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# Improving the System Capacity and BER Evaluation using Various M-Ary Symbol Mapping Constellations for Mimo Bicm-Id Model over block Fading Channels

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**ABSTRACT**

**In this paper, in order to improve BER and performance efficiency we have analyzed various symbol constellation/mappings for the MIMO BICM-ID over fading channels. To improve BER, minimizing pair-wise error probability plays a vital role for this an optimal constellation mapping is find out for the BICM-ID MIMO system. Also we will analyze the asymptotic pairwise error probability in the block fading MIMO channel by finding the minimum mean squared-error (MMSE) for the M-ary mapping. This analysis is then used to find out the optimized M-ary mapping scheme than can outperform over the various conventional mapping schemes of BICM-ID in the high SNR over block fading MIMO channels.**

## I. INTRODUCTION

Code diversity in wireless channels was introduced by Zehavi [1] by using a new technique called bit-interleaved coded modulation (BICM) and then later studied and improved by Caire et al. [2]. And Caire[2]proved that BICM performs much better than trellis coded modulation (TCM) [3] over fading channels. Further by applying iterative decoding to the bit-interleaved coded modulation (BICM-ID) [2] the drawbacks of traditional BICM was overcome. On both Gaussian and Rayleigh fading channels the BICM-ID bit error performance was much better as comparedto turbo TCM (TTCM) [4] with not much complexity. BICM-ID used only one SISO decoder as compared to TTCM which used two decoders. By designing the symbol mapping techniques for BICM-ID high harmonic mean Euclidean distance can be obtained for the better performance of BER in various fading channels. Furthermore the new concept of M-ary mapping was introduced for TCM in [5] which was applied upon the BICM-ID [6][7]. The multi-dimensional mappings gives better harmonic mean Euclidean distance over both Gaussian and Rayleigh fading channels. Also by these mappings neither the bandwidth was expanded nor was the power increased for reducing the bit error rate.

With the increasing demand of using various new wireless technologies and more secure services by using the limited radio spectrum a new techniquewas introduced knows as Multi Input Multi Output (MIMO) system which improved the spectrum efficiency and capacity of the system also[8][9]. To achieve high data rates in MIMO different spatial multiplexing techniques are introduced [10]. An example of it is V-BLAST (Vertical-Bell Labs Layered Space-time) but the use of these spatial techniques resulted in the loss of the diversity [11][12][13].Recently BICM technique for MIMO systems has been introduced for achieving the high data rates by not losing the spatial diversity. Müller-Weinfurtner [14] proved thatBICMMIMO system has very good performance in fast-fading channels. Furthermore the combination of BICM-ID and MIMO makes it an ease to work in low SNR region with high throughput that improves the bit error rate significantly [15].N. H. Tran and H. H. Nguyen proved that symbol mapping has a vital role in the bit error rate performance of BICM-ID system when the interleaver, signal constellation and the error code are kept constant or fixed[16][17][18]. And when this is applied on the BICM-ID MIMO channel this has same role in the performance of the system. In this paper multi-dimensional signal constellations are used instead of conventional mappings for improving BER and maximizing gain. By analysis and simulation results we will investigate the optimization of various mappings that can be used for the improvement of BICM-ID systems over various block fading MIMO channels.

This paper organization is as follows: In section II the MIMO system model is described. Section III gives the design criteria for various constellation mappings and pairwise BER over fading channels is shown. Section IV gives the comparison of various multi-dimensional symbol constellation mappings. Section V simulation results are presented and the discussion. In last the conclusion is provided in Section VI.

## II. MIMO BICM-ID SYSTEM MODEL

The multiple-access BICM-ID system model, consisting of the transmitter having channel encoder concatenated with the pseudorandom bit-interleaver combined with the M-ary mapper and the iterative receiver designed according to X. Li, A. Chindapol, and J. A. Rit[2], is shown in Fig. 1.

