DESIGN OF MINIMUM PARTIAL EUCLIDEAN DISTANCE BASED K-BEST ALGORITHM FOR HIGH PERFORMANCE MIMO DETECTOR

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ABSTRACT

Minimum Partial Euclidean Distance (PED) based K-best algorithm using wavelet modulation is proposed. It is based on breath- first search methods. The proposed design is independent of the constellation size, number of transmit and receive antenna. The minimum PED based K-best detector guarantees a Signal to Noise Ratio (SNR)-independent fixed throughput with a performance close to Maximum Likelihood Detection (MLD) method and constant Bit Error Rate (BER) with irrespective of constellations. The main innovations are the nodes are expanded and visited based on minimum PED rather than exhaustively, as well as it keep track of finally selecting the best candidates at each search phase. Being fixed-throughput in nature along with the fact that the breadth-first approaches are feed-forward detection schemes makes them especially attractive one for VLSI implementation. At first, the minimum PED based K-best algorithm is implemented using MATLAB and the number of transmitting and receiving antenna are 4 and 64 constellations is chosen. The input message signal is Quadrature Amplitude Modulation (QAM) modulated, and then the output complex domain is converted to wavelet signals. The packets are made suitable according to the MIMO system. Then the signal is transmitted using Additive White Gaussian Noise (AWGN) channel. Then the received signal from MIMO transmitter is detected using the minimum PED based K-best algorithm, Moreover, the algorithm efficiently expands a very small fraction of all possible children based on minimum PED and can be applied to the infinite lattices. Finally it provides the exact best node solution, i.e., the minimum PED node from transmission in Multiple Input Multiple Output (MIMO) system. Finally the scatter plot is compared in MATLAB simulation for both Fast Fourier Transform (FFT) and Wavelet Packet Transform (WPT) the scatter plot denotes which one provides the better signal strength. The calculation for wavelet based SNR vs. BER shows the AWGN channel using WPT provides the less amount of bit error involved in signal compared to Fast Fourier Transform (FFT) based scheme.

Keywords - Complex-domain detection, K-best detectors, PED, Multiple Input Multiple Output detector.

1. INTRODUCTION

MIMO systems today are considered to be a great challenging research area in the telecommunication. It is said to be one of the solutions for solving the bottlenecks of traffic capacity in the forthcoming broadband wireless internet access networks and to give high performance. The designing of a low-complexity, low-energy, less-BER, high-performance, and high-throughput receivers is the key challenge in MIMO receiver. Among several MIMO detection algorithms Maximum-Likelihood (ML) detection method is the optimal and minimizes the bit error rate (BER). But its computational complexity grows exponentially with constellation size and number of transmit antennas [1]. The potential of MIMO systems is to design a low-complexity high-throughput detection schemes with near Maximum-Likelihood (ML) performance [2] that is suitable for efficient 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 Cancelation (SIC) detectors [3] can greatly reduce the computational complexity, at the same time they have reduced performance.

Finally, to solve the tradeoff between complexity and performance loss, a large category of receiver detection algorithm has been proposed, which includes the depth-first and the breadth-first search algorithms. The most popular among depth-first strategy is the sphere decoder (SD) [4],

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which guarantees the optimal performance in case of unlimited execution time [5]. But the throughput results in extra over head in the hardware and significantly lower data rates in the lower SNR. Among the breadth-first search methods, the most well-known approach is the K-best algorithm, [6]. The K-best detection algorithm method guarantees a SNR-independent fixed-throughput with a performance close to ML. Being fixed-throughput in nature along with the fact that the breadth-first approaches are feed-forward detection schemes, makes them especially attractive one for VLSI implementation. Also some efforts are made towards the implementation in VLSI design [4], [7].

