IDMA System Based on Permutation Polynomial Interleaver over Integer Rings

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ABSTRACT: *In this paper, an algorithm for implementing Interleave Division Multiple Access (IDMA) is introduced and also a permutation polynomial interleaver (PPI) is suggested as a user specific interleaver in IDMA .The proposed technique can solve the memory cost problem for chip level interleavers and reduce the amount of information exchange between mobile stations and base stations to specify the interleaver used as there identifications. We compare the proposed PPI with recent interleaver designs such as Random, Tree and Prime Interleaver. Performance analysis of IDMA with Binary phase shift keying (BPSK) modulation employing the proposed PPI in Additive White Gaussian Noise (AWGN) channel is carried out. In addition to that, we compare between interleavers from point of view complexity & bandwidth against number of user.*

Keywords: Interleave Division Multiple Access, CDMA, IDMA, Polynomial Interleaver, Integer Rings

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1. Introduction

Interleave Division Multiple Access (IDMA) is recently proposed as a spread spectrum multiple access scheme similar to direct sequence spectrum code division multiple access (DS-CDMA). Instead of user-distinct spreading sequences for CDMA system, user-distinct interleavers are considered the unique feature to distinguish users for IDMA system. The user separation relies on iterative multiuser detection [1].

The chip by chip (CBC) detection technique in IDMA also reduces the complexity of receiver multi user detector (MUD) as compared to that used in CDMA system [3, 4].In IDMA systems, different interleavers are assigned to different users. In theory, the user-specific interleavers can be generated independently and randomly. In this case, the base station (BS) of a cellular mobile system for example, has to use a considerable amount of memory to store these interleavers, which may cause serious concern when the number of users is large. Also, during the initial link setting-up phase, there should be messages passing between the BS and mobile stations (MSs) to inform each other about their interleavers. Extra bandwidth resource will be consumed for this purposed if the interleavers used by the BS and MSs are long and randomly generated [5]. In [2, 4] Tree Base Interleaver (TBI) generation scheme has been presented employing two master interleavers, which are randomly selected. User specific interleaver has been designed using a combination of both master interleavers.

In IDMA system, the condition for IDMA to be successfully implemented is that the transmitter and receiver agree upon the same interleaver. For random interleavers, the entire interleaver matrix has to be transmitted to the receiver, which can be very costly. In this paper, we propose a permutation polynomial interleave (PPI) for IDMA that performs as well as random interleavers and satisfies two design criteria [2]:

(1) The interleaver is specified and generated which means that the transmitter and receiver can send a small number of bits between each other in order to agree upon an interleaver and then generate it.

(2) The interleavers do not collide.

This paper is organized as follows. Section 2 contains an survey of the IDMA communication system. Section 3 gives the details of the algorithim that can be used in implementing the IDMA. Section 4 contains a new design for proposed IDMA system based on permutation polynomials Interleaver (PPI). Section 5 illustrates simulation results of IDMA systems with PPI and random interleavers. Finally, Section 6 presents the conclusion.

2. IDMA Communication system

At the transmitter, the length-N input data sequence $d_k = [d_k(1), \dots, d_k(i), \dots, d_k(N)]^T$ of user k into $S_k = [S_k(1), \dots, S_k(j), \dots, S_k(J)]^T$, where J is the chip length. We call the elements in c_k '*chips*'. Then C_k is permutated by a chip-level interleaver π_k, producing the transmitted chip sequence $x_k = [x_k(1), \dots, x_k(j), \dots, x_k(J)]^T$. The channel observation at the receiver side $r = [r(1), \dots, r(j), \dots, r(J)]^T$ is represented by

$$r(j) = \sum_{k=1}^{K} h_k x_k(j) + n(j),\ j = 1, 2, 3, \dots J \tag{1}$$

Where, h_k is the channel coefficient related to user k, and $\{n(j)\}$ are samples of an additive white Gaussian noise (AWGN) process with zero-mean and variance $\sigma^2 = No / 2$. Assume that $\{h_k = 1\}$ are known a priori at the receiver. The CBC receiver consists of an elementary signal estimator (ESE) and a bank of K single-user a posteriori probability (APP) decoders (DECs), operating in an iterative manner. Figure1 shows an IDMA system with K simultaneous users:

