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# A Novel Precoder Design for MU-MIMO Networks with Universal Frequency Reuse

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**ABSTRACT**: The project involves utilization of various precoding techniques such as block-diagonalization (BD), block-diagonalization dirty paper coding (BD-DPC) in a multiuser system on a per-cell basis considering a multicell scenario. The multicell system is been analysed and examined using two modes of operation called competition and coordination. In the former mode, an approach named as noncooperative game (SNG) is considered, in which every base station (BS) selfishly chooses its BD precoding and BD-DPC precoding policy in a distributed way. These strategies are dependent on the information of the inter-cell interference given by its connected mobile station (MS). The existence and distinctiveness of a Nash equilibrium in this SNG are consequently evaluated using the game theory agenda. Whereas, in the coordination mode, in order to boost the network weighted sum rate (WSR) the design of block diagonalization precoders is done mutually over the numerous base stations. As the maximization of WSR is a nonconvex problem, a distributed algorithm is used to acquire atleast a local optimal solution. Eventually, the analysis considering another precoding technique called zero forcing precoding is carried out. Simulation outcomes got through MATLAB illustrates the improvements in the network sum rate as a consequence of utilizing the BD, BD-DPC, ZF precoders in the multicell scenario under the coordination mode in contrast to the competition mode. BD-DPC precoders perform better than the rest of the precoding techniques utilized.

**KEYWORDS**: MIMO, MU-MIMO, channel state information, inter cell interference, intra cell interference, frequency reuse, Nash equilibrium.

## I.INTRODUCTION

In past few years, wireless multiple-input, multiple output (MIMO) communication systems employing multiple antennas at transmitter and receiver have drawn significant attention. The main reason is that it provides promising improvement in performance by increasing signal transmission quality in any kind of scattering environment and bandwidth efficiency without any need of additional operational frequency bandwidth. MIMO system is of two types: single user (SU) or point to point MIMO and multi user MIMO (MU-MIMO). Single user MIMO system is less efficient than MU-MIMO as it requires expensive multiple antennas at both end users , here signals are more tolerant to interference near cell edges in the scattered environment this leads to degradation of throughput gain. The degraded performance of SU-MIMO leads to an important study of multi-user (MU) MIMO system. These systems combine high capacity achievable MIMO processing and benefits of space division multiple access on the base-station (BS) to concurrently multiplex data streams for multiple mobile-stations (MS). In the down-link scenario, a base station (BS) is equipped with multiple antennas and it is simultaneously transmitting to a group of users that are also equipped with multiple antennas, SDMA can significantly improve system spectral efficiency .Considering the economic benefit of the user,cheap mobiles with low power consumption is preferred andhence complex signal processing isperformed at the BS/AP. Toprovide high data rates to the large number of users the BS will use the channelstate information (CSI) available at the transmitter between all the user terminals or MSs and the base station.Since the users share the same channel,interferenceis occurred among them, to eliminate inter cell interference (ICI) and intra cell interference the base station is required to employ downlink precoding techniques. Precoding techniques are classified based on linearity as linear and non-linear techniques. Dirty paper coding (DPC) [1],[2] is one of the nonlinear precoding technique proven to achieve downlink system sum capacity by eliminating interference among users at base station by precoding strategy , having complete knowledge of Channel State Information(CSI) at Base station. However, due to its high complexity in implementationwhich involves random nonlinear encoding and decoding, DPC remains as a theoretical benchmark.

Alternatively using linear precoding techniques such as zero-forcing (ZF),minimum mean square error(MMSE) block-diagonalization (BD), become appealing due to their simplicity, no overhead,less computationally expensive and good performance. Among these techniques block-diagonalization (BD), is considered to be more efficient gaining similar sum capacity as DPC .With BD precoding, the transmitted signal from the BS is intended to a particular MS and is restricted to be in the null space created by the downlink channels associated with all the other MS's. Hence,all the inter-user interference within the cell at MSs can be fully suppressed. Multicell system is examined and compared under the two operating modes: competition and coordination.

## II.RELATED WORK

Paper [1] addresses an important problem of MU-MIMO systems to have communication from one base station (BS) to many mobile stations (MS) simultaneously. This problem can be solved by improving performance of multiuser space-division multiplexing (SDM) by transmitting multiple independent signal steams in same time slot and frequency. The objective of this paper was to enable multiuser channel SDM by developing a multiuser linear space-time precoder performing simultaneous channel diagonalization. The approach is based on diagonalizing MU channel using variationof successive Jacobi rotation.Paper [2] is about downlink MIMO using space-division multiple access (SDMA) provides high gain in system throughput. Challenging factor in this kind of systems is designingthetransmit vectors by considering theco-channel interference by other users. Typically optimizationproblems include capacity problem- maximizinginformationsum ratesubject to a power constraintor power control problem-by minimizing the transmitting power, this meetsthe quality of service of each user .None ofthese problems possess closed-form solutions. Hence this paper presents constrained solutions. The first solution discussed is "block-diagonalization",generalization of channel inversion when there aremultiple antennas at each receiver. This provides minimum powerormaximum transmission rate andthis approach leads to the optimal solution at high SNR.The second, is "successive optimization," this method is employed for one user at a time- power minimization problem and provides superior results in low SNR region.Paper [3] characterizes thesum capacity of nondegraded Gaussian vector broadcast channels, assumed to have a single transmitter with multiple transmit terminals sending independent information to multiple receivers. Coordination is permittedamong transmit terminals, but not among receiveterminals. Here the sum capacity is said to be a crucial point of theGaussian mutual information game, where the signal is considered as a player, it choosesa transmit covariance matrix to maximize the mutual information among the transmit terminals and noise player chooses a noise correlation to minimizethe mutual information. A precodingstrategy is employed to achieve the sum capacity for Gaussian channels with additive side informationwhich is not casually known at the transmitter end. In paper [4] study ofcooperativeprocessingof base station is explored to address the co-channel interference (CCI) elimination problem in downlink,multicellmultiuser MIMO networks, and it is shown to dramatically intensifies the system sum capacity with strong CCI. Dirty paper coding approach and several more joint transmission schemes are studied, with power base constraints, respectively. Besides the CCIelimination potential, other advantages of cooperative processing includes the power gain, channelrank, channel conditioning, and macro-diversity protection is also address.

