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Research paper

Optimal signal mapping scheme for MIMO-BICM-ID transmission over the different fading channel using whale algorithm

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Abstract

The designing of signal mapping scheme for bit-interleaved coded modulation (BICM) systems has been received significant interest among the researchers recently due to the growing interest of using Multiple Input Multiple Output (MIMO) system. The bit-interleaved coded modulation systems are need of effective design in constellation mapping with iterative decoding that outperformed the existing BICM coding in time varying characteristics of the channel. In this paper, the design of optimal constellation mapping of the BICM system with iterative decoding for MIMO channel is proposed. Based on minimizing cost, a design criterion is proposed to find the optimal constellation mapping for an MIMO-BICM-ID system. Here, a cost function is designed to search an optimal mapping scheme using the well-known optimization algorithm called, whale algorithm. Using this method, we find some optimal constellation mapping for 2-dimensional and 3-dimensional cases. The designed technique is evaluated with the help of BER curve for different fading channels.

Keywords: *Bit-interleaved coded modulation, multiple input multiple output, whale algorithm, iterative decoding, modulation, constellation mapping.*

1. Introduction

To enhance the information rate, MIMO frameworks make utilization of multiple transmit and receive antennas by expanding the channel limit and error execution over blurring channels [1] [2]. It has been demonstrated that when signal constellation, interleaver and error control code are settled, signal mapping impacts the error execution of a BICM-ID framework [3] [4] [5] [6]. Maximum likelihood (ML) interpreting of bit interleaved coded modulation scheme (BICM) is infeasible due to the vast number of states presented by the interleaver. The disservice of the ML receiver is the high computational complexity, which increments exponentially with the multiply of the quantity of transmit antennas and the quantity of bits per modulation symbol [7].

While preserving high diversity in BICM, the MIMO frameworks have been tended to as a powerful mean to accomplish high information rates [8]. Future remote communication frameworks require vigorous coding plans and a suitable arrangement in the modern day remote world is bit interleaved coded modulation (BICM) [9]. Just as of late some consideration has been given to the thought of channel coding in a bit and power loading algorithm as for the limit of bit interleaved coded modulation frameworks (BICM) [10]. The Bit-Interleaved Coded Modulation with Iterative Demodulation or Demapping (BICM-ID) conspire proposed in [11] depends on BICM utilizing a convolution code with extra soft feedback from the Soft-Input Soft-Output (SISO) decoder to the constellation de-mapper. For single information single yield (SISO) coded frameworks utilizing symbol interleaver, the symbol metric for most extreme probability (ML) recognition depends on the estimation of least separation between the received symbol and M constellation points on the intricate plane (M-cluster QAM alphabet).

In response to expanding interest in utilizing wireless communication frameworks and more solid administrations while the radio range is constrained, Multiple Input Multiple Output (MIMO) frameworks were presented. This propelled innovation guarantees critical change in otherworldly effectiveness and accordingly in framework limit. Utilizing BICM with iterative decoding (BICM-ID) over MIMO channels was proposed in [17], which enhances BER execution fundamentally. It has been demonstrated that when signal constellation, interleaver and error control code are settled, signal mapping affects the blunder execution of a BICM-ID framework over MIMO [18].

In this paper, we proposed an optimal signal mapping scheme for MIMO-BICM-ID system using whale optimization algorithm. The main objective is minimizing the BER of the system and maximizes the gain of iterative decoding. The basic organization of the paper is as follows: Section 2 presents the review of literature survey and the system model is described in section 3. The optimal location selection process is explained in section 4 and proposed methodology is explained in section 5. The Result and discussion part is presented in section 6 and the conclusion part is given in section 7.

2. Literature survey

A handful of researchers is available in the literature for symbol mapping for BICM as well as the MIMO-BICM system. Here, we review some of the recent work done in those two systems along with the different fading channel estimation methods used in the

BICM system. Alireza Kenarsari-Anhari and Lutz Lampe [12] have presented an analytical approach to evaluate the performance of BICM transmission over frequency-flat fading additive white Gaussian noise channels. The main objective of this paper was calculating probability density function of reliability metrics. Moreover, N. H. Tran and H. H. Nguyen [4] have explained signal mappings of 8-ary constellations for BICM-ID over a Raleigh fading channel. Here, they presented various 8-ary constellations for BICM-ID systems operating over a frequency non-selective block Rayleigh fading channel. In [13], F. Simoens *et al.* introduced multi-dimensional mapping for BICM-ID. Here, they derived a design criterion for optimal mappings and they provided such optimal mappings for BPSK and QPSK constellations.

