TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 5477-5484

Analysis of Optimum Interleaver for Code Domain NOMA System

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Article Info
Volume 83
Page Number: 5477 - 5484
Publication Issue:
May - June 2020

Article History
Article Received: *19 November 2019*
Revised: *27 January 2020*
Accepted: *24 February 2020*
Publication: *17 May 2020*

Abstract

In recently proposed multiple access techniques like IDMA , users are differentiatedusing user specific interleavers, unlike CDMA where user separation is achieved by user specific signature sequence. User specific Interleaver offer minimum probability of collision among themselves along with other meits like less bandwidth, memory requirement and low cost. In digital communication, interleavers plays a vital role in establishing reliable communication without reducing its bandwidth. It fulfill Shannon's capacity rule by rearranging the word length of information bits. In this paper we compared different interleavers based on memory requirement, complexity, bit error rate, and bandwidth requirement. Simulation result and data analysis demonstrate optimum performance of tree based interleaver and prime interleaver in comparison to random, power, helical and block interleavrer.

Keywords: *IDMA, Random Interleaver, Tree Interleavre Based, Master random Interleaver, Block Interleaver, Helical Interleaver.*

1. INTRODUCTION

In 1948, shannon predicted that by adding redundant information to a transmitted message, reliable communication can be achieved. However he did not proposed any such specific coding scheme neither he specify maximum delay due to added redundancy that has to be tolerated in order to communicate under Shannon limit. A lot of research has been done in this area , multi user detection (MUD) techniques for suppressing multiple access interference[1] which is used in Interleave division multiple access and OFDMA-IDMA[4] has drawn their attention. In IDMA interlevers are used for user separation and it perform better then CDMA system[2]. IDMA outperform CDMA by providing better immunity to MAI, higher user count, high data rate asynchronous transmission and diversity against fading and cross cell interference with reduced complexity[3]. The efficiency of IDMA system depends on the generation of various orthogonal pseudo random interleaving patterns for individual user [2]. In recent years researchers and academia are trying to reduce the amount of delay by choosing optimum interleaver technique for best performance, meeting Shannon capacity rule. This paper is organized as follows, firstly various interleaver are discussed , then their performance is compared based on required iteration, complexity in pattern generation, bandwidth and storage requirement, hardware requirement for stated interleaver and bit error rate by signal to noise ratio.

2. INTERLEAVER

Interleaving is a technique applied to overcomeoccurrence of burst error or fading effect during data transmission in channel. In this process input data is shuffled and split into different block using certain pattern before transmission which is rearrange at receiver end by applying reverse mechanism over received data and the process is known as De-interleaver. Itresults in reduced corelated noise that occurred during transmission in channel and better error correction capabilities are offered.

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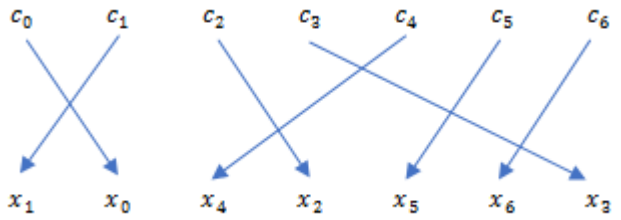

Figure 1. Data interleaving mechanism for input data of sequence length N, interleaved using X which is permutation of all elements of C.

At receiver end, de-interleaver restore the permuted data into original data sequence . let π and π^{-1} represent interleaving and de-interleaving pattern, the original sequence can be recovered using[10]:

$$\pi^{-1}[\pi[k]] = \pi[\pi^{-1}[k]] = k \quad (1)$$

Replace k by $\pi^{-1}[n]$ in eq (1) , we get

$$X^{\pi^{-1}[n]} = C^{\pi[\pi^{-1}[n]]} = C^{n} \quad (2)$$

Design consideration of an optimum interleaver include:

- Less complexity
- Low memory requirement
- Low bandwidth requirment
- Ease to generate interleaver
- Most important, low cross correlation between interleaver[5].

2.1. Random Interleaver

In Random interleaver , information bit are scrambled in according to a randomly generated pattern which further reduce noise generated during data transmission. For synchronization a message is assigned between base station and master station prior data transmission to setup a link informing type of interleaver used.

