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Structural Reduction in Front End Memory Requirement of Tree Based Interleaver Method Using the Concept of Invert Tree Based Interleaver in Multiuser Interleave Division Multiple Access Scheme

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Abstract

Interleave division multiple access (IDMA) scheme, uses interleavers for user separation. The selection of interleaver along with optimum design methodology for IDMA system leads to satisfactory results. An efficient interleaver must be easy to generate and should require low memory along with low correlation among interleavers. Existing Tree based interleaver has distinct advantage of low computational complexity but it suffers with the problem of higher memory requirement due to inherent transmission of two randomly generated interleavers. In this paper, a novel interleaver called Invert Tree Based Interleaver (ITBI) is proposed, which reduces the front-end memory requirement of Tree Based Interleaver by carrying out structural modifications. BER performance and correlation analysis of different interleavers for generating user specific interleaving sequences for different users in IDMA system is analyzed. To achieve similar BER performance, ITBI has simulated with lesser memory requirement and computational complexity compared to random and tree based interleaver in IDMA scheme.

Keywords: IDMA, Tree Based Interleaver, low memory, computational complexity, Bit Error Rate, low correlation

INTRODUCTION

DS CDMA has become one of the most popular multiple access in recent years. After the success of CDMA in IS-95, CDMA 2000, WCDMA and TS-SCSMA have utilized the CDMA technique [1]. In DS-CDMA communications, users are distinguished by distinct code waveforms. Due to Multiple Access Interference (MAI) from other users and Inter Symbol interference (ISI) by multipath fading the performance of DS-CDMA is restricted. Various equalization and multiuser detection technique [1][2] have been proposed to suppress these two interferences, but their high computational complexities restrict the practical implementation. After the introduction of turbo codes [3,4]the turbo principal has been widely applied in multiuser detection and thus produce a variety of iterative multiuser detection algorithm such as Parallel interference cancellation[5][6]SIC and PDA[7][8]turbo maximum a postetori probability(MAP) based multiuser detection[9],turbo MMSE based multiuser detection[3][10-14]. However achievable performance is still of concern and loss in the spectral efficiency is not negligible due to fixed frame structure of DS-CDMA system. Therefore, it is necessary to make adequate modification in the transmitter structure of CDMA system. All the above stated problems are due to the technique used for user separation in CDMA systems- PN-sequences. These sequences are orthogonal to each other. Spreaded data may lose its orthogonality in case of higher user count. As a solution to this problem a new scheme known as interleave division multiple access (IDMA) is introduced for user separation. In this scheme interleavers are used to differentiate signals from other users. The impending advantage of this scheme is fully discussed in [15][16-18].In [9] possibility of using interleavers for user separation in coded system is discussed. In [15] narrow band coded modulation schemes based on trellis code structures for is discussed. For wideband system, the improvement in performance is demonstrated by [16][18].In [17] chip interleaved CDMA and MRC for MAC with ISI has been studied, which demonstrate the advantage of chip level interleavers. In [19] IDMA is proposed with low receiver complexity. IDMA has taken over many advantages from CDMA like high flexibility in transmission rate, soft handoff; diversity against fading etc. It also permits very easy chip by chip iterative multiuser detection strategy. In IDMA users are separated by interleavers with low cross correlation. Here it is apparent that, in IDMA interleavers are core part of the system. To minimize the noise and MAI at the receiver side one should choose interleavers with a very low correlation.

In [23] random interleaver for user separation is proposed and it provides good performance. However, it needs to store many interleaving matrixes, the memory and bandwidth requirement are excessive in case of large scale system. In [20] interleaver called rotational interleaver was proposed which cuts down the memory but it is not suitable for user count exceeding 20.Orthogonal interleavers[24] are based on PN sequences, while different polynomials are assigned to different users to obtain pseudo random interleavers. Every user is assigned with its own polynomial to generate its interleaver, thus it reduces the memory requirement during transmission. But when number of user is large, the computational complexity to find primitive polynomials for pseudo random interleavers is very high. Master interleaver is proposed in [22] for IDMA system. Here every interleaver is a 'power' of master interleaver to generate a set of interleavers. If we compare this interleaver with random interleaver, it cuts down the memory requirements for storing interleaver patterns, and thus reduces the amount of bandwidth. However, in case of large number of users, generation of interleavers is slow and the computational complexity is very high. Hence, selection of pseudo random interleavers and power interleavers are not adequate choice when number of users is large for IDMA systems due to their computational complexity. In [25] tree based interleaver (TBI) is proposed, which uses two randomly selected master interleavers. The

The remaining interleavers are computed with the aid of these two interleavers. This scheme is efficient in terms of computational complexity but imposes a problem of extra memory requirement during the transmission. All the schemes shown discussed above was either reduces the memory or computational complexity, none of them gives the dual advantage of being less complex and lesser memory. For this reason, novel interleaver design method, i.e. an Invert tree based interleaver is proposed in this paper to get both advantages.