In each cycle, K (Parent of node) × M (child of node) children should be enumerated, which result in large computation complexity in K-Best algorithm. The base-centric search methodology [8], and the relaxed K-Best enumeration [9] are compared [2]. These schemes do not linearly scale with the constellation size when applied to the complex domain and has performance loss compared to exact K-Best algorithm scheme. The on-demand expansion scheme reduces the computational complexity and independent of constellation size [1], on the other hand the minimum Partial Euclidean Distance (PED) based has better improved performance than the on-demand expansion scheme. For 16-QAM, K is chosen to be 4 while for 64-QAM, K=8 meaning that the constellation quadruples but the K value only doubles, thus the increased sub-linear. It also has fixed critical path delay independent of the constellation, K value, and the number of antennas used. Moreover, it efficiently expands a very small fraction of all possible children in the K-best algorithm and it can be applied to an infinite lattices.

2. MIMO TECHNOLOGY

The MIMO technology uses the advantage of radio-wave phenomena called the multipath, where transmission signal bounces at different angle at different times, the MIMO overcomes the multipath behavior by using multiple, transmitters and receivers by adding the 'spatial' dimension to increase the performance and flexibility. As the result of using multiple antennas the channel capacity and throughput get increased. In MIMO environment the signal is propagating from the transmitter to the receiver along number of different paths, collectively referred as multipath. While propagating the signal power drops of due to three effects: path loss, macroscopic fading and microscopic fading. Fading of the signal can be reduced by different diversity techniques.

In order to achieve the diversity technology, the spatial multiplexing is been commonly used to increase the capacity of Multiple-Input-Multiple-Output (MIMO) communication [11], by transmitting the independent message in the same time slot and frequency band simultaneously from individual transmit antennas, and separation of multiple data streams at the receiver using channel information of each path of propagation, Fig. 1 shows the principal of spatial multiplexing, exploiting the spatial dimension of radio channel which allows to transmit different data streams simultaneously.

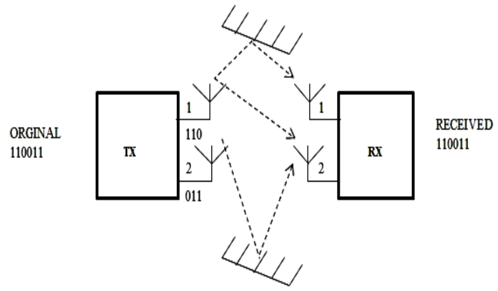

Figure 1. Spatial multiplexing of MIMO

In contrast to the spatial multiplexing or spatial diversity the other physical layer technologies like Orthogonal Frequency Division Multiplexing and time diversity technology are used for spectral efficiency and reduced complexity but these technologies suffer from reduced capacity link. The mobile devices use the frequency band, which is strictly restricted by its limited bandwidth. The reliability of the communication is achieved with maximum data rate and constant bit error rate (BER) for varying signal-to-noise ratio (SNR), this is achieved with Multiple Input Multiple Output (MIMO) system.

3. MIMO SYSTEM MODEL

Assume the MIMO system with Nt transmits and Nr receive antennas. For the Rayleigh fading channel the equivalent baseband between the transmitter and receiver is described in a complex-valued $Nr \times Nt$ channel matrix **H**. The complex-valued base band received signal is expressed as.

$$\mathbf{Y=Hx+e} \qquad (1)$$

Where **x** =[x1, x2, ..., xNt]T is the Nt-dimensional complex transmit signal vector, where each element is independently obtain from the complex constellation of QAM, **Y**=[Y1,Y2, ..., YNr]T is the Nr dimensional symbol vector of received signal, **e=**[e1, e2, ..., eNr]T is a

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complex-zero mean Gaussian noise with the variance of σ2 per dimension. In this paper we consider the complex domain frame work; on the other hand the real value decomposition can also be derived for the received signal [4].

The ultimate goal is to find 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 work Minimum Partial Euclidean distance (PED) based K-Best algorithm is used to solve the above problem in the complex domain with reduced computational complexity. Since the algorithm is based on the K-Best algorithm, first it is described in detail as follows.

