IDMA Technology and Comparison survey of Interleavers

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ABSTRACT : The recently proposed interleave-division multiple access (IDMA) system, a multiuser scheme where users are separated by unique interleaver sequences on the horizon of wireless communication world. The receiver involves a chip-by-chip iterative multi-user detection that uses low complexity turbo-like iterative receivers. Its complexity increases with the number of users, the number of iterations and the number of paths in the case of multipath channels. In IDMA the separation of the information of different users is achieved by interleaving. Criteria for design for a good interleaver IDMA include requirement low memory, low correlation among interleave, low complexity, low overhead synchronization between user and base station.
In this paper, we propose a novel interleaver based on prime numbers for generation of user specific interleavers to remove the problem of high consumption of bandwidth. The simulation results demonstrate the optimal performance of prime interleaver (PI) apart from other merits in comparison to random and other interleavers.

Index Terms- IDMA scheme, Random Interleaver (RI), Master Random Interleaver (MRI), Prime interleaver (PI), TBI

I. INTRODUCTION

In wireless communication, A new multiple access scheme called interleave-division multiple access (IDMA) was recently proposed. In IDMA scheme, the users are allotted with user-specific interleaver in place of PN-sequences as allotted. A multiple access scheme IDMA, in which interleaver are used as the only means for user separation. A low-cost iterative chip-by-chip multi-user detection algorithm is described with complexity independent of the user number and increasing linearly with the number of path.

In IDMA, FEC encoding and spreading may be done jointly by a single low-rate encoder, subsequently denoted by ENC. The spreader has no special task. Due to interleaving, the code is nonlinear. Accordingly, with IDMA high bandwidth/power efficiency can be achieved. Without loss of generality, we assume a superposition of binary (pseudo-)random sequences in the following. IDMA offers a number of features: rate/power adaptation, MIMO According to Shannon, typical sequences are generated and superimposed, fast fading, frequency-selective fading, complexity is linear with respect to the number of layers, number of chips/number of users, number of receiver antennas, number of channel taps, and the number of iterations, delivers reliable Soft-output information, Resource allocation, Low delay.
If random interleaver is employed for the purpose of user separation, then lot of memory space is required at the transmitter and receiver ends. In addition to it, the base station (BS) has to use a considerable amount of memory to store user-specific interleaver, which may cause serious concern, in case of large user count.
Attractive features such as dynamic channel sharing, mitigation of cross-cell interference, asynchronous transmission, low receiver cost, de-centralized (i.e., asynchronous) control, simple treatment of ISI, cross-cell interference mitigation, diversity against fading, high power efficiency, high spectral efficiency, flexible rate adaptation.
In an interleaver known as power interleaver or master random interleaver (MRI), has been proposed which alleviates concerns of extra bandwidth consumption and memory requirement at transmitter and receiver ends. In this scheme, user specific interleaver are generated with the help of one randomly selected master interleaver known as master random interleaver (MRI), for available user count at the transmission and receiver ends. During the transmission, only MRI and the user count need to be transmitted.
The Prime Interleaver is basically aimed to minimize the bandwidth and memory requirement that occur in other available interleaver with BER performance comparable to random interleaver.
In this section, the performance of proposed tree based interleaver (TBI) will be examined in comparison to that of random interleaver (RI) and master random interleaver (MRI).

II. IDMA SCHEME

At the IDMA transmitter, shown in upper part of the Figure 1, considering *K* simultaneous users, input data sequence are d_k= [d_k (1), d_k (2), d_k (3)……… d_k (i) , d_k (i+1),… ... d_k (N)]T of user k is encoded into chips c_k= [c_k (1), c_k (2), c_k (3),……………, c_k (j) , (c_k +1), ……….. c_k(J)]T based on low rate code *C*, where N is sequence length and J is the Chip length.
In transmitter, encoder-spreader block, the code C is constructed by forward error correction (FEC) code and repletion code of length-*sl*. The FEC code used here is Memory-2 Rate-1/2 Convolution coder. We may call the elements in the chips ck, are interleaved by a chip level interleaver 'π_k', producing a transmitted chip sequence x_k = [x_k (1), x_k (2), x_k (3), ……, x_k (j) , …. … x_k (J)]T . After transmitting through the channel, the bits are seen at the receiver side as r =[r_k (1),……r_k (j) ,……… r_k (J)]T. The channel opted for the simulations, is additive white Gaussian noise (AWGN) channel.