The goal of this paper is to improve the performance of tree based interleaver in terms of memory requirement. Simulation results confirm that proposed method can obtain nearly the similar performance as tree based interleaver with significant reduction memory. It is noteworthy that as only one interleaver along with user count must be sent to the receiver with data related to user, the transmission cost is decreased hugely.

IDMA System Model:

Figure 1 shows IDMA system model. For every user k, input data sequence dk is encoded through encoder. The output of an encoder is coded sequence ck. Then ck is permuted by interleaver ϕk, followed by spreading operation. In IDMA interleavers are different for the different users and also they are randomly and independently generated. By assuming channel to be memory less and after chip matched filtering, the received signal is[19],

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

Here it is assumed that hk known at receiver side and is known as the channel fading coefficient while {n(j)} is noise samples with zero mean, and variance=N0/2 [22]. Receiver uses turbo principal. It consists of ESE and APP decoder (DEC) one per user.DEC produces hard decisions on information bits during final iteration. Due to chip level interleavers, the correlation among spreading sequences of different users is much improved [19].

A priori log-likelihood ratios (LLR) about xk(j) for the ESE is given by[21]

$$l_{ESE}(x_k(j)) = \log\left(\frac{\Pr(x_k(j) = +1)}{\Pr(x_k(j) = -1)}\right), \qquad \forall\, k, j$$

Similarly, log-likelihood ratios (LLR) about xk(j) for the DEC is given by [19, 21]

$$l_{DEC}(c_k(j)) = \log\left(\frac{\Pr(c_k(j) = +1)}{\Pr(c_k(j) = -1)}\right), \qquad \forall\, k, j$$

ESE uses r(j) and l_{ESE} as its input. By assuming that hk is known at the receiver, a posteriori LLRs about $x_k(j)$ are given by

$$\log\left(\frac{(\Pr(x_k(j)=+1|r)}{(\Pr(x_k(j)=-1|r)}\right) = \log\left(\frac{p(r\,|\,(x_k(j)=+1)}{p(r\,|\,(x_k(j)=-1)}\right) + l_{ESE}(x_k(j)), \qquad \forall\, k, j$$

Since for a single path channel $x_k(j)$ is only related to r(j),output of ESE can be expressed as,[21]

$$e_{ESE}(x_k(j)) = \log\left(\frac{p(r(j)|x_k(j) = +1)}{p(r(j)|x_k(j) = -1)}\right)$$

Similarly, l_{DEC} is the input to the decoder (DEC) for user k, a posteriori LLR about $x_k(j)$ can be given [19]as,

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$$\log\left(\frac{Pr((c_k(j)=+1|(L`_{DEC})_k)}{Pr((c_k(j)=-1|(L`_{DEC})_k)}\right)=\log\left(\frac{Pr\left((c_k(j)=+1\left|\,{(L`_{DEC})_k}/{l`_{DEC}(c_k(j))}\right.\right)\right)}{Pr\left((c_k(j)=-1\left|\,{(L`_{DEC})_k}/{l`_{DEC}(c_k(j))}\right.\right)\right)}\right)+l`_{DEC}(c_k(j))$$

