High Performance MIMO Detector Using K Best Algorithm

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***Abstract*–Among the breadth-first search methods, the K-best algorithm is the most well-known detection method; The K-best detector guarantees a Signal to Noise Ratio (SNR)-independent fixed throughput and close to Maximum Likelihood Detection (MLD) method performance. Being fixed-throughput in nature along with the fact that the breadth-first approaches are feed-forward detection schemes and makes them especially attractive one for implementation in VLSI. At first, the K-best algorithm is implemented using MATLAB and the minimum child for transmission is selected for 10 cycles and 64 constellations. Moreover, it efficiently expands a very small fraction of all possible children and it is applied to the infinite lattices. At last it provides the exact K-best solution, i.e., the shortest path for transmission in Multiple Input Multiple Output (MIMO) system, and the proposed scheme denotes the input sequence merge with the shortest path and it is find using the K best algorithm, and also the signal is transmitted using Additive White Gaussian Noise (AWGN) channel based on Quadrature Amplitude Modulation (QAM) technique and 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. Bit Error Rate (BER) shows the AWGN channel provides the amount of error involved in signal is less compared with Fast Fourier Transform (FFT) based scheme.**

***Index Terms*– K-best detectors, Long Term Evolution (LTE) systems, Multiple Input Multiple Output detection**

I. Introduction

The growing demand of multimedia services and the growth of Internet related contents lead to increasing interest for high speed communication schemes. One of the main challenges in exploiting the potential of MIMO systems is to design a low-complexity high-throughput detection schemes with near Maximum-Likelihood (ML) performance [1] which is suitable for an efficient Very Large Scale Integration (VLSI) realization. But, the complexity of the optimal ML detection scheme grows exponentially with the number of transmit antennas and its constellation size. Lower-complexity detectors such as Zero-Forcing (ZF), Minimum Mean-Square Error (MMSE) or Successive Interference Cancelation (SIC) detectors [2] reduce the computational complexity, at the same time they suffer from significant loss of performance.

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Near-optimal non-linear detectors [3] are the other alternative method. Depending on how they carry out the non-exhaustive search, near-optimal non-linear detection methods generally fall into main categories, like depth-first search, breadth-first search, and best-first search. Depth-first Sphere Decoding (SD) [4] is one of the most attractive depth-first approaches whose performance under the assumption of unlimited execution time, [3] is optimal. However, the actual runtime of the algorithm is dependent not only the channel realization, but also the operating signal-to-noise-ratio [5]. Among the breadth-first search methods, the most well-known approach is the K-best detection [6]. The K-best detection method guarantees a SNR-independent fixed-throughput with close to a performance of ML. Being fixed-throughput in nature along with the fact that the breadth-first approaches are feed-forward detection schemes, makes them attractive one for VLSI realization [17]. Also some efforts are made to done their implementation in VLSI [7], [8].

Higher-order constellation schemes such as 64-QAM and 256-QAM, the current child expansion and sorting schemes in those architectures are not efficient or scalable. For higher-order constellation architectures, the delay of the critical path increases for higher modulation orders, this limits the maximum achieved throughput. Moreover, various published architectures for the implementation of 4 ×4 16-QAM systems; an efficient high-throughput application specific integrated circuit (ASIC) implementation for 64-QAM systems at high data rate is still a major challenge [10].

For 16-QAM, K is chosen to be 5 while for 64-QAM, K=10 meaning that K value only doubles but the constellation quadruples, thus the sub-linear increased. It also has fixed critical path delay independent of the constellation, K value, and the number of antennas used in this system. Moreover, it efficiently expands a very small fraction of all possible children in the K-best algorithm.

II. MIMO SYSTEM

The MIMO techniques have been proposed as a high-speed wireless systems and its efficient solution. The requirement for wide bandwidth, flexibility imposes the use of efficient transmission methods that would fit to the characteristics of wideband channels in wireless environment for the channel is very complicated. In wireless environment the signal is propagating from the transmitter to the receiver along with different paths, and it is referred as multipath. Three factors which propagating the signal power drops: path loss, macroscopic fading and microscopic fading.