Moreover, Ali Reza Rabbani Abolfazli and Yousef R. Shayan [8] have explained Bit Interleaved Coded Modulation systems with Iterative Decoding (BICM-ID) for Multiple Input Multiple Output (MIMO) channel. Binary Switching Algorithm was used to find optimal constellation mapping. Mutual information was utilized to evaluate the proposed constellation mappings. Similarly, Matthew R. McKay [7] has introduced multiple-input multiple-output bit-interleaved coded modulation (MIMO-BICM) with linear zero-forcing (ZF) receivers. They derived the link-level capacity (LLC) under ideal fast-fading conditions and showed that it approaches the maximum-likelihood (ML) LLC as the number of receive antennas approaches infinity. Their analysis provided insights to explain the relative performance of the ZF and ML receivers. In [14] Nghi H. Tran *et al.*, have generalized the application of SSD over a general keyhole Nakagami- fading channel. Here, the rotation matrix was optimally calculated based on asymptotic performance. Additionally, Matthew R. McKay *et al* [16] have explained error performance of MIMO-BICM with Zero-Forcing Receivers in Spatially-Correlated Rayleigh Channels. Here, they obtained the variety of spatial correlation based on the analytical results.

In [20], Jianguo Yuan *et al.*, have developed the mapping scheme can raise the unequal degree of the protection. Here, the channel capacity in BICM-ID system was comparatively analyzed with several previous constellation mapping schemes. Moreover, Zhanji Wu and Xiang Gao [21] have introduced the rotated modulation and space-time-frequency component interleavers, the proposed scheme globally optimises powerful forward error correction codes, rotated quadrature amplitude modulation, linear precoding MIMO, and OFDM thus can achieve modulation diversity and space-time-frequency diversities as much as possible. Similarly, Jianguo Yuan *et al.* [22] have developed a constellation mapping scheme of 16 quadrature amplitude modulation (QAM). The novel mapping scheme raised the unequal degree of the protection. The channel capacity in BICM-ID system was comparatively analyzed with several previous constellation mapping schemes. Moreover, Sanjeewa P. Herath et al. [23] have developed a channel code for vector perturbation (VP) precoded transmission in multiuser downlink and examines its achievable sum-rate performance. In particular, they first find the most suitable outer convolutional code (CC) for VP precoded transmission under bit-interleaved coded modulation with iterative decoding (BICM-ID) by applying a semi-analytic technique based on extrinsic information transfer charts.4)

3. System model

The main objective of this paper is to propose a new Mapping Schemes for the Multi-dimensional constellation in MIMO-BICM-ID Systems using whale optimization algorithm (WOA). The block diagram of proposed approach is shown in figure 1. The proposed work consists of two main stages such as transmitting stage and receiving stage. Here, the transmitter is a serial concatenation of the information source, an encoder, a bit-interleaver, a serial to parallel converter and a multi-dimensional Mapper. At first, the input information bits are given to the encoder. Here, the bits are encoded using outer convolution encoder before being bitwise interleaved. The bit interleaver (п) is used to break the sequential fading correlation and maximize diversity order to the minimum hamming distance of code [3]. After that, m successive bits of the interleaved coded sequence are grouped to form c_t, at the t^{th} interval. Then, the signals are given to the s/p converter. After that, the output is given to the modulator. Then, the output signal is given to the demodulator. Finally, we obtain the received signal.

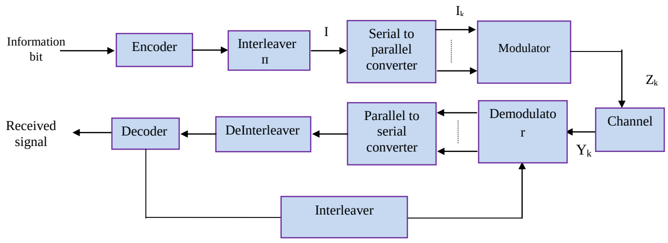

Figure 1: Block diagram of the BICM-ID system

Let us consider the input information bit (B), which is transmitted through the transmitter. In the proposed approach, the sequence of M coded and interleaved bits, $i_0, i_1, ..., i_{M-1}$ is grouped into blocks of n×m bits, which n=$\log_2 N$ is the number of bits per conventional complex symbol and n is the number of dimensions. Here, we assume a number of transmitted antennas is equal to the number of dimensions. The s^{th} block is denoted as;

