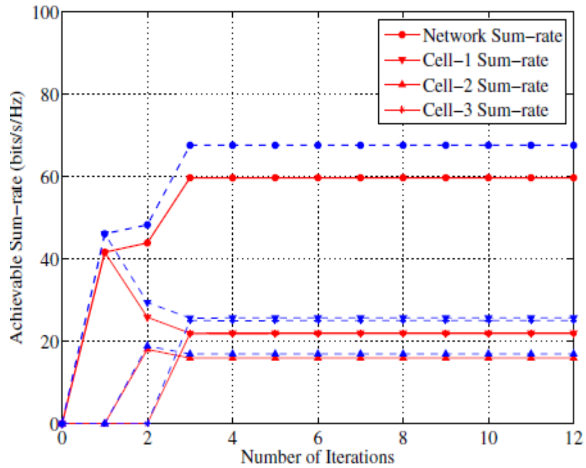

Figure 3: sum-rate VS number of iteration in IA mode [1]

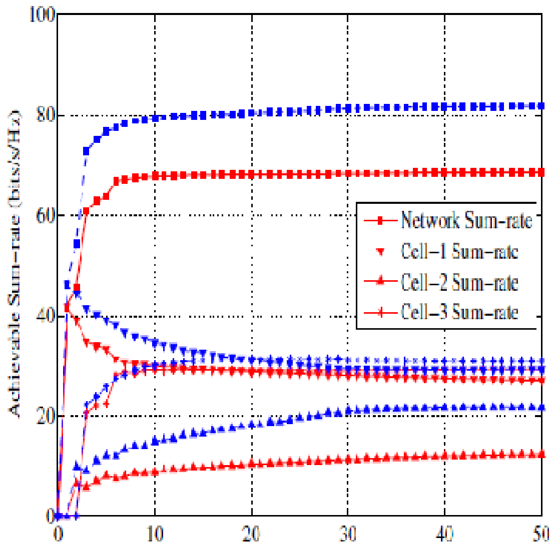

Figure 4: sum-rate VS number of iteration in IC mode [1]

5. Simulation Result and Discussion

Figure 5, indicates the variation of network-sum rate with intra-cell BS – MS distance for both in IC and IA mode. It shows that zero forcing (ZF) Precoding can provide almost same network sum-rate as that of block diagonalization (BD) Precoding.

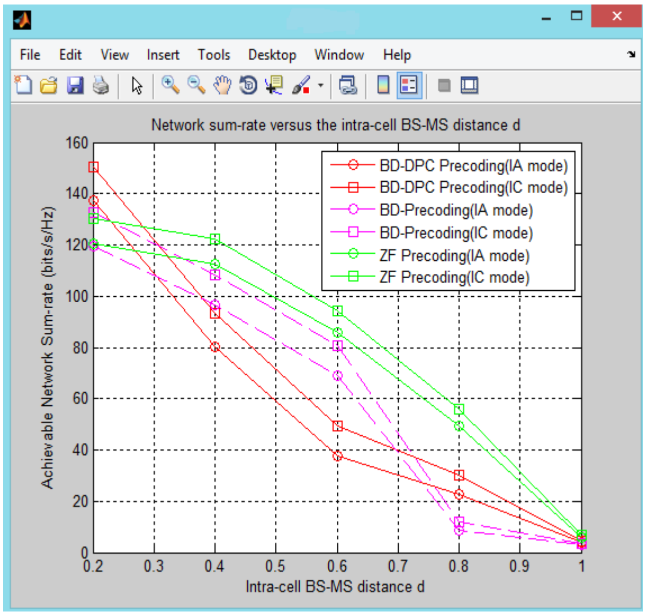

Figure 5: network sum rate VS BS-MS distance

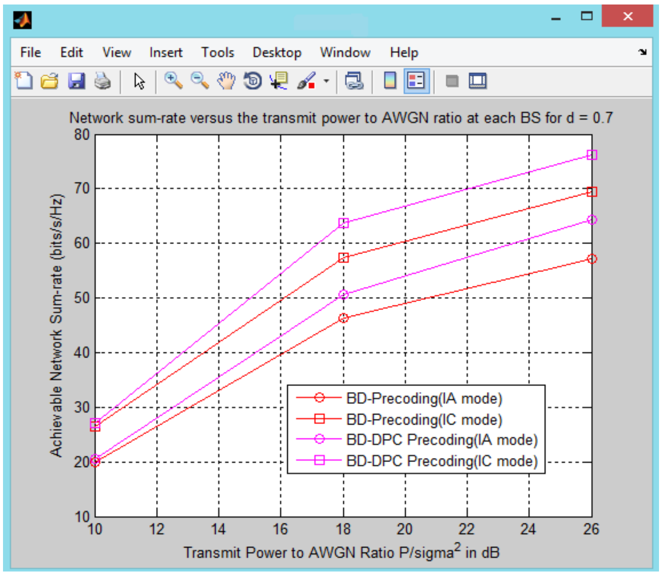

Figure 6: network sum rate VS transmit power at BS

It shows how the network sum rate varies with respect to power budget at BSs.

6. Conclusion

This paper examines the simulation result for multicell system with universal frequency reuse where BD, BD-DPC and ZF Precoding are applied on a per-cell basis. Simulation result shows that zero forcing (ZF) Precoding can achieve almost same network sum-rate as that of BD Precoding. Since zero forcing Precoder design avoided the use of singular value decomposition (SVD) so, its design is much simpler than BD Precoder. At the point when the multicell system is under competition mode, the conditions for existence and uniqueness of the multicell games' NE is investigated. Simulation results confirmed that the NE of the multicell games is unique if the ICI is sufficiently small. They also indicated that the BD-DPC multicell Precoding performs better then BD Precoding. When the multicell system is under coordination mode, a distributed ILA algorithm design is proposed to obtain at least a local optimal solution to the non-convex WSR maximization problems. Simulation results then show that the network sum-rate can be improved over the competition mode by coordinating the precoders for the multicell system.

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