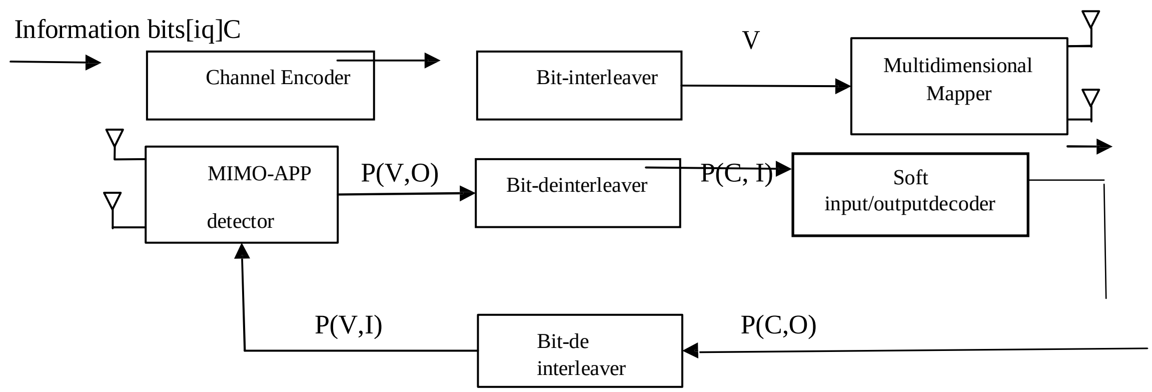


**Fig1.The transmitter and recieverofMIMO-BICM-ID system**

It is considered that the sequence of C coded and interleaved bits V, $[v_0,v_1,\ldots\ldots v_{n-1}]$arebreak into small blocks of x × ybits.Here $x = \log_2 X$ is the number of bits per conventional complexconstellationsymbol, X is the number of conventional constellation and y is the number of dimensions. Now the $n^{th}$symbolis denoted as

$$v_k = [v_{ko},v_{k1},\ldots\ldots\ldots.,v_{k(x\times y-1)}] \tag{1}$$

here$v_{ki}$ is combined coded and interleaved bit whose value is either 0 or 1. Now when these bits are mapped together with y paralled with X-ary signals that will result in much large constellation denoted as φ which have $X^y$ signals points. This mapping is now M-ary function given as

$$r_i=\mu(v_k) \tag{2}$$

hereμ denoted the M-ary function. As a result of this multi-dimensional mapping the bandwidth efficiency does not change because this mapping has a high data rate. For this the transmission technique used is the V-Blast and multi-dimensional antennas send the signals. Now the signal constellations can be represented as follows:

$$r_i = [z_{1,i},z_{2,i},\ldots\ldots\ldots.z_{n,i}]^t \tag{3}$$

Now the difference between this multi dimensional symbol mapping constellation and the various other simple mapping techniques is that here each symbol $z_{p,I}$ is a function of x × y bits while in simple mapping it is a function of only x bits which can be considered as function of only multi dimensional mapping where y=1 which does not change the spectral efficiency. Now these symbol bits are then transmitted over the Rayleigh fading MIMO channel having many transmitter $S_t$ and receiver $S_r$ antennas. Now at the receiver the baseband MIMO signal at a certain time interval having the Gaussian noise can be modeled as

$$b = Hc + n \tag{4}$$

where the received vector $b = [b_1,b_2, \ldots\ldots.b_{Sr}]^t$ and the transmitted vector $c = [c_1,c_2,\ldots\ldots\ldots,c_{St}]^t$ and the AWGN $n = [n_1,n_2, \ldots\ldots\ldots\ldots,n_{Sr}]^t$ with zero mean and variance. H denotes the complex MIMO matrix as $H\in C^{Sr\times St}$.

As shown in the above figure the receiver has a soft input and soft output decoder (SISO) which is explained by S. Benedetto, D. D ivsalar, G. Montorsi, and F. Poll[19]. The output of this SISO detector is P(C,O) which is the extrinsic probability received from the bit interleaver as P(C,I) and from the MIMO detector coded bits P(V,O). These two devices exchange this extrinsic information in interleaving manner and the de-interleaver takes input from the SISO as P(C,O) coded bits and gives priori probability as P(V,I). But the final iteration is done by the hard decision which is actually based upon post- priori probability.