## III.CONTRIBUTIONS

In a multicell system, current wireless networks implement universal frequency reuse where all the cells are enabled to use all available radio resources. Typically, most of the related works in downlink precoding designs focus on single-cell setting, here the co-channel interference orthe inter-cell interference (ICI), is treated as additional background noise at the MS's. Thus, the effect of ICI to a certain extent is neglected in the precoding design technique. However, with the universal frequency-reuse, the level of ICI is more prominent and should not be ignored.Network MIMO employs multiple BSs forming single large system with distributed antenna elements that are expensive increasing the cost of the system implementation. Though they provide good performance through full cooperation among BSs the benefit of it comes under high complexity in joint precoding/decoding and backhaul link is to be created for transmission of data and control signalling exchange.

This project is about multiuser multicell system where block diagonalization(BD) precoding is applied on per-cell basis. The BD precoding is studied under the two operatingmodes are considered to be: interference aware (IA) (competition mode) and interference coordination (IC) (coordination mode). Under these two operating modes, each

BS transmitsthe information data only to the MSs within its cell limits. Reason for studying BD precoding ona per-cell basis is due to the following three folds. Firstly, using this method, the multicell system is relieved from the requirementof backhaul links for data exchange among the BSs.Second, due to relatively close distance between the co-locatedMSs, the intra-cell interference seemsto be more dominantsource of interference than the ICI.Enforcing BD precoding on each cell, this intra-cell interference can be fullysuppressed. Finally, using the concept of DPC maximum network sum capacity can be achieved. The BD precoding is much simpler than the DPC in implementation and it's capable of achieving measurably closeperformance in many scenarios.

***Under the IA mode***, each MS that is aware of interference shallmeasure the level of ICI and the information is fed back to its connected BS. The strategiesgiven from other BSsreflected by ICI, each BS shall selfishly adjust its precodingstrategy to maximize sum-rate for its connected MS's.Thus in the multicellsystemthe BSs are said to be in competition with each other competing for the radio resource.

***Under the IC mode***, each BS transmits datainformation only to MSs within its cell limits, the precodersfrom all BSs are mutually designed to fully control ICI. Therefore, multicell system is said to be in coordination,since the transmissions from the BSs are fully coordinated.

## IV.SYSTEM MODEL

In MIMO systems consider a MU multicell where multiple users access the same channel using SDMA, here eachuser's unique channel stateinformation (CSI) is used to distinguish them. Consider Q separate cells operating on the same frequency channel.At some particular cell, say cell-q, BS with multiple-antenna concurrently sendsindependent information streams to $K_q$ remoteMSs, each MS is equipped with multiple receive antennas.Let $M_q$ be the numbers of antennas of aBS and $N_{qi}$ of i$^{st}$hmus of cell-q, respectively. The transmitted signal vector from BS-q is denoted as $x_q \in C^{M_q \times 1}$. In order to reduce the receiver design complexity downlink transmission is used. Pre-process transmitting is utilized to move part of the required signal processing from the MS to the base station. Hence linear precoding is performed at the BS $x_q$ the transmitted signal vector is represented as $x_q \sum_{i=1}^{K_q} W_{qi} s_{qi}$,where$W_{qi} \in C^{M_q \times L_{qi}}$ is a precoding matrix and $s_{qi} \in C^{L_{qi} \times 1}$ data symbol vector intended for MS-i with $L_{qi}$ number of transmitted symbols.

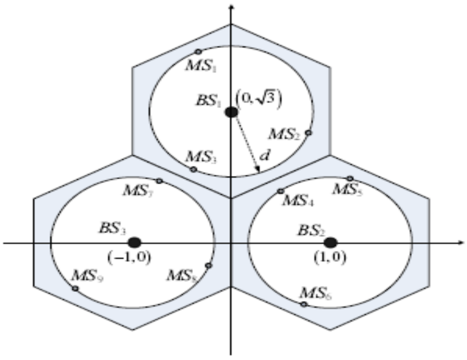

Figure 1: A multicell system configuration with 3 cells, 3 users per cell

$H_{rqi} \in C^{N_{qi} \times M_r}$ modelsthe channel coefficients from the BS-r to the MS-i of cell-q, and $z_{qi}$ models the zero-mean complexadditive Gaussian noise vector with an arbitrary covariancematrix$Z_{qi}$ . The received signal or input to MS-i at cell-q can be modelled as

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

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

From equation(1) the received signal at MS-i of cell-q comprises of 4 important components: the useful information signal $H_{qqi} W_{qi} s_{qi}$ , the intra-cell interference $H_{qqi} \sum_{j \neq i}^{K_q} W_{qj} s_{qj}$, the inter-cellinterference $\sum_{r \neq q}^{Q} H_{rqi} \sum_{j=1}^{K_r} W_{rj} s_{rj}$, and the Gaussian noise $z_{qi}$ .EachMS is assumed to measure its total interference and noise (IPN) power,estimates and feeds the downlink CSI and this IPN measured perfectly and frequently to its connected BS. BS now utilizes this information to design a precoderfor its connected MSs.

In competitive design of this system model, each BS only possessthe complete knowledge of downlinkchannels to MSs within its cell, but not about the channels to theMSs in other cells. As a result, the BS is not able to control itsinduced ICI to other cells, which is then treated as a backgroundnoise at the MSs.

On contradiction to this, in the coordinated designof this system model, the BS also possesses the complete knowledge of the CSI to theMSs in the other cells. This enables the BS to control the ICI as well.

