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Block Diagonalization Precoding using Genetic Algorithm for Multi-User MIMO System in Nakagami Channel

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Abstract – **Diversity in MIMO applications tends to ameliorate the architecture of system for compensation with upgraded hardware and software requirements. Single-user MIMO systems allow one user to be serviced per transmission interval. This maximizes the throughput of a single user, but its disadvantage is that it does not take advantage of multi-user diversity. Multi-user MIMO systems (MU-MIMO) have become the main technique for meeting the requirements.**

This paper presents Block Diagonalization and genetically optimized Block Diagonalization precoding for multi user MIMO system in Nakagami Fading Channel 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 genetic algorithm is proposed in this paper and the results are showing that the proposed technique significantly improves the performance of Block Diagonalization method.

Keywords – **BS, GA, MIMO, MU, SU.**

I. Introduction

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.

Digital wireless communications using MIMO has emerged as one of the most remarkable scientific revolutions in modern communications. In the downlink of a cellular system, one BS equipped with multiple antennas communicates with a number of user terminals, each possibly equipped with multiple receive antennas. If the traditional transmission scheme such as TDMA is employed, the BS transmits to a single user terminal on each time resource and it is limited to SU-MIMO. Alternatively, the BS can use MU-MIMO referred to as SDMA to simultaneously transmit to multiple receivers on the same time and frequency resource by appropriate utilization of spatial dimensions. Recently, the MU-MIMO downlink transmission technique has been well studied, beginning with information theoretic capacity results [1-4], and followed by practical implementations in the next generation of wireless communication. Wireless relay communication has attracted considerable interests due to its improvement of the coverage and the enhancement of the spectral efficiency, which will be applied in the next generation wireless communication.

OFDM is a practical technology to convert a broadband frequency selective channel to parallel flat fading channels over each subcarrier, making a lot of MIMO-related algorithms for flat fading channel easy to be implemented [5][6].

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.

Due to the low complexity realization at the user terminal, and the large diversity gain, transmit weight design (precoding techniques) for MU-MIMO systems with CSI known at BS has been a subject of downlink system of MU-MIMO. Many linear transmit weight design techniques such as CI (Channel Inversion) and BD (Block Diagonalization) and nonlinear transmit weight design methods such as VP (Vector Perturbation) and Dirty Paper Coding (DPC), have been proposed to process the transmit signals at BS to pre-subtract the IUI among user terminals [7].

BD is known as a technique to achieve perfect orthogonality and completely cancel IUI by directing a null to each antenna element of other users, and any detection scheme in SU-MIMO is individually applicable to each block SU-MIMO channel. However, since the number of transmit antennas at BS must be not less than the sum of

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receive antennas for all user terminals, any user in BD scheme has to assure no rows of its channel matrix correlate with other users', otherwise this may lead to no throughputs for some users and seriously degrade the system rate [8]. In addition, BD method consumes most of the transmit antenna resources for perfect zero cancellation so that it is different to obtain transmit diversity gain.
DPC is a technique that allows non-causally known interference to be pre-subtracted at the BS and can achieve the maximum rate of the system [2], [3], and [4]. In [9], Costa proved the surprising result that the capacity of the channel, when the non-causal additive Gaussian interference is perfectly known at the transmitter, is the same as if the interference was not present. In MU-MIMO downlink, IUI can be completely removed at BS and the achievable rate of system was obtained close to the capacity region by applying ZF-DPC technique [2].
However, in the conventional DPC based on LQ decomposition, the number of receive antennas at each user terminal, in fact, is limited in single antennal because of the independence during signal detection for each receive antenna at users [10]. In addition, when it comes to the effective user selection, such as for the cellar communication case, all of the possible user combinations need to be calculated, which leads to great calculation load. Moreover, the optimal transmission covariance matrix is still difficult because of the non-convex optimization problem [2]. Some successive cancellation methods, such as successive zero forcing, are proposed to deal with the above problems [11]. But most of these studies focus on the evaluation of system rate performance, and few works give the concrete solution of interference cancellation for the MU-MIMO downlink.
Motivated by these problems and findings, in this research work, we focus on not only the cancellation of IUI but also the improvement of achievable rate of system for MU-MIMO downlink system. Some effective transmit weight designs are proposed to ensure the zero IUI and avoid the loss of system rate in different MU-MIMO cases. The BER performance and achievable rate analysis of system verify the effectiveness of the proposed scheme.

II. Proposed Methodology

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

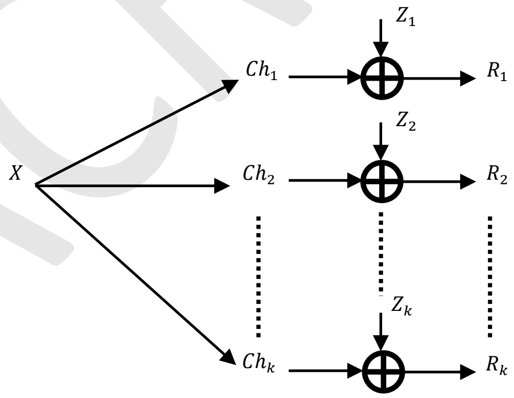

Figure 1: Downlink Channel Model for Multi-user MIMO system

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.