$$I_S = [I_{S,0}, I_{S,1}, ..., I_{S(m\times n-1)}] \quad (1)$$

Where, I_{si} is a coded and interleaved bit which obtains a value of either 0 or 1 ($0\leq i\leq m\times n-1$, $1\leq s\leq S$, and $S=M/n\times m$). After that, I_s bits are concurrently mapped to n-parallel M-ary signal points. This mapping performance makes a bigger constellation Φ in n dimensions, having N^m signal points, where;

$$Z_i = \mu(I_S) \quad (2)$$

Here, μ (.) denotes the multi-dimensional mapping function, choosing one of the n-dimensional signals according to m×n bits. In the proposed constellation each signal point can be represented as a vector:

$$Z_i = [z_{1,i}, z_{2,i}, ...z_{n,i}]^T \quad (3)$$

Where, $z_{p,i}$ represents the p^{th} conventional M-ary constellation point. At time period k, the channel output is the super position of the N_t transmitted symbols weighted by the correspondent path coefficient. This can be expressed as follows:

$$Y_k = H_k . Z_k + n_k \quad (4)$$

Where, $Y_k = \left[Y_{k,1}, Y_{k,2}, ..., Y_{k\,N_r}\right]^T$ is the received vector, $Z_k = [Z_{k,1}, Z_{k,2}, ..., Z_{k\,N_t}]^T$ is the transmitted signals vector and $n_k = [n_{k,1}, n_{k,2}, ..., n_{k\,N_r}]^T$ is an additive white Gaussian noise vector with zero mean and variance $\sigma^2 = N_0 I_{N_r}$ .In this paper, to avoid increasing complexity, we assume an equal number of transmitter and receiver antennas (Nt=Nr)

4. Optimal mapping using whale algorithm

The objective of this section is to select the optimal position using whale optimization algorithm (WOA). In the modulation stage, we used multi-dimensional Mapper. Here, each information bits are mapped into its corresponding position of multi-dimensional Mapper while decreasing the BER. If we obtain the minimum BER means, our system properly receives the input bit stream otherwise we assume it lose some of the information bits in the processing time. To reduce the BER and without loss we receive the information bit, in this paper, we proposed a WOA algorithm for optimally choosing the corresponding position of each bit. Basically, WOA is a metaheuristic algorithm, which inspired from the bubble-net hunting procedure. Algorithm depicts the particular hunting behavior of humpback whales, the whales follow the typical bubbles causes the making of circular or '9-shaped path' while circling prey amid chasing. The step by step process of optimal position selection process is explained below;

Step 1: Solution encoding

Solution encoding is an important process of the optimization algorithm. Here, at first, we randomly initialize the solution. In this paper, we utilized three types of constellation scheme such as 2-dimensional QPSK, 2-dimensional 8QAM constellation and 3-dimensional QPSK constellation. For solution encoding, we utilize the 2-dimensional QPSK. The 2-dimensional QPSK cancellation scheme is given in figure 2. For example, the length of information bit n=16 which consist of 0's or 1's. The information bit is [0110100010101111]. Here, the first bit is encoded into the 1 dimensional as well as 2dimnetional QPSK. The solution encoding format is given in table 1. Here, the very first bit "0" is first mapped into the position of X_{13} and X_{24}. The second bit "0" is mapped to the position of X_{11} and X_{22}. Like that we assign all the bits in the multi-dimensional Mapper.

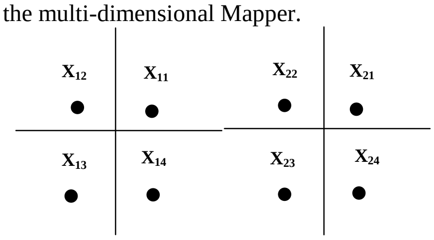

Figure 2: 2-dimentional QPSK Cancellation Scheme

Table 1: Solution Encoding for 2-dimensional QPSK

X_{13}	X_{11}	X_{14}	…….	X_{12}	X_{24}	X_{22}	X_{23}	…..	X_{21}
0	1	1	…..	1	0	1	1	…..	1
Dimension 1					Dimension 2				