By performing precoding techniques on a per cellbasis BScan fully manage the intra-cell interference within its cell. Block -diagonalization (BD) precoding for multiple-antenna MSs figure outs the complete suppressionof the intra-cell interference. To implement the BD precoding on a per-cell basis, the total number of receive antennas at the MSs does not exceedthe number of transmit antennas at their connected BS, i.e.,$\sum_{i=1}^{K_{qi}} N_{qi} \leq M_q$,∀q.

$Q_{qi} = W_{qi} W_{qi}^H$is the transmit covariance matrix intended for MS-i of cell-q, and$Q_q = \{Q_{qi}\}_{i=1}^{K_q}$is the precoding profile for $K_q$ MSs of cell-q. Similarly,$Q_{-q} = \{Q_1, \ldots, Q_{q-1}, Q_{q+1}, \ldots, Q_Q\}$ denotes precoding profileof all cells except cell-q. $R_{qi}(Q_{-q})$isdenotedas the covariancematrix of the IPN (with no intra-cell interference) at the MS-i of cell-q, which is defined as

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

ApplyingBD precoding on a per-cell basis at BS-q, theachievable data rate $R_{qi}$ to MS-i is given by

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

### A. *The Multicell BD Precoding -Competitive Design*

Here each BS will selfishly design its BD precoders without any coordination between the cells. Consider a game-theory framework, strategic non cooperative game (SNG), here players are the BSs and payoff functions are the sum-rates of the cells. At each cell, BS will strategically adapt its BD precoder on a per-cell basis;this greedily maximizes the sum rate to its connected MSs, subject to constraint on its transmitting power.

Let set of Q players be $\Omega = \{1, \ldots, Q\}$. Defining $R_q(Q_q, Q_{-q}) = \sum_{i=1}^{K_q} R_{qi}(Q_q, Q_{-q})$ as the payoff functionof the player-q. Then, $Q_{-q}$is the strategy profile given from the other players, player-q will selfishly maximize its payoff function by solving the following optimization problem

$$\underset{Q_{q1}, \ldots, Q_{qK_q}}{maximize} \; R_q(Q_q, Q_{-q}) \; (4) \qquad subject\ to \quad H_{qqi} Q_{qi} H_{qqi}^H = 0, \forall j \neq i$$

$$Q_{qi} \geq 0, \forall i$$

$$\sum_{i=1}^{K_q} Tr\{Q_{qi}\} \leq P_q$$

here$P_q$ is the power budget at BS-q. To attain maximum sum data-rate at cell-q, here it is assumed that the IPN matrix $R_{qi}(Q_{-q})$ is measured perfectly at the corresponding MS-i and it is fed back to its connected BS. The precoding strategy$Q_{-q}$is captured by IPN matrix $R_{qi}(Q_{-q})$ at MS-i, as indicated in eq (2).Therefore, whenever a BS other than BS-q changes its strategy; the IPN matrix $R_{qi}(Q_{-q})$is also changed. At this instance, MS-i needs to feed back the updated $R_{qi}(Q_{-q})$to its corresponding BS-q. Clearly, the optimization problem (4) shows that the optimal strategy of BS-q dependence on the strategies of the other BSs. Noting that the optimization problem (4) is conceded with only local information such as intra-cell CSI and IPN matrices between the MSs and its connected BS. Thus, the BD precoding game here is implemented in a fully distributed manner without any signalling exchangesamong the BSs.Considering the constraints $H_{qqi} Q_{qi} H_{qqi}^{H} = 0, \forall j \neq i$, eachcolumn of the precoder matrix$W_{qi}$ must be in null spacecreated by$\widehat{H_{qi}} = \left[H_{qq1}^{T}, \ldots, H_{qqi-1}^{T}, H_{qqi+1}^{T}, \ldots, H_{qqK_q}^{T}\right]^{T}$ .Suppose that one performs the singular value decompositionof the $\left(\sum_{j\neq i}^{K_q} N_{qj}\right) M_q$ matrix $\widehat{H_{qi}}$ as

$$\widehat{H_{qi}} = U_{qi} \Sigma_{qi} V_{qi}^{H} = U_{qi} \left[\widehat{\Sigma_{qi}}, 0\right] \begin{bmatrix} \widetilde{V_{qi}^{H}} \\ \widehat{V_{qi}^{H}} \end{bmatrix} (5)$$

where$\widehat{\Sigma_{qi}}$ is diagonal, $U_{qi}$ and $V_{qi}$ are unitary matrices, and$\widehat{V_{qi}^{H}}$ is formed by the last $(\widehat{N_{qi}}) \cong M_q - \sum_{j\neq i}^{K_q} N_{qj}$ columns of$V_{qi}$ . Then, any precoding covariance matrix $Q_{qi}$ is formulatedas $\widehat{V_{qi}} D_{qi} \widehat{V_{qi}^{H}}$, where $D_{qi} >= 0$ is an arbitrary $\widehat{N_{qi}} X \widehat{N_{qi}}$ matrix, would make $H_{qqi} Q_{qi} H_{qqi}^{H} = 0, , \forall j \neq i$.
Thus, the setof permissible strategies for player-q can be defined as follows:

$$S_q = \left\{Q_{qi} \in \mathbb{S}^{M_q X M_q} : Q_{qi} = \widehat{V_{qi}} D_{qi} \widehat{V_{qi}^{H}}, D_{qi} \geq 0, \sum_{i=1}^{K_q} Tr\{D_{qi}\} \leq P_q\right\} (6)$$

Mathematically, the game has the following structure

$$\mathcal{G} = \left(\Omega, \{S_q\}_{q\in\Omega}, \{R_q\}_{q\in\Omega}\right) \tag{7}$$

A pure Nash equilibrium (NE) of game G is defined when

$$R_q\left(Q_q^{*}, Q_{-q}^{*}\right) \geq R_q\left(Q_q, Q_q^{*}\right), \forall Q_q \in S_q, \forall q \in \Omega \qquad ( 8)$$

At a NE, given the precoding strategy from other cells, a BSdoes not have the incentive to unilaterally change its precodingstrategy, i.e., it shall achieve a lower sum-rate with the samepower constraint.