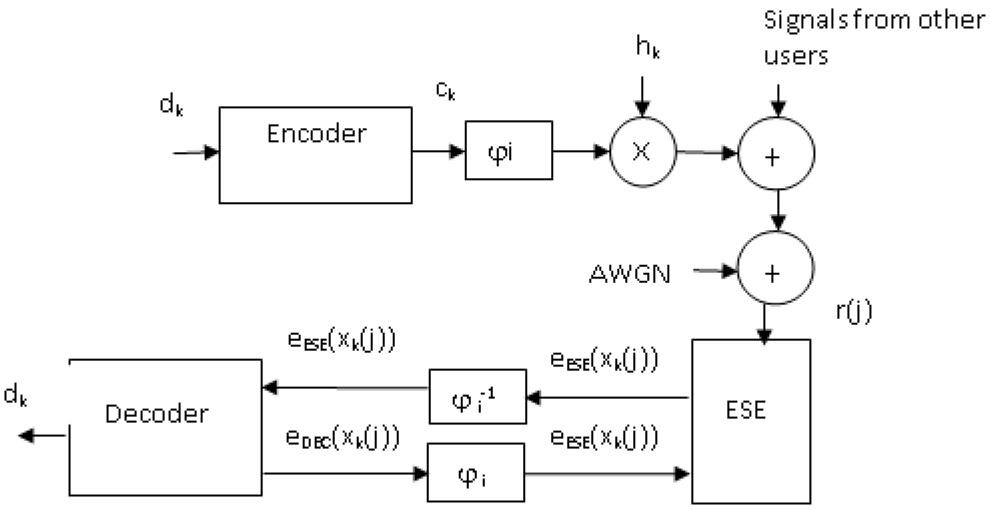

Figure 1: IDMA system model

The output of DEC for user k is the extrinsic LLRs of DEC. During the turbo process, the information generated by ESE/DEC is used as the a priori information in DEC/ESE.

INTERLEAVERS IN IDMA

A. Various interleavers in IDMA

The interleaver rearranges the ordering of a data sequence by means of a deterministic bijective mapping.

(i)Random Interleaver

Inbuilt IDMA system uses random interleavers [21]. The selection interleaver is random out of all possible combination of user specific interleavers. Better orthogonality is ensured in case of random interleavers due to random selection of any data out of all available data. But for enormous number of user set memory storage is a big concern.

(ii)Master Random Interleaver

Master random interleaver (MRI) method is proposed [22] in to lessen the memory problem of random interleaver. Here series of interleavers are obtained using only one master interleaver. Comparing with random interleaver memory cost is greatly reduce, however computational complexity of MRI is still high. In this method two randomly generated interleavers called master interleavers ϕ1 and ϕ2 which are orthogonal to each other are transmitted. The structure of Tree based interleaver

(iii)Tree Based Interleaver

Most of the Interleavers in literature have focused on method of selection of user specific interleavers. Still, the problem of

Computational complexity is unsolved for the IDMA system. To minimize this, tree based interleaver (TBI) is proposed in [25]. In this method two randomly generated interleavers called master interleavers ϕ1 and ϕ2 which are orthogonal to each other are transmitted. The structure of Tree based interleaver is shown in Figure 2, which is based on two master interleavers in a specific way. Since TBI uses two orthogonal interleavers, it suffers with the problem of extra memory requirement than MRI.

INVERT TREE BASED INTERLEAVER (ITBI)

Invert Tree Based interleaver (ITBI) modifies the structure of TBI proposed in [25]. As mentioned above, in TBI generation, due to transmission of two random interleavers ϕ1 and ϕ2, BS has to employ significant memory, which cost extra bandwidth. Proposed interleaver is aimed to resolve this extra bandwidth problem by transmitting one random interleaver.

A. Design principal of Invert tree based Interleaver

As shown in Figure 3, in case of ITBI generation one randomly selected master interleaver ϕ1 is taken initially and transmitted from BS. Now interleaver for user 2, let us say ϕ1' can be derived at the receiver by inverting ϕ1. Here ϕ1 and ϕ1'are orthogonal to each other. Interleavers for the other users are calculated using a combination of these two interleavers. For example, in case of 3rd user, the user specific Interleaver is decided with ϕ1 (ϕ1) and for the fourth user it will be ϕ1 (ϕ1').Here the upper branch is selected for odd number of while for the even number of user the lower branch is selected. So we can say that, during the transmission, one interleaver along with user count has to be sent to the receiver with data related to user, thus ITBI requires lesser memory compared to TBI method. Interpreting Invert Tree Based Interleaver mechanism, the case of interleaving with chip length of 6 is taken. Suppose interleaving sequence for user 1 is, ϕ1 (i)= {2,1,4,5,3,6}. To get the interleaving sequence for user 2, this can be updated by ϕ1'(i)= ϕ1 ((chiplength+1) – i)). So location of bits for ϕ1'(i) after interleaving for user 2 will be,

ϕ1'(1)= ϕ1 ((6+1)-1))= ϕ1 (6) ===> 6

ϕ1'(2)= ϕ1 ((6+1)-2))= ϕ1 (5) ===> 3

ϕ1'(3)= ϕ1 ((6+1)-3))= ϕ1 (4) ===> 5

ϕ1'(4)= π1 ((6+1)-4))= ϕ1 (3) ===> 4

ϕ1'(5)= π1 ((6+1)-5))= ϕ1 (2) ===> 1

ϕ1'(6)= π1 ((6+1)-6))= ϕ1 (1) ===> 2.