Step 2: Fitness calculation

After the solution encoding process, we calculate the fitness of each solution. Here, we have to minimize the objective function which is given in equation (6). The fitness function depends on the input information bit and received bit. On the other hand, the fitness function depicts the signal mapping effect on the asymptotic performance of MIMO-BICM-ID frameworks. The lesser BER is increased the performance of proposed methodology.

$$Fitness = \min\left(BER\right) \quad (5)$$

$$BER = \frac{N_R^E}{T_B} \quad (6)$$

Where N_R^E represents the number of bits received in error and T_B represents the total number of bits transmitted. An optimum mapping is the one that minimizes BER value defined in equation (6). It is obvious that for a crowded constellation, a comprehensive search to discover a mapping that yields the littlest estimation of the BER is impossible because of the complexity. Therefore, in this paper we utilize whale optimization algorithm (WOA) for reducing the cost function; avoid long searches and infeasible complexity.

Step 3: Update the position

Encircling prey

Humpback whales (little fishes) can perceive the location of prey and encompass them. For the unidentified location of the optimal design in the search space, the present best applicant solution is the objective prey or is near the optimum in the WOA algorithm. Once the best search agent is characterized, the other search agents will thus endeavor to update their locations towards the best search agent. The solution updating formula is given in following equations:

$$\vec{D} = \left|C.\vec{X}*(t) - X(t)\right|$$

$$\vec{X}(t+1) = \vec{X}*(t).\vec{A}.\vec{D} \quad (7)$$

Where, t represents the current iteration, $\vec{A},\vec{D}$ represents the coefficient vectors, $\vec{X}*(t)$ is position vector of the best solution, $X(t)$ represents the current position vector and $|.|$ represents an absolute value.

Coefficient vectors $\vec{A},\vec{D}$ are calculated as follows;

$$\vec{A} = 2\vec{a}*r - \vec{a} \quad (8)$$

$$\vec{C} = 2*r \quad (9)$$

Where $\vec{a}$ is a variable linearly decrease from 2 to 0 over the course of iteration and r is a random number [0, 1].

❖ **Bubble-net attacking (exploitation phase)**

In order to mathematically model the bubble-net behavior of humpback whales, two improved approaches are designed as follows:

1. Shrinking encircling mechanism
2. Spiral updating position

Shrinking encircling mechanism

This behavior is achieved by decreasing the value of an in the equation (8). Note that the fluctuation range of $\vec{A}$ is also decreased by $\vec{a}$. In other words $\vec{A}$ is a random value in the interval *[−a, a]* where *a* is decreased from 2 to 0 over the course of iterations. Setting random values for $\vec{A}$ in *[−1, 1]* the new position of a search agent can be defined anywhere in between the original position of the agent and the position of the current best agent.

Spiral updating position

A spiral equation is then created between the position of whale and prey to mimic the helix-shaped movement of humpback whales as follows:

$$\vec{X}(t+1) = \vec{D}*e^{bt}*\cos(2\pi k) + \vec{X}^*(t) \quad (10)$$

$$\vec{D} = \left|\vec{X}^*(t) - X(t)\right| \quad (11)$$

Where; *b* is a constant for defining the shape of the logarithmic spiral, k is a random number in [−1, 1], and ""* is an element-by-element multiplication. Note that humpback whales swim around. the prey within a shrinking circle and along a spiral-shaped path simultaneously. To model this simultaneous behavior, we assume that there is a probability of 50% to choose between either the shrinking encircling mechanism or the spiral model to update the position of whales during optimization. The mathematical model is as follows:

$$X(t+1)=\begin{cases} X^{*}(i)-\vec{A}.\vec{U} & if\ R<0.5 \\ D.e^{bk}.\cos(2\prod k)+X^{*}(t) & if\ R\geq 0.5 \end{cases} \tag{12}$$

Where, R is a random number in [0, 1]. In addition to the bubble-net method, the humpback whales search for prey randomly.