For analysing a strategic non-cooperative game (SNG) the two most fundamental queries are studied in this section: the existence and the uniqueness of theNEin game. Using the characterization (description) of NE enables us to predict astable outcome of non-cooperative BD precoding design ingame G.

For analysing the existence of a pure NE in game G, first, easily verify the strategy setSq for player-q, definedas in eq(6),which is compact and convex, ∀q.
As the utility function $R_q(Q_q, Q_{-q})$,is further written as

$$R_q(Q_q, Q_{-q}) = \sum_{i=1}^{Kq} \log\left|R_{qi}(Q_{-q}) + \quad H_{qqi} Q_{qi} H_{qqi}^{H}\right| - \sum_{i=1}^{Kq} \log\left|R_{qi}(Q_{-q})\right| \tag{9}$$

This utility function is now the combination summation and subtraction as it is continuous function in the profile strategies $(Q_q, Q_{-q})$ and the first term is concave in Qq this is because it is a composition of concave log determinant function that preserves its concavity. The first term consists of both the strategy profiles of player –q (Qq) and strategy profile of other player (Q-q) and the second summation is independent of (Qq). Thus this show$R_q(Q_q, Q_{-q})$ is a concave function in Qq. Consequently there exists at least one pure NE in game G.

Now to examine the uniqueness of NE in game G, the best response strategy at each player is first investigated. In an admissible set of strategies Sq for player –q the best response strategy must be of this 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 BS-qthe best response strategy $D_q$ canthen be obtained from the following optimization problem.

$$\underset{D_{q1,\ldots,Dq\,Kq}}{\text{maximize}} \quad \sum_{i=1}^{Kq} log\left|I + \hat{V}_{qi}^{H} H_{qqi}^{H} \hat{R}_{qi}^{-1}(D_{-q}) H_{qqi} \hat{V}_{qi} D_{qi}\right| \tag{10}$$

$$subject\ to \quad D_{qi} \geq 0, \forall_i$$

$$\sum_{i=1}^{Kq} Tr\{D_{qi}\} \leq P_q,$$

Where $\widehat{R}_{qi}(D_{-q})$is defined as

$$R_{qi}\left(D_{-q}\right) = R_{qi}\left(Q_{-q}\right) = \sum_{r \neq q}^{Q} H_{rqi} \left(\sum_{j=1}^{Kr} \hat{V}_{rj} D_{rj} \hat{V}_{rj}^{H}\right) H_{rqi}^{H} + Z_{qi} \qquad (11)$$

By eigen-decomposing $\hat{V}_{qi}^{H} H_{qqi}^{H} \hat{R}_{qi}^{-1}\left(D_q\right) H_{qqi} \hat{V}_{qi} = \hat{U}_{qi} \Lambda_{qi} \hat{U}_{qi}^{H}$, the optimal solution to problem (10) can be obtained easilyfrom the WF procedure.

$$D_{qi} \triangleq WF_{qi}\left(D_{-q}\right) = \widehat{U}_{qi}\left[\mu_q I - \Lambda_{\mathrm{qi}}^{-1}\right]^{+} \widehat{U}_{qi}^{H} \qquad (12)$$

where $\mu_q$ $is$ the water-level adjusted to meet the powerconstraint$\sum_{i=1}^{K_q} Tr\{\left[\mu_q I - \Lambda^{-1}\right]^{+}\} = Pq$.
$\hat{V}_{qi}$ only depends on the channels inside the cell at cell-q, so BS-q only needs tostrategically adapt its precoding matrices $D_{qi}$ ,$\forall i$ as in (11).From(11)for each player the best response strategy (Dq) can be obtained in a closed-form. Using the concept prescribed in[14]the block-diagonalWF solution$WF_q\left(D_{-q}\right) \triangleq blk\,\{WF_{qi}\left(D_{-q}\right)\}$, can be interpreted as a projection .From this Dq is said to be a closed and convex set.Projection onto a closed andconvex set holds the non-expansive property. This property is used to analyse the NE'suniqueness of the multicell BD precoding game $\mathcal{G}$[14].
Defining the multicell mapping $WF(D) = \left\{WF_q\left(D_{-q}\right)\right\}_{q \in \Omega}$.
Let $e_{WF_q} = \left|\left|WF_q\left(D_{-q}^{(1)}\right) - WF_q\left(D_{-q}^{(2)}\right)\right|\right|_F$ and $e_q = \left|\left|D_q^{(1)} - D_q^{(2)}\right|\right|_F$ for any given $D_q^{(1)} \neq D_q^{(2)}$ and $D_q^{(1)}, D_q^{(2)} \in D_q, \forall q$,
then using the set of inequalities, This prompts

$$e_{WFq} \leq \sum_{r \neq q}^{Q} [S]_{q,r} e_r$$

where$\hat{V}_r \triangleq [\hat{V}_{r1}, \ldots, \hat{V}_{rK_r}]$ and $S \in \mathbb{C}^{Q \times Q}$ is defined as

$$[S]_{q,r} = \begin{cases} \sum_{i=1}^{K_q} \rho\left(\widehat{V_{rj}^{H}} H_{rqi}^{H} H_{qqi}^{\#H} \widehat{V_{qi}}^{\#H} \widehat{V_{qi}}^{\#} H_{qqi}^{\#} H_{rqi} \widehat{V_{rj}}\right), & if\ r \neq q \\ 0, & if\ r = q \end{cases} \qquad (13)$$

Using the definitions of matrix norms and vector norms in paper [17] the contraction property of the game G . Using these the condition is setupif$\left|\left|S\right|\right|_{\infty,mat}^{w} < 1$WF(D) mapping is said to be in contraction and this implies the uniqueness in NE in game G. this condition also guarantees convergence of NE from any startingprecoding strategy $D_q \in D_q$. S is a non-negativematrix, therewill always exists a positive vector **w**

$$(C): \ \|S\|_{\infty,mat}^{w} < 1 \Leftrightarrow \rho(S) < 1 \qquad (14)$$

The constructed matrix S consists of all the channels of the system in this case it becomes very challenging to satisfy the condition C .To overcome this challenging task a centralized unit is required such as base station controller (BSC) as this helps in collecting all the channels from the BS and proceed further . In the intra-cell,when the BS-MS becomes closer than the distance between them is smaller when compared to the distance between the BSs, the inter cell interference(ICI) becomesless dominant. Due to this , the positive off-diagonal elements of Sbecome smaller. This shows a smaller spectral radiusof S. Therefore, as MSs are becomes closer to its connectedBS, the probability of meeting thecondition (C) is higher, whichthen guarantees the uniqueness of the NE.

