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Low Complexity Decoding Algorithm for Rotated Quasi Orthogonal Space Time Block Codes for Modified Sphere Decoder

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Abstract

In this paper, we have presented a new decoding algorithm based on the combination of spatial multiplexing and space time coding techniques under Rayleigh fading channel constraint in MIMO wireless communication systems to analyze the performance of modified Sphere decoder using different orthogonal space-time block coding techniques, like quasi and rotated quasi-orthogonal space-time block codes. It has been observed that noise and interference get reduced by our proposed encoders with lower complexity at the receiver end. This improves the noise and interference performance by offering low complexity at the receiver. The paper also focuses on the performance of the combining effect of the demodulation algorithms with several other STBCs in the outcome.

Keywords: Multiple Input Multiple Output (MIMO), Orthogonal Space Time Block Codes (OSTBC), Rotated QOSTBC, Sphere Decoder (SD),K sphere decoder & K+ sphere decoder.

INTRODUCTION

The complexity of ML detector is increased with the increase in a number of antennas and higher order modulation techniques resulting in significant performance degradation. In the case of QOSTBC, all the symbols are not completely decoupled, hence complexity increases exponentially. To overcome this problem we use sphere decoder instead of ML detector for the greater reduction of complexity. The sphere decoder introduced by Pohst in [41] and popularly named as the Fincke-Pohst algorithm, later it was modified by Fincke and Pohst in [42]. It is basically, a lattice decoding algorithm but later it became compatible with space time coding to reduce the complexity of ML detector. Lattice codes are set on digital transmission as high-rate signal constellations, which are turned by dividing a finite number of points from an n-dimensional lattice in the Euclidean space.

In literature, various algorithms are now available for decoding with an ever-improving efficiency. Conventional decoders do not take much advantage of the lattice structure which is beneficial for large bit-rate applications. These lattice codes are effective because they present a high modulation diversity algorithm proposed to solve the decoding problem for high dimensions practically. It basically searches through the points of the lattice which are found inside a sphere of given radius centred at the received point[37].This ensures that only the lattice points within the square distance radius from the received point are taken in the metric reduction. The advantage of sphere decoder is that its complexity does not depend upon the size of the constellation.

Authors in [2], presented a new fast maximum likelihood (ML)detection algorithm for quasi-orthogonal space-time block codes (QO-STBC) i.e. different from the conventional method. In [13], authors introduced the new scheme for quasi-orthogonal space-time block codes into two different Euclidean norms, thereby decoding separately by sphere decoder to find the two shortest vectors of two separate functions. With this scheme, the complexity gets reduced by 85 percent for more than four transmitting antennas, when compared to traditional SD algorithm. In [5], authors investigated the two decoding algorithm i.e. Maximum Likelihood and Sphere Decoder and observed that both the schemes have their own facts. Authors observed that full rate and full diversity QOSTBC with 16-QAM can be efficiently decoded by performing an exhaustive search. Further, it was observed that complexity was not sensitive to the number of receiving antennas and became independent of the SNR. The limitation of sphere decoder is its variable complexity and choosing the correct radius, which depends on the parameters, like, SNR and channel conditions.Fixed-complexity sphere decoder (FSD) of [30] can effectively “fix” the complexity order of conventional Sphere Decoder for $N_T \le N_R$ .However, the FSD is not strong enough for the condition $N_T > N_R$. For a MIMO system configuration with $N_T > N_R$, is not effective since the left pseudo inverse of channel matrix does not exist. To solve this problem, robustly fixed complexity sphere decoder (RFSD), which is robust to all the antenna configurations ($N_T > N_R$ and $N_T \le N_R$), proposed in [17] and has better BER performance as compared to FSD.The only issue with RFSD is its computational complexity. Authors in [16] proposed the solution to the drawback of RFSD by choosing a detection order, minimizing the upper bound of the power of the interference in single expansion (SE) stage. This is termed as “simplified robust fixed-complexity sphere decoder (SRFSD)”.