4. K-BEST DETECTION SCHEME

The breadth-first search method can also be implemented in Multiple-Input-Multiple-Output (MIMO) detection scheme, one of the common and well known approaches of breadth –first scheme is K-Best detection algorithm. The breadth-first algorithm searches for the best candidate node in forward direction only, but the best *K* node candidate are available at each level of sublattice. Hence, the breadth-first algorithms result in the constant decoding throughput, the K should keep as large as possible, compared with exhaustive-search Maximum Likelihood (ML) algorithm. The bit-error rate (BER) performance is close to the ML detection scheme.

The channel matrix **H** is QR decomposed as **H=QR**, where **Q** is the unitary Nr×Nt matrix and **R** is the upper triangular Nt×Nt matrix. By taking hermetian of Q or **(QH),** the nulling operation can be performed, which results in **Z=QH×Y,** which inturn equals to **Rx+w,** where **w=QH+e**, the nulling matrix is always known to be one, where the noise **w** after nulling remains spatially white. Since **R** is an upper triangular in nature, hence the equation (2) can be represented as

$$\ddot{\mathbf{x}} = \arg\min_{x \in O^{N_t}} \sum_{i=1}^{Nt} |zi- \sum_{j=i}^{Nt} | rij\ ej |^2 \quad (3)$$

we can consider the equation (3) as an tree-search problem with Nt levels, where, starting from the last row, one symbol is detected and, based on that, the next symbol in the upper row is detected, and so on. Thus starting from i=Nt the symbols are detected in K-Best algorithm in the iterative manner. The K-Best algorithm expands the individual *K* existing nodes at each level to produce *M* new possible children, from the given constellation size and calculates their updated Partial Euclidean Distance (PED). The result is that it produces *KM* nodes by sorting mechanism and then selects the *K* best nodes based on the lowest PED as the surviving node in the next level. The hard decision output of the detector is chosen as the path with lowest level of the PED at the first level. There are two computing procedures in the K-Best algorithm, which is discussed as follows.

4.1. Expansion

The K-Best algorithm in the complex domain can be expressed of *K* (parents of each level) ×*M* (Children per parent) children should be computed, which results in larger computational complexity. The base-centric search methodology [8] and relaxed K-Best algorithm based on QPSK modulation [9] are compared [2]. These schemes do not scale linearly with the constellation size even though it can be applied to the complex domain, and it has got the performance loss compared to the exact K-Best algorithm. In the on demand expansion scheme the nodes are expanded by considering all the nodes PED, which in turn reduces the performance for higher order constellations. To overcome the above two challenges in this paper the minimum PED based K-Best algorithm is proposed, which consider the node with the minimum PED as the parent node at each level. The computational complexity and performance will be better than the on-demand expansion scheme.

4.2. Sorting

KM children should be sorted in each level of the complex-domain in the K-Best algorithm. In [10] and [13], most of the sorting schemes such as bubble sorting [6], which is sorting mechanism on the basis of Schnorr-Euchner (SE) ([3], [12]) technique, and a distributed sorting scheme are compared. But these techniques take high time for large values of the *K* and *M* or it will be having a performance loss. To address this challenge the minimum PED based algorithm is implemented in this paper which overcomes all this challenges and works well for any values of *K* and *M* without any performance loss.

The MIMO detection algorithms have many challenges to implement them in the complex domain. The most of the MIMO detection algorithm address the problem in the real domain, to address the challenges in the complex domain the minimum PED based K-Best algorithm is proposed in this paper, which is independent of the constellation size, high performance and constant bit-error rate (BER) for varying signal-to-noise ratio (SNR).

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The step in the K-Best algorithm is described as follows.

Step 1) Initialize one path of the root node with the PED value of zero.

Step 2) Extend each node, retained from the previous level and update the accumulated metric of each path.

Step 3) Sort the paths according to the accumulated metrics and select the K-best path.

Step 4) Update the path history for each sorted path at the levels and discard the other paths.

Step 5) If the iteration arrives at the end sublattice then the algorithm is stopped; otherwise the algorithm is repeated from the (step 2).

The best part of the last iteration in the K-Best algorithm is, thus the hard decision output of the decoder, since the K-Best algorithm has a fixed throughput it can be easily implemented in the parallel and in pipelined manner.

