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A Comparative Analysis of BIT Error Rate of Different Symbol Mapping Schemes for BICM-ID on Different Fading Channels

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Abstract

The combination of signal constellation with symbol labelling both are important for the improvement in E_b/N_o and BER when SNR is high inBICM-ID. The conventional gray mappers perform better when the SNR is <3db for both AWGN and Rayleigh fading channels. However there is a very limited performance of it when we move from medium to high SNR. So in this paper we comparatively investigate the properties and channel capacity of various mappers of used in BICM-ID. We will find out that which technique perform better in bit error probability compared to gray mapping technique when we move from low to high signal to noise ratio over both AWGN and Rayleigh fading channels. This comparative study will definitely motivate the researchers to develop new mapping technique for better and optimized performance for the fading channels.

Key Words:BICM-ID, Constellation mapping, gray mapping, SP labelling, MSED, Rayleigh fading, channel capacity.

1. Introduction

Ungerboeck proposed Trellis coded modulation (TCM) in 1982[1]. This was the bandwidth-efficient signaling technique based on set partitioning mapping. This modulation maximized the free Euclidean distance (FED) which improved the performance of the non-binary signal constellations like ASK, PSK and QAM on additive white Gaussian noise (AWGN) channel[2]. Set partitioning mapping, as compared to the Gray mapping used in earlier uncoded systems, achieved more performance gains using TCM. Imai and Hirakawa in 1977 proposed multilevel-coded modulation (MLC)[3][4] to optimize the code in the Euclidean space instead of Hamming distance and in comparison to TCM[1][2] it provided more flexible transmission rates. However it has the disadvantage that MLC required more multiple encoders and decoders.

When the primary design criteria shifted to different fading channels instead of AWGN the performance of TCM was significantly degraded. Now to improve the performance of TCM over fading channels a new interleaving approach, proposed by Zehavi[5] called as bit-interleaved coded modulation (BICM) was used.

But bit interleaving in BICM[5][6][7] caused random modulation by which the free Euclidian distance was reduced that makes BICM even more badly than Ungerboeck's TCM[1] over the AWGN channel. To overcome the above in 1993 by Berrou*et al* turbo code[8] were introduced and then X. Li and J. A. Ritcey[2] applied it on coded modulation (iterative de-coding) with BICM which led to BICM with Iterative Decoding (BICM-ID). This Iterative Decoding significantly improved the BICM's performance over Rayleigh fading channel as well as AWGN channel[2].

With the increasing use of wireless communication systems but limited radio spectrum, Multiple Input Multiple Output(MIMO)[9] systems were introduced. This advance MIMO technology have significant improvement in spectral efficiency [9] [10]. By proper utilizing of different antennas in MIMO allows very high data rates as well as reliable communication [11] [12] [13].

For given signal constellation, interleaver and convolutional code the bit mapping[14][15][16] is very important to improve the performance of BICM-ID system. Through various studies in BICM-ID system[17][18], now the criteria has changed from bit to symbol mapping. Now the plan is changed from the binary indices to the complex signal points to accomplish a maximum coding gain over the iterations. On this point several symbol mappings are proposed. So in this paper, we will thoroughly compare the characteristics of labeling maps as well as compare various techniques to find optimized mappings. The goals of the paper is organized as follows in Section II, we provide the BICM-ID system's model and its iterative processing procedure. Then in Section III, we discuss about various constellation and various mappings used in this study. Simulation results will be shown in Section IV and finally in last section we will conclude this paper.