In [19], authors presented an efficient implementation scheme for sphere decoder algorithm that applies dynamic information storage and retrieval mechanism to keep away any repetition computation of past processed results. Memory-access architecture is constructed to make the implementation easier. The method puts forward uncommonly profits, the depth-first sphere decoder and its variants, as the simulation result shows 30–50 percent computational savings.Thus,it can be performed for any channelling. In [32], the authors compared the sphere decoder with other equalization techniques for both Rayleigh and Rician channel, constructed with different modulation techniques. The result shows Rayleigh channel shows better performance than the Rician channel in terms of BER.The results are depicted in tabular form.

In [14], the authors presented a new approach to fast decode the quasi-orthogonal space-time block codes. The analytical consistency between the phase of transmitted and received vectors also provided. It prefers proper applicants from pre-computed and arranged sets by emphasizing on the phase of an exact entry of the combined and decoupled vector. The ML metric of the most feasible applicants is first evaluated and the remaining candidates are determined i.e. based on the similarity between the phases. The advanced algorithm can be applied to perform with any form of the constellation like, QAM and PSK and supports concluded block-diagonal QOSTBCs.

Further, in [29], authors presented new widely linear sphere decoder for the detection of circular signals, like M-ary PSK and M-aryQAM.First of all, a mathematical model is derived to represent the conjugate symmetry of constellations like, M-PSK/M-QAM signals that depend upon the phase rotation matrix by separating the constellation of multiple inputs multiple outputs (MIMO) signals into subsets. Signals in the subset share the same PRM (phase rotation matrix). For detection at the receiver end, a widely used linear receiver is suggested in each subset. In order to avoid the repetitions of this widely used linear processing at each subset, a widely linear sphere decoder is added for MIMO systems. In [31], an algorithm, namely, hypercube demodulator was proposed for symbol detection in multidimensional constellations as a method to broadly used sphere decoder algorithms. The theoretical result indicates that the upper and lower bounds for the gain of the proposed demodulator algorithm give ten times better result than the conventional method. In[43], authors proposed a new two-stage detector on the K-best SD to achieve near-optimal result while imposing low computational burden at the receiver side for GSM channel. Basically, it considers the inactive antennas and the modulated symbols one-by-one manner by exploiting the null space of the GSM channel and the QL decomposition structure, respectively.

SYSTEM MODEL

Consider the system in which$M_T$represent the number of transmit antennas and $p$represent the numberof time periods for transmission of one block of coded symbols. Let us also assumethat the signal constellation consists of 2^mpoints. Then each encoding operationmaps a block of kminformation bits into the signal constellation to select $k$modulated signals $s_1, s_2, \dots\dots, s_k$, where each group of $m$bits selects a constellationsignal. These $k$modulated signals are then encoded in a space-time block encoderto generate $M_T$parallel signal sequences of length p, as shown in Figure 1. Thisgives rise to a transmission matrix S of size$M_T \times p$. These sequences are transmittedthrough which$M_T$transmit antennas simultaneously in $p$time periods. Therefore, thenumber of symbols the encoder takes as its input in each encoding operation is k. The number of transmission periods required to transmit the entire S matrix is p.The rateof the space-time block code is defined as the ratio between the numberof symbols the encoder takes as its input and the number of space-time codedsymbols transmitted from each antenna. It is given by

$$R = \frac{k}{p}$$

The spectral efficiency of the space-time block code is given by

$$\eta = \frac{r_b}{B} = \frac{r_s m R}{r_s} = \frac{km}{p}\frac{bits}{s}/Hz$$

where $r_b$and $r_s$are the bit and symbol rate, respectively, and $B$is the bandwidth. The entries of the transmission matrix S are so chosen that they are linearcombinations of the $k$modulatedsymbols$s_1, s_2, \dots\dots, s_k$and their conjugates$s_1^*, s_2^*, \dots . s_k^*$. The matrix itself is so constructed based on orthogonal designssuch that [8].

$$S.S^H = c\ (|s_1|^2 + |s_2|^2 + \cdots |s_k|^2) I_{M_T}$$

where c is a constant, $M_T$is the number of transmit antennas, $S^H$is the Hermitianof S, and $I_{M_T}$is an $M_T \times M_T$identity matrix. This approach yields a diversity ofM_T. These code transmission matrixes are cleverly constructed such that the rowsand columns of each matrix are orthogonal to each other (i.e., the dot product ofeach row with another row is zero). If this condition is satisfied, eq.(1) will besatisfied, yielding the full transmit diversity of M_T. Another way of looking at thisproblem is recalling from linear algebra, that if the rows of a matrix are orthogonal (i.e., their dot product is zero), then the rows of that matrix are seemed independent.