So ϕ1'(i)= {6,3,5,4,1,2}, which is exactly invert of ϕ1(i),and thus named invert tree based interleaver. The remaining interleavers are computed with the aid of these two master interleavers.

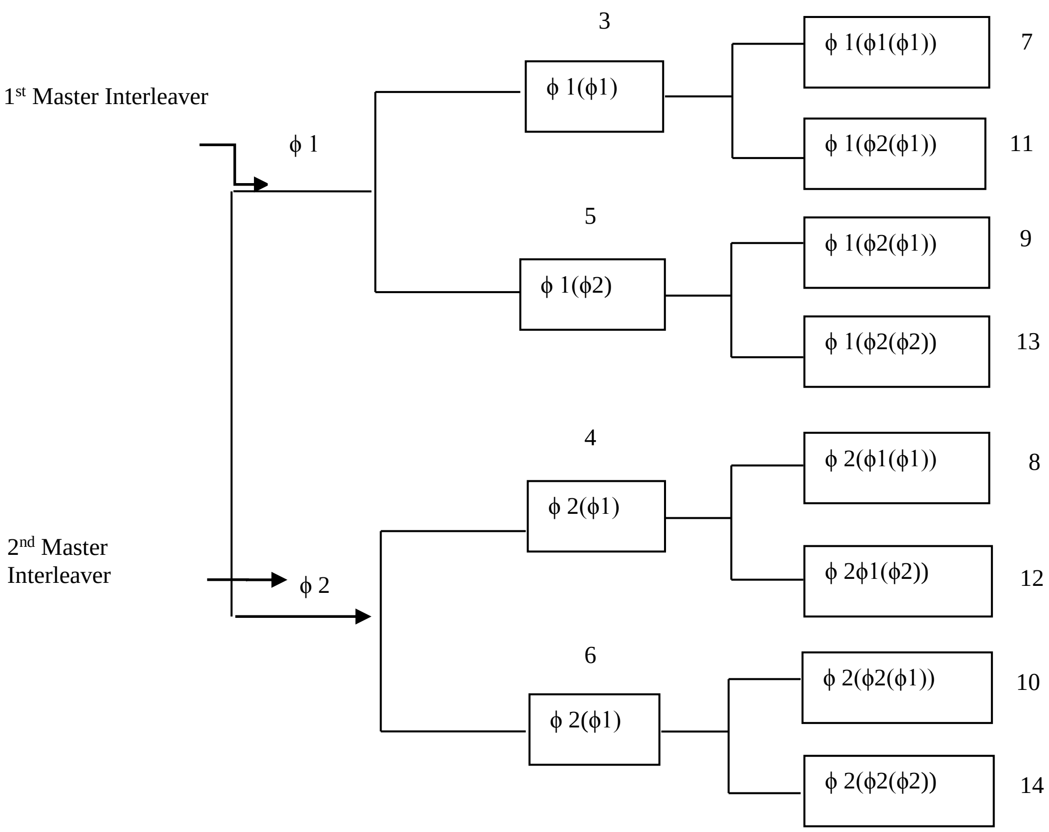

Figure 2: Structure of Tree Based interleaver [25]