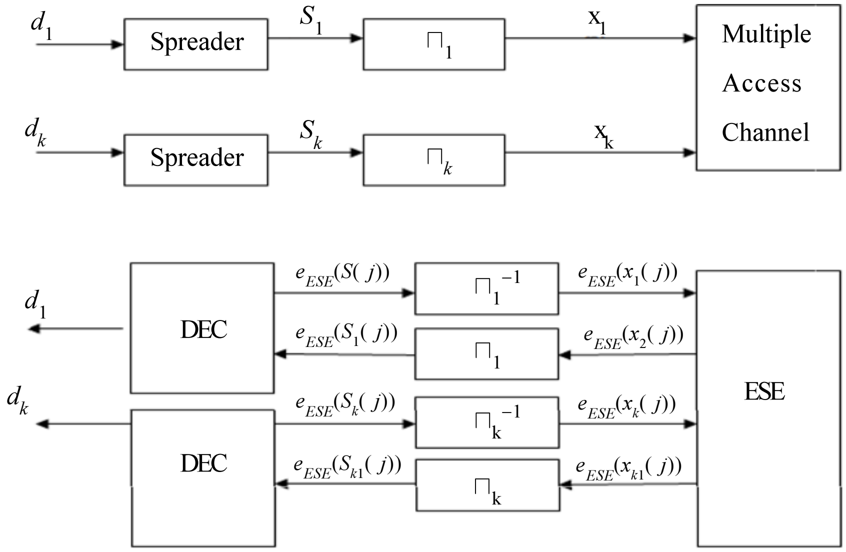

Figure 1. IDMA system structure with K simultaneous users, where π_k is the interleaver for user k

For simplicity, we assume binary phase shift keying (BPSK) signaling. The outputs of the ESE and DECs are extrinsic log likelihood ratios (LLRs) about $\{x_k(j)\}$ defined as [5]

$$e(x_k(j)) = \log \frac{P_r(x_k(j) = +1)}{P_r(x_k(j) = -1)},\ \forall\ k, j \tag{2}$$

Further denote by $e_{ESE}(x_k(j))$ and $e_{DEC}(x_k(j))$ the LLRs generated by the ESE and DECs [5] . For specific user k, we rewrite (1) as

$$r(j) = h_k x_k(j) + \zeta_k(j) \tag{3}$$

Where

$$\zeta_k(j) = \sum_{k' \neq k} h_{k'} x_{k'}(j) + n(j) \tag{4}$$

Represents a distortion term with respect to $x_k(j)$. From the central limit theorem, $\zeta_k(j)$ can be approximated by a Gaussian random variable if K is large. Where $E(.)$ and $Var(.)$ the mean and variance functions, respectively. In a serial scheme, the ESE operations and the APP decoding are carried out user-by-user [1], [3], [5].

3. The algorithm for IDMA implementation

An algorithm for implementing the IDMA is proposed. The algorithm is based upon the Serial CBC detection. Initially, set $e_{DEC}(x_k(j)) = 0, \forall k, j$.

- Step 1: Set k = 1
- Step 2: The ESE performs the following operations for user k [5]:

$$E(x_k(j)) = \tanh\left(e_{DEC}\left(\frac{x_k(j)}{2}\right)\right), \forall k, j \text{ and } Var(x_k(j)) = 1 - (E(x_k(j)))^2, \forall k, j \tag{5}$$

$$E_k(j) = \sum \zeta_{k' \neq k} h_{k'} E(x_k(j)), \forall k, j \text{ and } Var(x_k(j)) = \sum_{k' \neq k} (h_{k'}) Var(x_{k'}(j)) + \sigma^2, \forall k, j \tag{6}$$

After the estimation of interleave interference mean and variance, the Log Like Ratio (LLR) value are calculating as:

$$e_{ESE}(x_k(j)) = \log \frac{P_r(x_k(j) = +1)}{P_r(x_k(j) = -1)} = \frac{2h_k(r(j) - E(j))}{var(j)}, \forall k, j \tag{7}$$