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The receiver consists of a signal estimator block (SEB) and a bank of K single user a *posteriori* probability (APP) decoders (DECs), operating in an iteratively. The modulation technique used for simulation is binary phase shift keying (BPSK) signaling. The outputs of the signal estimator block (SEB) and decoders (DECs) are extrinsic log-likelihood ratios (LLRs) about $\{x_k\}$ defined as

$$e(x_k(j)) = \log\left(\frac{p(r/x_k(j)=+1)}{p(r/x_k(j)=-1)}\right), \forall k, j. \quad (1)$$

Where $\mathbf{r}$ denotes the received signal and $p(r/x_k(j)=+1)$ characterized by conditional Gaussian probability density function.

These LLRs are further distinguished by the subscripts i.e. $e_{SEB}(x_k(j))$ and $e_{DEC}(x_k(j))$, depending upon whether they are generated by SEB or DECOD-DESPREEADERs.

In receiver section, after chip matched filtering, the K users are first encoded by an encoder (ENC) based on a FEC code and then interleaved and transmitted over a Gaussian multiple access channel (MAC). The received signal can be written as

$$r(j) = \sum_{k=1}^{k} h_k x_k(j) + n(j), \quad (2)$$
$$j = 1, 2 \ldots j$$

Where

$x_k(j) \epsilon \{+1 -1\}$ is the j^{th} chip transmitted by user-k, h_k is the channel coefficient for k^{th} user,

$\{n(j)\}$ are the samples of an additive white Gaussian noise (AWGN) process with zero-mean and variance $\sigma^2 = N_0/2$

Due to the use random interleavers $\{\pi_k\}$, the SEB operation can be carried out in a chip-by-chip manner, with only one sample r (j) used at a time. So, rewriting (2) as

$$r(j) = h_k x_k(j) + \zeta_k(j), \quad (3)$$

where $\zeta_k(j) = r(j) - h_k x_k(j) \quad (4)$

and

$$\zeta_k(j) = \sum_{k' \neq k} h_{k'} x_{k'}(j) + n(j) \quad (5)$$

where $\zeta_k(j)$ is the distortion (including interference-plus-noise) in r (j) with respect to user-k. From the central limit theorem, $\zeta_k(j)$ can be approximated as a Gaussian variable.

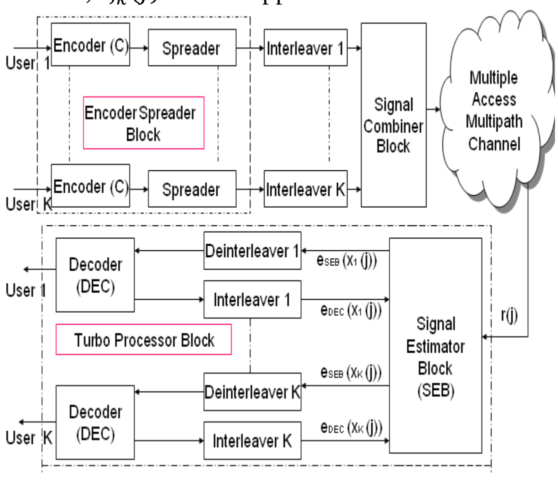


Figure 1. Transmitter and receiver structures for IDMA system

The CBC algorithm in single path detection

The brief description of CBC algorithm used in IDMA. The operations of ESEB and APP decoding are carried out user-by-user. The outputs of the ESEB as extrinsic log-likelihood ratios (LLRs) is given as,

$$e_{SEB}(x_k(j)) = 2h_k \cdot \frac{r(j) - E(r(j)) + h_k\, E(x_k(j))}{Var(r_j) - |h_k|^2 Var(x_k(j))} \quad (6)$$

The LLR output of SDEC, for S samples, is given as,

$$e_{SDES}\left(x_k(\pi(j))\right) = \sum_{j=1}^{s} e_{SEB}\left(x_k(\pi(j))\right) \quad (7)$$
$$j = 1, 2 \ldots\ldots\ldots S$$

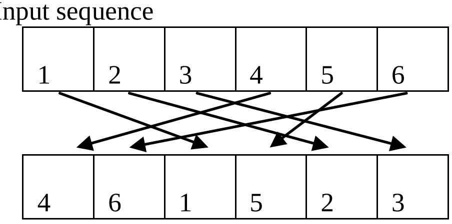
Now, these steps are repeated depending on no. of iterations and users.

