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Enhancing Performance of Block Diagonalization Precoding in Multi User MIMO Downlink using Cuckoo Search Algorithm

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Abstract –**The rapid development in the field of mobile telephony and the integration of new services, especially multi-media, opened the door for the development of new technologies that will be able to meet and satisfy these needs. It has been clearly established that the introduction of MIMO technology can increase throughput and improve quality through the two main techniques: spatial multiplexing and transmission diversity. On the user side there are two main modes which are: single user (SU) and multi-user (MU). The present work develops one of the many existing solutions to mitigate the co-channel interference present in a Cellular System, which uses multi-user MIMO (multiple inputs) technology, in order to increase the capacity of the system at the expense of signal processing in the transmitter. This paper presents Cuckoo Search (CS) optimized Block Diagonalization precoding for multi user MIMO system to reduce error rate in system.**

Keywords – **BD, Cuckoo Search, MU, MU-MIMO, SU.**

I. INTRODUCTION

MIMO technology consists of having more than one antenna in both the transmitter and the receiver. We will denote as "t" the number of antennas that the transmitting equipment has, which will communicate with a single receiver provided with several receiver antennas, which will be represented by the variable "r".

MIMO takes advantage of physical phenomena such as multipath propagation to increase the rate of transmission and reduce the error rate. In brief words MIMO increases the spectral efficiency of a wireless communication system through the use of spatial domain [1].

Previously, systems that only had one antenna, in addition to receiving the signal useful in the part of the receiver, captured the signals of the other transmitters, causing degradation of the useful signal, making reception difficult; the signals of the other transmitters were always regarded as interference. The advantage of MIMO is that it considers the channel as a matrix, taking advantage of its multiple antennas for the correct decoding of the signals sent.

Cellular networks are evolving more and more, and researchers are looking for ways to continue to do so. As we saw in the previous section, cellular systems have evolved a lot since the emergence of MIMO technology, but still limited by the amount of frequency bands allocated in the cell.

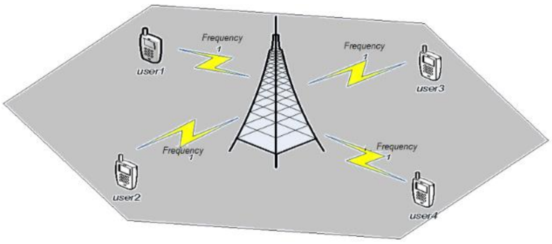

Figure 1: BS-users communication in the same frequency band

Imagine that we want to communicate with several users within a cell, but not in the conventional way, i.e. using several channels. This time, we will communicate with K users in the same band. If we do this, then we will be increasing the co-channel interference within the same cell. What it means is that we will have several users' co-channels with antenna arrangements that try to communicate on the same channel [2].

In MIMO-MU (Multiple Inputs - Multiple Outputs, Multi User), one of the major issues to be addressed is the elimination of co-channel interference. Multiuser MIMO is a set of advanced MIMO technologies, technologies that take advantage of the

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availability of multiple independent mobile users, in order to improve the communication capacity of each individual user. This technique has attracted a lot of attention because of its advantages in both the ability as well as the support of multiple users at the same time. In MU-MIMO an important issue is the elimination of co-channel interference (ICC), but this will be achieved with block diagonalization (BD) technique which is a method based on orthogonal projection [3].

In order to understand the problem that we wish to mitigate, it is necessary to review how the cellular system works, how frequency band assignments are made when a mobile wants to establish a call, in addition to understanding the MIMO (Multiple Inputs - multiple outputs) technology, Which in recent years has increased spectral efficiency in a very significant way in cellular networks. Understanding these two technologies, then we will cover the problem where we will focus, eliminate the co-channel interference generated in the same cell.

In contrast to SU-MIMO, where the spatial multiplexing gain is confined to a single user, MU-MIMO allows multiple users to be co-scheduled on the same time-frequency resources to exploit this gain among multiple user terminals. This is particularly beneficial as SU-MIMO transmission system is often limited by the number of antennas and antenna design constraints at the user terminal, whereas transmission using MU-MIMO technique is more feasible.

The main objective of this paper is to implement Cuckoo Search optimized Block Diagonalization Precoding for multi user MIMO system to reduce error rate in system.

II. System Model

MIMO Model

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, $u = 1,2,3, \dots\dots k$.

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:

$$R_u = Ch_u X + Z_u \quad (1)$$

$u = 1,2,3, \dots\dots k$.

