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" A NOVEL LOW COMPLEXITY DIAGONAL REDUCTION ALGORITHM OF LATTICE REDUCTION FOR SIGNAL DETECTION IN MIMO RECEIVER "

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ABSTRACT

This Paper analyses the performance of Multiple Input Multiple Output (MIMO) wireless communication system by combining it with an efficient algorithm Diagonal Reduction (DR). DR is a powerful tool to achieve more efficiently a high performance with less complexity when applied to MIMO detection. This paper proposes a DR algorithm in order to reduce its complexity named Greedy Diagonal Reduction (GDR) algorithm which gives reduced complexity with efficient performance at the receiver using the MATLAB communication tool box version 7.1 as a simulation tool. From the simulation results of various reduction algorithms it is observed that,DR can reduce the number of iterations using size reduction operations. Proposed DR algorithm gives identical Bit Error Rate (BER) performance with LLL algorithms when applied to Successive Interference cancellation (SIC) decoding. Greedy DR reduces the computational complexity in Multiple Input Multiple Output systems by improving the efficiency in terms of size reduction operations.

Keywords: *Mimo, Diagonal Reduction (Dr), Low Complexity, Greedy Diagonal Reduction (Gdr), Bit Error Rate (Ber)*

1. INTRODUCTION

MIMO technology can greatly enhance the capacity of wireless networks, the reliability of data transmission through wireless media. There is ever growing demand of wireless services of higher data rates with limited bandwidth. To achieve a high transmission rate, there is a need to have either high SNR (Signal to Noise Ratio) or wide bandwidth.

In wireless communications, since there are always limitations to increase SNR due to propagation loss, the bandwidth should be wide enough to support high data rate services. However, the lack of wireless spectrum has given the communication engineers a challenge on wireless communication systems with increasing data rate demands. To improve the spectral efficiency in wireless communications, multiple antennas are employed at both transmitter and receiver, where the resulting system is called the MIMO system. The multiple antennas can be used to increase data rates through multiplexing or to improve performance through diversity and it also offer high capacity to wireless systems and the capacity increases linearly with the number of antennas.

MIMO systems use multiple antennas at both link ends and offer good performance gains without requiring additional bandwidth or transmit power. Two important MIMO gains are the multiplexing gain, which corresponds to an increase of the data rate, and the diversity gain, which corresponds to an increase of the transmission reliability.

The transmitter and receiver are equipped with multiple antenna elements. The transmitted symbols go through a channel matrix which consists of multiple receive antennas at the receiver. Then the receiver gets the received signal vectors by the multiple receive antennas and decodes the received signal vectors into the original information. The mathematical equation is given in 1

$$Y = Hx+N \tag{1}$$

Where,
Y= out put signal vector,
H=Channel matrix,
X=Input vectors,

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N=Noise in Channel

2. LATTICE REDUCTION

Lattice Reduction mainly deals with finding improved representations of a given lattice using algorithms like Lenstra, Lenstra, Lovász (LLL) reduction. It is linked to the search for the shortest vector in a lattice, which in turn is related to the development of the famous sphere decoding algorithm lattice reduction turned out to be extremely useful for detection and pre-coding in wireless MIMO systems. The basic idea here is to develop the discrete nature of the digital data and view the channel matrix that acts on the data as a basis of a point lattice. Lattice reduction approaches have the high capability to get high performance at low computational complexity.

2.1 MIMO Ssystem with lattice

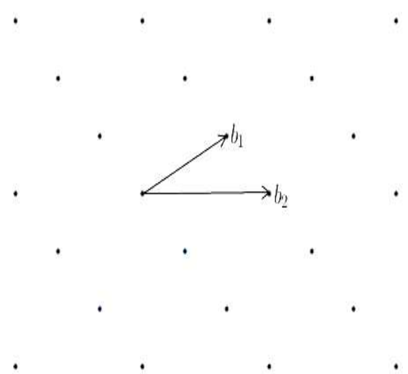

Figure 1 Lattice of Basis Vector

Let us **c**onsider a basis B consisting of M real-valued linearly independent basis vectors which are given by