To find the diversity, signal is transmitted by using multiple (ideally) independent fading paths e.g. in time, frequency or space. Multiple-input- multiple-output (MIMO) exploit spatial diversity schemes by using several transmit and receive antennas. However the paper "MIMO principles" assumed frequency flat fading MIMO channels. Several different diversity modes are used to provide radio communications more strong, even with varying channels. These include time diversity (channel coding and different timeslots), frequency diversity (spread spectrum, different channels, and OFDM), and also a spatial diversity.

The use of multiple antennas at the transmitter or the receiver end is required in spatial diversity. Multiple antenna systems are usually known as Multiple Input, Multiple Output systems (MIMO). Multiple antenna technology can also be used to increase the data rate (spatial multiplexing) instead of improving robustness.

In practice, both methods are used separately or in combination, depending on the channel condition. A MIMO system typically consists of m transmit and n receive antennas. By using the same channel, every antenna receives not only the direct components proposed for it, but also the indirect components proposed for the other antennas. While indirect connections from antenna 1 to 2 are identified as h_{21}. This is shown in Figure 3.1.The following transmission formula results from transmit vector **x**, receive vector **y**, and noise **n**:

The received vector is given by,

$$Y=\mathbf{H}x+n. \quad (1)$$

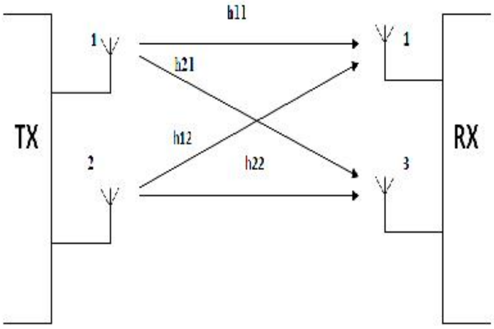


Figure 1. 2×2 MIMO system

Transmit Diversities are When a channel uses a multiple transmit antennas and multiple of receive antennas it is called a multiple-input, multiple output (MIMO) system.

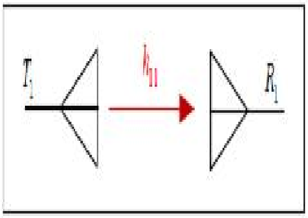


Figure 2. SISO channel

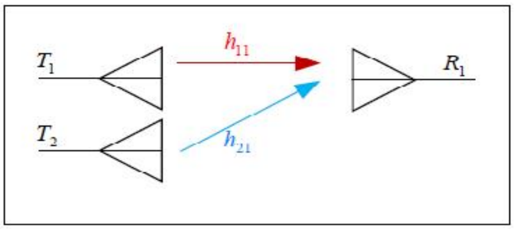


Figure 3. MISO channel

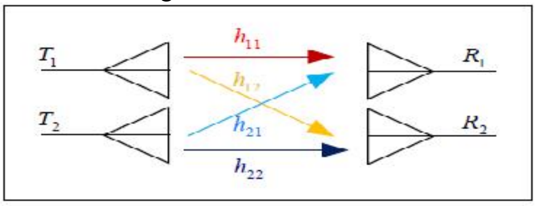


Figure 4. MIMO Channel

Functions of MIMO are classified as following:

Precoding is multi-stream beam forming, which is described in the narrowest definition. In more common terms, it is considered to be all spatial processing that occurs at the transmitter end.

Spatial multiplexing is defined as a high rate signal is split into multiple lower rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel. If these signals arrive at the receiver antenna array with suitably different spatial signatures, the receiver can divide these streams into (almost) parallel channels

Diversity Coding techniques are discussed when there is no channel knowledge at the transmitter end. In diversity methods, a single stream (unlike multiple streams in spatial multiplexing) is transmitted, but which the techniques called space-time coding used for to done the signal is coded.