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 [12] [13]. 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

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detection algorithm on-rolled in a MIMO network. Let $N_{M,u}$ denotes the number of antennas for the u^{th} user. Where $u = 1,2,3, \ldots .. k$.
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:

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

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

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, $u = 1,2,3, \ldots .. k$.
From equation (3), the interference free received signal is,

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

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

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

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

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

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

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

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. 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,

$$\dot{N_{RX}} = \boldsymbol{G}(N_{RX}) \quad (13)$$

Where $\boldsymbol{G}$ is Genetic operator. Which is optimized by Genetic Algorithm.

Genetic Algorithm

A genetic algorithm is a probabilistic search technique that computationally simulates the process of biological evolution. It mimics evolution in nature by frequently altering a population of candidate solutions until an optimal solution is found [14].

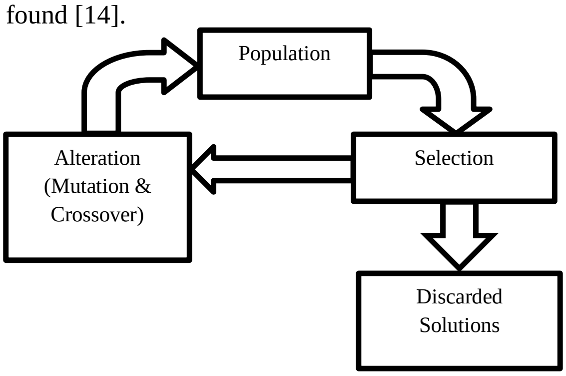

Figure 2: Genetic algorithm evolutionary cycle [15]

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The GA evolutionary cycle starts with a randomly selected initial population. The changes to the population happen through the processes of selection based on fitness, and alteration using mutation and crossover. The application of selection and alteration leads to a population with a higher proportion of improved solutions. The evolutionary cycle carry on until an acceptable solution is found in the current generation of population, or some regulator parameter such as the number of generations is exceeded [16]. The smallest unit of a genetic algorithm is called a gene, which denotes a unit of information in the problem domain. A series of genes, recognized as a chromosome, signifies one possible solution to the problem. Each gene in the chromosome signifies one component of the solution pattern.

The most common form of representing a solution as a chromosome is a string of binary digits. Each bit in this string is a gene. The procedure of converting the solution from its unique form into the bit string is known as coding. The specific coding system used is application dependent. The solution bit strings are cracked to enable their evaluation using a fitness measure.

A. Selection

In biological evolution, only the fittest survive and their gene pool contributes to the creation of the succeeding generation. Selection in GA is also based on a similar process. In a common form of selection, recognized as fitness proportional selection, every chromosome's likelihood of being selected as a decent one is proportional to its fitness value.

B. Alteration to improve good solutions

The alteration step in the genetic algorithm refines the good solution from the current generation to produce the next generation of candidate solutions. It is takes place by acting out crossover and mutation.

C. Crossover

Crossover may be regarded as artificial mating in which chromosomes from two individuals are combined to create the chromosome for the next generation. This is carried out by splicing two chromosomes from two different solutions at a crossover point and swapping the spliced parts. The fact is that some genes with good characteristics from one chromosome may as a result combine with some good genes in the other chromosome to create a better solution represented by the new chromosome [16].

D. Mutation

Mutation is a random adjustment in the genetic composition. It is beneficial for announcing new characteristics in a population – something not achieved through crossover alone. Crossover only reorders prevailing characteristics to give new combinations. For instance, if the first bit in every chromosome of a generation happens to be a 1, any novel chromosome created through crossover will also have 1 as the first bit.

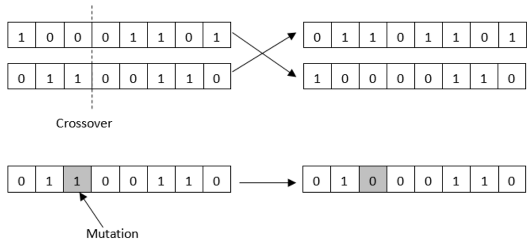

Figure 3: block representation of Crossover and Mutation

The mutation operator changes the current value of a gene to a different one. For bit string chromosome this modification amounts to flipping a 0 bit to a 1 or vice versa. Mutations can be counterproductive, and applied only randomly and infrequently.

The steps in the typical GA for finding a solution to a problem are listed below:

1. Generate an initial solution population of a certain size randomly.
2. Calculate each solution in the current generation and assign it a fitness value.
3. Select "good" solutions based on fitness value and discard the rest.
4. If satisfactory solution(s) found in the current generation or maximum number of generations is exceeded then stop.
5. Change the solution population using crossover and mutation to create a new generation of solutions.
6. Go to step 2.