## III. DESIGN CRITERIA FOR VARIOUS CONSTELLATION MAPPINGS

Alireza RabbaniAbolfazli, Yousef R. Shayan and XiaofangWang[27] derived an optimal mapping criteria which was based on pairwise error probability (PEP) expressed as $P(C_t \rightarrow \check{C}_t)$. When the decision is made only by the one signal duration of received signal then $P(C_t \rightarrow \check{C}_t)$ can be expressed as

$$P(C_t \rightarrow \check{C}_t) = R\left(\frac{d}{2\sigma_n}\right) \quad (5)$$

Where d is the Euclidean distance which can be expressed for a MIMO channel as

$$d = \sqrt{\left\|H((Ct \rightarrow \check{C}t)\right\|^2} \quad (6)$$

and$\sigma_n$ is the variance of Gaussian noise which can be denoted as $N_a/2$ so by putting these values in the equation (5) we get

$$P(C_t \rightarrow \check{C}_t) = R\left(\sqrt{\frac{\sqrt{\left\|H((Ct \rightarrow \check{C}t)\right\|^2}}{2N_a}}\right) \quad (7)$$

The chern off bound [20] gave Gaussian Tail approximation also known as upper bound for Q-function expressed as

$$R(x) \leq \frac{1}{2}\exp\left(-\frac{x^2}{2}\right), \ x \geq 0 \quad (8)$$

Now assuming two dimensional QPSK constellation scheme having two codewords as e and ê and having a hamming distance h then error probability can be given as

$$P(C_t \rightarrow \check{C}_t) = \left\{\frac{1}{q.2^q}\sum_{i=1}^{q}\sum_{b=0}^{1}\sum_{c_k \epsilon_{\varphi_b^i}}\sum_{\check{C}_k \epsilon_{\varphi_b^i}} P(Ct \rightarrow \check{C}t)\right\}^d \quad (9)$$

This pairwise error probability gives the performance of the mapping in error bounds where the Euclidean distance is very small. Based upon this the best mapping can be choosen by the optimization of the cost function denoted as δwhere

$$\delta = \frac{1}{xy.2^{xy+1}}\sum_{i=1}^{xy}\sum_{b=0}^{1}\sum_{c_k \epsilon_{\varphi_b^i}}\sum_{\check{C}_k \epsilon_{\varphi_b^i}} E_H\left[\exp\left(-\frac{\left\|H(Ct \rightarrow \check{C}t)\right\|^2}{4N_o}\right)\right] \quad (10)$$

From the above equation it is clear the δdepends upon the SNR and has symbol mapping effect on the overall performance of MIMO BICM-ID system. Smaller the value of δlower will be the BER performance.

Based upon [27] Muammar A. Alfasi, Yousef R. Shayan[28] further elaborated the multi dimensional mapping based upon the upper bound of the PEP and used coded sequences Y and Ŷ as follows

$$Y = (y_1, y_2, \ldots\ldots\ldots, y_d)$$
$$\hat{Y} = (\hat{y}_1, \hat{y}_2, \ldots\ldots\ldots, \hat{y}_d)$$

As both differ in the first d symbols and the PEP can be written as

$$P(Y, \hat{Y}|h_{i,j,b}) = Q\left(\sqrt{\frac{d_E^2\,(Y,\hat{Y})}{2N_o}}\right) \quad (12)$$

Here $d_E^2\,(Y,\hat{Y})$ is the Euclidean distance and for B block fading channels d is the multiple of B and then the Euclidean distance is

$$d_E^2\,(Y,\hat{Y}) = \sum_{b=1}^{B}\sum_{j=1}^{N}\sum_{l=1}^{d/B}\left|\sum_{i=1}^{M} x_{i,j,b}\,(z_{i,b,j} - \check{z}_{i,b,j})\right|^2 \quad (13)$$

Now according to [21] this Euclidean can be expressed as

$$E = d_E^2\,(Y,\hat{Y}) = \sum_{b=1}^{B}\sum_{j=1}^{N}\sum_{i=1}^{M}\lambda_{i,b}\left|\beta_{i,b,j}\right|^2 \quad (14)$$

Where $\left|\beta_{i,b,j}\right|$ is the Rayleigh distributed variables. Now if we consider the block fading channel of MIMO system and we apply the central limit theorem[22] on the Gaussian random variable [23] then the average pairwise error probability f(d,ψ,μ) on multi dimensional symbols is

$$f(d,\psi,\mu) \leq \left[\frac{1}{mn\, 2^{mn}} \sum_{x=\psi} \sum_{y=1}^{mn} \exp\left(\frac{-N}{4N_o} |u - \hat{u}(q)|^2\right)\right]^d \quad (15)$$

$\hat{u}(q)$ has the same number of bits as u except at q position where is a complement bit. This equation gives the impact of multi-dimensional mapping on the MIMO BICM-ID performance on the block fading Rayleigh channels. From the equation(15) the Cost function depends upon the number of antennas and the SNR, which is inversely proportional to the performance of the MIMO system. And to minimize the complexity of the system we again here used the BSA[24].