III. K-BEST ALGORITHM

The exhaustive-search ML detection is impracticable to implement for large constellation sizes (i.e., 64-QAM and larger) because of its exponential complexity. The K-best detection algorithm is a near-ML technique to solve this above problem with a much lower complexity. The K-best algorithm explores the tree from the root to the leaves by expanding each level and selecting those best candidates with the lowest path metric is possible in each level that are the surviving nodes of that level.

The path with the lowest Partial Euclidean Distance (PED) at the last level of the tree is the hard-decision output of the detector, whereas, for a soft-decision output, all of the existing paths at the last level are considered to calculate shortest path node. The size of this exhaustive expansion grows significantly when the constellation size is increased one. Therefore, at each level the better ways are needed to calculate the K best candidates without performing an exhaustive search.

There are two main computations that play critical roles in the total computational complexity of the algorithm, namely, 1) the expansion of the surviving paths, and 2) the sorting. Therefore, the important part of any VLSI realization of the K-best algorithm is an efficient architecture to implement these two computational techniques.

1) Expansion: The K-best algorithm establishas in each level all the possible children of a parent node. Since there are √M parent nodes at each level and children per parent, thus the path metrics of K√M children to be computed at every level, which incurs a large computational complexity. The phase shift keying (PSK) enumeration scheme [9], which is based on multiple base-centric circles, or its simplified analysis for an M-QAM systems, [11], have been proposed to simplify the enumeration process. Moreover, in [12], a different variation of the base-centric search methodology is used, in which the joint SD algorithm, successive interference cancelation methods are employed. A relaxed K-best enumeration scheme is also proposed in [13] based on the PSK enumeration. Although these methods are simpler to implement, they didn’t linearly scale with the constellation size (such as [10]) and having performance loss compared to the exact K-best implementation method (such as [12-13]).

2) Efficient expansion method called the on-demand expansion scheme, which avoids the exhaustive enumeration of the children while providing all the information required for the exact K-best implementation with no performance degradation, which, to the best of our knowledge, is the only expansion scheme to-date with a computational complexity proportional to the K value and independent of the constellation size.

2) Sorting: Based on the algorithm in each level of the tree there are K√M children to be sorted. Among all the sorting algorithms bubble sorting is the most effective one, which distributes the sorting over multiple cycles [6]. Using bubble sorting, it takes K√M cycles to obtain the sorted list in each level. This is time-intensive for large values of K and M, which ultimately limits the throughput. In [8], a distributed sorting method is proposed based on the Schnorr-Euchner (SE) ordered search technique.

However, it requires a parent node and it’s all the children to be calculated by a metric computation unit and is applicable only for K≤√M, and thus cannot be applied to K=10 and K=15. Moreover, for higher values of K, the proposed single-cycle merge core in [8] becomes increasingly complex resulting in a long critical path. Therefore, [8] is not a suitable platform to achieve high throughput for higher order modulations like 64-QAM and 256-QAM where the value of K is large (e.g. K=10 for 64-QAM and K=15 for 256-QAM).

IV. K-BEST DETECTION SCHEME

Consider level L of the tree and assume the set of K-best candidates in level L+1(denoted by KL+1) is known. Each node in level L+1 have √M possible children, so there are K√M possible children in level. One of the main elements of our proposed scheme is to find the children of each node on-demand and in the order of increasing PED rather than calculating the PED of all the children exhaustively.

In other words, the key idea of the proposed distributed K-best scheme is to find the first child (FC) of each parent node in KL+1. Among these first children the one with the lowest PED is definitely one of the K-best candidates in KL. That child is selected and replaced by its next best sibling. This process repeats K times to find the K-best candidates in level L (KL). The same procedure is performed for each level of the tree.

The proposed scheme [1] is pictorially depicted In Fig. 6 for level L where √M =4 and K=3. It shows the way that KL is derived from KL+1. The input to the algorithm is the K best selected nodes of level L+1 that are the current parents with corresponding PEDs of 0.1, 0.4, and 0.6. Each parent can be further expanded to four off springs resulting in 12 children whose PEDs are shown in Fig. 6 Each parent can find its own first child without visiting all its children. Let CL represent the set consisting of all the current best children of all parents, and DL represent their corresponding PEDs in Fig. 6, CL= {-1,-3, 3}, With DL= {0.9, 0.6, 0.3}. Note that using the proposed scheme; only 5 children of 12 possible children are visited in Fig. 6 This savings becomes increasingly significant for large M values [1].