$$B = \{b_1, b_2, b_3 \ldots\ldots b_M\} \tag{2}$$

where $b_1, b_2, b_3 \ldots\ldots b_M$ represents linearly independent basis. Since a lattice can be generated from an integer linear combination of a basis, with B, then lattice defined by

$$\text{Lattice} = \sum_{m=1}^{M} z_m b_m \in \mathbb{Z} \tag{3}$$

Where, z_m is a scalar, b_m is a linearly independent vector, $\mathbb{Z}$ denotes the set of integer numbers.In this, b_m should be real vector and z_m should be an integer. MIMO channel model is compared with lattice, its parameters changed as follows.'H' becomes the basis Thus, the basis vectors of H should be real-valued . 'x' is used to produce an integer linear combination of the basis. Therefore, the elements of s need to be integer. 'Y'becomes a vector in the lattice generated by the basis H.Using the real-valued matrix transformation H can be converted to real valued basis vectors (i.e., column vectors with real values only), and then MIMO channel model can be rewritten as

$$\begin{bmatrix} R(y) \\ \Im(y) \end{bmatrix} = \begin{bmatrix} R(H) & -\Im(H) \\ \Im(H) & R(H) \end{bmatrix} \begin{bmatrix} R(s) \\ \Im(s) \end{bmatrix} + \begin{bmatrix} R(n) \\ \Im(n) \end{bmatrix} \tag{4}$$

Where R(.) , $\Im(.)$ denote the real and imaginary parts

LR can be applied to MIMO systems to improve the performance of suboptimal MIMO detection, where the resulting detection methods are regarded as the LR-based MIMO detection. Consider two bases H and G that has the same lattice, where each column vector of a basis is an integer linear combination of the column vectors of the other basis. Then it is given by

$$H = GU \tag{5}$$

Where **U** is a uni-modular matrix. Then, the received signal can be rewritten as

$$Y = GUs + n \tag{6}$$

$$Y = GC + n \tag{7}$$

where C=Us is a transformed vector.

In linear algebra, the QR decomposition of a matrix is to decomposition the matrix into an orthogonal and a triangular matrix. QR

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decomposition is the tool that generates an orthogonal basis in the sense of an uni-modulary transformation . It is also often denoted as QR factorization. As these names indicate the QR decomposition disjoints an intended matrix into two matrices The first matrix contains the orthogonalized portion of A. The second matrix has upper triangular form and shapes the relation between A and Q. A QR decomposition of a real square matrix A is a decomposition of A as

$$A = QR \qquad (8)$$

where Q is an orthogonal matrix ($QQ^T = I$) and R is an upper triangular matrix.QR decomposition can be done by two methods namely Gram-Schmidt process and Givens Rotations.

2.2 Modified Diagonal Reduction (MDR) algorithm

An implementation of the DR algorithm especially in real time communication systems suffers from the fact that the complexity depends on the number and positions of column swaps. In comparison to the original DR algorithm, the flow control has been removed and replaced by a fixed complexity structure. The modified DR algorithm have been developed in order to improve the implementation in real-time MIMO communication systems, where lattice reduction techniques can help to improve linear detection at the receiver. In this no back tracking occurs.

2.2.1 Algorithm for MDR

INPUT: Take H = QR where Q € C^{mxn}, R € C^{nxn},w(1/2 < w < 1)

OUTPUT: Updated Q and R which is diagonal reduced with parameter w and a unimodular Z that reduces R.

STEP 1: Initialize the unimodular matrix as $Z \leftarrow I_n$

STEP 2: Check the condition

While R is not diagonally reduced, do

for k =2,3,4,5……n do

$$\mu_k \leftarrow \lfloor R(k-1,k)/R(k-1,k-1)\rceil$$

STEP 3 : If the condition $\left|r_{k-1,k} - \mu_k r_{k-1,k-1}\right|^2 + r_{k,k}^2 \geq w r_{k-1,k-1}^2$, for all 1< k ≤ n is not satisfied then

STEP 4: Check the condition, if $\mu_k \neq 0$ then $R(1:k-1,k) \leftarrow R(1:k-1,k) - \mu_k R(1:k-1,k-1)$
$Z(:,k) \leftarrow Z(:,k) - \mu_k Z(:,k-1)$

STEP 5: end if

STEP 6: Now perform swap restore operation by swapping the columns k-1 and k in R and Z.

