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GWO Optimized Block Diagonalization in Multi-User MIMO System

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Abstract – **This paper presents Block Diagonalization and Grey Wolf Optimized Block Diagonalization precoding for multi user MIMO system to reduce error rate in system. Both the method reduces the error probability efficiently as shown in results, to enhance the performance of system. The optimization of Block Diagonalization process using Grey Wolf Optimization is proposed in this paper and the results are showing that the proposed technique significantly improves the performance of Block Diagonalization method.**

Keywords – **BS, Block Diagonalization GWO, MU-MIMO.**

I. INTRODUCTION

With the innovation of MIMO technology (Multiple inputs - multiple outputs), the cellular system has found a way to increase its data rates by applying MIMO technology, in addition to achieving high spectral efficiency within cellular networks, achieving great evolution of this system [1]. MIMO technology consists of having more than one antenna in both the transmitter and the receiver [2]. MIMO increases the spectral efficiency of a wireless communication system by using the spatial domain [3].

In MU-MIMO (Multi-user Multiple Inputs-Multiple Outputs), one of the biggest issues to deal with is eliminating co-channel interference [4]. This is because we will concentrate different users within the same frequency, increasing the interference between users [5].

If we manage to eliminate inter-user interference within the cell, then we are increasing the capacity of the system, the main objective of our algorithm to study. It is very important to have the Channel Status Information (CSI), since the development of our algorithm depends on this [6].

The solutions implemented so far, counteract the co-channel interference generated by different users, eliminating it almost entirely, but at the cost of signal processing on both the transmitter and receiver sides [7] [8] [9].

This paper is organized as follows: Section II presents the proposed GWO optimized block diagonalization to suppress inter-user interference, Section III the results of the simulations, and finally, in section IV, the conclusions.

II. PROPOSED METHODOLOGY

A. System Model

For our work, we will consider Rayleigh, Rician and Nakagami channels. Being a Rayleigh type, we are saying that there will be no line of sight (NLOS) between the transmitter and the receiver. And being flat, then all frequency bands undergo the same magnitude of fading.

With respect to users, it will be assumed that they are very far apart, so the user's channel will be independent with respect to the rest. We know that Channel Status Information (CSI) is very important in the transmitter, so it will be considered an ideal feedback channel between base station and user. Finally, the number of transmitting antennas will be equal to the product between the number of receiving antennas, with the number of users.

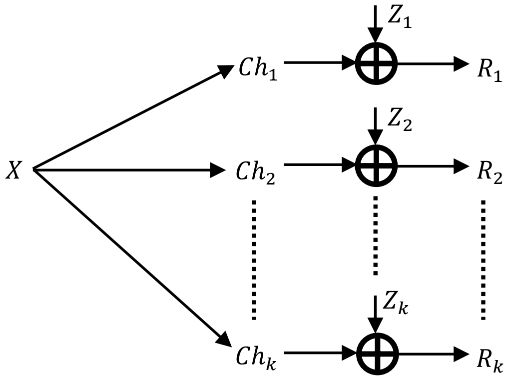

Figure 1: Downlink Channel Model for Multi-user MIMO system [10]

Assuming multiuser communication system where multiple mobile stations are served by single base station. N_B and N_M are the antennas of base station and mobile station respectively.

As k independent user, with $k.N_M$ antennas will communicate with base station (BS) with N_B antennas, where end to end communication for downlink is considered as $(k.N_M) \times N_B$ mimo system.

In multiuser communication system, multiple antennas allows the base station to transmit the multiple user data stream to be decoded by each user in downlink.

By considering k independent user, where $X \in C^{N_B \times 1}$ is the transmit signal from the BS and $R_u \in C^{N_M \times 1}$ with received signal at the u^{th} user, where, $u = 1,2,3, \ldots\ldots k$.

Let $Ch_u \in C^{N_M \times N_B}$ represent the channel gain between BS and the u^{th} user. The received signal at the u^{th} user is expressed as:

$$R_u = Ch_u X + Z_u \qquad (1)$$
$$u = 1,2,3, \ldots\ldots k$$

Where $Z_u \in C^{N_M \times 1}$ is the additive zero mean circular complex Gaussian random vector [.] for all user.

Where X is the set of transmitted signal $(Ch_1, \ldots Ch_k)$. The main difficulty in data transmission in Broadcast Channel (BC) is that the coordinated signal detection on the receiver side is not straight forward thus interference cancelation of downlink is required. This paper utilizes Block Diagonalization precoding.