FIRST/NEXT CHILD SELECTION PROCEDURE

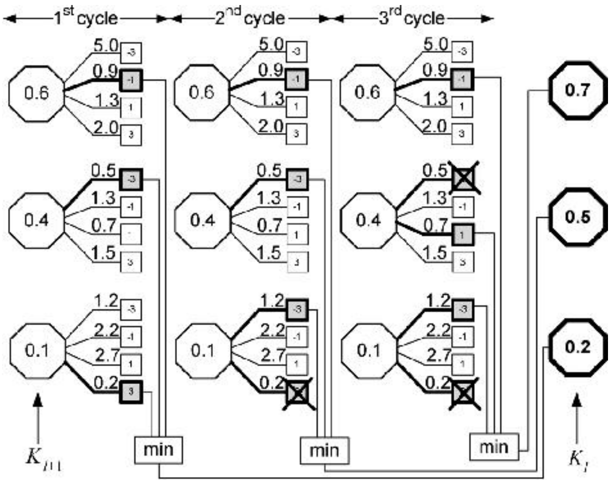


Figure.5. The K-best algorithm for √M =4 and K= 3and example PED values [1].

The features for the proposed scheme:

1) Hardware complexity does only scale weakly with the constellation size.

2) With respect to the K value, complexity scales sub-linearly with the constellation size.
3) Finds K best candidates in K clock cycles.
4) Has a fixed critical path delay independent of the constellation size and the K value.
5) Expands only 2K-1 out of KM possible children in the exhaustive K-best approach.
6) Can be applied to infinite lattices and be jointly applied with lattice reduction.
7) Provides the exact K-best solution with no approximation.
8) Can be easily extended to the complex domain.

K-Best Decoder is a Breadth-First algorithm [15] that expands only those K survivor nodes that show the smallest accumulated PEDs at each level of the decoding tree.

The detected signal vector ˆs is given by the path from the root up to the leaf node with the smallest total Euclidean distance. The main advantage of this method is that the maximum number of paths is limited, that yields a fixed computational effort and makes the algorithm hardware implementation easier. Variants of this algorithm also include a sphere radius in order to reduce the number of explored paths but unfortunately, this number is then non-fixed and unknown [20]. Thus the method can also be modified to work with different K values at different decoding levels, which is called Dynamic K-Best [18]. Dynamic K-Best will have the disadvantage of not having the same complexity at every level. For instance, for 16-QAM, K is chosen to be 5 while for 64-QAM, K=10 meaning that the constellation quadruples but the K value only doubles, thus the sub-linear increase.

It also has fixed critical path delay independent of the constellation order, K value, and the number of antennas. Moreover, it efficiently expands a very small fraction of all possible children in the K-best algorithm and can be applied to infinite lattices [16]. Finally it provides the exact K-best solution.

Consider level L of the tree and assume that the set of K-best candidates in level L+1 (denoted by) KL+1 is known. Each node in level L+1 have √M possible children, so there are K √M possible children in level. One of the main elements of our proposed scheme is to find the children of each node on-demand and in the order of increasing PED rather than calculating the PED of all the children exhaustively. In other words, the key idea of the proposed distributed K-best scheme is to find the first child (FC) of each parent node in KL+1. Among these first children the one with the lowest PED is definitely one of the K-best candidates in KL [19]. That child is selected and replaced by its next best sibling. This process repeats K times to find the K-best candidates in level L (KL). The same procedure is performed for each level of the tree.

V. CHANNEL SCHEMES

Additive white Gaussian noise (**AWGN**) is a channel model in which the only destruction to communication is a linear addition of white noise with a constant spectral density and a Gaussian distribution of amplitude. This model does not report for fading, selectivity, interference. The AWGN channel is a good model deep space communication links.