This implies that each row contributes an eigenvalue (i.e., the matrix is of full rank). Hence, full transmit diversity s is achieved as each transmit antenna contributes toone row in that matrix. The code rates will, however, vary depending on how thematrix is constructed. Based on eq.(2), we can have R = 1, which is a full rate. This implies that there is no bandwidth expansion involved, whereas a code withrate $R < 1$ implies a bandwidth expansion factor of $1/R$. Code rates of unity (i.e., full rates) are relatively easily achievable ifthe matrix is real, but the choice for full-rate codes is more restricted if the matrixis complex. Using eq.(2), the orthogonality achieved in all cases enables us toachieve full transmit diversity, irrespective of the code rateand additionally allowsthe receiver to decouple the signals transmitted from different antennas. Consequently, a simple maximum likelihood decoding, based only on linear processingof the received signals, can be employed at the receiver.

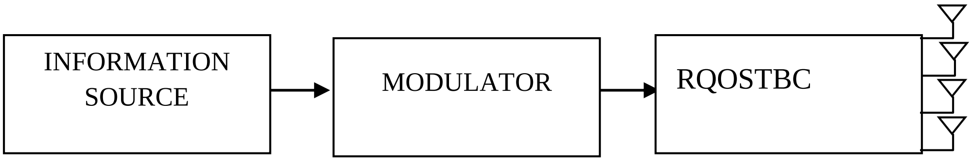

Figure 1: Encoder for RQOSTBC

OPTIMAL SOLUTION

The system capacity is defined as the maximum possible transmission rate such that the probability of error is arbitrarily small [56]. We assume that the channel knowledge is unavailable at the transmitter andknown only at the receiver.

The capacity of MIMO channel is defined as [4, 5]

$$C = \max_{f(s)} I(s;y)$$

where,f (**s**) is the probability distribution of the vector **s** and I (**s**; **y**) is the mutualinformation between vectors **s** and **y**. We note that

$$I(s;y) = H(y) - H(y|s)$$

where $H(y)$ is the differential entropy of the vector (y), while $H(y|s)$is the conditionaldifferential entropy of the vector **y**, given knowledge of the vector **s**. Since, the vectors **s** and nare independent, $H(y|s) = H(n)$. From (5),

$$I(s;y) = H(y) - H(n)$$

If we maximize the mutual information I (**s**; **y**) reduces to maximizing H(**y**).The covariance matrix of$y, R_{yy} = \in \{yy^H\}$,satisfies

$$R_{yy} = \frac{E_s}{M_T} HR_{ss}H^H + N_0 I_{M_R}$$

where $R_{ss} = \in \{ss^H\}$is the covariance matrix of **s**. Among all vectors **y** with a givencovariance matrix R_{yy}, the differential entropy H(y) is maximized when yisZMCSCG. This implies that **s** must also be ZMCSCG vector, the distribution ofwhich is completely characterized byR_{ss}. The differential entropies of the vectors y and n are given by

$$H(y) = \log_2(\det(\pi e R_{yy}))\ bps/Hz$$

$$H(n) = \log_2(\det(\pi e \sigma^2 I_{M_R}))\ bps/Hz$$

Therefore.$I(s;y)$ in (6) becomes

$$I(s;y) = \log_2 \det(I_{M_R} + \frac{E_s}{M_T N_0} HR_{ss}H \quad (10) \quad /Hz$$

From (4),the capacity of the MIMO channel is given by

$$C = \max_{T_r(R_{ss})=M_T} \log_2 \det(I_{M_R} + \frac{E_s}{M_T N_0} H \quad (11) \quad ps/Hz$$