B. Broadcast Channel Transmission via Block Diagonalization

Among the various solutions available to mitigate the problem we are dealing with, i.e. co-channel interference produced inside a cell by communicating several users in the same frequency band, we will deal with a so-called Block Diagonalization (BD). It uses a linear pre-coding matrix to transmit multiple frames of data to each user while removing inter-user interference at the same time. When we solve the mathematical part in the next section, we will realize that multiplying the pre-coding matrix, with the channels of the interfering users, inter-user interference will be cancelled instantaneously, transmitting only the signal to the desired user. And even if the interference from the other user is cancelled, inter-symbolic interference (ISI) will still be present in the receiver.

The channel inversion method is effective on its parts in clipping the interferences (any signal else the target signal). But it also introduces considerable noise enhancement in signals [11] [12]. Block Diagonalization on other hand cancels only interferences of other user's signals at the stage of precoding. The inter-interference of signals from antenna if occurred could be tackled by various detection algorithm on-rolled in a MIMO network.

Let $N_{M,u}$ denotes the number of antennas for the u^{th} user. Where $u = 1,2,3, \ldots\ldots k$.

For the u^{th}signal $\tilde{x}_u \in C^{N_{M,u} \times 1}$, the received signal, $R_u \in C^{N_{M,u} \times 1}$ can be expressed as:

$$R_u = Ch_u \sum_{k=1}^{K} p_k \tilde{x}_k + Z_u$$
$$= Ch_u p_u \tilde{x}_u + \textstyle\sum_{k=1, k \neq u}^{K} Ch_k p_k \tilde{x}_k + Z_u \qquad (2)$$

Where $Ch_u \in C^{N_{M,u} \times N_B}$ is channel matrix between BS and u^{th} user.

$w_u \in C^{N_a \times N_{M,u}}$ is the precoded matrix for the u^{th} user and Z_u denotes the noise vector.

From equation (2), $\{Ch_u p_k\}_{u \neq k}$ increases interference to u^{th} user unless,

$$Ch_u p_k = O_{N_M \times N_{M,u}}, \forall\, u \neq k \qquad (3)$$

Where $O_{N_M \times N_{M,u}}$ is a zero matrix.

To meet the total power constraints the precoder $p \in C^{N_B \times N_{M,u}}$ must be unitary, $u = 1,2,3, \ldots\ldots k$.

From equation (3), the interference free received signal is,

$$R_u = Ch_u p_u \tilde{x}_u + Z_u \qquad (4)$$
$$u = 1,2,3, \ldots\ldots k.$$

For obtaining the value of $\tilde{x}_u$, various signal detection algorithms now can be employed for estimation.

To obtain $[P_k]_{k=1}^{K}$, let us take channel matrix of all users except u^{th} user.

$$\widetilde{Ch}_u = [(Ch_1)^{Ch} \ldots . (Ch_{u-1})^{Ch} (Ch_{u+1})^{Ch} \ldots\ldots Ch_k]^{Ch} \qquad (5)$$

Where $N_{M,total} = \sum_{u=1}^{k} N_{M,u} = N_B$

$$\widetilde{Ch}_u p_u = O_{(N_{M\,total} - N_{M,u}) \times N_{M,u}} \qquad (6)$$
$$u = 1,2,3, \ldots\ldots k.$$

Hence, precoding matrix $P_u \mathbb{C}^{N_B \times N_{M,u}}$ should exist in null space of $\widetilde{Ch}_u$ and precoders should satisfy the equation (6). For this the singular value decomposition (SVD) $\tilde{V}_u^{zero}$ of $\widetilde{Ch}_u$ is expressed in terms of non-zero singular values and zero singular values.

$$\widetilde{Ch}_u = \widetilde{U}_u \widetilde{\Lambda}_u [\widetilde{V}_u^{non\ zero}\ \widetilde{V}_u^{zero}]^{Ch} \tag{7}$$

Where $\widetilde{V}_u^{non\ zero} \in C^{(N_{M,total} - N_{M,u}) \times N_B}$ and $\widetilde{V}_u^{zero} \in C^{N_{M,u} \times N_B}$ are composed of right singular vectors that correspond to non-zero singular values and zero singular values, respectively.

From equation (7) multiplying $\widetilde{Ch}_u$ with $\widetilde{V}_u^{zero}$, we get following term,

$$\widetilde{Ch}_u \widetilde{V}_u^{zero} = 0 \tag{8}$$

Multiplications of both the terms i.e. channel gain and SVD results in zero. The zero received signals at destination end indicate the minimization of interference in signals. Thus, $P_u = \widetilde{V}_u$ can be employed to pre-code the signal of u^{th} user.

