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High Performance Mimo Detection Based On Genetic Algorithm

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ABSTRACT

Multiple-Input Multiple-Output (MIMO) technique improves the capacity and the reliability of wireless communication. In this paper, Genetic algorithm based detection of high performance MIMO system using wavelet modulation is proposed. The proposed method is independent of number of transmit and receive antenna and also on constellation size. Genetic algorithm based detection provides guarantee on Signal-to-Noise (SNR) ratio which is independent of fixed throughput and reduction in Bit Error Rate (BER) with irrespective of constellations. The main innovation of proposed algorithm founds the best cost signal and high performance when compared to other previous methods by keep tracking the symbols at each level. Being fixed-throughput in nature along with the fact that genetic algorithm makes especially attractive one for VLSI implementation. It is used at the receiver side to detect the signal from the transmit antenna based on the number of generations and cost of the received signal. It reduces the levels of detecting the best signal and also contains both Rayleigh and Additive white Gaussian noise (AWGN) for MATLAB simulation. The SNR vs. BER for the channel path of signals in proposed algorithm is compared with existing algorithms.

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INTRODUCTION

MULTIPLE-INPUT MULTIPLE-OUTPUT (MIMO) systems have been considered as an important and challenging area of research in the field of telecommunication. It has the capability to achieve high spectral efficiency, high data rate, and robust wireless link, with an acceptable implementation complexity in wireless systems. MIMO provides the best solution for solving the bottlenecks of traffic capacity in the forthcoming broadband wireless internet access networks and to achieve higher performance.

MIMO receiver contains some of the challenging factors like designing of a low complexity, low energy, less-BER, high performance and high throughput receiver. Among several MIMO detection algorithms Maximum-Likelihood (ML) detection method is the best in optimal and minimizes the bit error rate (BER). But it exhibits exponential growth in computational complexity with constellation size and the number of transmit antennas (Mojtaba Mahdavi and Mahdi Shabany, 2013). The main role of MIMO system is to design a low complexity and high throughput detection schemes with nearer to Maximum Likelihood (ML) performance (Mahdi Shabany and P. Gleen Gulak, 2012) that proves efficient for Very Large Scale Integration (VLSI) realization. On the other hand, linear detection algorithms such as the Zero-Forcing (ZF), Minimum Mean-Square Error (MMSE) or Successive Interference Cancellation (SIC) detectors (Shabny, M. and P.G. Gulak, 2009) can greatly reduce the computational complexity, at the same time there will be reduction in performances.

Finally, as a tradeoff between complexity and performance loss, a large category of the detection algorithm, which include the genetic algorithm (Jigna Desai, 2012) and it is a family of computational models inspired by evolution. These algorithms are used to find out the global solution of the given problems in the search space. It provides SNR-independent fixed throughput with a performance close to K-best method. In genetic algorithm, the degree of convergence depends on the number of generations G and/or the population size P. Although the genetic algorithms are attractive for VLSI Implementations, there are still some challenges, such as an efficient selection and reproduction scheme, in order to achieve higher throughputs.

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Mimo System Model:

Consider a MIMO system with N_T transmits and N_R receives antennas. For the Rayleigh fading channel, the equivalent baseband model between transmitter and receiver is described by a complex-valued N_R x N_T channel matrix **H**. The equivalent model for complex baseband can be expressed as

$$\mathbf{y} = \mathbf{Hx} + \mathbf{n} \quad (1)$$

Where $x = [x_1, x_2, ..., x_{NT}]^T$ is the N_T-dimensional complex transmit signal vector, in which each element is independently obtained from the complex constellation of QAM, $y = [y_1,y_2,….,y_{NR}]^T$ is the N_R dimensional symbol vector of received signal, $e = [e1,e2,….,e_{NR}]^T$ is a complex-zero mean Gaussian noise with the variance of σ^2 per dimension. In this paper we consider the frame work in a complex domain and the received signal is derived using real value decomposition (Guo, Z. and P. Nilsson, 2006).

The main goal of the MIMO detection method is to find out the closest lattice point **x** for the received signal vector **y**.

$$\ddot{\mathbf{X}} = \arg\min_{X \in O^{NT}} \|\mathbf{y} - \mathbf{Hx}\|^2 \quad (2)$$

Where O is the set of vectors from the real entries in the constellation, e.g., $O = \{-3,-1, 1, 3\}$ in case of 16-QAM. In this, genetic algorithm is used to overcome the problems in the complex domain with reduced computational complexity. Thus the existing and proposing algorithm in MIMO is described in detail as follows.