III. Random Interleaver (RI)

In random interleaver, the base station (BS) has to use a considerable amount of memory to store the random patterns of interleaver which may cause serious concern of storage when the number of users is large. Also, during the initial link of setting-up phase, there should be messages assign between the BS and mobile stations (MS) to inform each other about their respective interleaver.

Random interleaver scrambles the data of different users with different pattern. Patterns of scrambling the data of users are generated arbitrarily. Because of the scrambling of data, burst error of the channel is randomized at the receiver side. The user specific Random Interleaver rearranges the elements of its input vector using a random permutation [Ping 2006]. The incoming data is rearranged using a series of generated permuter indices. A permuter is essentially a device that generates pseudo-random permutation of given memory addresses. The data is arranged according to the pseudo-random order of memory addresses. If random interleaver is employed for the purpose of user separation, then lot of memory space will be required at the transmitter and receiver ends for the purpose of their storage. Also, considerable amount of bandwidth will be consumed for transmission of all these interleaver as well as computational complexity will be increase at receiver ends. After randomization of the burst error which has rearranged the whole block of the data the latter can now be easily detected and corrected. Spreading is the important characteristic of random interleaver.

Input sequence



Output sequence

Figure 2. Random interleaver of data

Random Interleavers are generated independently and randomly. Random interleavers for IDMA need to satisfy two design criteria.

1) They are easy to specify and generate, i.e., 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 interleaver does not “collide”.

The collision among interleaver is interpreted in the form of the uncorrelation among the interleaver. If the interleaver is not randomly generated, the system performance degrades considerably and the MUD is unable to resolve MAI problem at the receiver resulting in higher values of Bit Error Ratio (BER). On the other hand if the interleaving patterns are generated more and more random, the MUD resolves the MAI problem more quickly and better values of BER are obtained for the same parameters.

IV. MASTER RANDOM INTERLEAVER (MRI)

In master random interleaver or 'power- interleaver' method, a master interleaver pattern φ is assigned, each user has a user specific interleaver $\{\pi_k\}$ having length equal to chip length 'J'. Then *K* (*K* is an integer) interleavers can be generated using $\pi_k = \varphi_k$. Here, $\varphi_k\ (c)$ is,

$\varphi_1(c) = \varphi\ (c)$

$\varphi_2(c) = \varphi(\varphi(c))$

$\varphi_3(c)\ = (\varphi(\varphi(\varphi(c)))$

By this rule, every interleaver is a 'power' of φ.

The principle for this method is that if φ is an 'ideal' random permutation, so are all $\{\varphi_k\}$, and these permutations are also approximately independent from each other. Now BS assigns the power index k to each user *k*, and then φ_k will be generated at the MS for user *k* accordingly. This method of generating patterns increases the performance in the term information that has to be sending by the base station to the mobile station

This method not only reduces the amount of information exchange between Base Station (BS) and Mobile Stations (MS), but also greatly reduces the memory cost in comparison to random interleaver. If the intermediate variables are not stored, then for generating the interleaving sequence for the k^{th} user, (k-1) cycles are needed. Even if the intermediate values are stored, it is mentioned that a maximum of 2(n-1) cycles are needed for generating the required interleaver, if $2^{n-1}<k<2^n$, where n>1 is an integer.