It is not a excellent model for most global links because of multipath, terrain blocking, interference. Still, for comprehensive path modeling, AWGN is commonly used to simulate background noise of the channel under study, in adding together to multipath, terrain blocking, interference, ground clutter and self-interference that modern radio systems encounter in terrestrial operation. The channel capacity of the AWGN channel is denoted,

$$c = \frac{1}{2}\log(1 + \frac{p}{n}) \tag{2}$$

VI. TRANSFORMATION TECHNIQUES

FFT and IFFT:

In MIMO system, the key components are the inverse FFT at the transmitter and FFT at the receiver, which performs reversible linear mappings between N complex data symbols and N complex MIMO symbols. An N-point FFT requires N log N multiplications rather than N^2. Due to this, an MIMO system typically requires fewer computations per unit time. Transmission of data in the frequency domain using an FFT, results in robustness against ISI in the time domain.The complexity of the receiver a guard symbol is introduced as a prefix extension. This converts the linear convolution of the signal and channel to a circular convolution. This technique, the guard interval should be greater than the channel delay spread. Thus, the relative length of the cyclic prefix depends on the ratio of the channel delay.

WPT and IWPT:

In Wavelet Modulation, if the message is not received at one rate due to channel disturbances, it can be received at another rate where the channel is clear. The wavelet transform is discrete both in time as well as scale and the transform is implemented using filters. It has two filters low-pass filter (LPF), while the other is a high-pass filter (HPF) is focused by down-sampler is to make the transform efficient.

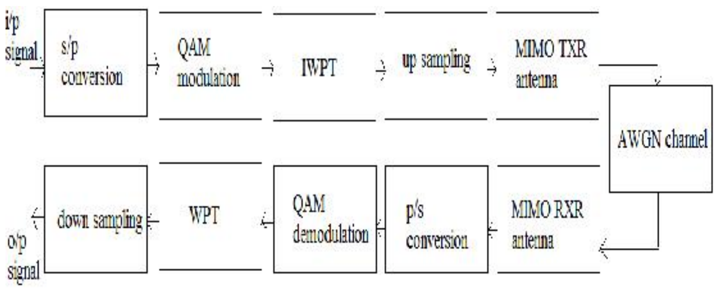


Figure 6.proposed WPM transceiver

WPT is equal to filtering a signal with a low pass and High pass filter bank, while the IWPT is corresponding to combining a low pass and high pass signal into one signal. The WPM transceiver as used in MIMO is illustrated in

Fig.6. The input signal is first converted from serial to parallel form and then modulated. There is an up sampling of input signal in each iteration of inverse wavelet packet transformation (IWPT). Now the signal is decomposed with HPF and LPF. In the receiver side, Wavelet Packet Transformation (WPT) is performed to convey the signals back to their original domain. In an iteration of WPT input signal is filtered by HPF and LPF, decaying original signal into two parts. Each of the decayed parts is then down sampled by two [21] & [22].

VII. EXPERIMENTATION RESULTS

Formation of Parent and Child Nodes

Random node generation from 1 to 10 nodes

X1= 0.8187 0.6020
0.5994 0.5602

Y1= 0.7305 0.9459
0.4895 0.8801

Similarly the node values from X2, Y2 to X10, Y10 are generated with the random 2x2 matrix sequence with above values.

Generation of Euclidean Distance to the Nodes

The minimum of 1st cycle=1.003592e-001
The minimum of 2 cycle=1.012401e-001
The minimum of 3 cycle=1.102664e-001
The minimum of 4 cycle=1.408507e-001
The minimum of 5 cycle=1.467164e-001
The minimum of 6 cycle=1.931812e-001
The minimum of 7 cycle=2.503752e-001
The minimum of 8 cycle=2.628570e-001
The minimum of 9 cycle=3.081613e-001
The minimum of 10 cycle=3.089010e-001