Similarly Ali Reza Rabbani Abolfazli, Yousef R. Shayan[29] in 2011 find the pair wise error probability by finding the average of all symbols constellation as follows

$$P(S_t \rightarrow \hat{S}_t) = \left\{\frac{1}{q.2^q} \sum_{i=1}^{q} \sum_{b=0}^{1} \sum_{c_k \epsilon_{\varphi_b^i}} \sum_{\check{C}_k \epsilon_{\varphi_b^i}} P(Ct \rightarrow \check{C}t)\right\}^d \quad (11)$$

It is clear from the above equation that the derived criterion depends upon the pairwise error probability and the Euclidean distance is maximized for a crowded constellation. So for a complex mapping Binary Search Algorithm can be used to avoid very long searches and minimize the complexity. Namshik Kim, Jinwoo Kim, Seung-Chan Lim, and HyuncheolPark[30] find the upper bound on BER of multi dimensional mapping. In this analysis of BER the derivation of moment generating function(MGF) of SNR is done at the output of MMSE detector and the upper bound of BER at the current cycle is find out as follows

$$P_b \leq \frac{1}{x} \sum_{y=y_f}^{\infty} c_d P(d) \quad (16)$$

Where $P_b$ is the BER of upper bound and $y_f$ is the Euclidean distance, $c_d$ is the error weight[25] and P(d) is the PEP for the codeword at the distance d. Now if we consider that all zero code words are transmitted then

$$P(d) = P_r\left\{\sum_{i=1}^{d} L_i < 0\right\} \quad (17)$$

In close form it is very difficult to calculate the value of $L_i$ we find approximately PEP value based upon MGF of $L_i$

$$P(d) = \int_{-c+j\infty}^{c+j\infty} M_{\sum_{i=1}^{d} L_i}(t) \frac{dt}{t} = \int_{-c+j\infty}^{c+j\infty} [M_L(t)]^d \frac{dt}{t} \quad (18)$$

The value of $M_L$ can be find out using the MGF of SNR as

$$M_L(t) = E_{z_k,b_k,n_k,i}[\exp(t.L)] \approx \sum_j p_j M\left(\frac{t(1-t)N_t}{E_s} d_j\ ;\ \acute{p}\right) \quad (19)$$

Now based upon the above equations we can now easily calculate the upper bound on the BER using MGF of SNR of the current cycle.

## IV. COMPARISON OF VARIOUS MULTI-DIMENSIONAL SYMBOL CONSTELLATION MAPPINGS

According to [27][28] and equation (10) we have seen that by minimize the cost function δ in each M-ary constellation the desired mapping can be obtained. With the help of binary search algorithm multi dimensional mappings can be obtained for 2 dimensional QPSK, 3-dimensional QPSK and 2-dimensional 8QAM and these are shown in fig 2, fig3. And fig 4 and their corresponding constellation diagrams are shown in table I,II and III.


**Fig.2:-dimensional QPS Kconstellation[27]**

**Table 1: Theproposedmappingfor2-dimensionalQPSKscheme**

| | | | |
|---|---|---|---|
| Y13,Y24→1 | Y11,Y21→2 | Y13,Y22→3 | Y11,Y23→4 |
| Y12,Y22→5 | Y14,Y23→6 | Y12,Y24→7 | Y14,Y21→8 |
| Y11,Y24→9 | Y13,Y21→10 | Y11,Y22→11 | Y13,Y23→12 |
| Y14,Y22→13 | Y11,Y23→14 | Y14,Y24→15 | Y11,Y21→16 |