5. PROPOSED MINIMUM PED K-BEST ALGORITHM

The implementation of various detection algorithms in the real domain is much simpler than to implement in the complex domain, as in the real domain it is straight forward to implement as the next child can be sorted based on the zigzag movement around the unconstrained received value without any Partial Euclidean Distance (PED). The proposed minimum PED K-Best algorithm is based on the breadth-first tree search method. The algorithm is initialized by considering the level l of the trees and assumes the candidate nodes in the level l+1 is known in the tree. The individual nodes in the level *K*l+1 will be having √M possible children's and the number of cycles or K value also will be based on the square root of constellation order, so there will be $\sqrt{K}\times\sqrt{M}$ possible children in the tree. The one of the main objective of the proposed scheme is to find the First Best Child (FBC) of the initial parent node, based on the minimum Partial Euclidean Distance (PED) of the received first $\sqrt{M}$ children of the initial parent node, assuming that initial parent node is non-numerical value. In other words, the key innovation behind the proposed minimum PED based K-Best algorithm is to find the First best child (FBC) of each initial parent node in the level *K*l+1, among these children the best candidate at level *K*l+1, is the one which is having the minimum PED value among all other children's to the first parent node. The best candidate selected act as a parent node for the next level. The children's for the second level parents are generated and it replaces the first level siblings. This process is repeated *K* times to find the best path. The same procedure is performed for each level of tree.

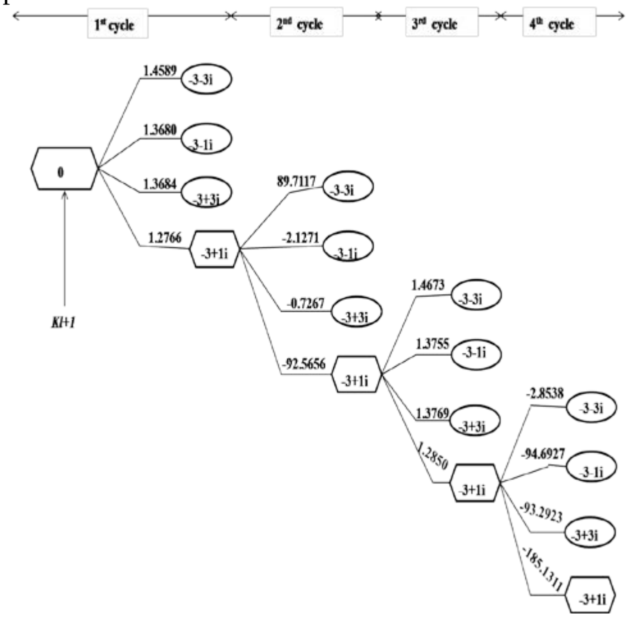

Figure 2. The proposed minimum PED based K-Best algorithm for $\sqrt{M}=4$ and K=4 and simulated PED values.

5.1. First parent node and child generation

In the minimum PED based K-best algorithm, it is required to detect the first parent node and generate siblings for the first parent node. In the proposed scheme the first parent node is assumed to be zero PED value. The first child $C_l^{[1]}$ of a first parent node in the level K_{l+1}, is represented by rewriting the equation (2) as.

$$C_l^{[1]} = ((\arg(Z-R\mathbf{x}))^2 - FBC\,l+1) \qquad (4)$$

Where FBC is the first best child in the level *K*l+1, which is initially assumed to be zero during the algorithm starting stage, By taking hermetian of Q or **(QH)** in the equation (2), the nulling operation can be performed, which results in **Z=QH×Y**. All the children's are generated at the first cycle by applying the equation (4), then for the first parent node, the best candidate is selected based on the minimum Partial Euclidean Distance (PED). The selected best candidate at the level *Kl+1*, act as an parent node for the level *Kl+2,* again the children's are generated for the second level parent node and the process is repeated until all the points in the constellations are checked for the closest lattice point. The proposed scheme is pictorially represented in Fig. 2 for level *l* where we considered the modulation order *M* is to be 16, so the total number of levels are given by $\sqrt{M}=4$, and the value of *K* is also equal to 4.