The capacity C in (11) is also called error-free spectral efficiency or data rateper unit bandwidth that can be sustained reliably over the MIMO link. Thus, ifour bandwidth is W Hz, the maximum achievable data rate over this bandwidthusing MIMO techniques is WC bit/s [57]. (5)

The SNR at the receiver is given by$(\rho/M_T)\|H\|_F^2$and the capacity is given by [58]

$$C_{ROSTBC} = r_s(1 + \rho/M_T)\|H\| \quad (12)$$

Where$r_s$is the code rate. (6)

We know from the capacity of a MIMO channel when the channel isunknown to the transmitter is given by

$$C = \log_2 \det(I_{M_R} + \frac{E_s}{M_T N_0} HH^H)$$

$$= \log_2 \prod_{k=1}^{r} (1 + \rho/M_T \lambda_k) \quad (13)$$

(7)

$$= \log_2 \left(1 + \frac{\rho}{M_T}\|H\|_F^2 + \frac{\rho^2}{M_T}(.) \right. \quad (14)$$

$$\geq C_{RQOSTBC}$$

where $\lambda_k$are the eigenvalues of HH^H. The capacityof orthogonal space-time block code (OSTBC) channels is inferior to the channelwith optimal coding except in the case of Alamouti's scheme wherein the code rate$r_s = 1$ causing $C = C_{RQOSTBC}$. However, the outage properties of RQOSTBC will besuperior to the outage obtained with ((8) l coding for a given transmission rate,because RQOSTI (9) ıdamentally improves the link.

A. Quasi Orthogonal Space Time Block Codes (QOSTBC)

Full- rate orthogonal designs with complex elements in itstransmission matrix are impossible for more than two transmitantennas. The only example of a full-rate full-diversitycomplex STBC using orthogonal designs is Alamoutischemes[7].The generator matrix [7] of Alamouti code is given as

$$AorA_{12} = \begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{pmatrix}$$

Here, the subscript 12 shows the indeterminate x_1 and x_2 in the transmission matrix. To design full rate codes with complex constellation, we consider codes with decoding pair of symbols [12] Such codes are called QOSTBC's as shown below

$$A_J = \begin{bmatrix} A_{12} & A_{34} \\ -A_{34}^* & A_{12}^* \end{bmatrix} = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 \\ -x_2^* & x_1^* & -x_4^* & x_3^* \\ x_3^* & -x_4^* & x_1^* & x_2^* \\ x_4 & -x_3 & -x_2 & x_1 \end{bmatrix}$$

we denote the ith column of above matrix by v_i, then for any intermediate variable we have x_1, x_2, x_3, x_4, we have

$$(\mathrm{v}_1, v_2) = (v_1, v_3) = (v_2, v_4) = 0$$

where, in equation (19) symbols are inner product of each other independently. Therefore, the by v_1 and v_4 is orthogonal to v_2 and v_3 .So, it is named as "quasi-orthogonal" for the code.

B. Rotated Quasi Orthogonal Space Time Block Codes (R-QOSTBC)

It is impossible to achieve full rate and full diversity codeif all symbols are chosen from same constellation. To providefull diversity, different constellations are used for differentsymbols. This can be done by rotating the symbolsconstellation [10] before transmission. Let we rotate symbols $x_3$and x_4. before transmission and their rotated versions can berepresented as$\hat{x}_3$and$\hat{x}_4$.The generator matrix for such codesare given as

$$= \begin{bmatrix} x_1 & x_2 & \hat{x}_3 & \hat{x}_4 \\ -x_2^* & x_1^* & -\hat{x}_4^* & \hat{x}_3^* \\ \hat{x}_3^* & -\hat{x}_4^* & x_1^* & x_2^* \\ \hat{x}_4 & -\hat{x}_3 & -x_2 & x_1 \end{bmatrix}$$

Such codes will provide full diversity, full rate and simple pair-wise decoding.

DECODINGOF RQOSTBC

The decoding ofRQOSTBC is similar to the one proposed for Alamouti's scheme. We present the formula for decoding *G*3 and *G*4 [8].