❖ **Search for prey (exploration phases)**

The same approach based on the variation of the $\vec{A}$ vector can be utilized to search for prey (exploration). In fact, humpback whales search randomly according to the position of each other. Therefore, we use $\vec{A}$ with the random values greater than 1 or less than −1 to force search agent to move far away from a reference whale. In contrast to the exploitation phase, we update the position of a search agent in the exploration phase according to a randomly chosen search agent instead of the best search agent found so far. This mechanism and $|\vec{A}|>1$ emphasize exploration and allow the WOA algorithm to perform a global search. The mathematical model is as follows:

$$\vec{U}=\left|\vec{C}.X_{rand}-X\right| \tag{13}$$

$$X(t+1)=X_{rand}-\vec{A}.\vec{U} \tag{14}$$

Where X_{rand} is a random position vector (a random whale) chosen from the current population. At each iteration, search agents update their positions with respect to either a randomly chosen search agent or the best solution obtained so far. The parameter a is decreased from 2 to 0 in order to provide exploration and exploitation, respectively. A random search agent is chosen when $|\vec{A}|>1$, while the best solution is selected when $|\vec{A}|<1$ for updating the position of the search agents. Depending on the value of R, WOA is able to switch between either a spiral or circular movement.

Step 4: Termination criteria

Repeat process, until a better fitness or a maximum number of iterations,is met. The obtained solution is used for further processing. Figure 3 shows the flowchart of whale optimization algorithm

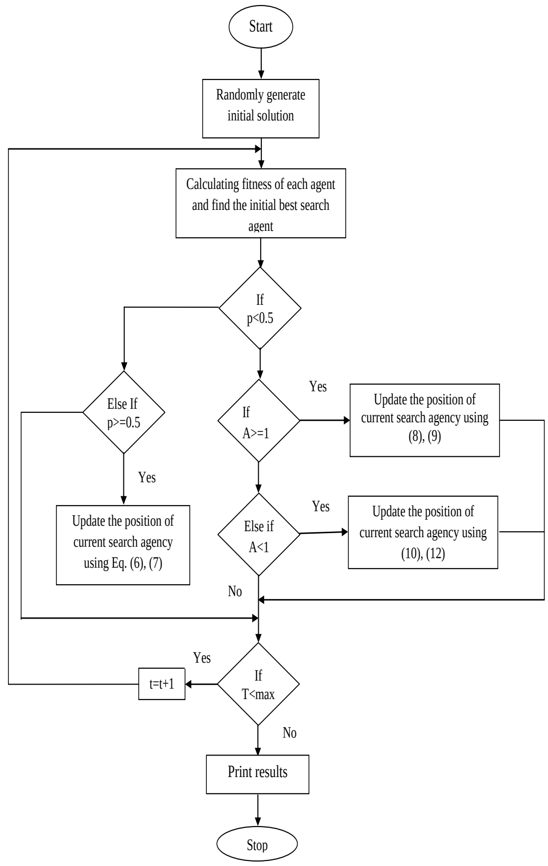

Figure 3: Flow chart of whale optimization algorithm

5. Proposed signal transmission system

The main objective of this paper is to propose a new mapping Schemes for the Multi-dimensional constellation in MIMO-BICM-ID Systems using whale optimization algorithm (WOA). In each multi-dimensional case, the necessary mapping can be obtained by minimizing the BER which is given in equation (6). In this paper, we calculate the mapping for 2-dimensional 2QPSK, 2-dimensional 8QAM and 3-dimensional QPSK using whale optimization algorithm. Using this method, we can send the information without any loss. The overall diagram of proposed methodology is shown in figure 4.

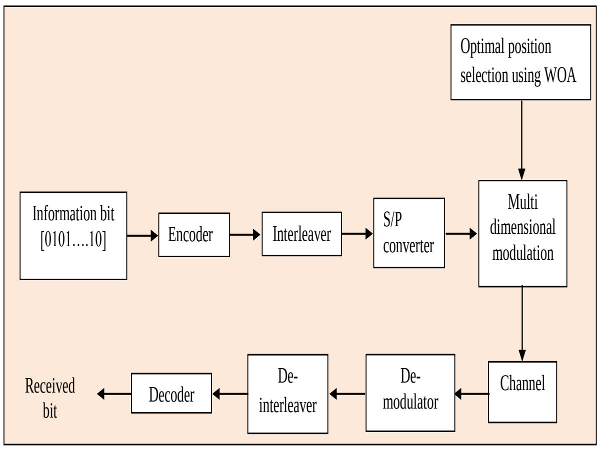

Figure 4: Overall diagram of proposed methodology

The proposed mapping for 2-dimensional 8-QAM is depicted in figure 5. Index assignment for corresponding constellation scheme is shown in Table 2. QAM is mainly used for digital transmission for radio communication applications. This QAM carry higher data rates than ordinary amplitude modulation schemes. When utilizing QAM, the constellation points are usually formed in a square grid with equal vertical and horizontal spacing and as a result, the most common forms of QAM use a constellation with the number of points equal to a power of 2 i.e. 4, 16, 64 . Here, in thispaper, we utilize a 2-dimensional 8-QAM for the mapping process.