V. TREE BASED INTERLEAVER (TBI)

The IDMA systems using power interleaver require high computational complexity for computation of interleavers at transmitter and receiver ends. In iterative IDMA systems, each user is assigned with its own user-specific random interleaver $\{\pi_k\}$ having length equal to chip length 'J'. Hence, considerable amount of memory is required for storing the indices for these interleaver.. The tree based interleaver is basically aimed to minimize the computational complexity and memory requirement that occurs in power interleaver & random interleaver respectively

In case of generation mechanism of tree based interleaver, two master interleavers are chosen, randomly. Let π_1 and π_2 be the two randomly chosen interleavers. The combinations of these two interleavers in a particular fashion as shown in the figure (3.a) are used as interleaving masks for the users [8] the allocations of the interleaving masks follow the binary tree format. The interleaving masking diagram is shown in figure (3.a) for 14 users which may be enhanced for higher count of users. It is clearly shown through the figure (3.a) that, for obtaining the interleaving sequence related to 14^{th} user, it needs only 2 cycles.

$\pi_{14} = \pi_2(\pi_2(\pi_2))$……. (8.a)

$\pi_7 = \pi_1(\pi_1(\pi_1))$…….. (8.b)

$\pi_{13} = \pi_1(\pi_2(\pi_2))$……. (8.c)

The algorithm for generation of TBI tree is given below.

Step 1: Master interleaver π_1 is randomly generated having the length of data block (data length × spreader length).

Step 2: Master interleaver π_2 is randomly generated having the length of data block (data length × spreader length).

Step 3: According to user k, level (L) of Tree is determined. Hence, Number of users in that level $=2^L$

Step 4: All the possible combinations (2L) of interleavers are generated as $\pi_1(\pi_2), \pi_2(\pi_1)$ …..and so on.

Step 5: According to the user k particular combination of Master interleaver i.e. π_1 and π_2, is chosen and there after data is interleaved accordingly.

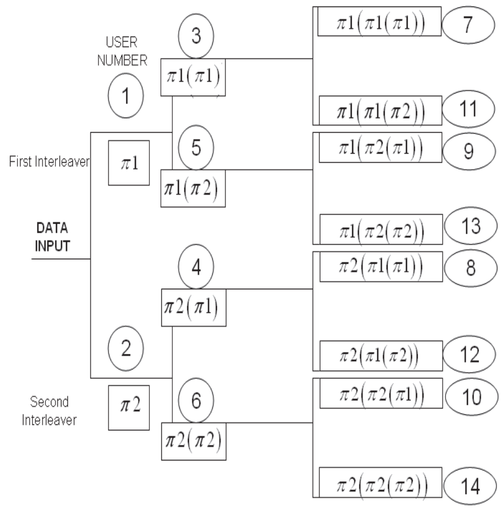


Figure 3. Interleaving mask allocation for the proposed Tree based interleaving scheme

VI. PRIME INTERLEAVER (PI)

The Prime Interleaver is basically aimed to minimize the bandwidth and memory requirement during transmission with lesser time, that occur in other available interleaver with BER performance comparable to random interleaver.

In generation of prime interleaver we have used the prime numbers as seed of interleaver. Here, user-specific seeds are assigned to different users. For understanding the mechanism of prime interleaver, let us consider a case of interleaving n bits with seed p. First, we consider a gallois field GF (n). Now, the bits are interleaved with a distance of seed over GF (n).

In case, if {1, 2, 3, 4, 5, 6, 7, 8…….. n} are consecutive bits to be interleaved with seed p then location of bits after interleaving will be as follows:

1===> 1

2===> (1+p) mod n

3===> (1+2p) mod n

4===> (1+3p) mod n

. .

. .

n===> (1+(n-1)p) mod n

For Example if we have to interleave 8 bits such that {1, 2, 3, 4, 5, 6, 7, 8} and we wish to interleave these bits with seed 3 then the new location of bit will be as follows

1===> 1

2===> (1+1*3) mod 3===>4

3===> (1+2*3) mod 3===>7
4===> (1+3*3) mod 3===>2
5===> (1+4*3) mod 3===>5
6===> (1+5*3) mod 3===>8
7===> (1+6*3) mod 3===>3
8===> (1+7*3) mod 3===>6
Now, the new order of bits will be {1, 4, 7, 2, 5, 8, 31, and 6}.
The bandwidth required by the Prime Interleaver (PI) is smaller than other available interleaver as now only seed is to be transmitted, in addition to very small amount of memory required at the transmitter and receiver side.
For the simulation purpose, the data length is opted to be 512 bits while 16. The iteration at the receiver is chosen to be 15. The simulation has been performed for 100 users. The prime interleaving scheme reduces the computational complexity that occurs in master random interleaving scheme; however, it is higher to that of tree based interleaving scheme due computation involved for calculation of user specific interleaver.