From equation (9) It can be seen that pre-coding matrix $P_u = \widetilde{V}_u$ for the u^{th} user. Where $\widetilde{V}_u$ is composed of zeros and non-zero singular values. Size of $\widetilde{V}_u$ depends on size of $\widetilde{Ch}_u$. If $\widetilde{V}_u$ is a large matrix than it consist greater number of non-zeros singular values which causes equation (3) to be:

$$\widetilde{Ch}_u P_k > 0 \quad \forall\, u \neq k \tag{9}$$

If $\widetilde{V}_u$ is a smaller matrix than it consist less number of non-zeros singular values which causes equation (3) to be:

$$\widetilde{Ch}_u P_k < 0 \qquad \forall\, u \neq k \tag{10}$$

Both the cases causes a significant co-channel interference for user u, since channel matrix is not completely block diagonalization. Thus size of $\widetilde{V}_u$ should be optimum for a better performance.

Since the size of $\widetilde{V}_u$ depends on size of $\widetilde{Ch}_u$, we can manipulate the size of $\widetilde{Ch}_u$by setting the number of receiving antennas N_{RX} for each user.

To find an optimal value of N_{RX} an objective function can be drawn as:

$$\min\ f(\widetilde{Ch}_u) = |\widetilde{Ch}_u P_k| \tag{11}$$

Where,

$$\widetilde{Ch}_u = f(\dot{N}_{RX}) \tag{12}$$

The value of $\dot{N}_{RX}$ can be found as,

$$\dot{N}_{RX} = G(N_{RX}) \tag{13}$$

Where G is an operator which is optimized by Grey Wolf Optimization.

C. Grey Wolf Optimization

1. Grey wolves wander in search of its prey depending on the alpha, beta and delta positions. They go away (divergence) from each other in search of a prey and gather again (convergence) while attacking the prey [13]. This divergence can be mathematically given by A and convergence is represented by C.

$$\vec{A} = 2.\vec{a}.\vec{r}_1 - \vec{a} \tag{14}$$

$$\vec{C} = 2.\vec{r}_2 \tag{15}$$

Where, $\vec{r}_1$ and $\vec{r}_2$ are random vectors:

2. The initialization of GWO population is given by at counter iteration t=0:

$$X_i = (1,2,3 \ldots \ldots \ldots \ldots n) \tag{16}$$

3. Further A, C and a are also initialized
4. Now the fitness function for each searching agent is evaluated and is represented as:
   X_α denotes best searching agent
   X_β denotes 2nd best searching agent
   X_δ denotes 3rd best searching agent
5. If the total no. of iterations is given as $t = n$, then
   For $(t = 1; t \leq n)$
   Using above equations update the position of searching agents
   End for
6. Update A and C coefficients
7. Evaluate fitness function for each searching agent
8. Update $X_\alpha, X_\beta, X_\delta$
9. Set $t = t + 1$ (iteration counter increasing)
10. Return best solution X_α

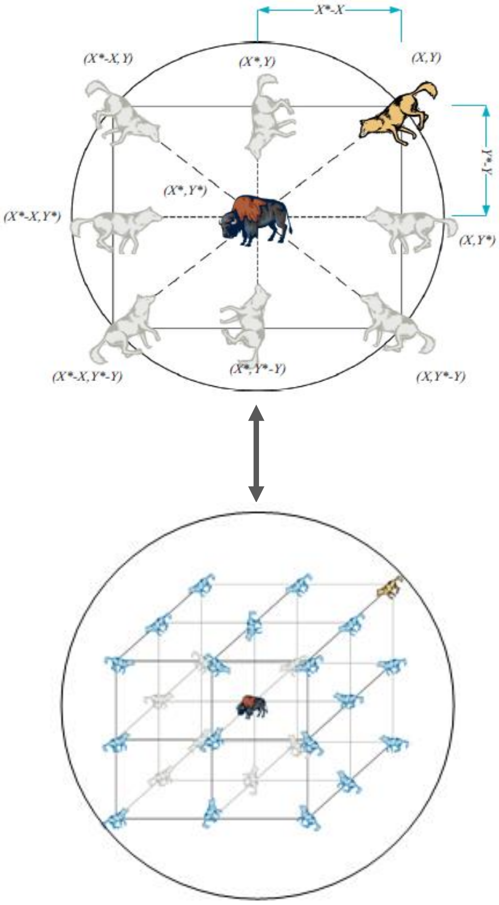

Figure 2: Extension of encircling shape into sphere [13]