The decoder for *G*3 minimizes the decision metric [8].

$$\left\| \left[\sum_{j=1}^{m} \left(r_1^j \alpha_{1,j}^* + r_2^j \alpha_{2,j}^* + r_3^i \alpha_{3,j}^* + r_4^i \alpha_{4,j}^* + \left(r_5^j\right)^* \alpha_{1,j} + \left(r_6^j\right)^* \alpha_{2,j} + \left(r_7^j\right)^* \right) \right] - s_1 \right\|^2 \quad (15)$$

$$+ \left(-1 + 2 \sum_{j=1}^{m} \sum_{i=1}^{3} \left|\alpha_{i,j}\right|^2 \right) |s_1|^2$$

for decoding s_1, the decision metric

$$\left\| \left[\sum_{j=1}^{m} \left(r_1^j \alpha_{2,j}^* - r_2^j \alpha_{1,j}^* + r_4^i \alpha_{3,j}^* + \left(r_5^j\right)^* \quad \left(r_6^j\right)^* \alpha_{1,j} + \left(r_8^j\right)^* \alpha_{3,j} \right) \right] - s_2 \right\|^2 \quad (16)$$

$$+ \left(-1 + 2 \sum_{j=1}^{m} \sum_{i=1}^{3} \left|\alpha_{i,j}\right|^2 \right) \quad (17)$$

for decoding s_2, the decision metric

$$\left\| \left[\sum_{j=1}^{m} \left(r_1^j \alpha_{3,j}^* - r_3^j \alpha_{1,j}^* - r_4^i \alpha_{2,j}^* + \left(r_5^j\right)^* \alpha_{3,j} - \left(r_7^j\right)^* \alpha_{1,j} - \left(r_8^j\right)^* \alpha_{2,j} \right) \right] - s_3 \right\|^2$$

$$+ \left(-1 + 2 \sum_{j=1}^{m} \sum_{i=1}^{3} \left|\alpha_{i,j}\right|^2 \right) |s_3|^2$$

for decoding s_3, the decision metric

$$\left\| \left[\sum_{j=1}^{m} \left(-r_2^j \alpha_{3,j}^* + r_3^j \alpha_{2,j}^* - r_4^i \alpha_{1,j}^* - \left(r_6^j\right)^* \alpha_{3,j} + \left(r_7^j\right)^* \alpha_{2,j} - \left(r_8^j\right)^* \alpha_{1,j} \right) \right] - s \right\|^2 \quad (18)$$

$$+ \left(-1 + 2 \sum_{j=1}^{m} \sum_{i=1}^{3} \left|\alpha_{i,j}\right|^2 \right) |s_4|^2$$

for decoding s_4.

The decoder for *G*4 minimizes the decision metric

$$\left\|\left[\sum_{j=1}^{m}\left(r_1^j\alpha_{1,j}^* + r_2^j\alpha_{2,j}^* + r_3^i\alpha_{3,j}^* + r_4^i\alpha_{4,j}^* + \left(r_5^j\right)^*\alpha_{1,j} + \left(r_6^j\right)^*\alpha_{2,j} + \left(r_7^j\right)^*\alpha_{3,j} + \left(r_8^j\right)^*\alpha_{4,j}\right)\right] - s_1\right|^2 + \left(-1 + 2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)|s_1|^2$$

for decoding s_1, the decision metric

$$\left\|\left[\sum_{j=1}^{m}\left(r_1^j\alpha_{2,j}^* - r_2^j\alpha_{1,j}^* - r_3^j\alpha_{4,j}^* + r_4^j\alpha_{3,j}^* + \left(r_5^j\right)^*\alpha_{2,j} - \left(r_6^j\right)^*\alpha_{1,j} - \left(r_7^j\right)^*\alpha_{4,j} + \left(r_8^j\right)^*\alpha_{3,j}\right)\right] - s_2\right|^2 + \left(-1 + 2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)|s_2|^2$$