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

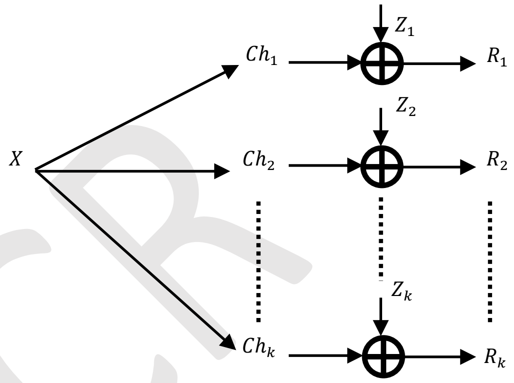

Figure 2: Downlink Channel Model for Multi-user MIMO system

Where X is the set of transmitted signal $(Ch_1, \dots Ch_k)$. 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.

Broadcast Channel Transmission via Block Diagonalization

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 [4] [5]. 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 $u = 1,2,3, \dots\dots k$.

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:

$$R_u = Ch_u \sum_{k=1}^{K} p_k \tilde{x}_k + Z_u$$

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

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,

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

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, $u = 1,2,3, \dots .. k$.

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

$$R_u = Ch_u p_u \tilde{x}_u + Z_u \quad (4)$$

$u = 1,2,3, \dots .. k$.

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.

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

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

$$\widetilde{Ch}_u p_u = O_{(N_{M\,total} - N_{M,u}) \times N_{M,u}} \quad (6)$$

$u = 1,2,3, \dots .. k$.

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.

$$\widetilde{Ch}_u = \tilde{U}_u \tilde{\Lambda}_u [\tilde{V}_u^{non\,zero}\ \tilde{V}_u^{zero}]^{Ch} \quad (7)$$

Where $\tilde{V}_u^{non\,zero} \in C^{(N_{M,total} - N_{M,u}) \times N_B}$ and $\tilde{V}_u^{zero} \in C^{N_{M,u} \times N_B}$ 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 $\tilde{V}_u^{zero}$, we get following term:

$$\widetilde{Ch}_u \tilde{V}_u^{zero} = 0 \quad (8)$$

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

From equation (8) It can be seen that pre-coding matrix $P_u = \tilde{V}_u$ for the u^{th} user. Where $\tilde{V}_u$ is composed of zeros and non-zero singular values. The size of $\tilde{V}_u$ depends on size of $\widetilde{Ch}_u$. If $\tilde{V}_u$ is a large matrix than it consist greater number of non-zeros singular values which causes equation (3) to be:

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

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

$$\widetilde{Ch}_u P_k < 0 \quad \forall\, u \neq k \quad (10)$$

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

Since the size of $\tilde{V}_u$ 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:

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

Where,

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

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

$$\dot{N}_{RX} = \boldsymbol{C}(N_{RX}) \quad (13)$$

Where $\boldsymbol{C}$ is Cuckoo operator.

Cuckoo Search Algorithm (CSA)

The CSA Algorithm has been developed by X. S. Yang and S. Deb in 2009 [6]. The algorithms inspired by the cuckoo are new evolutionary optimization mechanisms developed on the basis of behaviour of Cuckoos (a type of bird), combined with Levy's flight of some birds and fruit flies.

The implementation of the Levy flight in the Cuckoo Search approach is aimed to produce a novel resolution during the exploration process [7].

$$x_i^{t+1} = x_i^t + \alpha \oplus Levy(\lambda) \quad (14)$$

Where, $\alpha(\alpha > 0)$ is the jump size, x_i^{t+1} is the new solution and x_i^t is the current solution. This equation represents a random step called the Markov chain. This means that the next solution depends on the current solution and the probability of transition. $Levy(\lambda)$ follows a Levy distribution with infinite mean and infinite variance $(1 < \lambda \leq 3)$, Equation (15). This allows a part of the generation to move away from the current solution, preventing the algorithm from being trapped in the local minimums [7].

$$Levy(\lambda) \sim u = t^{-\lambda}, \quad (1 < \lambda \leq 3) \quad (15)$$

The cuckoo search technique works on the basis of the ideal rules, which are as follows:

- Each egg of the cuckoo in a nest represents a solution.
- Each cuckoo lays a single egg at once, and choose to nest "randomly". Therefore, each

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single cuckoo algorithm holds the right to randomly produce only one new solution.