Communication Channel (Nakagami Fading Channel)

Nakagami Fading occurs for multipath scattering with relatively larger time-delay spreads, with different clusters of reflected waves. Within any one cluster, the phases of individual reflected waves are random, but the time delays are approximately equal for all the waves. As a result the envelope of each cluster signal is Rayleigh Distributed. The average time delay is assumed to differ between the clusters. If the delay times are significantly exceed the bit period of digital link, the different clusters produce serious inter-symbol interference. The Nakagami Distribution termed the magnitude of the received envelope by the distribution.

$$p(r) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_p}\right)^m r^{2m-1} exp\left\{-\frac{mr^2}{\Omega_p}\right\} \quad (14)$$

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III. SIMULATION AND RESULTS

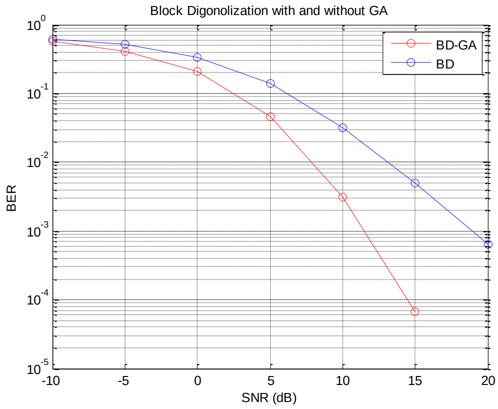

Figure 4: BER performance analysis for BD and BD-GA with zero forcing technique

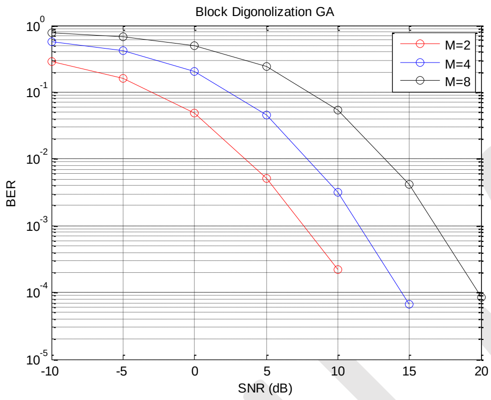

Figure 5: Optimized BER curve with BD-GA for different modulation order

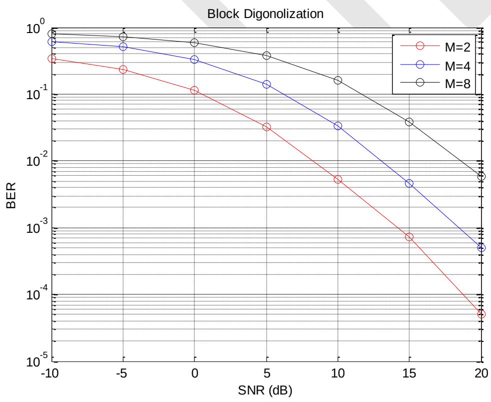

Figure 6: Optimized BER curve with BD for different modulation order

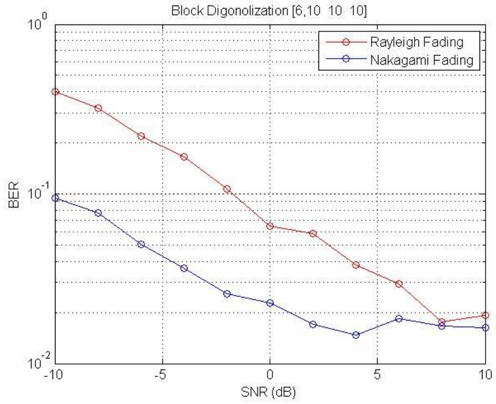

Figure 7: Genetically optimized BER curve with BD for different fading channels

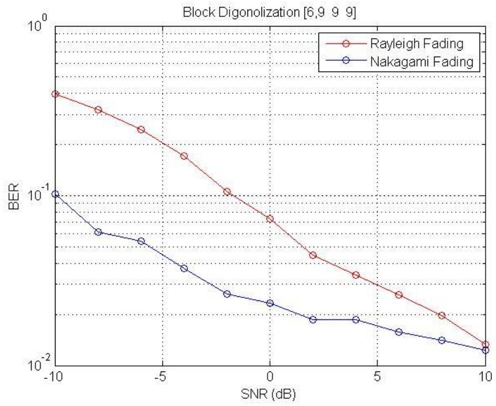

Figure 8: Genetically optimized BER curve with BD for different fading channels

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 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 Genetic algorithm with Nakagami Fading channel having an objective of minimum bit error rate. Results are showing that BER for MIMO system is less with genetically optimized method.

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