2. BICM-ID System Model

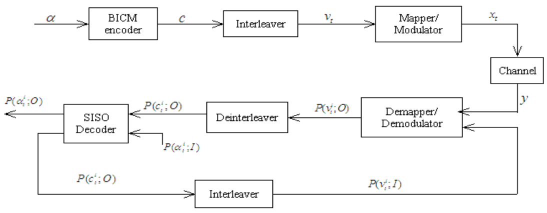


Fig. 1: Basic BICM-ID System Model

Fig 1 shows the block diagram of bit interleaved coded modulation with iterative decoding[5][6] in which the transmitter is a serial concatenation of BICM encoder, a bit interleaver(π) and a high order memory less modulator.In the fig 1 it is shown that the information sequence $\{\alpha t\}$ is encoded and the coded binary sequence $\{c_t\}$ is then given to the bit interleaver whose function is to break the fading correlation and also to increase the order of diversity with a minimum hamming code distance. Then the consecutive bits got from interleaver are grouped as $V_t=[v_t^1, v_t^2, v_t^3]$, that are mapped with help of memoryless mapper/modulator onto signal set given by χ which has a size of $|\chi| = M=2^m$ by using one to one mapping $\mu:\{0,1\}\rightarrow \chi$, $x=\mu(t)$ followed by the 8PSK signal[5][19] at a given time t by x_t,

$$x_t = \mu(x_t), x_t \in \chi \quad (1)$$

Here the 8-PSK signal above mentioned set is $\chi=\{\sqrt{E_s}e^{j2n\pi/8}, n = 0,1,2,\ldots\ldots,7\}$[19] where $Es$is the symbol energy. Now for a frequency non-selective Rayleigh fading channel with coherent detection, the received discrete-time signal can be expressed as

$$y_t= \rho_t x_t + n_t (2)$$

$x_t$is the transmitted symbol in M complex-valued and $\rho t$is the Rayleigh random variable with $E(\rho t) = 1$ giving the fading amplitude of the signal received. n_t is complex AWGN with one-sided spectral density N_0. For the AWGN channel, $\rho t$is set to 1. At the receiver side of the above figure of BICM-ID demodulation and convolutional decoding has been used as a suboptimal iterative process. As shown the demapper procedure receives complex symbols y_t and the respective priori log likelihood ratios known as LLR of the coded bits.

$$L_a(c_k(i)) = \log[\frac{P(ck(i))=0}{P(ck(i))=1}] \qquad (3)$$

and the extrinsic LLR is shown by equation

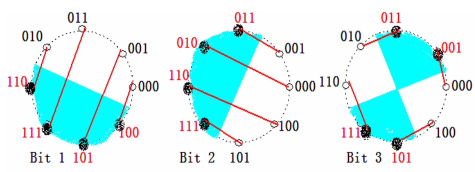
$$L_e(c_k(i)) = \log[\frac{P(ck(i))=0|rk,La(ck)}{P(ck(i))=1|rk,La(ck)}] - L_a(c_k(i)) \quad (4)$$

3. Comparison of Various Signal Constellations and Labeling Map

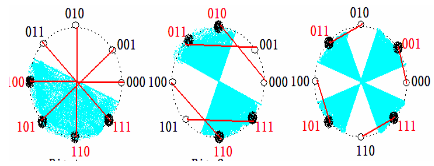
Various signal constellation labels are very important for the optimization of various decoding methods. Various signal constellations and labeling maps have been discussed here.

Classic Constellation Mapping Schemes

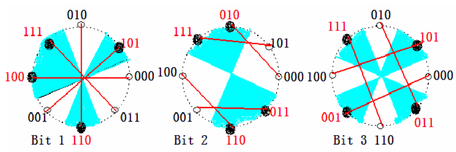
First the comparison of different labels [5] are shown in Fig 2.



Gray Labelling



Set Partitioning Labelling



Semi Set Partitioning Labelling

Fig. 2: Three labeling maps Gray, Set Partitioning and also Semi Set partitioning are shown in which the shaded regions represent the decision regions for value of one for each bit. The blue regions represents χ (i,1) , and the white χ (i,0)[5]

From the above fig it is clear that these three labeling techniques have different Hamming distance properties of the labels for neighboring constellation points but the same intersubset Euclidean distances. After seeing the above labeling it is clear that the signal labeling impacts critically on the BICM-ID[5] performance. This can be approximated by the equation over Rayleigh fading channel as follows

$$\mathrm{Log}_{10}P_a = \frac{-d(C)}{10}[R d_h^2(\mu))_{db} + (\frac{E_b}{N_o})_{db}] + \text{constant} \quad (5)$$