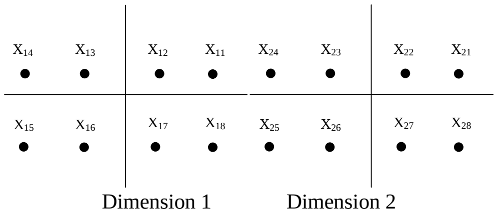

Figure 5: 2-dimnetional 8QAM constellation scheme

Table 2: The Proposed Mapping for 2-dimensional QAM Scheme

X12,X26→1	X13,X28→2	X17,X24→3	X16,X22→4
X15,X24→5	X17,X23→6	X14,X27→7	X11,X21→8
X15,X21→9	X13,X25→10	X17,X21→11	X12,X25→12
X12,X22→13	X15,X28→14	X11,X23→15	X15,X26→16
X11,X26→17	X16,X28→18	X12,X24→19	X16,X27→20
X15,X25→21	X12,X23→22	X15,X27→23	X12,X21→24
X14,X25→25	X18,X27→26	X14,X23→27	X17,X22→28
X17,X25→29	X13,X23→30	X17,X27→31	X14,X21→32
X18,X21→33	X16,X24→34	X17,X28→35	X14,X24→36
X13,X22→37	X18,X28→38	X13,X24→39	X17,X26→40
X18,X26→41	X16,X21→42	XS11,X24→43	X14,X22→44
X15,X23→45	X11,X27→46	X16,X26→47	X11,X28→48
X15,X22→49	X18,X23→50	X13,X27→51	X11,X25→52
X12,X27→53	X14,X26→54	X11,X22→55	X16,X23→56
X13,X21→57	X16,X25→58	X12,X28→59	X18,X25→60
X18,X22→61	X14,X28→62	X18,X24→63	X13,X26→64

The proposed mapping for 3-dimensional QPSK cancellation scheme is depicted in figure 6. Index assignment for corresponding constellation scheme is shown in Table 3. The steps involved in proposed approach are given in table 4

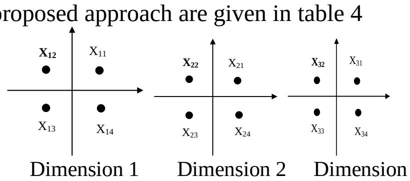

Figure 6: 3-dimensional QPSK constellation scheme

Table 3: The Proposed Mapping for 3-dimensional QPSK Scheme

X13,X23,X32→1	X11,X21,X33→2	X13,X23,X33→3	X11,X21,X31→4	X13,X24,X31→5
X11,X23,X32→6	X11,X22,X33→7	X13,X21,X34→8	X13,X21,X32→9	X11,X23,X33→10
X14,X21,X31→11	X13,X23,X34→12	X12,X24,X34→13	X13,X22,X31→14	X11,X22,X32→15
X14,X23,X31→16	X14,X24,X33→17	X12,X21,X34→18	S12,S21,S32→19	S14,S23,S34→20
X14,X23,X33→21	X12,X21,X31→22	X12,X23,X34→23	X14,X21,X34→24	X11,X21,X32→25
X14,X22,X32→26	X12,X23,X33→27	X12,X24,X33→28	X13,X24,X34→29	X11,X22,X31→30
X11,X24,X33→31	X12,X22,X31→32	X14,X24,X32→33	X12,X22,X34→34	X12,X24,X32→35
X14,X22,X34→36	X14,X22,X33→37	X12,X24,X31→38	X14,X21,X33→39	X12,X23,X31→40
X14,X24,X31→41	X12,X22,X33→42	S14,S24,S34→43	S12,S22,S32→44	X14,X23,X32→45
X12,X23,X32→46	X14,X21,X32→47	X13,X23,X31→48	X11,X21,X34→49	X13,X24,X33→50
X11,X22,X34→51	X14,X22,X31→52	X13,X24,X32→53	X13,X22,X34→54	X11,X24,X34→55
X13,X22,X32→56	X11,X24,X32→57	X11,X23,X31→58	X13,X21,X33→59	X13,X22,X33→60
X11,X23,X34→61	X11,X24,X31→62	X13,X21,X31→63	X12,X21,X33→64	