### B. *The Multicell BD Precoding -Coordinated Design*

The coordinatedmulticell BD precoding designis investigated in order to jointly maximizethe network WSR through the following optimization

$$\underbrace{maximize}_{Q_1,\ldots,Q_Q} \sum_{q=1}^{Q} \alpha_q \sum_{i=1}^{K_q} \log\left|I + H_{qqi}^{H} R_{qi}^{-1}\left(Q_{qi}\right) H_{qqi} Q_{qi}\right| \qquad (15)$$

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

$$Q_{qi} \succcurlyeq 0, \forall q$$

$$\sum_{i=1}^{K_q} Tr\{Q_{qi}\} \leq P_q, \forall q$$

where$\alpha_q \geq 0$ is the nonnegative weight associated withBS-q. Herein, $\alpha_q$'s allows the allocated sum-rates to be exchangedbetween the BSs. When BS-q, as high priority at its sum rate ,then its weight $\alpha_q$ is assignedat a larger value compared to others. Since the constraints of BD removed by the precoding covariance matrix $Q_{qi}$ can beformulated as $\hat{}V_{qi} D_{qi}\, \hat{}V_{qi}^H$, as this removes the constraints of BD , where $D_{qi}$ is an arbitrary $\hat{}N_{qi} \times \hat{}N_{qi}$ and $\hat{}V_{qi}$ given in (5), then optimization problem (15) can be restated as

$$\underbrace{maximize}_{D_1,\dots,D_Q} \textstyle\sum_{q=1}^{Q} \alpha_q \sum_{i=1}^{K_q} \log \left| I + \widehat{V_{qi}}^H H_{qqi}^H R_{qi}^{-1}(D_{qi}) H_{qqi} \widehat{V_{qi}} Q_{qi} \right| \tag{16}$$

$$subject\ to\ D_{qi} \succ= 0, \forall q, \forall i$$

$$\sum_{i=1}^{K_q} Tr\{D_{qi}\} \leq P_q, \forall q$$

due to presence of $D_{rj}$ 's in the ICI term $\hat{}R_{qi}(D_{-q})$'s the objective function is not concave and hence (16) is not convex. To overcome this problem low complexity algorithm is proposed in [14] which can findat least locally optimal solution.

The WSRmaximization problemcan be locally solved using iterative linear approximation (ILA) algorithm this method . Denoting$f_q(D_q, D_{-q}) = \sum_{r\neq q}^{Q} \alpha_r \sum_{j=1}^{K_r} R_{rj}\ (D_q, D_{-q})$as WSR of all other cells except cell-q.$f_q(D_q, D_{-q})$ is nonconcave in $D_{qi}$ , $i = 1,\dots,K_q$. By using the Taylor expansion for a given value of $(\overline{D}_q, \overline{D}_{-q})$, the value is approximated to $f_q$ around $\overline{D}_{qi}$, $i = 1,\dots,K_q$, and retaining the first linear term

$$f_q(\mathbf{D}_q, \bar{\mathbf{D}}_{-q}) \approx f_q(\bar{\mathbf{D}}_q, \bar{\mathbf{D}}_{-q}) - \sum_{i=1}^{K_q} \mathrm{Tr}\left\{\mathbf{A}_{q_i}\left(\mathbf{D}_{q_i} - \bar{\mathbf{D}}_{q_i}\right)\right\}, \tag{17}$$

where$A_{qi}$ is the negative partial derivative of $f_q$ with respectto the $D_{qi}$ , evaluated at $\overline{D}_{qi}$ , given by

$$A_{qi} = -\left.\frac{\partial f_q}{\partial D_{qi}}\right|_{Dqi=\overline{D}_{qi}}$$

$$= -\sum_{r\neq q}^{Q} \alpha_r \sum_{j=1}^{K_r} \left.\frac{\partial R_{rj}}{\partial D_{qi}}\right|_{Dqi=\overline{D}_{qi}}$$

$$= \textstyle\sum_{r\neq q}^{Q} \alpha_r \sum_{j=1}^{k_r} \hat{V}_{qi}^H H_{qr_j}^H \left[\hat{R}_{r_j}^{-1} - \left(\hat{R}_{r_j} + H_{rr_j} \hat{V}_{r_j} D_{r_j} \hat{V}_{r_j}^H H_{rr_j}^H\right)^{-1}\right] H_{qr_j} \hat{V}_{qi}\Big|_{Dqi=\overline{D}_{qi}} \tag{18}$$

This problem can be solved individually at each BS-q. IfQ BSs approximate the original problem(16) then this can be solved based on Q per cell separate problem. This term $\sum_{i=1}^{K_q} Tr\,\{A_{qi} D_{qi}\}$ is the penalty charged term which is charged on the ICI induced by the BS-q to MSs in other cells,$A_{qi}$ is theinterference price. In the absence of this penalty term the BS would only think of maximizing the sum rate for its connected MS. The problem also points that if weight( $\alpha_q$) is set at a larger value than other weights then BS-q starts focusing more on maximizingits own sum-rate thanminimizing its induced ICI. As the problem is convex the solution can be obtained in closed-form solution using Lagrangian duality.