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The input to the algorithm is zero PED value. In the proposed scheme the parent can find its own children's without visiting all the nodes in the tree. Let the representation of *Sl* consist of the best selected child for the first parent, and let *PT* represents the corresponding PED values (in Fig. 5, {*S114* = -3+3i} and {*PT14*=1.2766}, where *Sij* represents the jth child of the ith parent node in the first level of the algorithm). From the above diagram it is observed that the child with the lowest PED value is definitely the best child selected at the level 1. Thus the best child selected at the level K_{l+1} , act as a parent node for the second cycle. In order to find the next best parent node at cycle 3, the corresponding PED values in the previous cycle are removed from the *Sl and PT*. Taking the same approach to generate the siblings for the second cycle as in first cycle. This procedure is repeated up to K=4 cycles to find all the K-best candidates (see Fig.5). The final best path lists are S^l14, S^l24, S^l34, S^l44 with their corresponding PED values are 1.2766, -92.5636, 1.2850, and 185.1311 respectively. It is observed from the Fig.5, that only four children out of 16 possible children are visited. This approach takes an advantage of reduced computation complexity, when applied to higher modulation order *M* and when large number of transmit and receive antennas are used.

The features of the proposed scheme are listed:

1) Easily implemented in VLSI design.
2) The proposed scheme has constant bit-error rate (BER), with irrespective of constellation size and number of antennas used.
3) Provides the exact K-best solution, without any rounding and approximation.
4) Increased performance is obtained when implemented using Wavelet packet modulation (WPT) with the added white Gaussian channel (AWGN).
5) The proposed scheme can be easily applied to the infinite lattices and can be jointly applied with lattice reduction.
6) It can be easily implemented in the real domain.
7) The proposed scheme has less computational complexity, than any other approach.

6. ACHIEVING HIGH PERFORMANCE WITH THE PROPOSED ALGORITHM

The high performance MIMO detector for the proposed minimum PED based K-best algorithm is achieved when implemented with the architecture represented in the Fig.3.

The input message signal at the first stage is converted into parallel form using the serial-to-parallel converter (S/P), then from the symbols obtained the signal is Quadrature Amplitude Modulated (QAM), with various modulation order, then the output of the signal is applied with various transformation techniques and the final stage of transmitter the bit stream obtained is reshaped and split according to the number of transmitter antennas in the MIMO system, on the other hand at the receiver side the proposed detection algorithm identifies the best candidate node of the received signal and demodulation operation is performed in order to retain the original message signal. The Performance of various transformation techniques and channel schemes on the proposed minimum PED based K-Best algorithm is discussed as follows.