Table 4: Steps involved in multi dimensional signal cancellation

Input:
Information bit
Output:
Received bit
1. given the information bit to encoder
2. output is given to interleaver
3. apply serial to parallel converter
4. given to multi dimensional modulator
   * use modulator as a 2-dimensional QPSK
   *optimally find the position using WOA
   * Calculate the BER value
   * Go to step 5
   * use modulator 2 dimensional 8QAM
   *optimally find the position using WOA
   * Calculate the BER value
   * Go to step 5
   * use modulator 3 dimensional 8QAM
   *optimally find the position using WOA
   * Calculate the BER value
   * Go to step 5
5. apply de-modulator to the received bit
6. given to the de-interleaver
7. decode the bit stream
8. Obtain received signal.

6. Result and discussion

In this section, we discuss the result obtained from the proposed optimal signal mapping scheme for MIMO-BICM-ID transmission over the different fading channel using Whale Algorithm. We have implemented in the working platform of MATLAB (version7.12). This technique is performed on a windows machine having configuration processor® Dual-core CPU, RAM: 1 GB, Speed: 2.70 GHz with Microsoft Window7 professional operating system. Here, we tested three types of mapping constellation such as 2-dimensional QPSK, 3-dimensional 8 QAM, and 3-dimensional QPSK

Experimental results

In this section, we analyze the signal mapping using 2-dimensional QPSK, 2-dimensional 8 QAM, and 3-dimensional QPSK. Here, we analyze our proposed work using BER. Bit-interleaved permutes a 5000-bit block. MIMO system with two transmit antennas and two receive antennas are employed. We assume that channel state information CSI is available at the receiver side. The objective of this paper is to optimal signal mapping using whale optimization algorithm

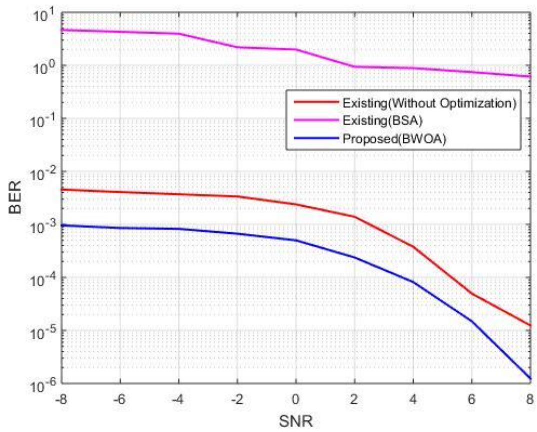

Figure 7: BER comparison based on proposed 2-dimensional 8QAM using 2×2 MIMO systems over fading channel

References

[1] Ungerboeck G, "Channel coding with multilevel/phase signals" *IEEE Trans. Inf. Thoery*, Vol.28, (1982), pp.55–67.

[2] Li X & Ritcey JA, "Trellis-Code modulation with bit interleaving and iterative decoding", *IEEE Journal On Selected Areas In Communication*, Vol.17, No.4, (1999), pp.715-724.

[3] lmni H & Hirakawa S, "A new multilevel coding method using error-correcting codes", *IEEE Trans. Infonn. Tlleoiy.*, (1977), pp.371-377.

[4] Hofmann E, "Multilevel Codirrung(MLC) in Digital Radio Mondiale (DRM)", *Kleinheuburlrer Berichre*20W, Vol.44, (2000), pp.274-278.

[5] Zehavi E, "8-PSK Trellis codes for a Rayleigh channel", *IEEE Trans. Commun.*, Vol.40, No.5, (1992), pp.873-884.

[6] Caire G, Taricco G & Biglieri E, ''Bitinterleaved coded modulation", *IEEE Transactions on Information Theory*, Vol.44, No.3, (1998), pp.927–946.

[7] Yih CH & Geraniotis E, "Performance optimization of bit-interleaved coded modulation with iterative decoding",*Proceedings MILCOM*, Vol.1, (2002), pp.737-742.

[8] Berrou C, Glavieux A & Thitimajshima P, "Near Shannon Limit Error-Correcting Coding and Decoding: Turbo-codes", *Proc. of Int'l Conference on Commun*, (1993), pp.1064-70.