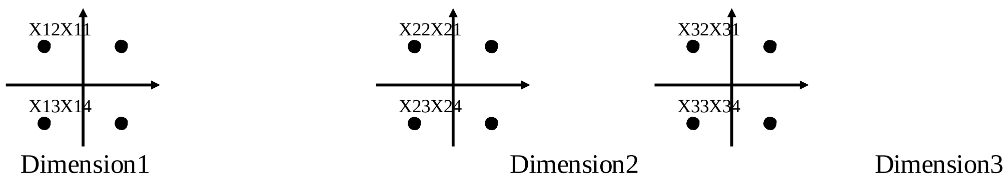


**Fig.3:-dimensional QPS Kconstellation**

**Table: 2-dimensional QPS Kscheme**

| | | |
|---|---|---|
| Y14,Y21,Y32→1 | Y12,Y23,Y32→2 | Y13,Y23,Y31→3 |
| Y11,Y21,Y34→4 | Y13,Y24,Y33→5 | Y14,Y22,Y31→6 |
| Y11,Y22,Y34→7 | Y13,Y24,Y32→8 | Y13,Y22,Y34→9 |
| Y11,Y24,Y34→10 | Y11,Y24,Y32→11 | Y13,Y22,Y32→12 |
| Y11,Y23,Y31→13 | Y13,Y21,Y33→14 | Y13,Y22,Y33→15 |
| Y11,Y24,Y31→16 | Y11,Y23,Y34→17 | Y13,Y21,Y31→18 |
| Y12,Y21,Y33→19 | Y14,Y23,Y32→20 | Y12,Y22,Y31→21 |
| Y11,Y24,Y33→22 | Y14,Y24,Y32→23 | Y12,Y22,Y34→24 |
| Y12,Y24,Y32→25 | Y14,Y22,Y33→26 | Y14,Y22,Y34→27 |
| Y12,Y24,Y31→28 | Y14,Y21,Y33→29 | Y12,Y23,Y31→30 |
| Y12,Y21,Y31→31 | Y14,Y23,Y33→32 | Y12,Y23,Y34→33 |
| Y14,Y21,Y34→34 | Y11,Y21,Y32→35 | Y12,Y23,Y33→36 |
| Y14,Y22,Y32→37 | Y12,Y24,Y33→38 | Y13,Y24,Y34→39 |
| Y11,Y22,Y31→40 | Y11,Y21,Y33→41 | Y13,Y23,Y32→42 |
| Y13,Y23,Y33→43 | Y11,Y21,Y31→44 | Y13,Y24,Y31→45 |
| Y11,Y22,Y33→46 | Y11,Y23,Y32→47 | Y13,Y21,Y34→48 |
| Y13,Y21,Y32→49 | Y11,Y23,Y33→50 | Y13,Y23,Y34→51 |
| Y14,Y21,Y31→52 | Y12,Y24,Y34→53 | Y13,Y22,Y31→54 |
| Y11,Y22,Y32→55 | Y14,Y24,Y33→56 | Y14,Y23,Y31→57 |
| Y12,Y21,Y34→58 | S12,S21,S32→59 | S14,S23,S34→60 |
| Y12,Y22,Y33→61 | Y14,Y24,Y31→62 | S14,S24,S34→63 |
| S12,S22,S32→64 | | |

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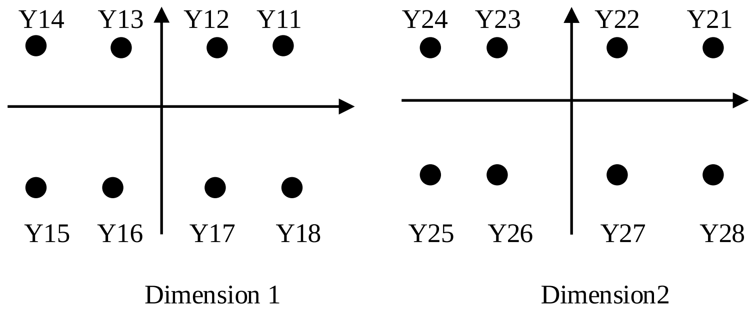