STEP 7: Find givens rotations G to restore the upper triangular matrix of R by satisfying the conditions
$R(k-1:k,k-1:n) \leftarrow GR(k-1:k,k-1:n)$
$Q(:,k-1:k) \leftarrow Q(:,k-1:k)G$

STEP 10: else increment k as $k \leftarrow k+1$

STEP 11: end if condition, for condition and while condition

In this algorithm, $k \leftarrow \max(k-1,2)$ step is not used. So, there is no back tracking problem and hence number of iterations and complexity is reduced.

From the complexity analysis, the efficiency of a diagonal reduction algorithm depends on the rate of reduction in the size of diagonal elements. The iterations required are very less compared to all other LLL and DR algorithms and obtains more efficiency. In each iteration selects randomly a column from all possible columns for performing

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selective size reduction and column swap, so that diagonal reduction is maximized. The algorithm steps is given below as

2.2.2 Algorithm for Greedy Diagonal Reduction

INPUT: Take H = QR where Q € $\mathbb{C}^{mxn}$, R € $\mathbb{C}^{nxn}$,w(1/2 < w < 1)

OUTPUT: Updated Q and R which is diagonal reduced with parameter w and a unimodular Z that reduces R.

STEP 1: Initialize the unimodular matrix as
$Z \leftarrow I_n$

STEP 2: Use the condition to compute γ_k
$\gamma_k = (|r_{k-1,k} - \mu_k r_{k-1,k-1}|^2 + r_{k,k}^2)/ r_{j-1,j-1}^2$
where
$\mu_k \leftarrow \lfloor R(k-1,k)/R(k-1,k-1) \rceil$

STEP 3: Choose k value as $k \leftarrow \operatorname{argmin} \gamma_k$

STEP 4: Check the condition

While $\gamma_k < w$ do

STEP 5 : If the condition

$|r_{k-1,k} - \mu_k r_{k-1,k-1}|^2 + r_{k,k}^2 \geq w r_{k-1,k-1}^2$
, for all 1< k ≤ n is not satisfied then

STEP 6: Check the condition, if $\mu_k \neq 0$ then
$R(1{:}k-1,k) \leftarrow R(1{:}k-1,k) - \mu_k R(1{:}k-1,k-1)$
$Z(:,k) \leftarrow Z(:,k) - \mu_k Z(:,k-1)$

STEP 7: end if

STEP 8: Now perform swap restore operation by swapping the columns k-1 and k in R and Z.

STEP 9: Find givens rotations G to restore the upper triangular matrix of R by satisfying the conditions
$R(k-1{:}k,k-1{:}n) \leftarrow GR(k-1{:}k,k-1{:}n)$
$Q(:,k-1{:}k) \leftarrow Q(:,k-1{:}k)G$

STEP 10: Update the upper triangular matrix

STEP 11:the value of k as $k \leftarrow \operatorname{argmin} \gamma_k$

STEP 12: end while condition

2.2.3 Procedure for Size Reduction

Take input matrix and perform QR decomposition where Q has ortho-normal columns and R is upper triangular should satisfy the condition,

$$2|r_{i,j}| \leq |r_{i,i}| \quad (9)$$

If the condition is not satisfied then the following size reduction procedure is applied to satisfy the condition,

Step 1: reduce (i,j)

Step 2: calculate $\gamma = \lfloor r_{i,j} / r_{i,i} \rceil$

Step3: form $z_{i,j} = I_n - \gamma e_i e_j^T$

Where e_i is the i^{th} unit vector

Step 4: apply $z_{i,j}$ to both R and A

R $\leftarrow Rz_{i,j}$, A $\leftarrow Az_{i,j}$

Step 5: check the condition in current R

If $|r_{i,j}| > \frac{1}{2}|r_{i,i}|$

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If it is true then in the updated R

$$|r_{i,j}| \leq \frac{1}{2}|r_{i,i}|$$

2.2.4 Swap Restore Operation

Take input as A=QR where Q has Orthonormal columns and the updated R matrix as input where R is upper triangular should satisfy the condition,

$$r^2_{i,i} + r^2_{i-1,i} \geq w r^2_{i-1,i-1} \qquad (10)$$

2.2.5 Procedure for swap restore

Step 1: swap Restore (i)