[9] Telatar IE, "Capacity of multi-antenna gaussian channels", *European Transactions on Telecommunications*, Vol.10, (1999), pp.585–595.
[10] Foschini G & Gans M, "On limits of wireless communications in a fading environment when using multiple antennas", *Wireless Personal Communications*, Vol.6, (1998), pp.311–335.
[11] Alamouti SM, "A simple transmit diversity technique for wireless communications",*IEEE journal on select areas in communications*, Vol.16, (1998).
[12] Tarokh V, Seshadri N & Calderbank A, "Space-time codes for high data rate wireless communications: Performance criterion and code construction", *IEEE Transactions on Information Theory*, Vol.44, (1998), pp.744–765.
[13] Tarokh V, Jafarkhani H & Calderbank AR, "Space-time block code from orthogonal designs", *IEEE Transactions on Information Theory*, Vol.45, (1999), pp.1456–1467.
[14] Fang W & Li J, "Optimization of symbol mapping for Bit-Interleaved Coded Modulation with Iterative Decoding", *IEEE International Conference on Communication Technology*, (2010), pp.346- 350.
[15] Zhao L, Lampe L & Huber J, "Study of Bit-Interleaved Coded Space-Time Modulation with Different Labeling", *Information Theory Workshop (ITW)*, (2003).
[16] Tan J & Stüber GL, "Analysis and design of interleaver mappings for iteratively decoded BICM", *IEEE International Conference on Communications (ICC)*, Vol.3, (2002), pp.1403–1407.
[17] Ten Brink S, "Designing iterative decoding schemes with the extrinsic information tranfer chart", *AEU International Journal of Electronics and Communications*, Vol.54, No.6, (2000), pp.389-398.
[18] Tan J & Stuber GL, "Analysis and design of symbol mappers for iteratively decoded BICM", *IEEE Transactions on Wireless Communications*, Vol.4, (2005), pp.662-672.
[19] Li X, Chindapol A & Ritcey J, "Bit-interleaved coded modulation with iterative decoding and 8PSK signaling", *IEEE Transactions on Communications*, Vol.50, No.8, (2002), pp.1250-1257.
[20] Na L, Jianping L & Chaoshi C, "An adaptive symbol mapping on 8-ary constellation for BICM-ID", *IEEE 2nd International Conference Software Engineering and Service Science (ICSESS),* (2011).
[21] Tian X & Li L, "An optimized symbol mapping of 8PSK modulation for BICM-ID in low SNR", *2nd International Conference Artificial Intelligence, Management Science and Electronic Commerce (AIMSEC)*, (2011), pp.1916–1919.
[22] Yuan J, Song Y, Jia Y, Ye C, Yu P & Jinzhao L, "A novel optimized constellation mapping scheme of the 16QAM for the BICM-ID in optical communication systems", *Optik - International Journal for Light and Electron Optics*, Vol.126, No.3, (2015).
[23] Na L, Jianping L & Qing C, "An Impoved Symbol Mappings on 16QAM Constellation for BICM-ID", *International Conference on Communication, Electronics and Automation Engineering*, (2012), pp.175-180.
[24] Yao R, Zhu Y, Xu J, GAO F & Wang L, "Improving 3D-Turbo Code's BER Performance with a BICM System over Rayleigh Fading Channel", *Radio engineering*, Vol.25, No.4, (2016), pp.790-800.
[25] Na L, Qing C & Jianping L, "An Improved Symbol Mapping on 8-ary Constellation for BICM-ID", *Physics Procedia*, Vol.24, Part A, (2012), pp.618-625.
[26] Wang J, Zhang H & Lv Y, "An optimized mapping design of 8PSK for BICM-ID", *IEEE 3rd International Conference on Communication Software and Networks*, (2011), pp.472–475.
[27] Samahi SS, Goff S & Sharif BS, "Comparative study for bit-interleaved coded modulation with iterative decoding", *IEEE AICT* (2009), pp.316–318.
[28] Krasicki M, "Packet appending for BICM-ID", *IEEE Commun. Lett.*, Vol.18, No.4, (2014), pp.544-547.
[29] Xie Q, Wang Z & Yang Z, "Simplified soft demapper for APSK with product constellation labeling", *IEEE Trans. Wireless Commun.*, Vol.11, No.7, (2012), pp.2649-2657.
[30] Navazi HM & Hossain Md.J, "A Novel Symbol Mapping Method for BICM-ID Systems for Higher Order Signal Constellations", *IEEE Communications Letters*, Vol.18, No.8, (2014), pp.1323-1326.