In the above equation P_a is the bit error probability, d(c) is the minimum Hamming distance code, harmonic mean is denoted by $d_h^2(\mu)$ where information rate is R. $d_h^2(\mu)$ can be calculated for any M-ary constellation as follows

$$d_h^2(\mu) = \left(\frac{1}{m2^m}\sum_{i=1}^{m}\sum_{b=0}^{1}\sum_{x_t=X_b^i}\frac{1}{||x-z||}\right)^{-1} \quad (6)$$

From the above equation is it clear that to design the labelling map μ ||x-z|| must be larger for all x so that ID gain is achieved and also we have to maximize the $d_h^2(\mu)$ so that the first iteration will work well.

Improved Symbol Mappings for BICM ID

Based upon the above Liu Na, Li Jianping, CaiChaoshi [20] proposed an improved modulation scheme composed of two QPSK with different radius. The new signal set is given by

$$\chi = r_a\sqrt{E_s}e^{j2\pi/4 + 2\pi/8} \text{ where n = 1,……,4} \quad (7)$$

$$\chi = r_b\sqrt{E_s}e^{j2\pi/4 + 2\pi/8} \text{where n = 5,……,8} (8)$$

Now the new signal constellation and design mappings given by Liu Na, Li Jianping, CaiChaoshi [20] it is verified that the new mapping could provide thebetter performance for high SNR than Gray, SP, SSP as they have large $d_h^2(\mu)$.

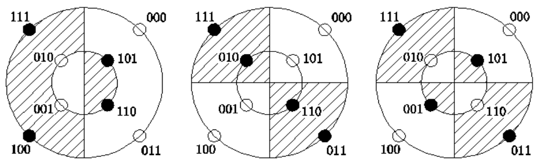


Fig 3: The Improved Symbol Mapping given by Liu Na, Li Jianping, CaiChaoshi[20]

Above fig shows that the two points in the inner circle and the outer circle are in the same phase and $r_a$is the radius of the outer circle and $r_b$is the radius of the inner circle. The ratio between the radius of the outer and inner circles is approximate to 2.5, which is larger than the ratio in [14]. After that XinjiTian and Lin Li [21] proposed a new 8PSK signal mapping using binary switching algorithm.

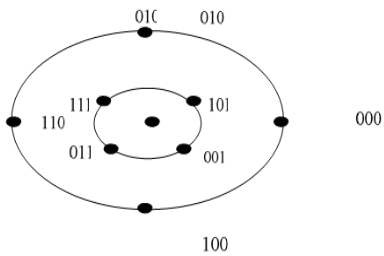


Fig. 4: The New 8PSK Signal Mapping that XinjiTian and Lin Li Proposed[21]

XinjiTian and Lin Li [21] used three basic mappings which are Set partition, Semi Set partition and Maximum Set partition as illustrated in the Fig 5 and calculated the average number *t* bits which has different constellation mapping signal points and it is shown in table 1 that the proposed new 8PSK signal modulation mapping has minimum*t*.

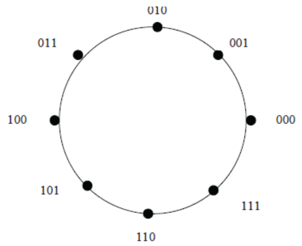


Fig. 5a: 8PSK SSP Mapping

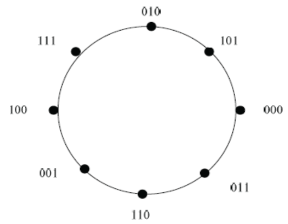


Fig. 5b: 8PSK SP Mapping

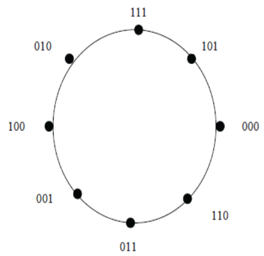


Fig. 5c: 8PSK MSP Mapping

Jianguo Yuan, Yang Song, YuexingJia ,Chuanlong Ye, Pang Yu, Lin Jinzhao[22] focused the design criteria on mutual information and the parameter used was the channel capacity. They proposed two novel symbol mapping