for decoding s_2, the decision metric

$$\left\|\left[\sum_{j=1}^{m}\left(r_1^j\alpha_{3,j}^* + r_2^j\alpha_{4,j}^* - r_3^i\alpha_{1,j}^* - r_4^i\alpha_{2,j}^* + \left(r_5^j\right)^*\alpha_{3,j} + \left(r_6^j\right)^*\alpha_{4,j} - \left(r_7^j\right)^*\alpha_{1,j} - \left(r_8^j\right)^*\alpha_{2,j}\right)\right] - s_3\right|^2 + \left(-1 + 2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)|s_3|^2$$

for decoding s_3, the decision metric

$$\left\|\left[\sum_{j=1}^{m}\left(r_1^j\alpha_{4,j}^* - r_2^j\alpha_{3,j}^* + r_3^j\alpha_{2,j}^* - r_4^j\alpha_{1,j}^* + \left(r_5^j\right)^*\alpha_{4,j} - \left(r_6^j\right)^*\alpha_{3,j} + \left(r_7^j\right)^*\alpha_{2,j} - \left(r_8^j\right)^*\alpha_{1,j}\right)\right] - s_4\right|^2 + \left(-1 + 2\sum_{j=1}^{m}\sum_{i=1}^{3}\left|\alpha_{i,j}\right|^2\right)|s_4|^2$$

for decoding s_4.

SIMULATION RESULTS

In this section, simulation results (24) ning to the performance of RQOSTBC on Rayleigh fading channels is shown. It is assumed that the receiver has perfect CSI and that the fading between transmit and receive antennas is mutually independent.

Figure 2 shows BER vs. SNR curves for Sphere Decoder. For conventional OSTBC two transmit antennas are used with one receive antenna. The RQOSTBC with 4 transmit and one receive antenna does not have any effect on the system performance as the BER for both techniques is same. The RQOSTBC along with proposed SD algorithm reduces the BER of the system as depicted from the figure. Thus, better system performance in terms of BER is a (25) d.

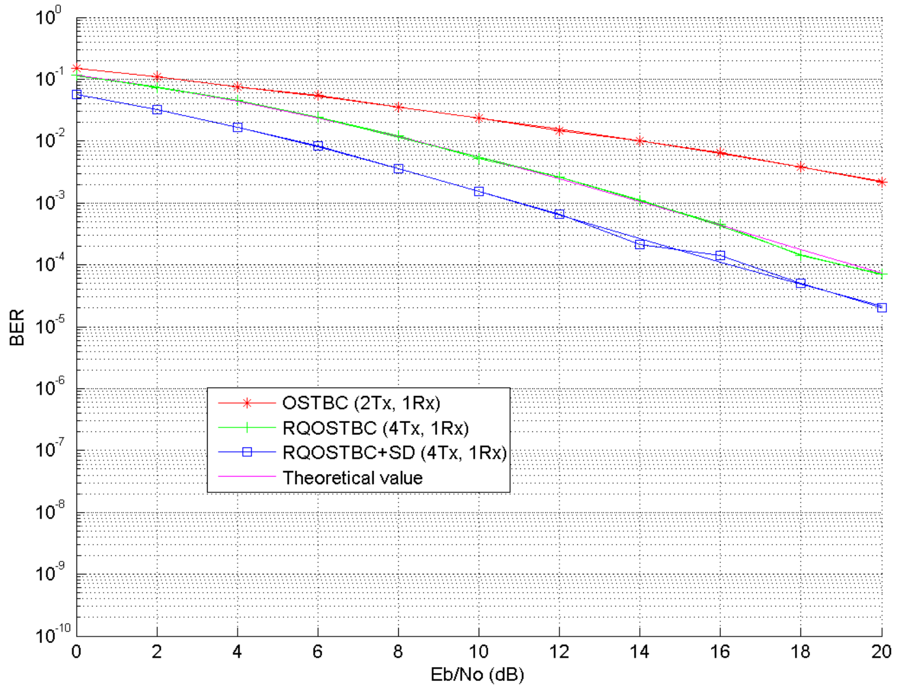

Figure 2: BER vs. SNR curves for Sphere Decoder with different STBCs

Figure3, shows the BER vs. SNR for proposed K shaped Sphere Decoder. In this Sphere Decoder even the conventional OSTBC with 2*1 combination has better performance than theoretical value with BER curve falling to 10^{-2} from 10^{-1}. The RQOSTBC further decrements the BER and the combination of RQOSTBC along with K SD algorithm reduces the BER to less than 10^{-3}.