**Fig.4:-dimensional8QAMconstellationscheme**

**Table 3-dimensional8QAMscheme**

| | | | |
|---|---|---|---|
| Y18,Y26→1 | Y14,Y22→2 | Y16,Y21→3 | YS11,Y24→4 |
| Y15,Y23→5 | Y11,Y28→6 | Y11,Y27→7 | Y16,Y26→8 |
| Y15,Y22→9 | Y11,Y25→10 | Y18,Y23→11 | Y13,Y27→12 |
| Y12,Y27→13 | Y16,Y23→14 | Y14,Y26→15 | Y11,Y22→16 |
| Y13,Y21→17 | Y18,Y25→18 | Y16,Y25→19 | Y12,Y28→20 |
| Y18,Y22→21 | Y13,Y26→22 | Y14,Y28→23 | Y18,Y24→24 |
| Y12,Y26→25 | Y16,Y22→26 | Y13,Y28→27 | Y17,Y24→28 |
| Y15,Y24→29 | Y11,Y21→30 | Y17,Y23→31 | Y14,Y27→32 |
| Y15,Y21→33 | Y12,Y25→34 | Y13,Y25→35 | Y17,Y21→36 |
| Y12,Y22→37 | Y15,Y26→38 | Y15,Y28→39 | Y11,Y23→40 |
| Y11,Y26→41 | Y16,Y27→42 | Y16,Y28→43 | Y12,Y24→44 |
| Y15,Y25→45 | Y12,Y21→46 | Y12,Y23→47 | Y15,Y27→48 |
| Y14,Y25→49 | Y17,Y22→50 | Y18,Y27→51 | Y14,Y23→52 |
| Y17,Y25→53 | Y14,Y21→54 | Y13,Y23→55 | Y17,Y27→56 |
| Y18,Y21→57 | Y14,Y24→58 | Y16,Y24→59 | Y17,Y28→60 |
| Y13,Y22→61 | Y17,Y26→62 | Y18,Y28→63 | Y13,Y24→64 |

The parameter δ having SNR 10db is shown in Table IV. The cost function δ from equation (10) becomes relative to the harmonic mean distance for the bits ($d_h^2$) when average symbol energy is normalized to one. This effects the performance of MIMO BICM-ID system and it is shown that the mapping having the lower cost function have lower performance in the MIMO BICM-ID system. So for the optimum performance of any mapping we need to have the lower cost function δ and by taking into account the constellation diagram it is clear that the 3-dimensional QPSK has the smallest cost function δ.

**Table 4: Cost function δf or the above thr eemappings**

| Constellation and Mapping Type | δ | BER |
|---|---|---|
| 2-dimensionalQPSK | 8.33e-02 | 3.49db |
| 2-dimensional8QAM | 7.47e-02 | 2.68db |
| 3-dimensionalQPSK | 4.53e-02 | 2.41db |

Also now if we further move towards to find out more optimum mapping for any M-ary constellation multi dimensional mapping symbol over the Rayleigh fading channel we can also assume to have a 4-dimensional QPSK[28]. Again for minimizing the complexity of the system we again uses the BSA and implement this many times on the 4-dimensional QPSK with each time we take different initial mapping. With $N_r$ = 2 and SNR = 4db and implementing BSA on the 4-D QPSK over the Rayleigh fading channel gives us the result as shown in table V. In the Table VI it is shown that the traditional Gray mapping has the highest values for the cost function and the lowest value of harmonic mean Euclidean distance and this makes it worst performer in M-ary mapping. Then if we compare the optimized 4 dimensional mapping with the conventional 3-dimensional mapping purposed in [27], the optimized 4 dimensional mapping performs better.

**Table 5: Optimized 4-Dimensional QPS KMapping Index Assignments**

| | |
|---|---|
| 0000 | Y3Y3 |
| 0001 | Y2Y1 |
| 0010 | Y4Y1 |
| 0011 | Y1Y3 |
| 0100 | Y1Y2 |
| 0101 | Y4Y4 |
| 0110 | Y2Y4 |
| 0111 | Y3Y2 |
| 1000 | Y1Y4 |
| 1001 | Y4Y2 |
| 1010 | Y2Y2 |
| 1011 | Y3Y4 |
| 1100 | Y3Y1 |
| 1101 | Y2Y3 |
| 1110 | Y4Y3 |
| 1111 | Y1Y1 |