- Step 3: De-interleaving: the process $e_{ESE}(c_k(j)) = \pi_k^{-1}(e_{ESE}(x_k(j)))$ is performed and then APP decoding [5] is performed in the DEC.
- Step 4: The generated LLRs $\{e_{DEC}(c_k(j)), \forall k, j\}$ are re-interleaved before sent to the ESE as feedbacks. Then the mean and variance for each chip are updated. When $k < K$, we go back to step 2 for the next user with $k = k+1$. When $k < K$, this iteration is finished, and we recommence at step 1 for the next iteration. During the final iteration, the DECs produce hard decisions on information bits $\{(d_k(j)), \forall k, j\}$.

4. Permutation Polynomials Interleaver (PPI)

The PPI has been introduced as an interleaver for turbo coded communications [8].The main characteristic of this class of interleavers is that they can be algebraically designed to fit a given component code. Moreover, since the interleaver can be generated by a few simple computations, storage of the interleaver tables can be avoided [8].In [8] the authors introduced many second order degree permutation polynomials such as $P(x) = bx^2 + ax + c \bmod L$. Best permutation polynomial for frame size 265 are given in [8] where $c = 0$. The authors in [8] ignore the constant "c" in the permutation polynomial and set $c = 0$. A new concept is presented here to make use of constant "c" as a user index because it acts as cyclic rotation in the interleave sequence. We center $c = 0$ as a master interleaver and $c < L$ as the user index for each user. Using the concept of PPI in IDMA system, we proposed polynomial interleaver with a = 16 and b = 15 i.e. $16x^2 + 15x + c \bmod J$, where J is the chip length in IDMA system. In IDMA system, the block size of each user is 256 bits, the final block size of each user is 264 bits where 8 extra bits are used for termination which is represented the user index "c" value.

We compare between different PPIs in Figure 2. As shown in Figure 2 the PPI $16x^2 + 15x \bmod (256)$ has the best cyclic shift property, so we select it as the proposed PPI in the IDMA system. In this PPI we put "c" = 0 for the master interleaver, $c = 1$ as a first user index and so on. This idea solves the problem of look up table in the receiver, and hence decreases the complexity and bandwidth.

5. Simulation Results

Computer simulation has been carried out to demonstrate a performance of the proposed IDMA system based on PPI. The performance of the proposed system is evaluated by calculating the bit error rate (BER) measurement in AWGN channel. A comparison of bandwidth requirement for transmission of different interleaving masks is also presented. In Figure 3, the performance of the proposed IDMA system based on both random interleaver and PPI is illustrated. In the simulation, we assume that data length is 264 for each user, number of users is 8, spreading length is 16 for all users, and the number of iterations is 8.As shown in Figure 3 the BER performance of the proposed IDMA with PPI are similar to the BER performance of IDMA system based on random interleaver. Figure 4 shows the BER performance of the proposed IDMA based on PPI with different users. We note that the performance improves as the number of users increase. Figure 5 shows the performance of the proposed IDMA based on PPI with different block sizes.