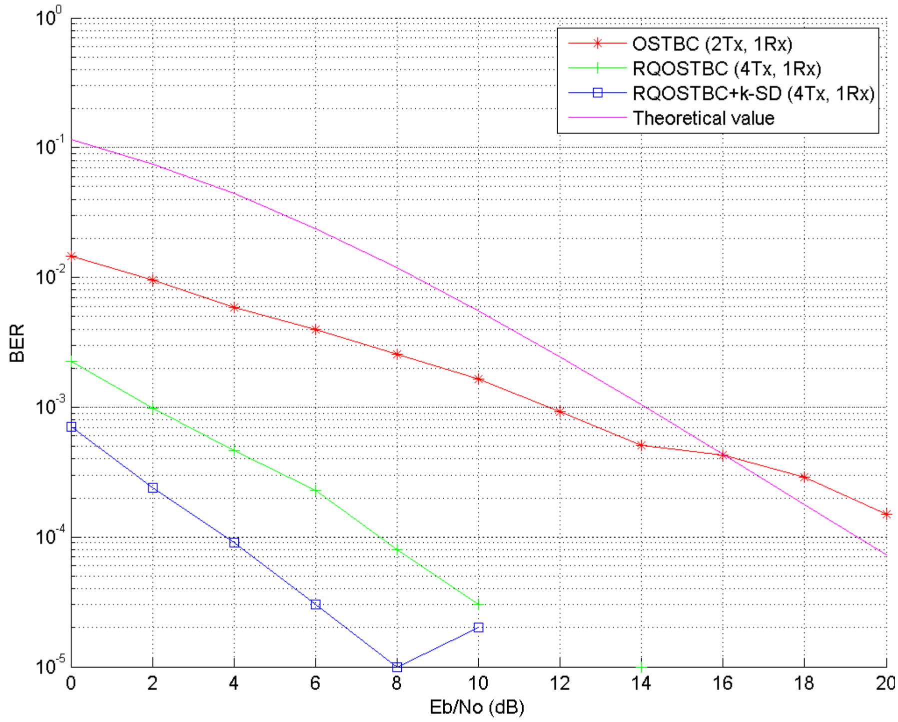

Figure 3: shows the BER vs. SNR for proposed K shaped Sphere Decoder

Figure4,shows BER vs. SNR for proposed K1 Sphere decoder. In the modified K1 Sphere Decoder our system drastically improves for all techniques. There is the significant reduction in BER as depicted from plots. The conventional OSTBC reduces the BER to $10^{-2.5}$. The proposed RQOSTBC reduces the BER to almost $10^{-3.8}$. The proposed k1- SD along with RQOSTBC further decrements the BER to almost $10^{-4.6}$. Thus the system performance gets improved drastically with new Sphere Decoding algorithm.