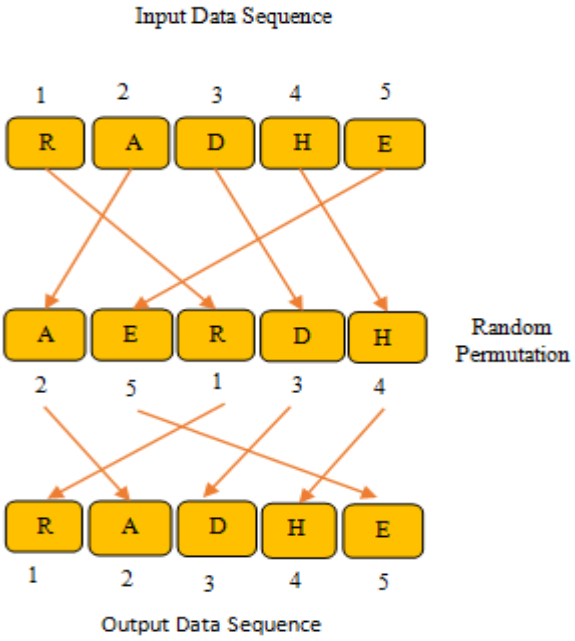

Figure 2. Structure of Random Interleaver in which input data is interleaved using random permutation and deinterleaved using reverse key.

2.2. Master Random or Power Interleaver

In this interleaving process a general master interlever is used to generate interleaving pattern for individual user by generating power of basic master interleaver in accordance to power index which is assigned to each user.

For 'N' interleaver it generate $\pi_N = \phi^N$

Where ϕ is the master interleaver, defined as

$$\phi^1(c) = \phi(c)$$

$$\phi^2(c) = \phi(\phi(c))$$

$$\phi^N = \phi(\phi(\phi(c))) \ldots\ldots\ldots\ldots \quad (3)$$

In this each user is assigned with power index N by the transmitter which generate ϕ^N for each N^{th} user.[11]. as compared to random interleaver it require less memory for storage as it has to store single pattern rest all pattern are simply generated by power of master interleaver.

2.3. Tree Based Interleaver

In tree based interleaver user specific chip level interleaving sequence is generated for every user, this pattern is generated by opting simple computational technique which offers less

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computational complexity as compared to power interleaver and also improves storage requirement by reducing amount of information exchange between both statationi.emobile station and base station which reduce memory cost as compare to random interleaver.[12]

In Tree based interleaver, users are divided into even and odd numbered form where two randomly generated Master interleaver with zero cross correlation are considered one for each.[8] it allow large number of user allocation with less complexity. In this interleaver is generated by simply following evend and odd sequence after diving user into groups of even users and odd users.

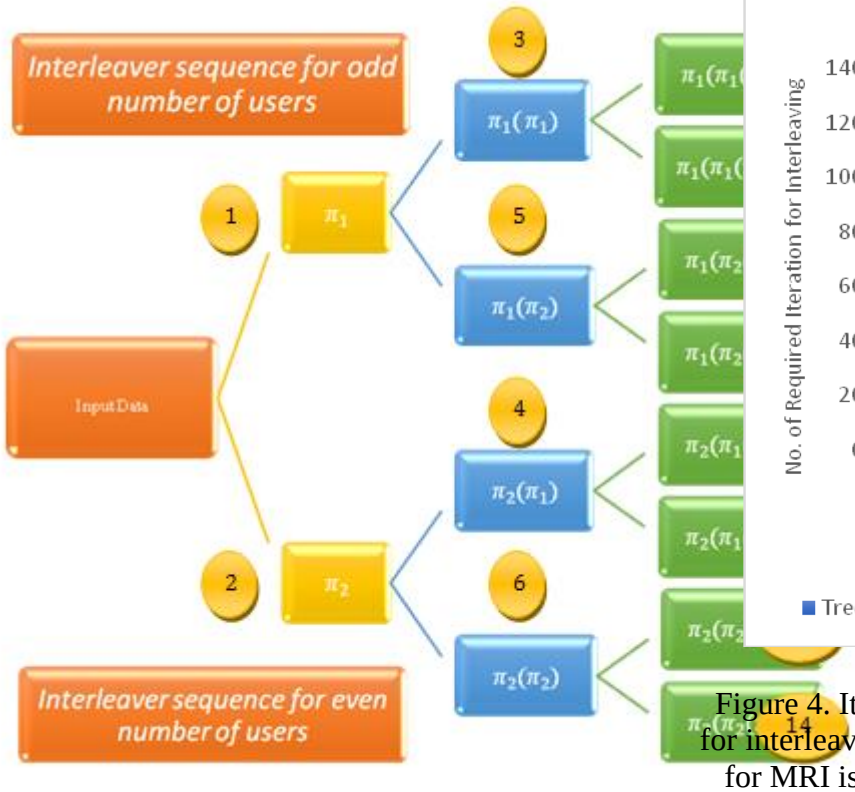

Figure 3. Pattern of Tree Based Interleaver generation, in which upper part represent interleaver pattern for odd number of users and lower part represent interleaver pattern for even number of users.