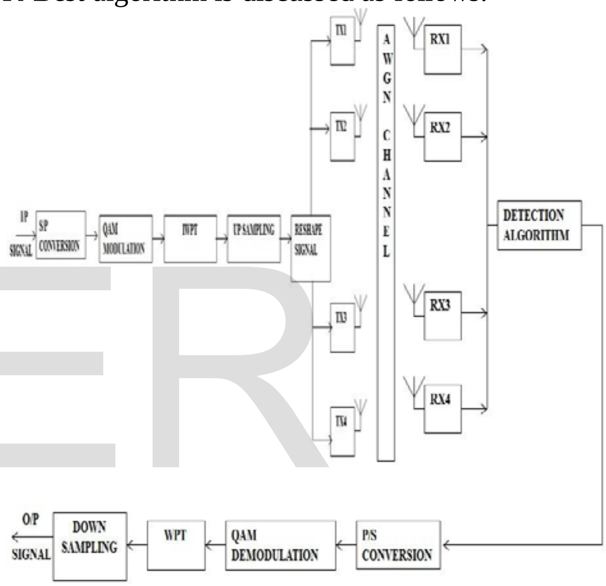

Figure 3. High performance MIMO system

6.1. FFT and IFFT transformation techniques

The Fast Fourier Transform (FFT) at the receiver side and Inverse Fast Fourier Transform (IFFT) at the transmission side, are the major important components used in tradition mechanism of MIMO systems. The transformation techniques of FFT and IFFT have an advantage of minimizing the fading channel effects in the wired as well as wireless systems [13, 14]. On the other hand in order to remove the Inter Symbol Interference (ISI), the cyclic prefix is added. The addition of cyclic prefix effects in reduced bandwidth and performance loss [15], to overcome this we replace the FFT and IFFT transformation techniques by Wavelet Packet transformation (WPT) at the receiver side and Inverse Wavelet Packet Transformation (IWPT) at the transmission side of the MIMO system.

6.2. Wavelet based MIMO system

The wavelets can be derived by simply using the reconstruction filters. In the proposed design two channel filter banks split the given signal into low frequency component and high frequency component. The signal components are mapped into frequency domain and each output point is a wavelet packet transformation node (WPT) and corresponds to particular frequency band. The sampling (down sampling, up sampling) is done in order to ensure that the overall number of coefficients is still same and there is no redundancy.

6.3. Channel Models

In the AWGN channel scheme, zero-mean white Gaussian noise is added with the constant spectral density. This model does not account for fading, selectivity, interference, on or dispersion. The basic resource of the AWGN channel is the received power P and the bandwidth W, on increasing the power P suffers from a law of diminishing the marginal returns: the higher the signal-to noise ratio (SNR), the smaller the effect on capacity. Thus when the SNR increases the BER decreases and the capacity increases linearly.

7. SIMULATED RESULTS AND ANALYSIS

The experiment is simulated using Matlab by considering the number of transmitting antennas (Nt=4), and the number of receiving antennas (Nr=4), modulated using 64 QAM scheme with K=8.

7.1. Formation of random message signal

The input message signal is applied in the form of 6×2 matrix.

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

The random bits plot in the (Fig. 4), shows the values of either 0 and 1, the values in the plot reflects the input message signal, it is seen from the above figure that, the points 1, 2, 4, 5, 8, 9, 10 remains at binary value of 1 and other points remains at binary value of 0.

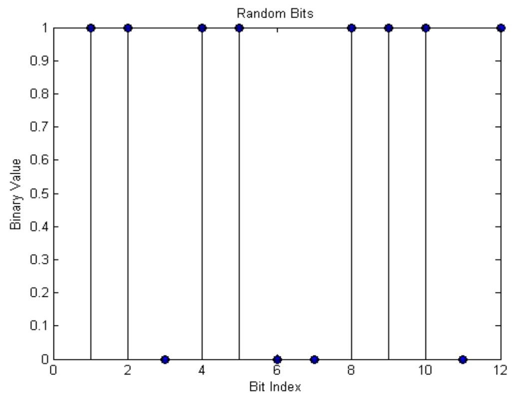

Figure 4. Random bits plot for the input binary stream

7.2. Symbol plot

The input binary stream or message signal (x), should be preprocessed before modulating using QAM scheme. The random symbols are generated by converting the input message stream in to decimal value and system index. In order to reduce the error the bit addition can be repeated. The symbol plot is pictorially represented in the Fig. 5.

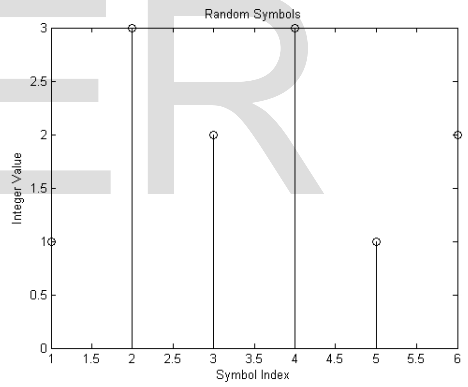

Figure 5. Symbol plot for input binary stream

7.3. Best candidates for the proposed detection algorithm

The best candidate's PED for the proposed minimum PED based K-Best algorithm obtained as a result of simulation for the given input message stream (x) are listed below.