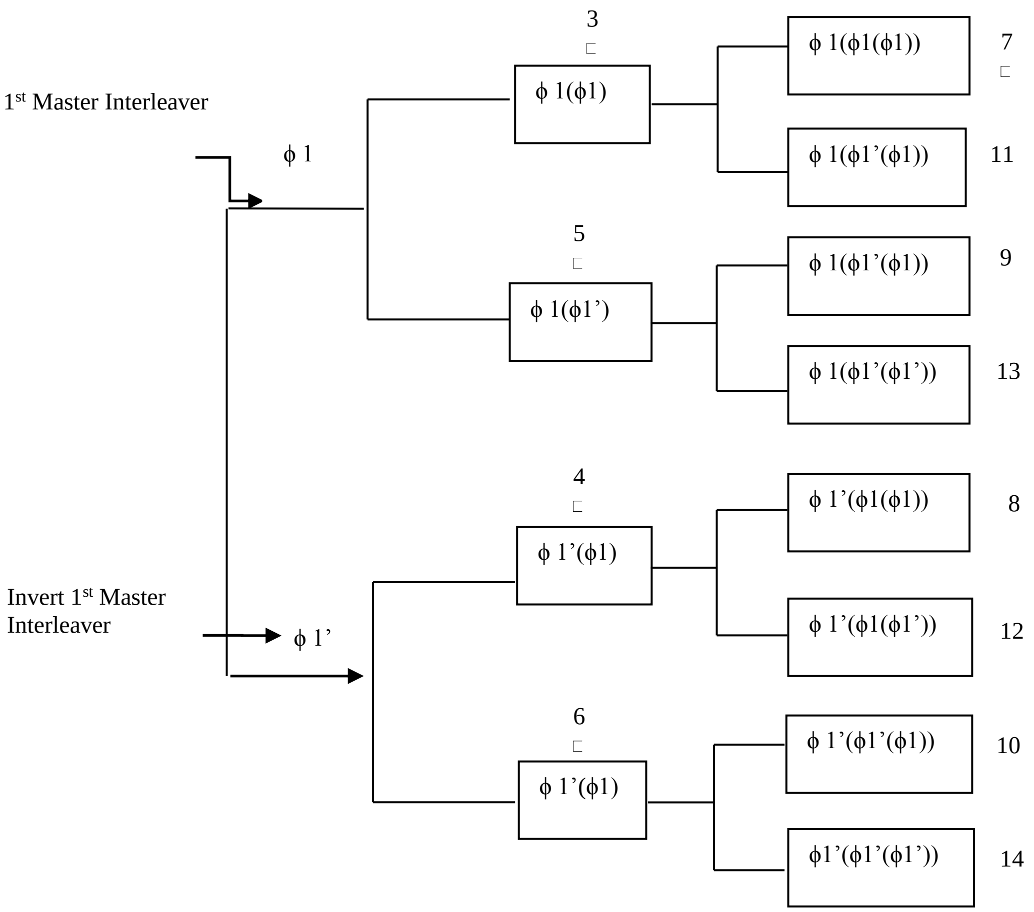

Figure 3: Structure of Invert Tree Based Interleaver with reduced memory concept attributes

B. Comparison of Data formats for TBI and ITBI required for transmission

With TBI

1st Master Interleaver sequence	2nd Master Interleaver sequence	User Number	Data

With ITBI

1st Master Interleaver sequence	User Number	Data

C. Calculation of reduction in memory requirement

The storage requirement of proposed interleaver with various other interleavers is shown in table 1. It is calculated based on number of times interleaving with different interleavers. The result shows that in case of Random interleaver, memory required for storing indexes is dependent on user number. While in case of ITBI, memory requirement is low when compared with either RI or TBI. Figure 6 shows simulation result of memory requirement of proposed interleaver, which confirms the argument. The proposed method also, cut down the computational complexity of MRI. For example, to get the interleaving sequence of the 14th user, ITBI mechanism requires only 2 cycles while 6 cycles needed in case of MRI. Simulation result shown in Figure 7 illustrate that computational complexity of proposed Interleaver is significantly reduced in comparison to the MRI whereas it is little bit high in comparison to that needed for RI.

Table 1: Memory requirement of different interleavers for IDMA scheme

User	RI	TBI	ITBI
2	1	2	1
6	6	2	1
14	14	2	1
30	30	2	1
62	62	2	1
126	126	2	1

CORRELATION OF INTERLEAVERS

IDMA uses interleavers for user separation. Most important design criteria for interleaver are that two interleavers should “collide” as little as possible [24]. To avoid the collision amongst users, interleavers must be orthogonal in nature. This section presents measurement of collision of interleavers by calculating its correlation. For example, to carry out correlation, first of the user specific interleaving sequences is cross correlated with each other and then after computed cross correlation of each user is added in a user specific pattern. The highest value amongst this represents the peak resultant cross correlation. If this value is higher than it shows the poorer decorrelation between the users. For this calculation, MATLAB environment has been used.