Step 2: swap the columns i-1 and i of R and A

Step 3: find Givens Rotation

$$G^T_i \begin{bmatrix} r_{i-1,i} & r_{i-1,i-1} \\ r_{i,i} & 0 \end{bmatrix} = \begin{bmatrix} \hat{r}_{i-1,i} & \hat{r}_{i-1,i-1} \\ 0 & \hat{r}_{i,i} \end{bmatrix}$$

And apply G_i to R then the updated matrix R is

$$R \leftarrow \begin{bmatrix} I_{i-2} & & \\ & G_i & \\ & & I_{n-i} \end{bmatrix}^T R$$

3. SIMULATION RESULTS

The Simulation result shows the comparison of Greedy Diagonal Reduction with Modified Diagonal Reduction and Diagonal Reduction and also includes the comparison of Greedy Effective LLL algorithm with Parallel Effective LLL and Effective LLL. From the graph shown in figure 2, it is inferred that proposed MDR show a better performance characteristics than DR algorithm.

Figure 2 Performance Comparison Of Mdr And Dr Algorithm.

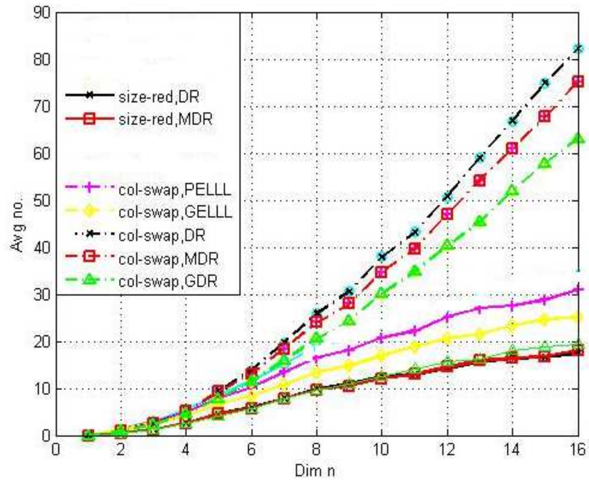
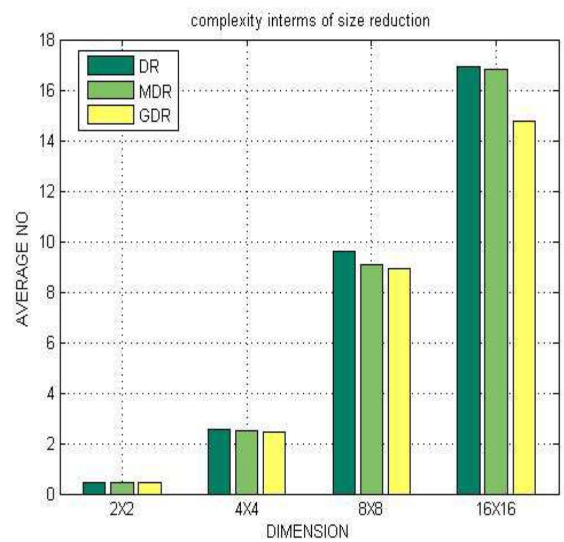


Figure 3 Bar Graph Comparison Of Mdr ,Gdr And Dr Algorithm For Computation Complexity Involved.



From Figure 3 it is inferred that MDR algorithm gives a better result in terms of computation complexity compared to DR algorithm.

4. CONCLUSION:

Greedy Diagonal Reduction algorithm reduces the computational complexity in MIMO (Multiple Input Multiple Output) systems by improving the efficiency in terms of size reduction operations and column swap operations. It is inferred that MDR algorithm is better than DR algorithm in terms of computation complexity. Further Soft Computing techniques can be explored for reduced complexity reduction.

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