Existing Method:

In real domain, the implementation of different detection algorithms is much easier when compared to the complex domain. Recently, a type of detection scheme is used to provide the high performance in MIMO. Minimum PED based K-Best algorithm (Balakrishnan, C. and R. Poornima, 2014) is based on the breadth-first tree search method. The breadth-first algorithm finds the best candidate node in forward direction only but the best k node candidate available at the level of sublatice. The channel matrix **H** is calculated using QR decomposition as **H = QR,** where **Q** is the unitary N_R x N_T matrix and **R** is the upper triangular N_R x N_T matrix. By applying hermetian of Q, the nulling operation is performed which results in $\mathbf{Z} = \mathbf{Q}^{\mathbf{H}}\mathbf{y}$, which in turn equals to **Rs + w**, where $\mathbf{w} = \mathbf{Q}^{\mathbf{H}} + \mathbf{e}$. The nulling matrix is always known to be one, where the noise **w** remains spatially white after nulling, **R** is upper triangular in nature, hence the equation (2) can be rearranged as

$$\ddot{\mathbf{X}} = \arg\min_{X \in O^{NT}} \sum_{i=1}^{N_T} \left| z_i - \sum_{j=1}^{N_R} |r_{ij}\, e_j| \right|^2 \quad (3)$$

Considering equation (3) as a tree-search problem with N_T levels, where initial from the last row, one signal is detected and based on that the next signal in the upper row is detected and so on. Thus initial from $i = N_T$ all the signals are detected using K-Best algorithm in the iterative mode. The K-Best algorithm expands the individual K existing nodes at each level to produce M new possible children nodes from the given constellation size and calculate their updated Partial Euclidean Distance (PED). This result is based on the smallest PED by applying sorting mechanism. Two computing procedures in the K-Best algorithm are discussed as follows.

1) Expansion:

In complex domain, the K-Best algorithm can be represented as K (parents of each level) x M (children per parent). At each level children nodes are computed which results in lager computational complexity. The base-centric search methodology (Lin, H.L.,) and relaxed K-Best algorithm based on QPSK modulation (Chen, S., 2007) are compared (Mahdi Shabany and P. Gleen Gulak, 2012). These methods do not scale linearly with the size of constellation even though applied in complex domain and produces the less performance when compared to the correct K-Best algorithm. In on demand mechanism method, by expanding the nodes based on the consideration of PED reduces the higher order constellation performances.

2) Sorting:

At each level, KM children should be sorted in the complex domain in K-Best algorithm. In (Shurti Trivedi, 2012; Bingham, J.A.C., 1990) sorting scheme such as bubble sorting (Wong, K.W., 2002) which is based on Schnorr-Euchner technique (Schnorr, C.P. and M. Euchner, 1994) and comparison of distributed sorting scheme is shown.

The step of K-Best algorithm is as follows:

Step1) Initialize PED value as zero with one path of the root node.

Step2) from the previous level, retain the values and update the accumulated metric of each path, then extend each node.

Step3) Sort the paths according to the accumulated metrics and select the K-best path.

Step4) Update the path history for each sorted path at the each level and discard the others.

Step5) if the iterative arrives at the end sublatice then the algorithm is stopped; otherwise the algorithm is repeated from the step (2).

The algorithm starts by initializing the l as level of the tree and each level is known as l+1. The level K$l+1$ have the √M possible children's and the number of cycles K depends on the order of the modulation scheme, √K x √M possible children's in the tree. The best node signal at the level Kl+1 will act as the parent for next level; again the children's are generated. The process repeats until all the points in the order of modulation are checked.

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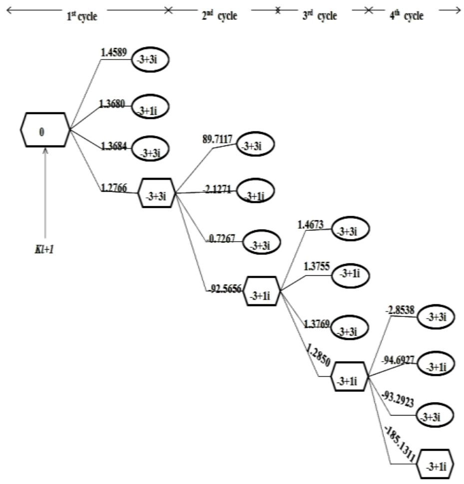


Fig. 1: minimum PED based K-Best algorithm for √M=4 and K=4 and simulated PED values.

IV. ***Proposed Method:***

The simplest form of genetic algorithm involves three types of operators: selection, cross over and mutation. Genetic algorithm is based on optimization variables, optimization cost and cost function.