Table 1: Various Mappings and their Respective Value of t

Mapping	***t***
SP Mapping	1.74
SSP Mapping	2.23
MSP Mapping	1.812
Proposed Mapping	1.0

techniques as shown in Fig 6. Various measurements were taken to improve the existing conventional mapping technique. Different regions were analyzed using the values of $d_1d_2 \in \{11,01,00,10\}$ and also $d_3d_4 \in \{01,10,11,00\}$, and so based upon these regions the uppaer part of mapping is made. By finding the negative values of d_1d_2 at their symmetric position the new mapping scheme is presented and based upon this $d_E^2$is given by

$$d_{E,d1}^2 = \frac{\sqrt{13}\,\beta + \sqrt{5}\,\beta}{2}, \quad d_{E,d2}^2 = \sqrt{5}\,\beta,\ d_{E,d3}^2 = 2\sqrt{2}\,\beta,\ d_{E,d4}^2 = \frac{\sqrt{13}\,\beta + \sqrt{5}\,\beta}{2} \quad (9)$$

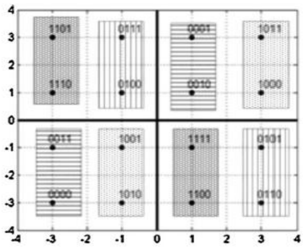


Fig. 6a: Novel 1 16QAM Mapping Proposed

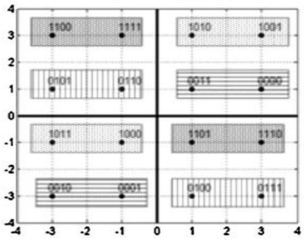


Fig. 6b: Novel 2 16QAM Mapping Proposed

By comparing this with the conventional Gray mapping it was clear that the novel approach has a degree increase of bit protection. Liu Na, Li Jianping, and CheQing[23] presented a symbol mapping having two M-PSK constellations both differ in radius and phases and named it as (4,12) symbol mapping. They gave a comparison between various symbol labeling schemes which shows that gray without ID $\boldsymbol{d_{E1}^2}$ performs better. However MSP, MSEW performance was good after ID but their harmonic mean before feedback $\boldsymbol{d_{E1}^2}$was poor. The table 2 clearly shows that the (4,12) 16-QAM symbol labelling technique has better harmonic mean before and after feedback and fig 13 clearly shows that (4,12) achieves 0.01 db better code gain over gray in Rayleigh fading channel.

Table 2: Harmonic Mean of MSED and the Asymptotic Gain

Over Various Labeling

Labeling	$\boldsymbol{d_{E1}^2}$**(before)**	$\boldsymbol{d_{E2}^2}$**(after)**	**Asymptotic Gain(db)**
(4,12)	0.739	2.118	1.46
MSEW	0.400	2.364	1.77
MSP	0.420	2.279	6.65
Gray	0.492	0.514	0.19

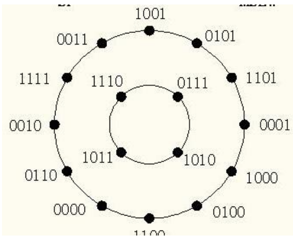


Fig. 7: (4,12) 16-QAM Technique

4. Simulation of Different Mappings Used in BICM-ID

In this section, we will discuss the effects and performance of BER of various symbol mappings on the BICM-ID over AWGN and Rayleigh fading channels. According to XinjiTian and Lin Li [21] and table 1 the symbol mapping they proposed has the lowest value of t. Based on the value of *t* a graph is made having the values of SP, SSP, MSP and a new proposed mapping with parameters as BER and E_b/N_o . Fig 8, shows the better performance of the new symbol labelling scheme.