Algorithm for Tree Based Interleaver[10]

- Master interleaver is generated randomly with a block length (data length x spreader length) for odd number of users.
- Master interleaver is generated randomly with a block length (data length x spreader length) for even number of user.
- As per the user "k" , level "L" is assigned in interleaver tree.
- Therefore total number of users in desired level will be .
- Generate All possible combinations .
- As per the user N, desired pattern of master interleaver is chosen and data is interleaved.

From *fig 3*.interleaver for user 3 it will be $\pi_1(\pi_1)$, for user 4 it will be $\pi_2(\pi_1)$, for user 7 it will be$\pi_1(\pi_1(\pi_1))$, for user 8 it will be $\pi_2(\pi_1(\pi_1))$, and so on.

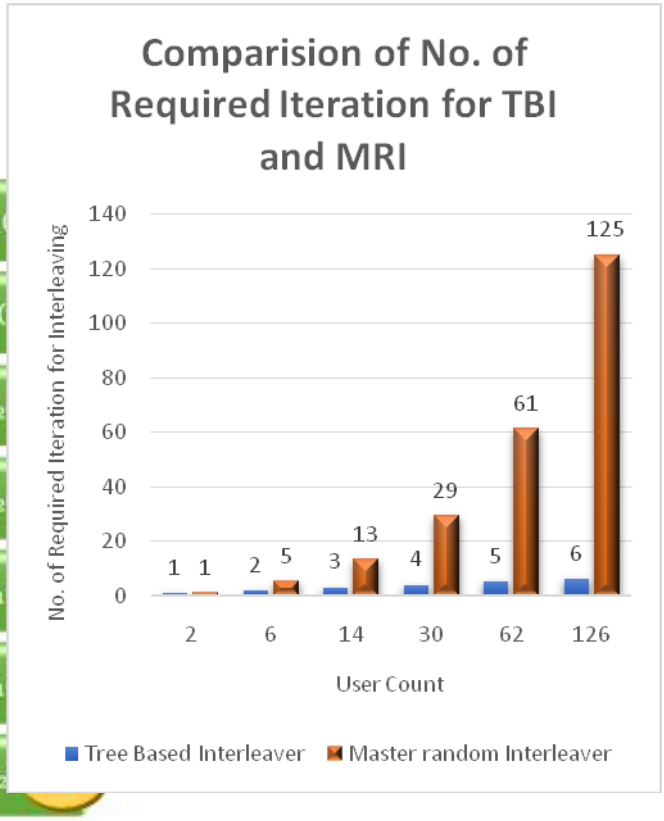

Figure 4. It compare number of required iteration for interleaving in TBI and MRI. Required iteration for MRI is very high as compared to TBI which clearly reflect that complexity level of MRI is quite high as compared to TBI.[10]

2.4. Prime Interleaver

Prime interleaver use prime number as seed and each user is assigned its own unique seed algorithm for interleaving 'n' bit data using seed 'p'. Let us consider an example where 'n' bit data is interleaved by a distance of seed over Galois field $GF\ (n)$.

Let $\{1, 2, 3, 4, 5, 6, 7, 8\}$ are the positions to be interleaved using seed P = 3; then the new position after interleaving will be calculated using

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$$n \Rightarrow (1 + (n-1)\,p) \bmod n == m, \quad (4)$$

where ‘m’ is interleaved position, ‘p’ is seed value and ‘n’ is the position to be interleaved.

$$\begin{aligned}
n &\Rightarrow (1 + (n-1)\,p) \bmod n == m \\
1 &\Rightarrow (1 + (1-1)\,3) \bmod 8 == 1 \\
2 &\Rightarrow (1 + (2-1)\,3) \bmod 8 == 4 \\
3 &\Rightarrow (1 + (3-1)\,3) \bmod 8 == 7 \\
4 &\Rightarrow (1 + (4-1)\,3) \bmod 8 == 2 \\
5 &\Rightarrow (1 + (5-1)\,3) \bmod 8 == 5 \\
6 &\Rightarrow (1 + (6-1)\,3) \bmod 8 == 8 \\
7 &\Rightarrow (1 + (7-1)\,3) \bmod 8 == 3 \\
8 &\Rightarrow (1 + (8-1)\,3) \bmod 8 == 6
\end{aligned}$$