The peak resultant cross correlations of various interleavers are provided in Table 2. For comparison, performances of random interleavers, MRI, TBI and ITBI are shown in Table 2. Spread length of 16 and data length of 1024 with total number block of 2000 with different number of users are used in numerical analysis. From the table we can say that, the value of peak resultant cross-correlation is similar for all the interleavers with lower values. Hence at this point, the BER performance is approximately same for all interleavers. With increment in user count the value of peak resultant cross-correlation also increases and so MAI increases which shows increment in BER. However, the value of resultant cross-correlation, for proposed interleaver, is observed to be at lowest level.

Table 2: Peak resultant user specific cross correlation

Sr. no	User no	Peak resultant user specific cross correlation			
		RI	MRI	TBI	ITBI
1	10	1.0981	1.0298	1.0334	1.0415
2	16	1.0674	1.0498	1.0566	1.0505
3	25	1.1245	1.1211	1.0903	1.0718
4	48	1.131	1.143	1.1479	1.1372
5	50	1.1406	1.1729	1.1643	1.1597

SIMULATION RESULTS

Performance of IDMA systems with ITBI discussed above is compared in this section. The performance of RI and TBI are also given for comparison.

A. MATLAB Simulation with Various Interleavers

For the simulations, the coded and uncoded IDMA with BPSK signaling and AWGN channel is considered. The block size for each user is 200. The spreading code {1, 1, 1, 1} with the length of 16 is used. The frame length N in chips is taken as 16384. The MUD algorithm for IDMA systems as defined in [21] is used. The number of iterations used is 30. We can see from Figure 4 and Figure 5 that the performance of ITBI is all the time near to that of random interleavers for coded and uncoded IDMA case with user number 32 or 48.

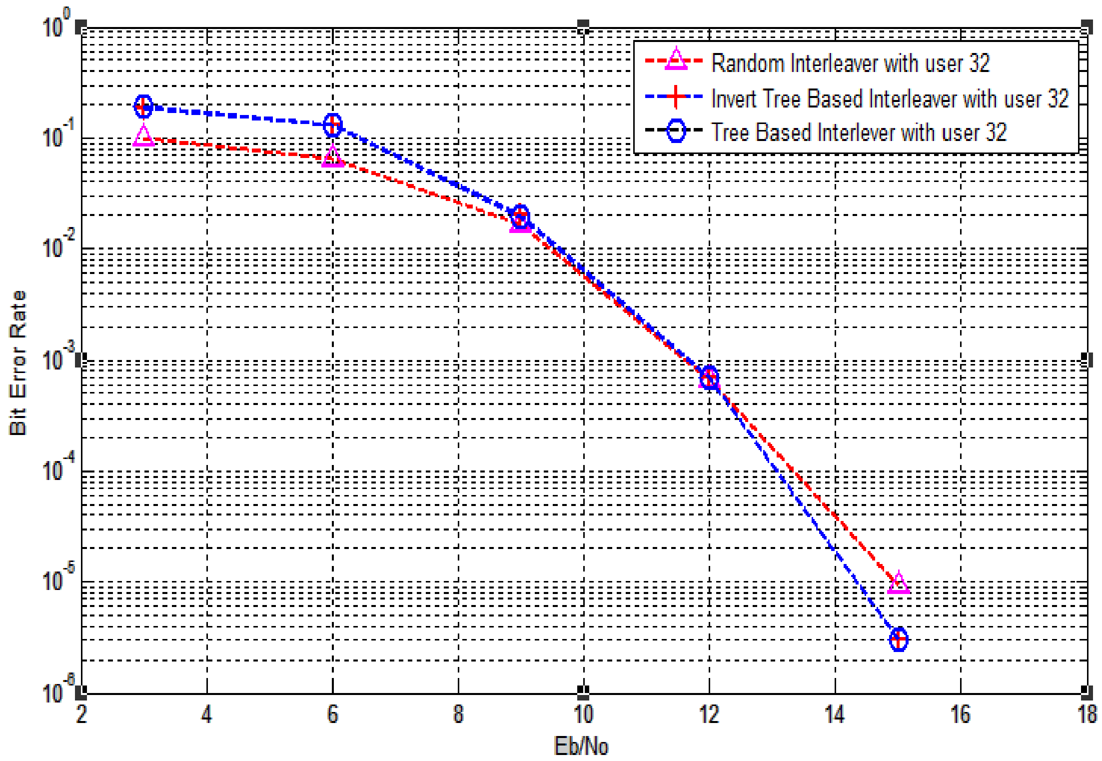

Figure 4: Comparison of RI,TBI and ITBI with different users for uncoded IDMA systems.