**Table 6: The cost function □andd$^2$ For Different QPS KMappings**

| Mapping | □□ | $d^2$ |
|---|---|---|
| Gray QPS Kmapping | 8e-02 | 2.0 |
| 3-dimensional QPSKProposedin[27] | 4.53e-02 | 4.78 |
| 4-dimesional | 5.22e-04 | 6.03 |

## V. SIMULATION RESULTS

In this section simulations are carried out for finding the error performance of the M-ary mapping symbols. We have studied many M-ary constellations in that tables IV and VI and these constellations are when applied to the MIMO system with parameters taken at transmitter as convolutional code a1 = {1101} and a2 = [1111][27] and the bit interleaver at 5000 bit block. The MIMO channel with spatial diversity with V-BLAST method for high data rate is taken. At the receiver two SISO blocks with detector and decoder exchange information in iterative manner. Also Maximum Likelihood (ML) detector and List Sphere Decoder is used to avoid the complexity. Fig 4 shows the comparison of BER for 1st and 5th iterations of set partitioning conventional QPSK and the 2-dimensional QPSK mappings which are applied to the 2x2 MIMO system. At very low SNR set partitioning conventional QPSK mapping performs better than the 2-dimensional QPSK mapping for the 1st iteration. Fig 5 shows the results using the 2-dimensional 8 QAM for the 2x2 MIMO system and fig 6 shows the 3-dimensional QPSK 3x3 MIMO channel. From table IV[27] it is clear that at lower SNR 3-dimensional QPSK desirable BER is achieved for lower cost function value. Fig 7 gives the comparison between the 3-dimesional QPSK[27] and the 4-dimesional QPSK[28] and iterations are taken from 1st to 7th. The BER for the 4-dimensional mapping is better than the 3-dimesional QPSK by 0.8 db nor by increasing the complexity or the cost factor. Also for the analytical equation of upper bound BER (18)(19) we use a 4-QAM constellation diagram(Nt=Nr=4).andnon recursive convolution code (NRC) with a fixed length for the code at 576 and for the interleaver at 23040 bits[30]. The Euclidean distance $d_f$ is taken as 10 and Rayleigh block coding and then it is find out performance of MIMO BICM-ID BER at high SNR region fig 8.