Initialization:

In MIMO detection, the form of ML search space is coded as binary string which is called as chromosomes. At first, initialization of population is done and output from linear/non-linear detector is derived. Each chromosomes is a combination of probable solution for all the transmit antennas. Population size Npop is measured as the product between *N*, number of transmit antennas and *C* , number of all possible solutions of each transmit antenna.

$$Npop = 2^b \times N \qquad (4)$$

Selection:

Selection is based on the fitness function. Population is evaluated for each generation and fitness value. Cost function is used to evaluate the fitness of each chromosome by using following equation,

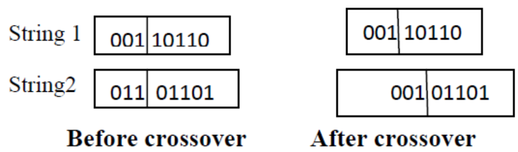
$$F = \|r - Hx\|^2 \qquad (5)$$

From the equation (5), the minimum value is obtained as the best solution. In a generation, the best chromosomes should have the best fitness function. Each generation value is compared with the previous values of fitness function and the least value is chosen as the best solution.

Reproduction:

Reproduction makes extra copies of improved strings in a new population. Reproduction is usually the first operator applied on a population. Reproduction selects good strings in a population and also replaces the largest value of fitness function with the best solution. It contains two operator namely, crossover and mutation.

A crossover operator is used to recombine two strings to get an improved string. In crossover operation, recombination process creates different individuals in the successive generations by combining material from two individuals of the previous generation. In crossover, new strings are created by exchanging information between the parent node which are selected randomly and creates offspring.



Mutation simply changes each bit of the randomly selected binary chromosome. It individually replaces the worst fitness value by the best solution. In mutation probability, the bit is inverted, so that zero becomes one and one becomes zero. This helps in introducing a bit of diversity to the population by scattering the occasional points. This random scattering would result in the better optimal, or even modify a part of genetic code that will be beneficial in later operations.

Termination:

Generation process is repeated until a termination condition has been reached. This can be when the fixed number of generations has been reached or the allocated level has reached.

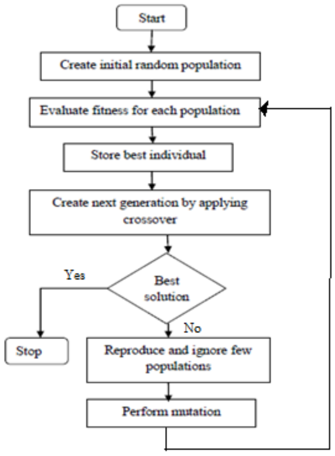


Fig. 2: Flow chart of Genetic Algorithm.

Application of these operators on the current population creates a new population. This new population is used to generate subsequent populations and so on, yielding solutions that are closer to the optimum solution. The values of the objective function of the individuals of the new population are again determined by decoding the strings. These values express the fitness of the solutions of the new generations. This completes one cycle of genetic algorithm called a generation. In each generation if the solution is improved, it is stored as the best solution. This is repeated till convergence.

Some features of proposed algorithm are listed as follow,

1. It can be easily implemented in the real domain.
2. The proposed algorithm has less computational complexity when compared to other schemes.
3. It can be easily implemented in VLSI design.
4. Concept of proposed algorithm is easy to understand.
5. Easy to utilize previous or alternate solutions.
6. Execution depends on cost and generation and also calculates the best solution without any rounding and approximation.
7. Modulation is involved to increase the performance of MIMO systems.

Achieving High Performance With The Proposed Algorithm:

The architecture shown in fig.3 is implemented with the help of proposed genetic algorithm to achieve the high performance of MIMO system. The input message signal is converted into Parallel form by using Serial-to-Parallel converter (S/P) during first stage, and then the symbol is obtained as output. The signal is modulated with different order of Quadrature Amplitude Modulation (QAM) schemes, then the output is applied to various transformation forms and bit streams are obtained as the output of final stage of the transmitter and that is reshaped and split according to the number of transmitter antennas used in MIMO system. At receiver side, the proposed detection algorithm is used to identify the best signal and demodulates to obtain the original transmitted input signal. Various transformation forms for proposed algorithm are discussed as follows.