therefore interleaved positions are {1,4,7,2,5,8,3,6}

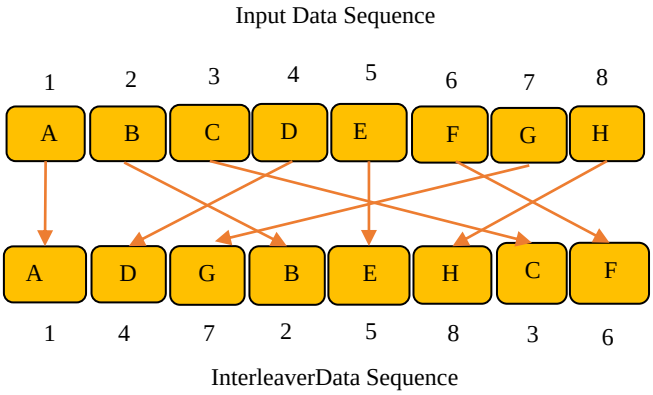

Figure 5. Structure of Prime interleaver in which input data is interleave using unique seed algorithm assigned to each user.

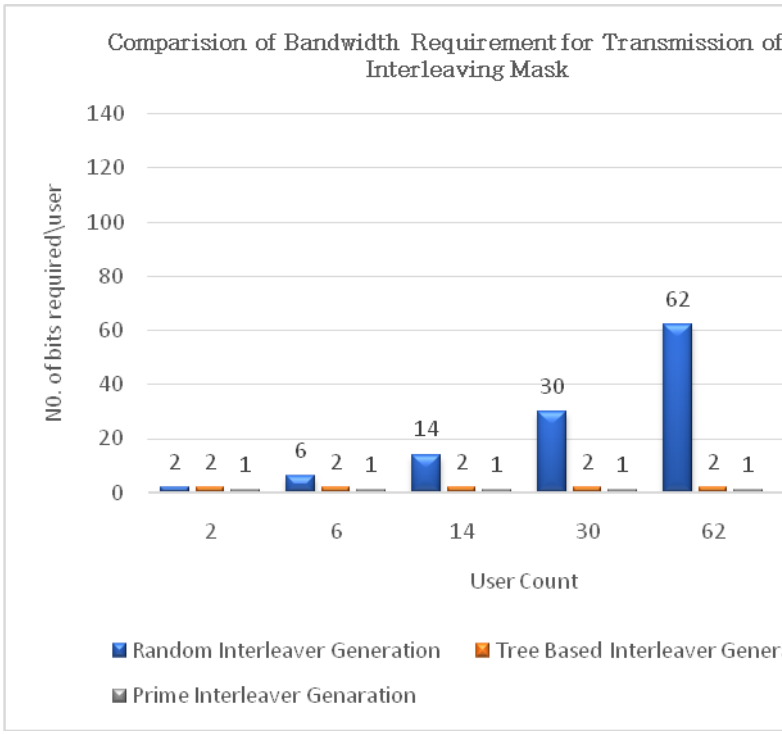

Figure 6. It compare bandwidth requirement for the transmission of interleaving mask for RI, TBI and PI. It increases with increase in number of users for RI but remain same for TBI and PI. Where PI offers least bandwidth requirement.[6]

Prime interleaver offers less memory requirement, reduced bandwidth and computational complexity as compare to Master interleaver but higher then tree based interleaver.

Table 1. Comparison based on parameters of RI,MRI,TBI and PI [8] [13]

Parameters	**Random Interleaver**	**Master Random Interleaver**	**Tree Based Interleaver**	**Prime Interleaver**
Memory requirement	High	Low	Low	Lowest
Bandwidth requirement	$1.5\text{x}10^{6}$	$0.01\text{x}10^{6}$	$0.02\text{x}10^{6}$	$0.0001\text{x}10^{6}$
Complexity	High	Very High	Lowest	Low
BER for Eb/No=10 (24 users)	10^{-4}	10^{-4}	$0.4\text{x}10^{-4}$	$0.5\text{x}10^{-4}$
Bit error rate in coded environme	$0.6\text{x}10^{-5}$	$0.6\text{x}10^{-5}$	$0.4\text{x}10^{-6}$	$0.4\text{x}10^{-6}$

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nt for Eb/No=10 (24 users)				
Bit error rate in coded environment for Eb/No=10 (24 users)	$0.6x10^{-4}$	$0.2x10^{-4}$	$0.2x10^{-5}$	$0.2x10^{-5}$
Specific user cross correlation	Low	Low	High	High