- The best nests of better quality eggs will lead us to the new generations. Here, we have implicitly introduced the notion of advancement or research around the best solutions.
- Some of the solutions have to be managed by the L'evy flights around the best possible solutions of time. This accelerates the local search.
- The no. of cuckoo nests are limited, and the bird's egg is hence easily discovered by the host with a probability $p_\alpha \in [0,1]$. In this case, the host bird chooses to get rid of the egg, or abandon the nest and rebuild another nest somewhere. For simplification, the latter hypothesis will be approximated by the fraction p_α of n nids which are replaced by new ones (new random solutions).
- A significant proportion of the new solutions must be produced by remote-area hikes and the placements must be far away from the best existing solution, so there are no chances of system for being trapped in a local optimum.
- Each nest can contain several significant eggs a set of solutions.

Pseudo-Code of the Algorithm

1. Fitness function $f(x), x = (x_1, \ldots, x_d)^T$
2. Produce the initialize the n nests population xi (= 1, 2, ..., n)
3. while (t <Max Generation) or (the stop criterion) do
4. According to flights from Levy find Cuckoo.
5. Calculate the quality / fitness F_i
6. Choose a random nest out of n
7. if $(F_i < F_j)$ (minimization) then
8. Replace j by i
9. end if
10. The fraction (p_α) representing bad nests is ignored and builds new ones.
11. Find the best solutions
12. Sort solutions and get the best current
13. end
14. Post-process results and visualization

III. Simulation And Results

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

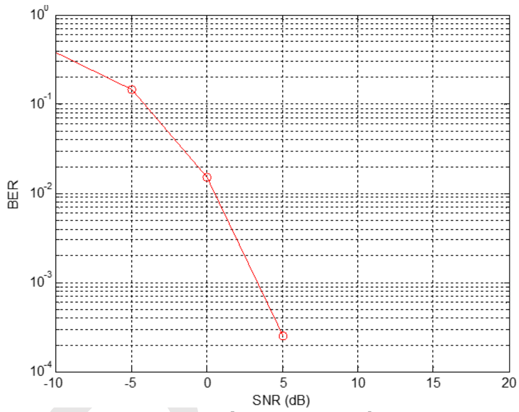

Figure 3: Optimized BER curve with BD-CSA

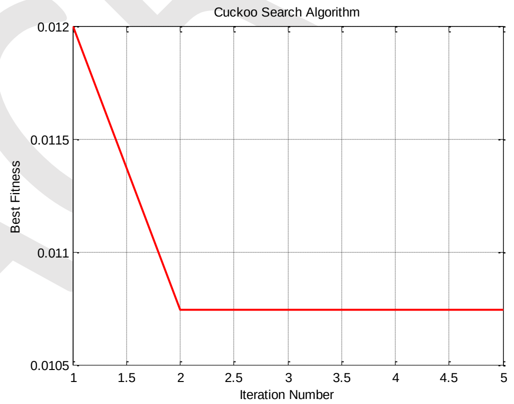

Figure 4: Cuckoo search iteration graph

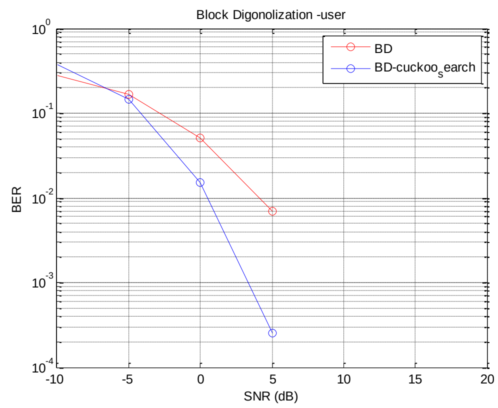

Figure 5: BER performance analysis for BD and BD-CSA

IV. Conclusion

MIMO Wireless system uses antenna arrays at both transmitter and receiver end to provide communication link with diversity and capacity. Impact of spatial multiplexing can be increase with precoding for performance improvement. Multi-user

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MIMO systems consists of allocating a single time frequency resource to several users to exploit multi-user diversity in the space domain, resulting in significant gains over SU-MIMO, especially in the presence of spatially correlated channels. We have presented an optimal Block Diagonalization method for MU-MIMO using Cuckoo Search optimization with Rayleigh Fading Channel having an objective of minimum bit error rate. Results are showing that BER for MIMO system is less with CSA optimized method.

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