FFT and IFFT transformation techniques:

The Inverse Fast Fourier Transform (IFFT) at the transmitter side and Fast Fourier Transform (FFT) at the receiver side are the two important equipments used for the mechanism of MIMO systems. In both wired and wireless communication, the role of FFT and IFFT shows the advantage of reducing the effects of channel fading). The cyclic prefix is added in order to reduce the Inter Symbol Interference (ISI) and the effect of cyclic prefix reduces the bandwidth and performance loss (Bhagawat, P., 2009). To overcome this problem FFT and IFFT form is replaced by Wavelet Packet Transformation (WPT) at the receiver side and Inverse Wavelet Packet Transformation (IWPT) at the transmitter side of MIMO systems.

Wavelet based MIMO system:

Conventionally Fourier transform furnishes information only about the spectral characteristics and mechanism based on stationary signal. In general, all real time signals are non-stationary. In order to overcome this drawback, Wavelet based MIMO is used under the proposed algorithm. With help of construction filter, wavelet can be obtained. The proposed algorithm contains two filter banks to divide the frequency into lower and higher levels. Each signal component is mapped to the frequency domain and the output obtained as wavelet packet transformation which corresponds to the particular frequency band. The sampling is done to reduce the redundancy and number of coefficients used. The features of wavelet over FFT are as follows.

1. It achieves transmission integration.
2. It provides signal diversity similar to spread spectrum.

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3. No limitation of sub carrier.
4. High degree of flexibility.

Channel Models:

Mobile radio channels establish the performance of wireless communication because transmission integration is complex when compared to wired communication. In communication system, the measurements are specially designed based on modeling of radio channel. The signal propagation for the channel modeling describes the signal travelling from transmitter to receiver.

At receiver side, the signal will not reach the receiver directly often due to obstacles, so that the multipath reflection takes place. This mechanism is called as multipath propagation and causes fluctuation in both amplitude and phase. In wireless communication, the channel is modeled by random attenuation which is also called as fading followed by additive noise. The proposed genetic algorithm is used to provide the better BER when implemented with Additive white Gaussian noise (AWGN).

The zero-mean white Gaussian noise is added with the constant spectral density in the AWGN channel. This scheme does not consider fading, selectivity, interference, or dispersion. The AWGN channel contains the basic resources such as received power P and bandwidth W, and on increasing the power P it suffers from a law of diminishing the marginal returns. When the SNR increases with decrease in BER, there is a linear increase in capacity.

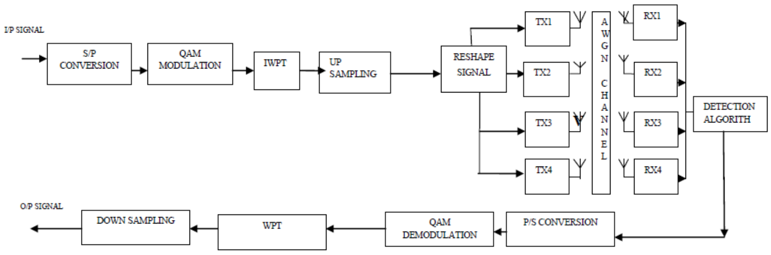

Fig. 3: High performance MIMO systems.

Simulated Results And Analysis:

The simulated results considering the number of transmit antennas (N_T=2) and the number of receive antennas (N_R=2), modulated using 4 QAM scheme is given

Formation of random signal:

The input message signal is applied in the form of 6x2 matrixes.

$$S = \begin{matrix} 1 & 0 \\ 1 & 1 \\ 0 & 1 \\ 1 & 1 \\ 1 & 0 \\ 0 & 1 \end{matrix}$$

The input message signal is plotted in the random bit form as pictorially shown in fig. 4. The random bits plotted in fig.4 shows the values either in 0 or 1 which reflects the input message signal. The point 1, 2, 4, 5, 8, 9, 10 remains at the binary value of 1 and other points remains at the binary value of 0.

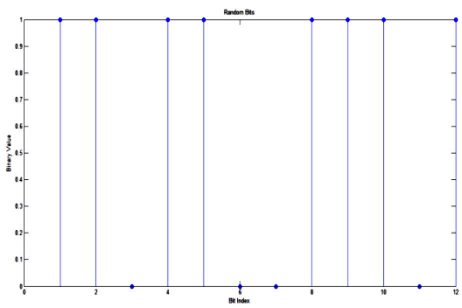

Fig. 4: Random bits plot for the input binary stream.

Symbol plot:

The input binary message signal should be preprocessed before modulating using QAM. The random symbols are generated by converting the input message stream in to decimal value and system index. In order to reduce error and repeated addition.

Signal strength and BER plot:

The scatter plot for the FFT based scheme and wavelet based scheme for MIMO system with the proposed detection scheme are shown in fig. 6 and fig. 7.