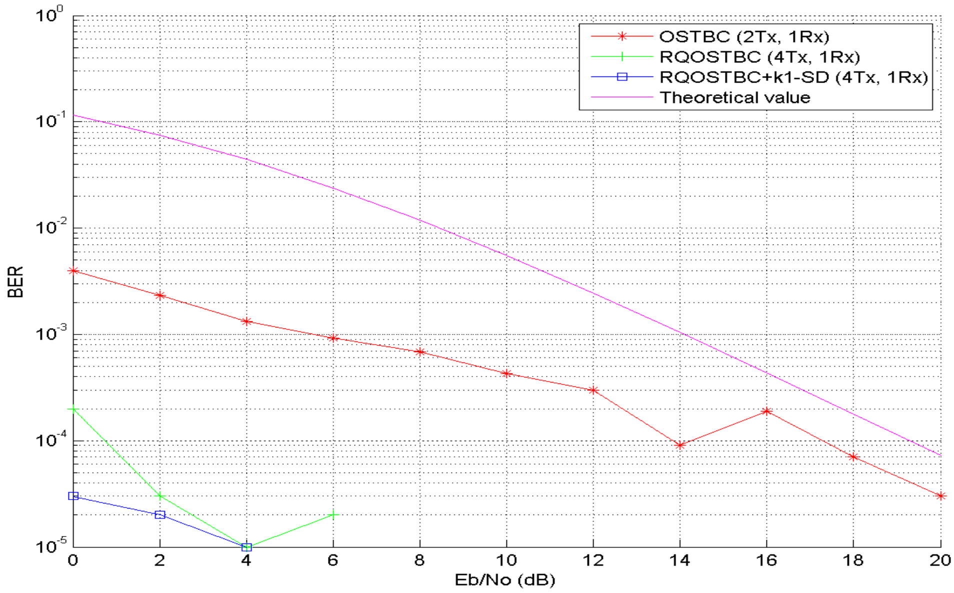

Figure 4: BER vs. SNR for proposed K1 Sphere decoder

Figure 5 compares all the proposed Sphere Decoders. The original Sphere Decoder has BER of about $10^{-2.4}$. The modified K Sphere Decoder has BER of about $10^{-3.9}$. Further modification in our algorithm that lead to k1 Sphere Decoder has BER of about $10^{-4.4}$. Thus it can be concluded the our modified k and K1 SD have better performance.

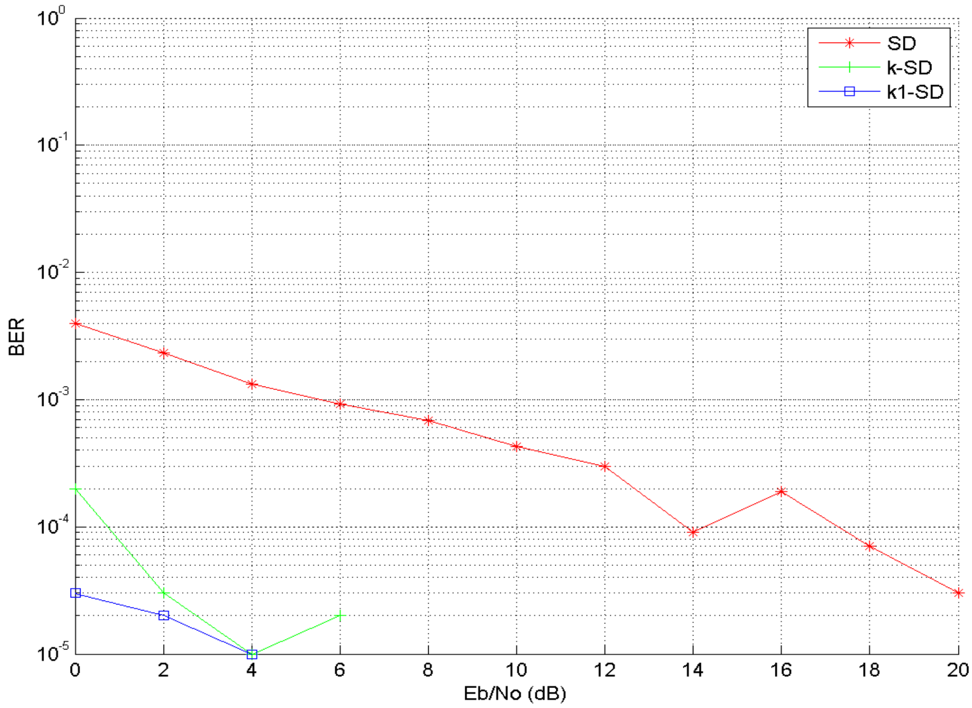

Figure 5: Comparisonof all the proposed Sphere Decoders

CONCLUSION

In this paper various steps have been taken to evaluate the performance of various Sphere Decoders under 64 QAM modulation techniques. A new k1 and k shaped Sphere decoder have been proposed to significantly reduce the BER. The proposed K1 SD provides significant system performance and can be used for next generation wireless communication system especially for 5G environment and IOT based devices.

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