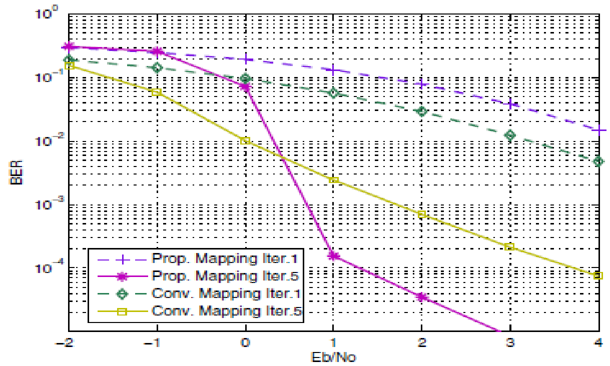


**Fig 5 BER comparison of 2-dimesional QPSK and set partitioning QPSK for 2 × 2MIMO**

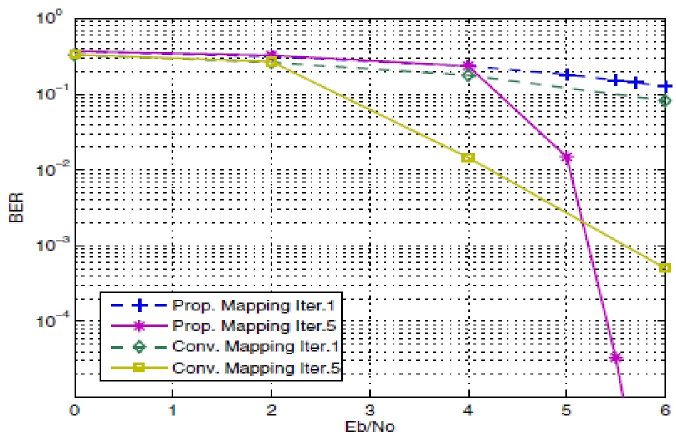


**Fig 6: BER comparison 2-dimesional 8QAM and set partitioning 8 QAM for 2×2MIMO**

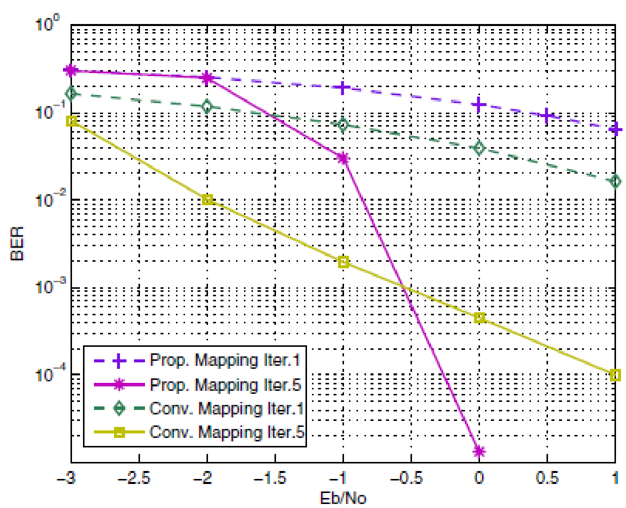


**Fig 7: BER comparison 3-dimesional QPSK and set partitioning QPSK 3x3 MIMO**

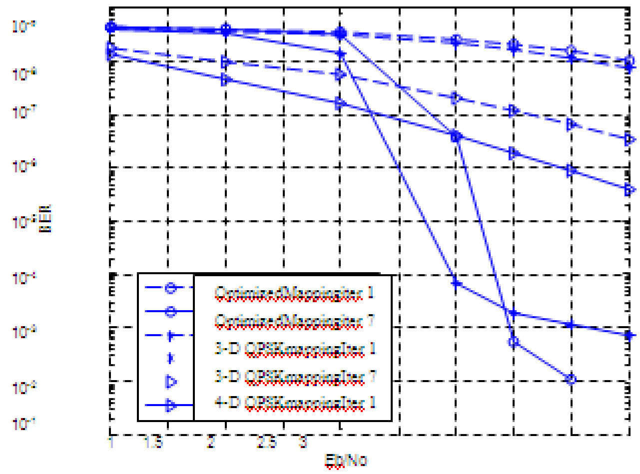


**Fig 8: BER performance for various QPSK mappings**

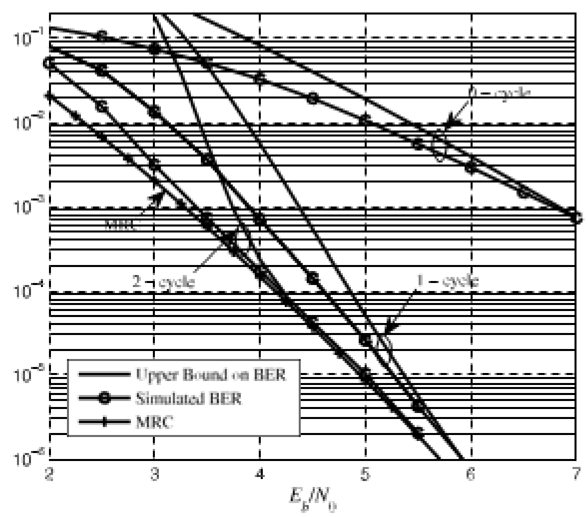


**Fig 9: BE Rateachcycle (Nt=Nr=4).**

## CONCLUSION

In this paper we investigated the MPW error probability and find the performance of various M-ary mappings for MIMO BICM-ID systems. Using the BSA for removing the complexity of M-ary mappings first we studied the cases for 2-dimensional QPSK, 2-dimensional 8QAM and 3-dimensional QPSK with the use of LSD at the receiver side. The simulations results above showed us that 3-dimesional mapping give better results at high SNR. These results showed us that 3-dimensional QPSK has a BER improvement over block fading channels 2.4dB. Now as we move towards the upper bound of pairwise error probability over a MIMO BICM-ID block fading channel the 4-dimensional QPSK performs more better having the same cost factor and using BSA. But the BER of MIMO BICM-ID calculated at the MMSE detector gives better performance for the upper bound MRC system.

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