Shortest Path Formation

D1=0.3221, 0.6507, 0.5301, 0.7667
D2=0.4238, 0.5166, 0.4380, 0.7280
D3=0.6697, 100, 0.6791, 100
D4=0.7052, 100, 0.9851, 0.5131
D5=0.5587, 0.8055, 100,100
D6=0.5198, 0.4794, 0.6229, 0.5301
D7=0.9881, 0.6166, 0.7755, 100
D8=100, 0.8547, 0.3395, 0.4412
D9=0.5776, 0.9162, 0.5492, 0.357
D0=100, 100, 100, 0.4696

Random Input Binary Stream

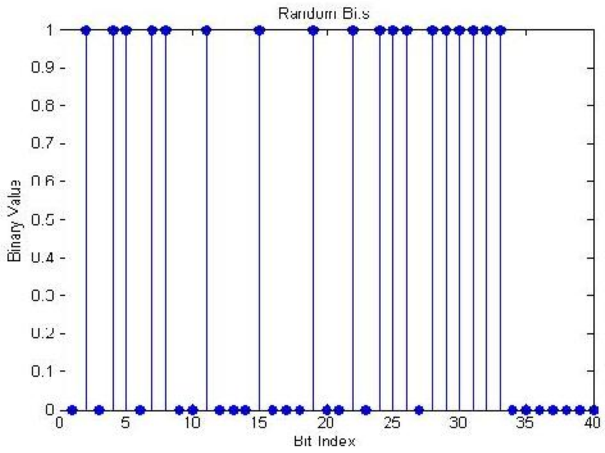
$$X = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$$

Input Stream through Shortest Path

(Input Signal)

X4= (3000X1) matrix

Figure 7.Random bits plot



The above figure shows the random bits generation for corresponding binary value with bit index, here o's and 1's are the binary value for all the random bits generated.

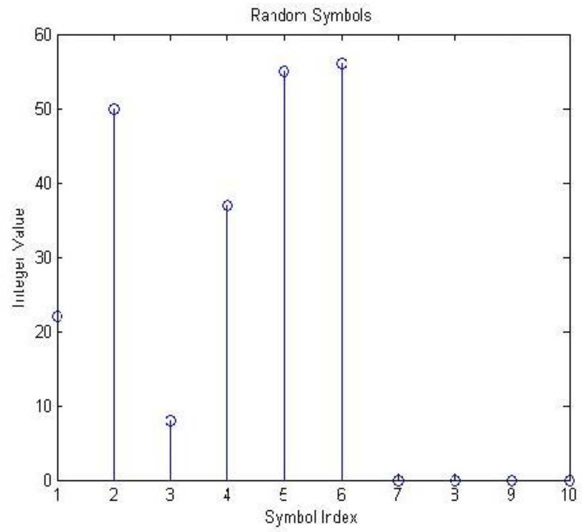


Figure 8. Random symbol plot

Random symbol plot is constructed with respect to integer value and system index, normally Redundancy can also add in the encoded bits for error correction, in that Serial to parallel converter the data symbol is split in to several data blocks to perform IFFT and IWPT operations.

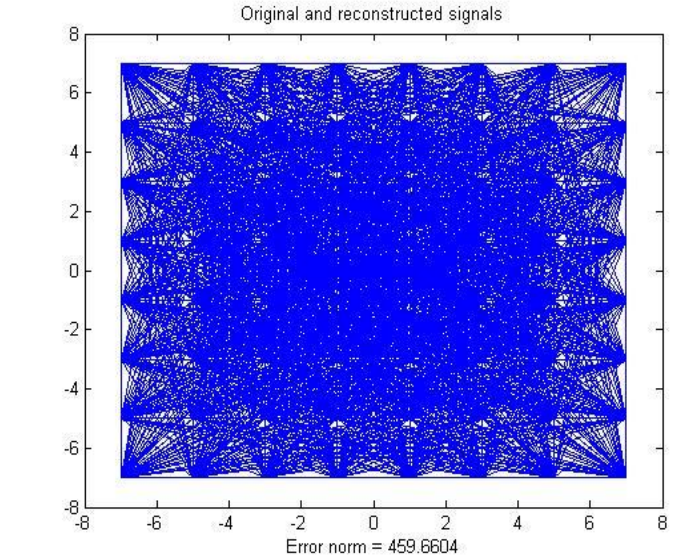


Figure 9.Reconstructed plot for WPT

Reconstructed plot for wavelet packet transform technique denotes it provides the multi rate transmission for corresponding normalized error value.