### *C. BD-DPC Precoding on a Per-cell Basis*

The ZF –DPCis usually referred for single–antenna receiverswhere the receivers take advantage of both ZF and DPC precoding.When ZF-DPC is applied at BS the information signalsareencoded in sequence before sending to multiple users so that the receiver at any user cannot see any inter-user interference. Using this same conceptBD-DPC precodingtechnique is referred for multi-antenna receiversby applying the encoding process at each BS .

At any BS,let's say BS-q,the encoding sequence is denoted as $\pi_q = \left[\pi_{q(1)}, \ldots, \pi_{q(K_q)}\right]^T$ for its K$q$ connected MSs . Theconcept of BD-DPC is now briefly explained as follows:

- BS-qwill freely design the precoder$W_{\pi_q(1)}$ forits $MS - \pi_q(1)$.
- BS-q, has no causal knowledge of the codeword intended for $MS - \pi_q(1)$ ,using DPC it is designed in such a way that $MS - \pi_q(2)$does not see the codeword for $MS - \pi_q(1)$as interference. At the same time, the precoder $W_{\pi_q(2)}$ for $MS - \pi_q(2)$ is designed on the null space caused by the channel $H_{q\pi q(1)}$ to eliminate its induced interference to $MS - \pi_q(1)$.
- Similarly, the code-words for $MSs\ \pi q(1), \ldots, \pi q(i-1)$, is utilized by theBS-qto encode the signal for user-i, and designs $W_{\pi_q(i)}$ on the null space caused by $\hat{}H_{q\pi_q(i)} = [H_{q\pi_q(1)}, \ldots, H_{q\pi_q(i-1)}]$.

### *D.The Multicell BD-DPC Precoding-Competitive Design*

A new game is considered here as $\mathcal{G}'$,using the same concept as in*A*. where each BS will strategically adapt its BD-DPC precoders to maximize the sum-rate to its connected MSs. Mathematically, game $\mathcal{G}'$ can be defined as

$$\mathcal{G}' = \left(\Omega,\ \{\mathcal{S}'_q(\pi_q)\}_{q\in\Omega},\ \{R_q\}_{q\in\Omega}\right) \tag{19}$$

The set of admissible strategies $S^{'}_{q(\pi_q)}$ is now defined as

$$\begin{aligned}\mathcal{S}'_q(\pi_q) \ = \ \Big\{\mathbf{Q}_{\pi_q(i)} \in \mathbb{S}^{M_q \times M_q} : \mathbf{Q}_{\pi_q(i)} = \hat{\mathbf{V}}_{\pi_q(i)} \mathbf{D}_{\pi_q(i)} \hat{\mathbf{V}}^H_{\pi_q(i)}, \\ \mathbf{D}_{\pi_q(i)} \succeq 0, \sum_{i=1}^{K_q} \mathrm{Tr}\left\{\mathbf{D}_{\pi_q(i)}\right\} \leq P_q\Big\},\end{aligned} \tag{20}$$

Here $\hat{}V_{\pi_q(i)}$ is null space formed by $\hat{}H_{\pi_q(i)}$. Similarities exist between games $\mathcal{G}$and$\mathcal{G}'$, thus characterization of game $\mathcal{G}'$ can be right away applied from game$\mathcal{G}$. Thus there exist at least one NE in game $\mathcal{G}'$at any point of interval and this NE is unique if

$$(C^{'}): \rho(S^{'}) < 1 \tag{21}$$

$$[S]_{q,r} = \begin{cases} \sum_{i=1}^{K_q} \rho\left(\widehat{V^H_{\Pi r}} H^H_{r\Pi q(i)} H^{\#H}_{q\Pi q(i)} \widehat{V\ _{\Pi q(i)}}^{\#H} \widehat{V_{\Pi q(i)}}^{\#} H^{\#}_{q\Pi q(i)} H_{r\Pi q(i)} \widehat{V_{\Pi r}}\right), & if\ r \neq q \\ 0 & ,if\ r = q \end{cases} \tag{22}$$

At each base station the encoding order depends upon the characterization of game$\mathcal{G}'$.
The base station BS$_{\text{-q}}$ has a different encoding order thus the optimal strategies at BS-q which maximizes the sum rate are also different. The uniqueness of game $\mathcal{G}'$ the condition $C^{'}$ at each base station BS$_{\text{-q}}$ depends on the encoding order. Game $\mathcal{G}'$ facilitates the high degree of freedom when it is encoded in a particular order at each BSs. The condition $C'$ in game $\mathcal{G}^{'}$is more firm than game $\mathcal{G}$ for uniqueness of Nash equilibrium.

### *E. The Multicell BD-DPC Precoding -Coordinated design*

The BD-DPC precoding for multicell system is implemented under IC Mode. For network maximization of weighted sum rate under the consideration of joint BD-DPC Precoding design.

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$$\begin{aligned} &\underset{\mathbf{Q}_1,\ldots,\mathbf{Q}_Q}{\text{maximize}} && \sum_{q=1}^{Q} \alpha_q R_q \\ &\text{subject to} && \mathbf{Q}_q \in \mathcal{S}'_q, \forall q. \end{aligned} \tag{23}$$

### *F. Zero-Forcing(ZF)*

Here zero forcing is compared with BD and BD-DPC where ZF nulls interference caused by multi users in multicell system .nulling of inter-user interference is done using channel inversion.This is computationally less complex by consuming less time when compared to SVD computation. Performance is better in environment that has more number of antennas at transmitter and receiver. ZF precoding may achieve full multiplexing gain but only provided that accuracy of the channel feedback increases linearly with signal–to-noise ratio (in dB).