1) THE BEST CANDIDATE OF 1 CYCLE IS 3.283351e+003.
2) THE BEST CANDIDATE OF 2 CYCLE IS -1.083299e+002.
3) THE BEST CANDIDATE OF 3 CYCLE IS 3.279795e+003.

4) THE BEST CANDIDATE OF 4 CYCLE IS -2.166598e+002.
5) THE BEST CANDIDATE OF 5 CYCLE IS 3.393075e+003.
6) THE BEST CANDIDATE OF 6 CYCLE IS -3.249897e+002.
7) THE BEST CANDIDATE OF 7 CYCLE IS 3.389520e+003.
8) THE BEST CANDIDATE OF 8 CYCLE IS -4.333195e+002.

7.4. Signal strength and BER plot

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

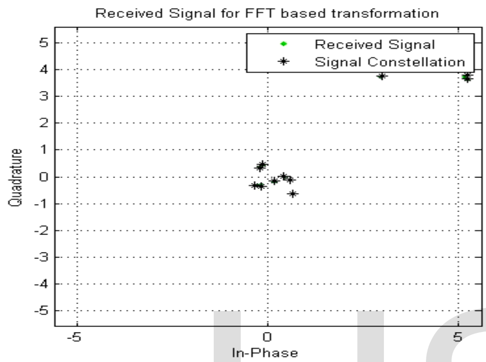

Figure 6. Scatterplot for the FFT based scheme

It is seen from the above Fig. 6, the received signal strength is less for the constellation size of 64 QAM.

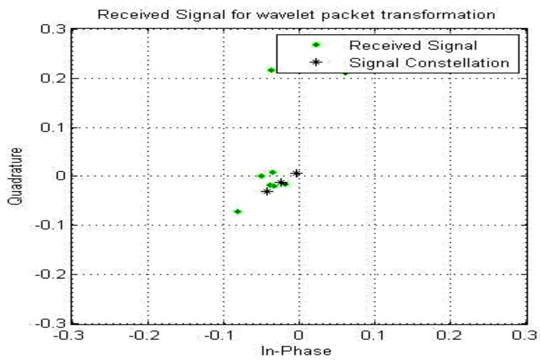

Figure 7. Scatterplot for the WPT based scheme

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. 8, which shows there is 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.

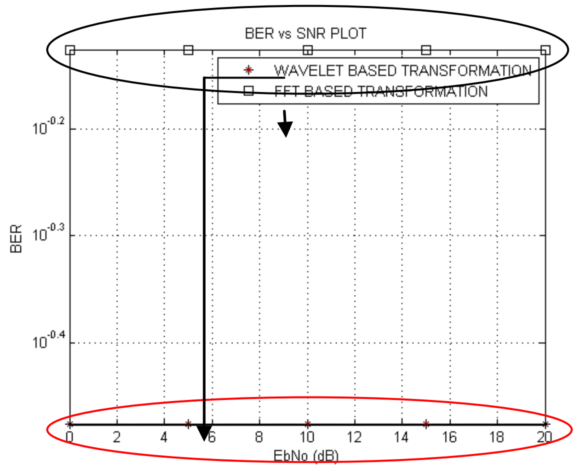

Figure 8. BER comparison for FFT and Wavelet scheme

8. CONCLUSION

A minimum PED based K-best algorithm using wavelet modulation, for high performance MIMO detector has been proposed in this paper. The proposed algorithm gives a reduced Bit-Error, Rate, irrespective of variable signal-to noise ratio, constellation size and finally the computational complexity is low irrespective of number of transmit antennas (Nt), number of receive antennas (Nr), and the algorithm is independent of the constellation size. The proposed algorithm is carried out by simulating, both in terms of FFT scheme and wavelet scheme, the results show better performance and decreased BER when implemented using wavelet packet modulation scheme (WPT). The future work includes the implementation of proposed scheme in Real time wireless communication, in order to decrease the response time and increase the throughput in real time embedded applications for achieving high performance.

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