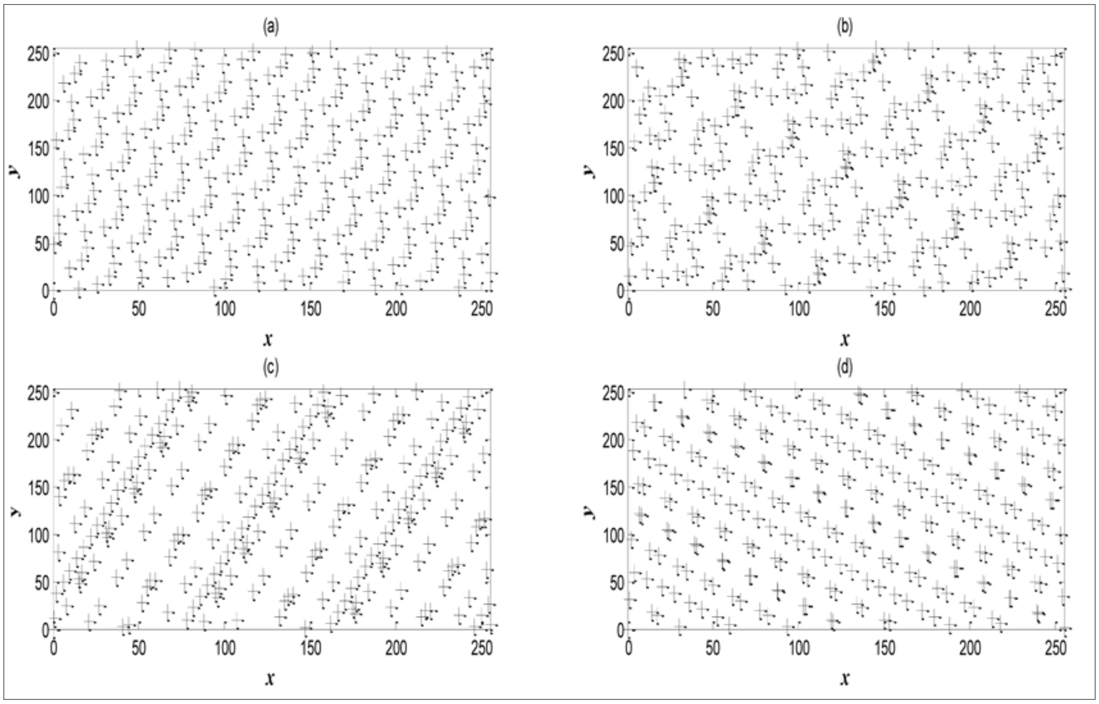

Figure 2. Different PPI second order mapping (a) $32x^2 + 15x$ mod (256),
(b) $8x^2 + 7x$ mod (256), (c) 8 (x ^2)+ 3x mod (256), (d) $16x^2 + 15x$ mod (256)

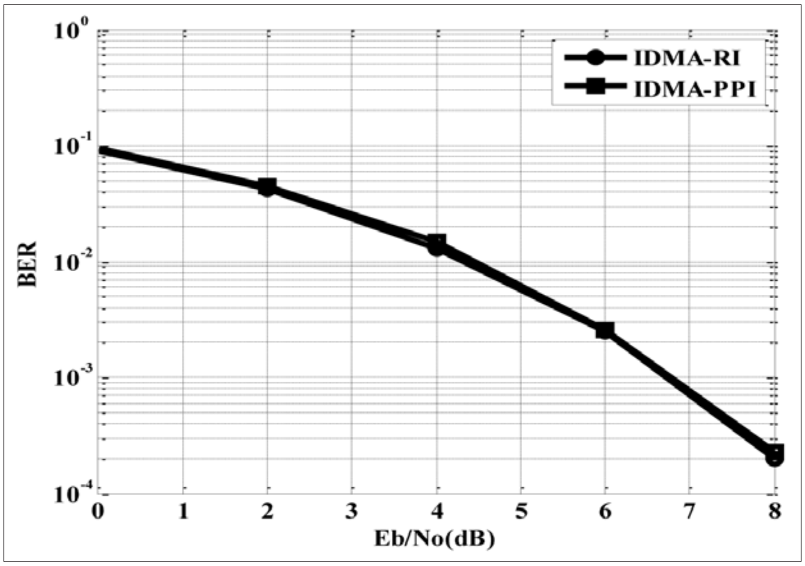

Figure 3. BER performance of proposed IDMA with PPI and IDMA system based RI (2 users)