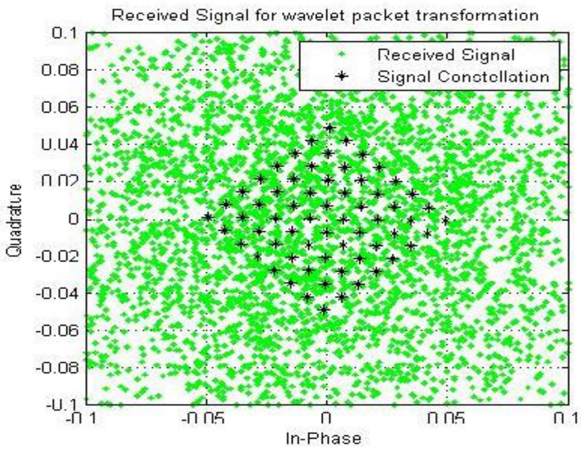


Figure 10.scatterplot for WPT

Scatterplot for WPT denotes the signal strength is better than FFT method of transformation.

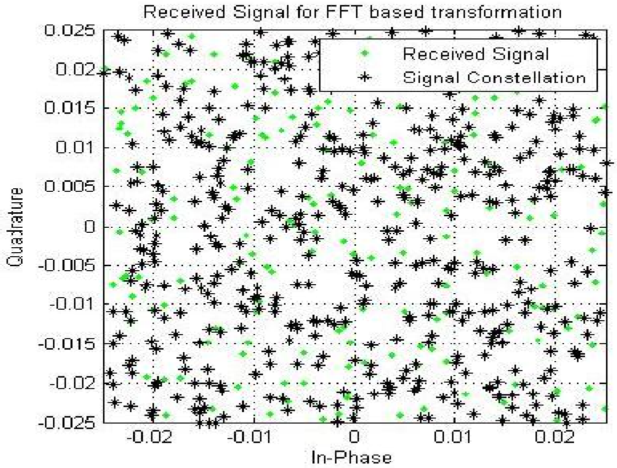


Figure 11.scatterplot for FFT

Scatterplot for FFT denotes the signal strength is poor than WPT method of transformation.

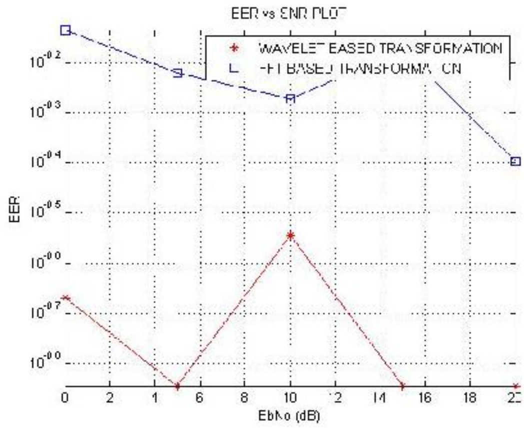


Figure 12.BER vs.SNR plot

VIII. CONCLUSION

This work discusses about improvement in performance of Multiple Input Multiple Output system based on K best algorithm. To achieve this aim, the project was carried out with following objectives. PED based K best algorithm which is used to provide the shortest path in between source to destination. To merge the input sequence with the shortest path and sent via the Additive White Gaussian Noise channel corresponding to the FFT and WPT transformation techniques and to provide the better signal strength for WPT compared with the FFT. SNR Vs. BER calculated for both FFT and WPT transformation techniques. In future, to implement the proposed WPT based MIMO system using Field Programmable Gate Array (FPGA) implementation and also adds the features of data rate, throughput and latency per cycle's calculations for proposed system.

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