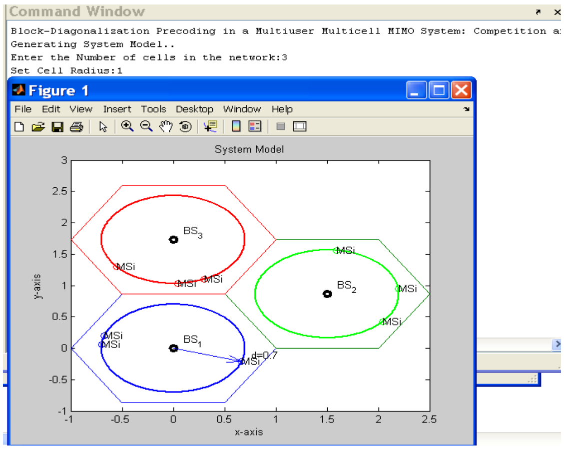
## V.SIMULATION RESULTS

The results are obtained by performing the simulation using the MATLAB Tool.The simulation results carried out here validates the convergence and uniqueness of NE in both the gamesG and G′. Here the system model is setup for 3 cells consisting of 3 MSs per cell and sharing same channel frequency. The parametric values used are as shown below:

| PARAMETERS | VALUES |
|---|---|
| Number of cells in the system | 3 |
| Number of base stations | 3 |
| Number of users per cell | 3 |
| Number of base station antennas | 8 |
| Number of antennas at each mobile station | 2 |
| Signal to noise ratio (SNR) at the cell edge | 20 |
| Power constraint Pq is set at each BS | 1 |
| AWGN at each MS Zqi=$\sigma^2 I$ ,$\sigma^2$ | 0.01 |
| Cell radius | 1Km |

Table 1: performance parameters

Figure 3,4 and 5 displays the precoding profile Q ,is generated for all the three cells in three precoding techniques((3-D)format using MATLAB function surf) .Here each precoding profile is unique from one another with different values .if the all three figures it is observed that if the MSs reaches the cell edge then it is more effected by the ICI levels. No interference is observed in centre of the cell. Fig 6 evaluates only the sufficient conditions (C) and (C’) for game G and G’. If the distance between the BS and MS within the cell becomes closer, then this is said to be low ICI region. The NE uniqueness is guaranteed if the ICI is sufficiently small. A stronger uniqueness of NE is observed in BD-DPC then in other two precoding techniques.Fig7 compares the IA and IC mode in terms achievable network sum rate. If the distance D is increased obviously the network sum rate will decrease .In the IA mode when the game converges to one NE then network sum rate is measured. On the other hand in IC mode network sum rate can be significantly improved by having coordination among the BS s especially in high ICI region.On comparing both the modes from the figure it can be observed that IC in all precoding techniques provides better performance than IA mode. Fig 8 illustrates that increasing the transmit power at each BS will progress the network sum-rates in both modes. However, in the multicell precoding games, at very high level of transmit power; the network sum-rates obtained becomes saturated. This happens because when intra-cell information signal powers increases this also relatively increases the ICI. At this situation it is desirable to limit the amount of ICI by coordinating using the IC mode. This is completely proved in graph that IC mode performs better in all three precoding techniques. Here BD-DPCin IC mode outperforms in more efficient manner.Fig 9 illustrates convergence of the multicell precoding in both the games. For this to take place randomly the channels are selected and realized for many number of iterations. Here considering 1000 channels and 15 iterations. In both the games the BS will sequentially update its precoder, the network sum rate and each cell sum rate is plotted for each instance of updating. Both the games converge every quickly for few iterations. In fig 10 the convergence of proposed ILA algorithm to maximize the network sum rate under the IC mode. The realization is done for the same channels. In both the cases of BD and BD-DPC ILA algorithm will converge monotonically with sequential updates at coordinated BSs. For each update even though the cell sum –rate decreases, the network sum-rate is always improved. ILA algorithm is providing the better sum –rate than the other two games in all three precoding techniques.



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Block-Diagonalization Precoding in a Multiuser Multicell MIMO System: Competition a
Generating System Model..
Enter the Number of cells in the network:3
Set Cell Radius:1
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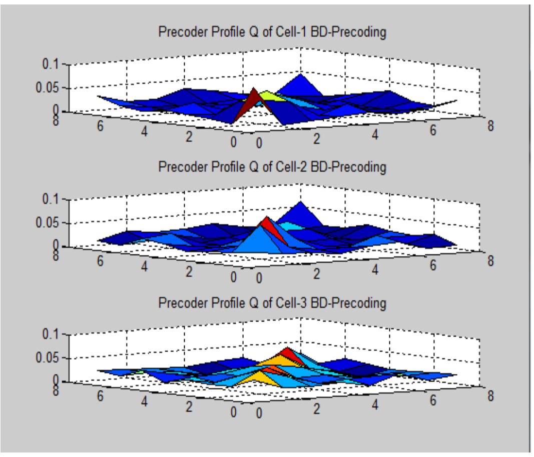
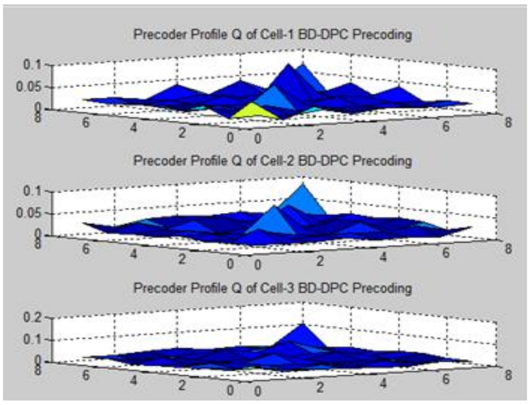


Fig 2: A multicell system configuration with 3 cells,

Fig 3: precoding profile Q for 3 cells with BD precoding 3 users per cell.