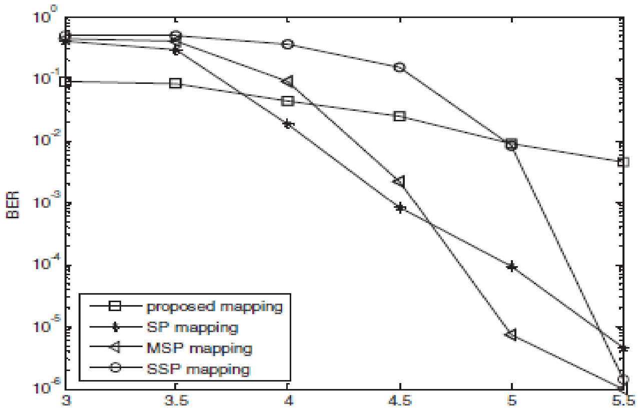


Fig. 8: BER Comparison of SP, SSP and MSP Mappings with the New One Proposed[21]

Numerical results of Euclidean distance before d_{E1}^2 and after feedback d_{E2}^2 were shown by Liu Na, Li Jianping, CaiChaoshi[20]. According to table 3 which gave a quick comparison between various symbol mappings it is clear that new improved mapping performs better with increasing SNR. However it does not show large d_{E1}^2 i.e. SNR as compared to gray mapping. This effect of symbol mapping is shown in Fig.9 where it was observed that without ID, the improved mapping is better than other mapping scheme when SNR is high.

Table 3: Euclidean Distance d_{E1}^2 before and d_{E2}^2 after Feedback Asymptotic Gain Over various Symbol Labeling

Labeling	d_{E1}^2(before)	d_{E2}^2(after)	Gain(dB)
Improvedmapping	0.5971	2.0680	5.3950
MSEW mapping	0.5858	2.8766	5.7442
Mixed mapping	0.5858	1.1082	1.6016
SSP mapping	0.5858	2.8766	5.7442
SP mapping	0.6641	1.2210	2.0226
Gray mapping	0.7665	0.8093	0.2365

However Gray mapping scheme performs better when SNR is low (<5db) and because of this the improve mapping can be replaced by Gray mapping under low SNR situations so an adaptive labelling scheme can be used which can be a mixture of Gray for low SNR and improved one for medium and high SNR.

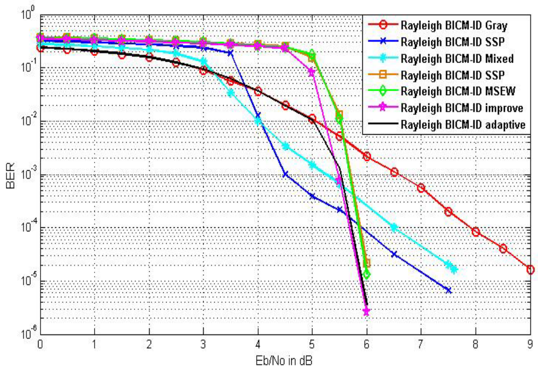


Fig. 9: Performance Comparisons of Various Mappings[20]

Rugui YAO, Yongjia ZHU, Juan XU, Fangqi GAO, Ling WANG[24] used QAM technique by replacing the 8PSK constellation[25][20][21] and turbo decoder and proposed a rotated mapping which showed more improvement that 8PSK constellation but as they compared the performance of new rotated QAM mapping with QAM gray mapping in AWGN channel and SNR ration was <3db, gray performed better. However with high SNR and for Rayleigh the BER performance of rotated mapping QAM was better as shown in fig 10. For the BICM system having a medium SNR (3.3>db<5.2) both the gray and rotated labeling have almost same BER performance. So for this a rotated mapping QAM with 2D iterative soft demodulating-decoding algorithm is used which achieves a larger gain of around 0.8-1.0 dB at BER = 10^6.