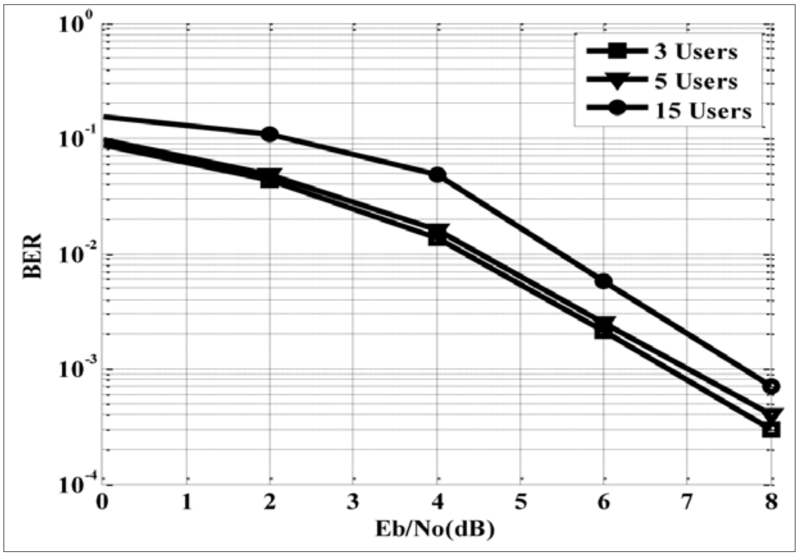

Figure 4. BER performance of the proposed IDMA based on PPI with different users

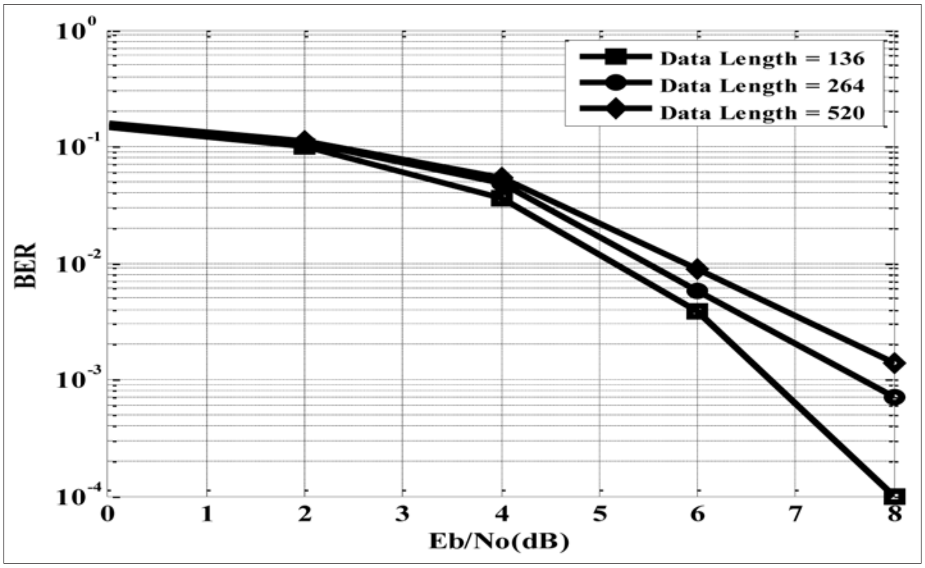

Figure 5. BER performance of IDMA based on PPI with different block size

The comparison between interleavers from point of number of users is given in table 1 and the comparison between interleavers from point of view complexity & bandwidth is given in table 2.

No. of user	No. Random Interleaver	No. Tree Interleaver	No. PPI
2	2	0	1
6	6	1	1
14	14	2	1
30	30	3	1
62	62	4	1
126	126	5	1

Table 1. Comparison between interleavers from point of view number of users

Interleaver Paramter	Random Interleaver	Tree Based Interleaver	PP Interleaver
Complexity	High	less	least
Bandwidth	Large	small	smallest

Table 2. Comparison between interleavers from point of view complexity &bandwidth

As shown in table 1 and table 2, the number of interleavers required by PPI is smaller than both of random and tree interleavers also, the complexity & bandwidth required by PPI is smaller than both of random and tree interleavers.

6. Conclusion

The proposed IDMA system based on PPI has been presented. PPI is very easy to generate and is better than the random and tree interleaver in terms of bandwidth consumption problems. The BER performance of the permutation polynomial interleaver is similar to IDMA system based on random interleaver. According to literature review the most perfect interleaver is random interleaver according to bandwidth. So, we compared random interleaver with the PPI having the second order function $(16x^2+15x + C)$ mod Chip length (256) in AWGN channel. We found that the proposed model is more efficient than others in terms of processing time, reliability, bandwidth, complexity and in cost at the same BER. Future work can extend the analysis of using the proposed technique in faded channels.

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