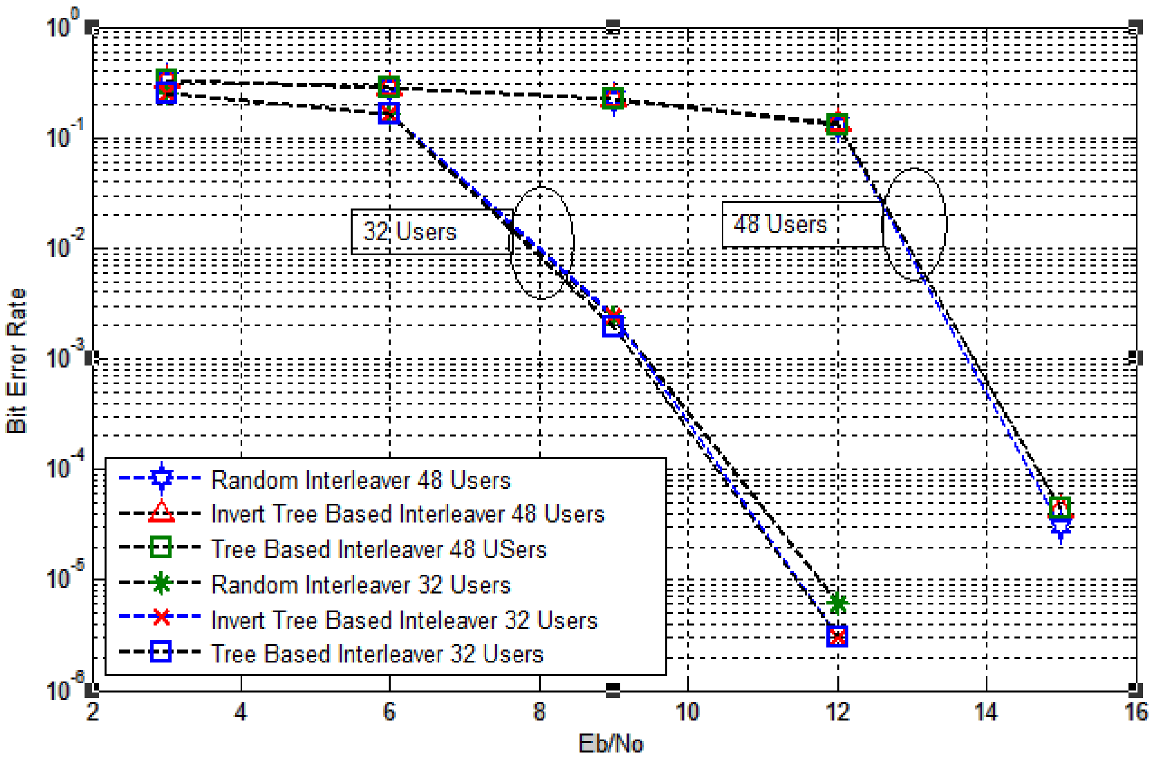

Figure 5: Comparison of RI ,TBI and ITBI with convolutionally coded IDMA systems.

B. Memory Requirement of Interleavers

Figure 6 demonstrates that the memory requirement of random interleaver is high because the memory required for storing the interleavers is user dependent. For the ITBI the memory requirement is lesser when compared with RI and TBI. So the bandwidth consumption of ITBI is found to be at lowest level because of transmission of only one interleaver. Figure 7 demonstrates that the computational complexity of ITBI is extremely less than that MRI while it is little bit higher than that of RI. Obviously, Invert Tree Based Interleaver is more suitable for the IDMA system