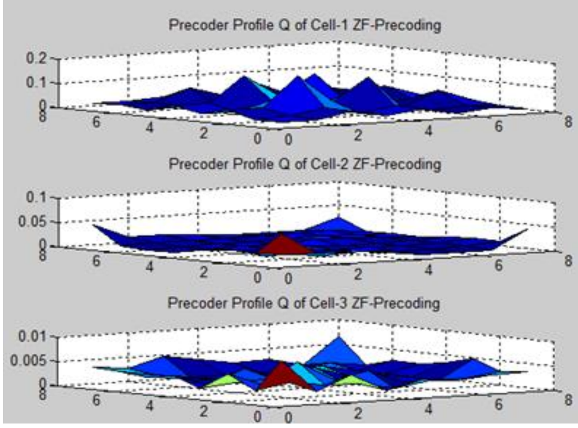


Fig4: Precoding profile Q for 3 cells with

Fig 5: Precoding profile Q for 3 cells with ZF precodingBD-DPC precoding

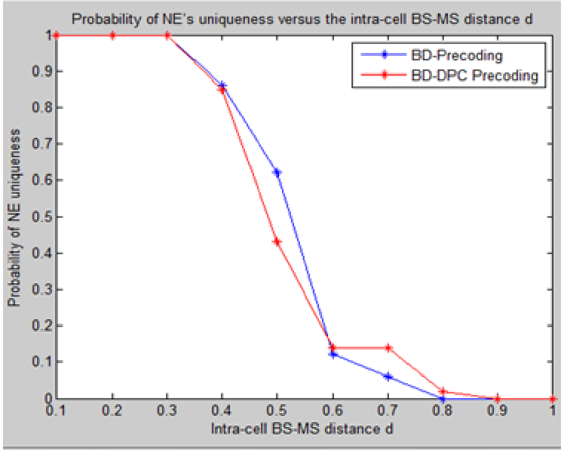


Fig6: Probability of NE's uniqueness versus the intra-cell BS-MS distance ddistance d

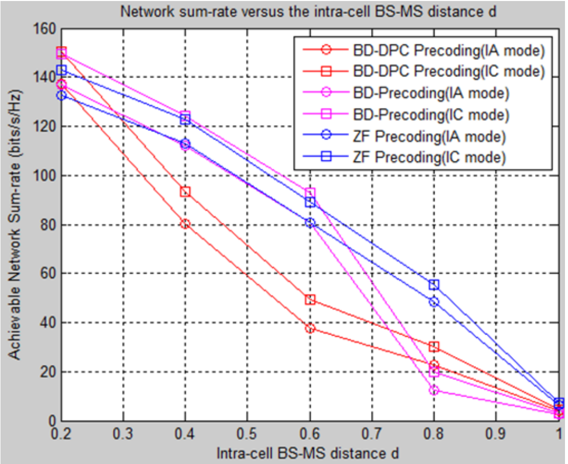


Fig7: Network sum-rate versus the intra-cell BS-MS

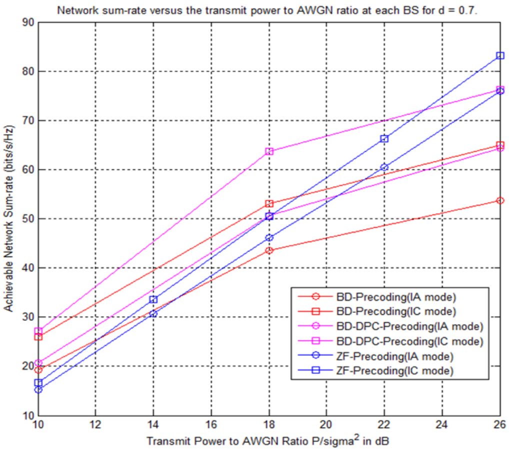


Fig8:Network sum-rate versus the transmit power to AWGN ratio at each BS for d = 0.7.

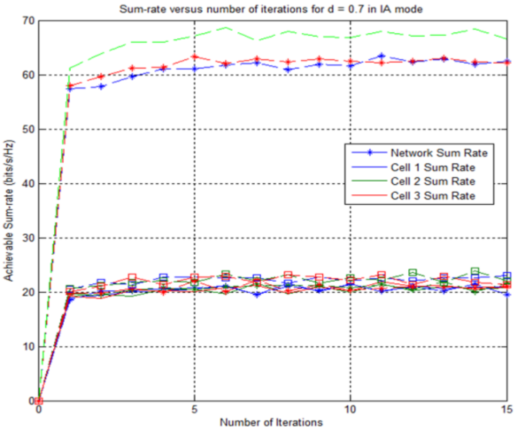


Fig 9 :Sum-rate versus number of iterationsfor d = 0.7 in the IA mode

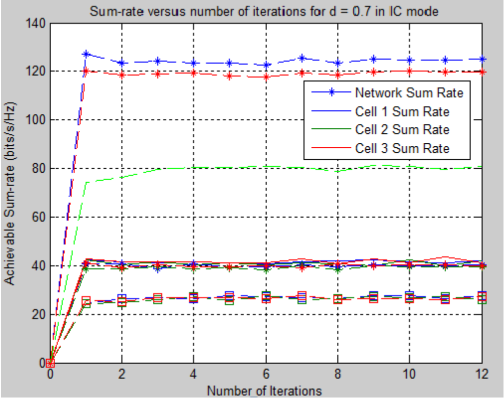


Fig10: Sum-rate versus number of iterations for d = 0.7 in the IC mode

## VI. CONCLUSION AND FUTURE SCOPE

The performance of various precoding techniques on a per cell basis is analysed in a multicell scenario with universal frequency reuse. Under competition mode, circumstances on the subsistence as well as uniqueness of the multicell games NE is been investigated. A simulation outcome shows that the multicell games NE is distinctive if the inter-cell interference is adequately less. It also point outs that the BD-DPC multicell precoding game performance is better than the BD game and achieves a sum-rate closer in contrast to the DPC precoding game. Considering the multicell system in coordination mode, the distributed ILA algorithm is been proposed. This algorithm is hence used to attain a local optimal solution for the nonconvex WSR maximization problems. Simulation outcomes subsequently prove that the network sum rate can be enhanced compared to the competition mode through coordinating the BD or else BD-DPC precoders over the system of multicell. In the project it is prominent that the analysis is restricted to single carrier systems. Whereas, in multi-carrier systems, it is likely that one can assign the resource across the frequency realm first. Further, the designs of competitive and coordinated are to be functional on a per-carrier basis. Broaden the work to the situation of joint resource allocation, power allocation plus precoding design across frequency in addition to space is potential and will be a remarkable future effort.

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