GWO Working

1. The GWO resolves the optimization problem by generating the best solutions available during iterations [14].
2. The encircling behaviour gives an idea about the neighbouring circle around the solution which could be further extended into sphere (as shown in Figure 2).
3. A and C coefficient vectors help solutions to have random radii hyperspheres.
4. The hunting behaviour permits the solution to define the exact location of the prey.
5. Values of a and A are responsible for exploitation and exploration.
6. If the value of A decrease, then total number of iterations are equally divided and assigned for exploitation and exploration respectively.

III. SIMULATION AND RESULTS

The performance of proposed approach has been studied by means of MATLAB simulation.

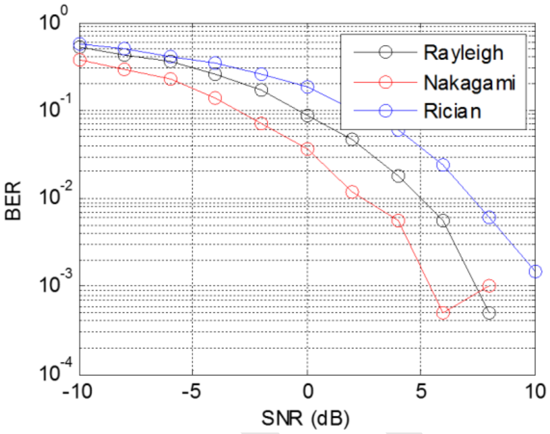

Figure 3: Comparative graph of BER for block diagonalization using Rayleigh and Rician and Nakagami fading

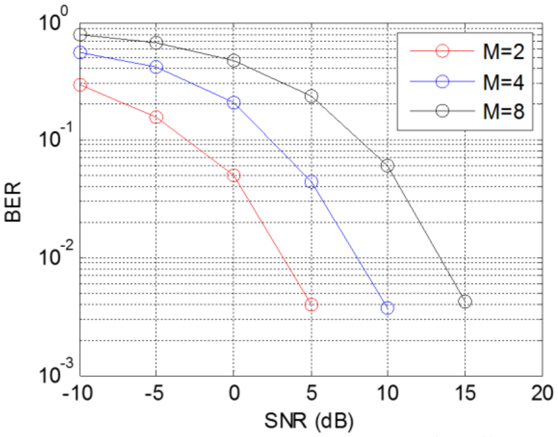

Figure 4: BER curve with GWO optimized BD for different modulation order

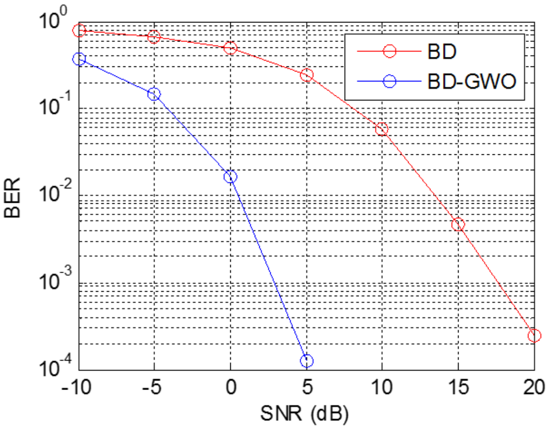

Figure 5: BER performance analysis for BD and GWO-BD

Figure 5 shows the comparative analysis of BD and GWO-BD WITH SNR range from -10dB to 20dB. At 5 dB SNR, the BER of GWO-BD is around 10^{-4}, while the BER for BD is around 10^{-1}. It is clear that the GWO-BD outperforms BD.

IV. CONCLUSION

The elimination of inter-user interference depends a lot on the knowledge of the channel, which, varies with time, and is selective in frequency, that is, in real environments, eliminating the interference, in the best case, would do so partial. It is necessary to have a return channel to send the channel status to the transmitter, so that it generates the correct pre-coding matrices and can mitigate co-channel interference. It greatly influences the performance of the system. If we do not have the return channel well dimensioned, it will not achieve the desired end. It is a very easy solution to implement in a cellular system, since only matrices are handled. However, it does involve additional signal processing at base stations. Comparing the performance of the system with the complexity of the algorithm, it is notable that the proposed solution is effective in mitigating inter-user interference. Results are showing that BER for MU-MIMO system is less with Grey Wolf optimized method.

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