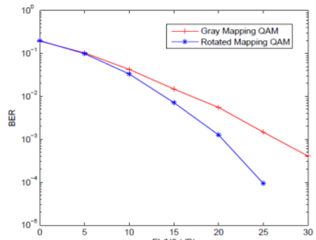


Fig. 10a: BER Performance of Gray Mapping and Rotated Mapping QAM Over Rayleigh Fading Channel for High SNR

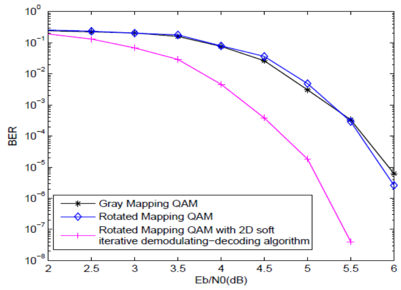


Fig. 10b: Performance of Different Mapping Schemes Over Rayleigh Fading Channel for Medium SNR

Jiaye Wang, Huaqing Zhang, YadongLv [26] also worked upon various symbol mappings and find the BER performance of BICM-ID over both the AWGN and Rayleigh fading channels Fig 11. It is shown that the newly proposed the OPT-MSEW which is a labeling scheme having two QPSK and different radius and phases can perform better when SNR is >7db over both the channels but for lower SNR again Gray mapping is the best.

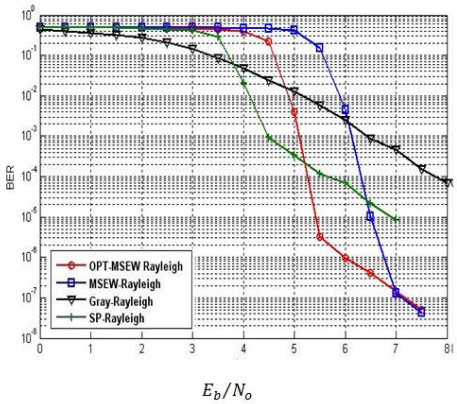


Fig. 11a: BER of Various Signal Constellation Labeling Methods of BICM-ID Over Rayleigh

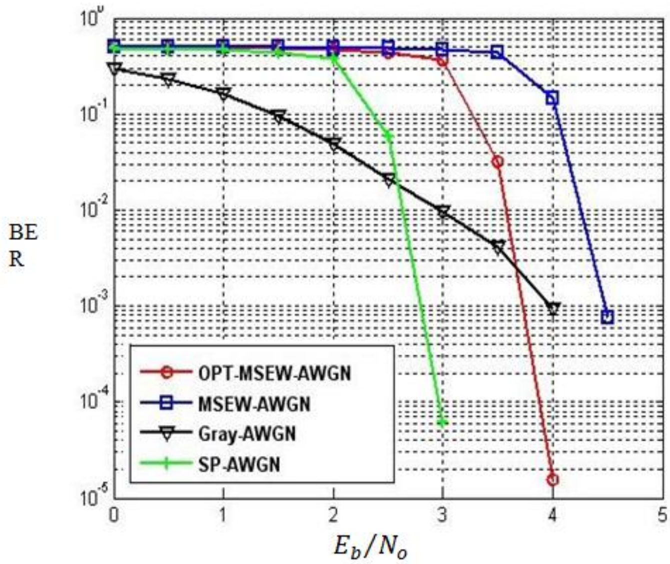


Fig. 11b: BER of Various Signal Constellation Labeling Methods of BICM-ID Over AWGN

Then Jianguo Yuan, Yang Song, YuexingJia, Chuanlong Ye, Pang Yu, Lin Jinzhao [22] gave the symbol labeling scheme for 16 QAM which give degree increase in the bit protection for the medium to high SNR as compared to gray mapping. It is shown through graph that capacity of the channel against SNR that is shown as E_b/N_o for different 16QAM constellations over an AWGN channel. After calculations it is shown that while gray mapping scheme keeps high capacity at lower SNR but at medium to high SNR is achieved with new novel approaches and the graph of capacity curve of both new symbol labeling and the gray mappings have a cross over point at SNR expressed in $E_b/N_o = 12.5\ db$ and the new novel approach have 1.58 bit/channel user which is much greater than the gray one at high SNR >7 db. And the transfer function is depicted in the EXIT charts (extrinsic information transfer) that optimized decoding performance. Their design objective turns out to accommodate mutual information transfer attributes of LDPC decoders by using variety of variable node degrees (VND). Commonly there tend to be the equivalent check node degrees (CND). whenever the Gray mapping is chosen the EXIT function of VND is nearly flat, although the Antigray mapping maintains greater EXIT performance. Whenever it comes to the projected novel symbol labeling strategy, complete feature of reduced region inside the EXIT chart is presented at the simulated EXIT line.