VII. Comparison Analysis

In the simulation, we observe that the PI demonstrates superior performance in terms of memory requirement [Figure 9]with RI and in terms of computational complexity with MRI. In unequal power allocation technique, PI [figure7] and TBI [figure6] gives almost similar Bit Error Rate (BER) performance of all the interleavers that of the RI [figure4], MRI [figure5], based interleavers, MRI give in coded environment in IDMA system. Therefore, PI and TBI adopted replacing random interleaver in iterative IDMA systems.
In master random interleaving scheme the computational complexity and transmitter and receiver end is quite high due to calculation of user-specific interleaving masks.
The memory required by TBI generation method is extremely less than that required for RI generation method and is independent of user count of TBI over RI. For the simulation purpose, the performance of RI, MRI, TBI, PI has been demonstrated in [8]. In figure 7, the performance of tree based interleaver is shown TBI with IDMA till 64 users receivers in rate ½ convolutionally code environment.
The prime interleaving scheme reduces the computational complexity that occurs in master random interleaving scheme; however, it is higher to that of tree based interleaving scheme due computation involved for calculation of user specific interleavers

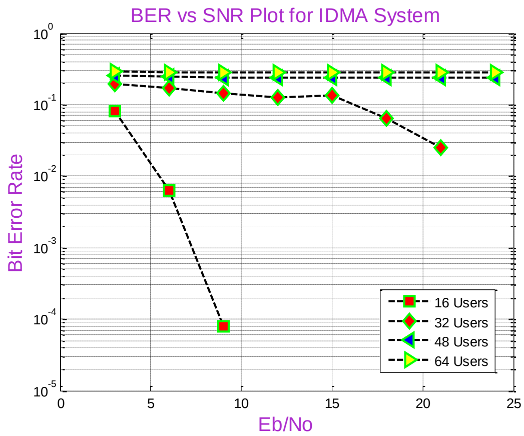


Figure 4. Random Interleaver

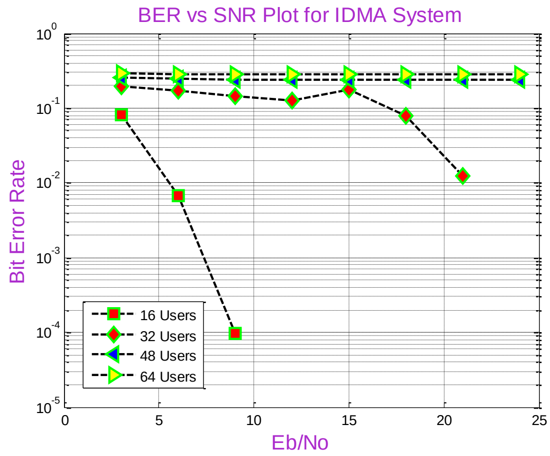


Figure 5. Master Random Interleaver

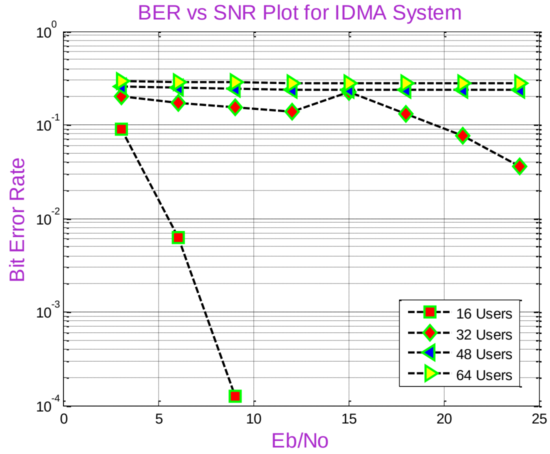


Figure 6. Tree Based Interleaver

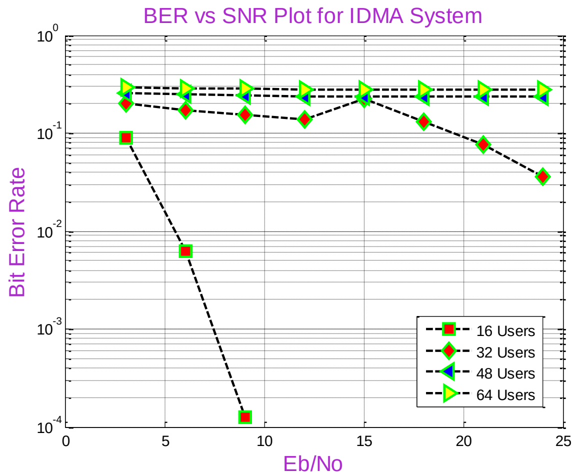


Figure 7. Prime Interleaver