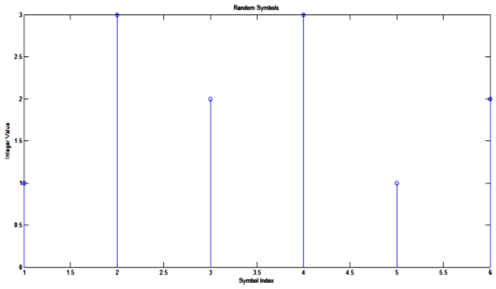

Fig. 5: Symbol plot for input binary stream.

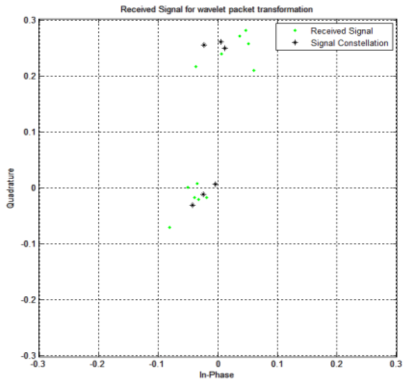

Fig. 6: Received signal for FFT based transformation.

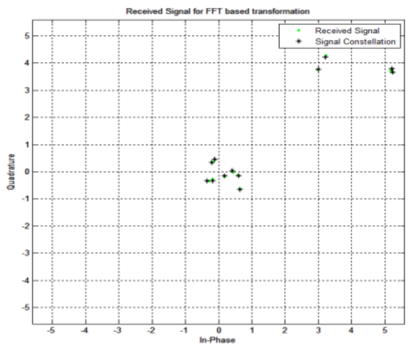

Fig. 7: scatter plot for the WPT based scheme.

The analysis of the wavelet based scheme provides the better received signal strength with help of proposed algorithm.

The analysis of the wavelet based scheme shows better received signal strength, with the proposed algorithm than in FFT scheme. The Bit-error rate (BER) is compared with the FFT as well as wavelet scheme as shown in fig. 7, which shows a constant BER in the proposed algorithm irrespective of the Signal-to-noise ratio (SNR) and the BER is less when implemented using wavelet scheme than in FFT scheme.

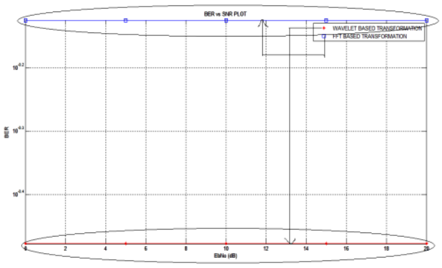

Fig. 8: BER comparisons for FFT and Wavelet scheme.

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Best solution for the proposed detection algorithm:

The best solution of the proposed Genetic Algorithm obtained as a result of simulation for the given input message signal (x) is given below:
Genetic Algorithm (real coding)
num_of_fun_evaluation = 3150
max_point_GA = 7.968037981869408 14.198040959048500
maxvalue_GA = 22.088009259128803

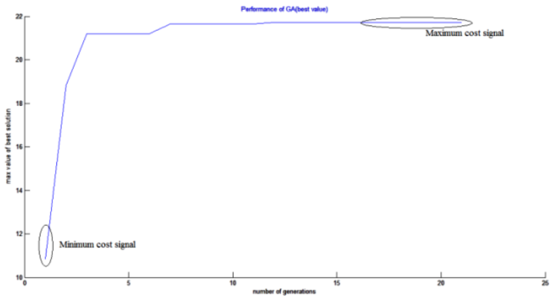

Fig. 9: Best solution of Genetic Algorithm.

Table I: Design Comparison of MIMO Detectors.

Method	K- Best Algorithm	Genetic Algorithm
Domain	Complex	Complex
Modulation	16-QAM	16-QAM
Antenna	2 x 2	2 x 2
SNR	5	5
BER	2.5	1
Number of channel used	Less than 200	More than 50
Function evaluation	N = 3000	N = 4000
Selection process	Based on Euclidian distance	Based on Fitness function

Conclusion:

In this paper, Genetic algorithm using wavelet modulation for the high performance MIMO detector has been proposed. The proposed algorithm results in constant bit-error rate (BER), irrespective of variable signal to noise ratio, constellation size and finally the computational complexity is low with respect to the number of transmit antenna (N_T) and the number of receive antenna (N_R) . The proposed algorithm is carried out by simulating in terms of both FFT and Wavelet scheme which results in better performance and decreased BER when implemented using WPT. The future work of this paper includes the implementation of proposed algorithm in real time wireless communication, in order to increase the throughput and decreased response time in real time applications for achieving higher performance.

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