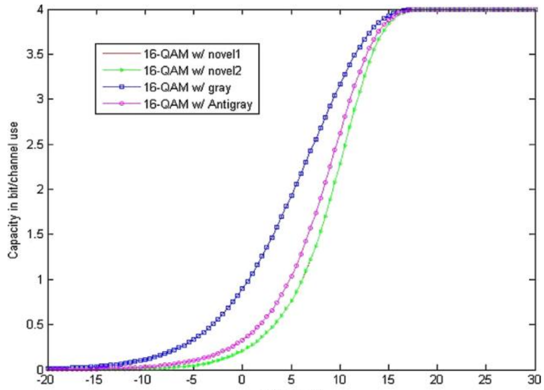
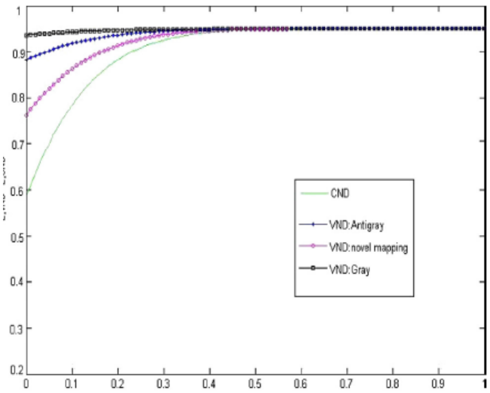


Fig. 12 a: The Capacity of Different Signal Mappings of BICM-ID Signal Mappings (Eb/N0= 6.43 dB)



E_b/N_o

Fig. 12b: EXIT Chart for BICM-ID Using Various System in AWGN

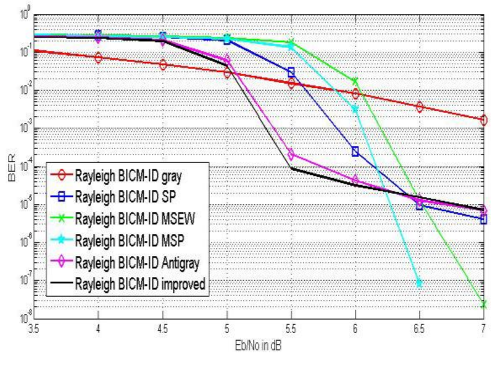


Fig. 13: Performance Comparison of Gray and Other Conventional Mappings with (4,12) Mappings

5. Conclusion

In this paper we have carefully reviewed the various attributes of symbol mapping labels. Also we have analyzed various methods for choosing the better and improved symbol mapping techniques. In this process we have analyzed the two QPSK with various radius technique for BICM-ID which performs very well on many conventional symbol mappings at high SNR for both AWGN and Rayleigh channels. After that an adaptive symbol mapping technique outperforms over conventional mappings for 0.2db and the low SNR can also be compensated by Gray symbol mapping. However an improved symbol mapping scheme which was based on MSEW labeling over 8PSK also showed larger Euclidean Distance than the previous used MSEW labeling technique. Now if we use 16-QAM instead of 8-PSK the new improved MSWE mapping showed more than 0.1db code gain and also at low to medium SNR areas. So based on 16-QAM a novel mapping scheme can be designed which can perform better in terms of capacity for AWGN with 1.58 bit/channel capacity on the EXIT charts.

The enhanced (4,12) 16-QAM symbol labeling maps definitely outshine earlier suggested types at high signal-to-noise ratio and this (4,12) 16-QAM can obtain more than 0.01db gain compared to Gray mapping and also other conventional mappers at low to medium SNR over Rayleigh channel. These optimization techniques can be practiced as well as expanded towards any kind of arbitrary signal constellation.

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