Table 1. Comparison Graph of Bandwidth Requirement for transmission of interleaving mask

User Count	RI Generation	TBI Generation	PI Generation
2	2	2	1
6	6	2	1
14	14	2	1
30	30	2	1
62	62	2	1
126	126	2	1

Table 2. Comparison on the Basis of Parameter

Parameter	RI	MRI	TBI	PI
Memory requirement	High	Low	Low	Lowest
Bandwidth requirement	1.5×10^{6}	0.01×10^{6}	0.02×10^{6}	0.0001×10^{6}
complexity	High	Very High	Low	Little high than TBI
BER for Eb/No=10(24 users)	10^{-4}	10^{-4}	0.4×10^{-4}	0.5×10^{-4}
BER(Coded) for Eb/No=10(24 users)	0.6×10^{-5}	0.6×10^{-5}	0.4×10^{-6}	0.4×10^{-6}
BER(UnCoded) for Eb/No=10(24 users)	0.6×10^{-4}	0.2×10^{-4}	0.2×10^{-5}	0.2×10^{-5}
Specific user cross correlation	Low	Low	High	High

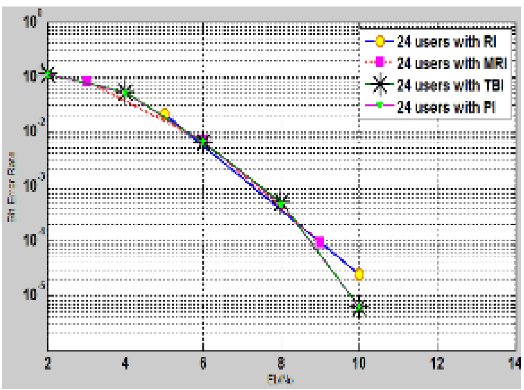


Figure 8.Comparison between RI, MRI, TBI and PI

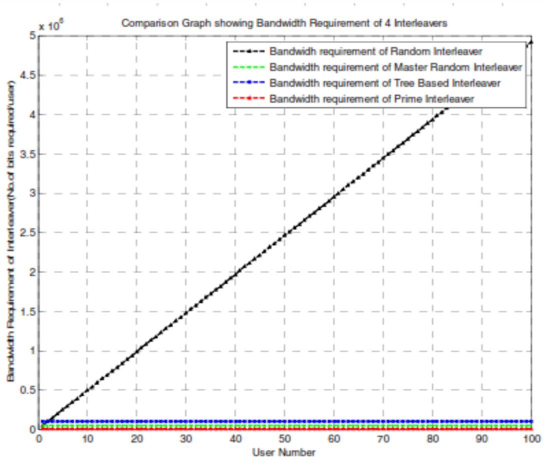


Figure 9: Comparison Graph of Bandwidth Requirement of various Interleavers

VIII. CONCLUSION

The computational complexity of PI and TBI is extremely less in comparison to MRI. The memory required by TBI generation method is extremely less than that required for RI generation method. The BER performance of all the interleaver including RI and TBI is almost similar. The bandwidth required by the PI is smaller than other available interleaver. The prime interleaving scheme reduces the computational complexity that occurs in master random interleaving scheme

Among all the comparisons discussed so far, the features of Tree Based Interleavers and Prime interleaver shows their suitability for the IDMA technology for fourth generation communication

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