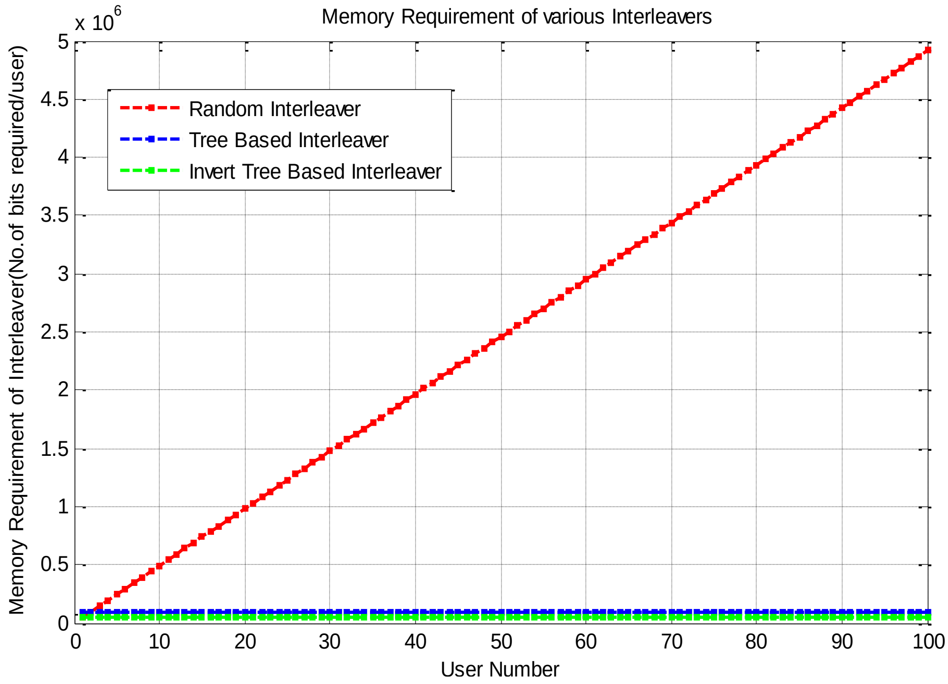

Figure 6: Memory requirement b/n RI,MRI,TBI and ITBI

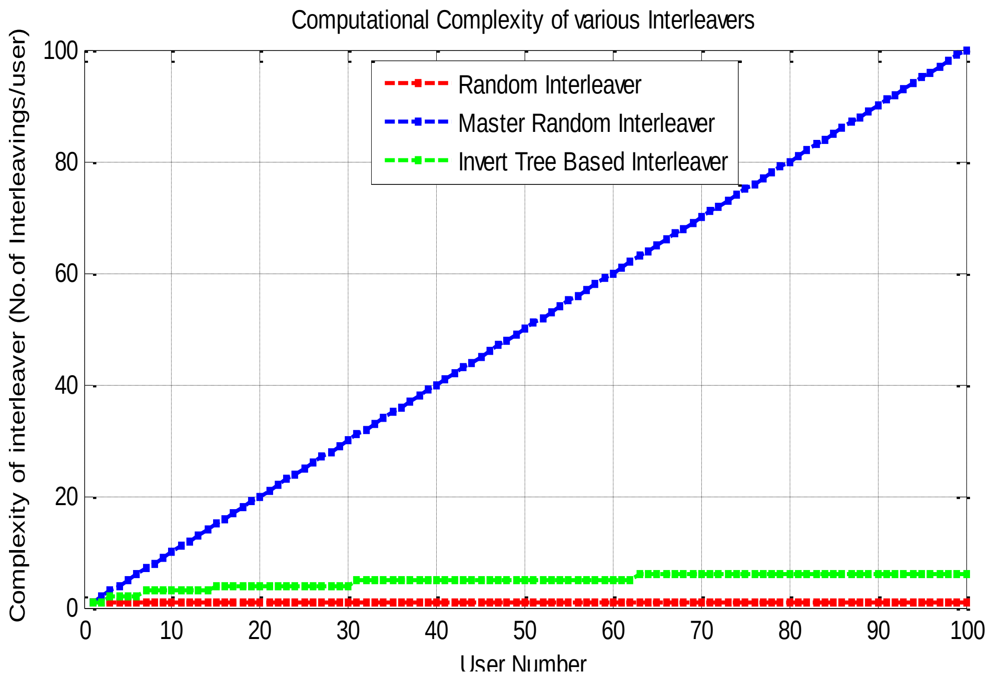

Figure 7: Computational Complexity b/n RI, MRI,TBI and ITBI

CONCLUSION

Simulation results in section 6 shows that proposed 'Invert Tree based Interleaver solves the problem of extra bandwidth requirement which occurs in tree based interleaver by providing design modification. It can be seen that proposed interleaver performs quite superior to random and after mentioned interleavers in terms of storage requirement and also it is easy to generate. Invert Tree Based Interleaver shows its superior performance than master random interleaver when it comes to the calculation of computational complexity. Compared to tree based interleaver the proposed interleaver requires less memory. From the result, it can be seen that the BER performance of all the interleavers are almost similar. The proposed interleaver seems to be optimal in case of memory requirement and computational complexity and so it gives similar performance as random or any other interleaver without performance loss.

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