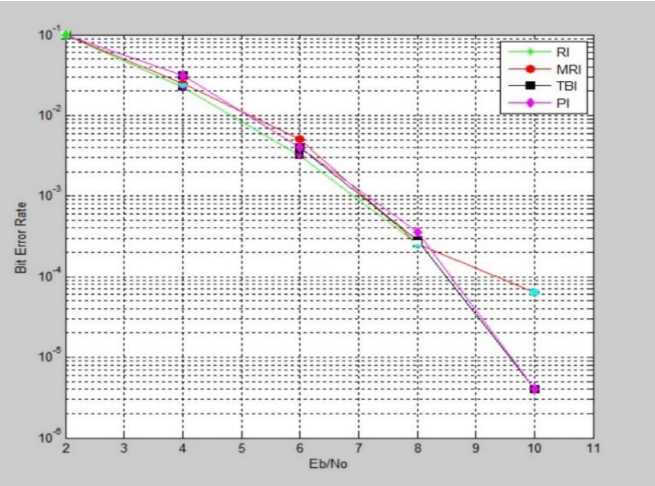


Figure 7. Result compare BER to (E_b/N_o) for RI, MRI, TBI and PI for 24 users in which at initial all show almost similar output but with increase in Eb/No, PI and TBI gives better results as compare to RI and MRI.[13]

2.5. Helical Interleaver

Algorithm for Helical Interleaver generation[14]

In helical interleaver data in the form of a matrix i.e row and column wise and readout that data diagonally to form interleaver. Initially a master interleaver is defined from which series of helical interleaver are generated by reading interleaver indices in a pre defined order. Length of master interleaver is defined as $Nc = Mr.Mc$, where Mr and Mc is number of rows and column.

- Only 1st interleaver sequence is generated by reading indices column wise in matrix.
- Remaining interleaver are obtained by diagonally reading the interleaver indices from the matrix
- In the last column , 1st unread column is wrap around.

Mathematical representation for i^{th} helical interleaver is given as

$$\pi_i(k) = \pi\,(l \bmod N_C), \qquad 0 \le k \le N_c \tag{5}$$

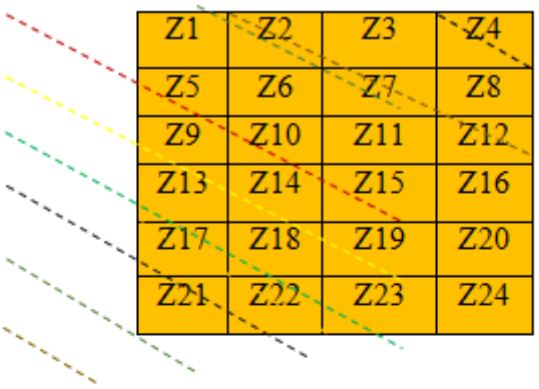
Where

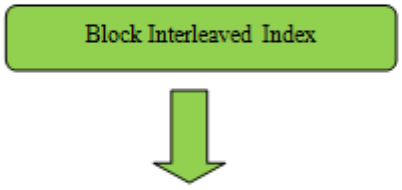
$$l = k \bmod M_r \cdot M_C + \left(\left\lfloor \frac{k}{M_r} \right\rfloor + (k \bmod M_r . (i-1))\right)_{mod\ M_C} \tag{6}$$

Using equation 2 , equation 1 can be modified as

$$\pi_i(k) = \pi[(l + i\,.S)]_{mod\ N_c} \tag{7}$$

Where S is a pre-defined constant integer used to describe shift between interleaver.





Z1	Z6	Z11	Z16
Z5	Z10	Z15	Z20
Z9	Z14	Z19	Z24
Z13	Z18	Z23	Z4
Z17	Z22	Z3	Z8
Z21	Z2	Z7	Z12

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Figure 8. Structure of Helical interleaver in which data is entered row wise and column wise and readout diagonally.[14]

2.6. Block Interleaver

In Block interleaver data is arranged in R x C matrix, where R and C is number of rows and column in the matrix. In this input data entre row wise and readout column wise.

Algorithm for Block Interleaver generation[10]

Let 'I' be the interleaving degree of block codes to be generate, 'n' is the code length of block code

- firstly, I(n,k,t) linear block codes are entered row wise in an array of I x n .
- Then data is transmitted column wise.
- At deinterleaver, data enter column wise and arranged column wise.
- Finally data readout rank by rank row wise.

the main advantage of block interleaving is that it can avoide 'error propagation' at decoding stage as it provide separation between long burst errors effectively.

Figure 9. Structure of Block interleaver and deinterleaver in which data is entered row wise at interleaver, transmitted and entered column wise at deinterleaver and readout row wise at output of deinterleaver.

Table 2.Comparison between BI, HI, and RI [14]

Parameters	Block Interleaver	Helical Interleaver	Random Interleaver
Bandwidth requirement	Low	Moderate	High
Complexity	Low	Low	High
Application	High Data rate wireless transmission	Noisy Environment	High Data Rate

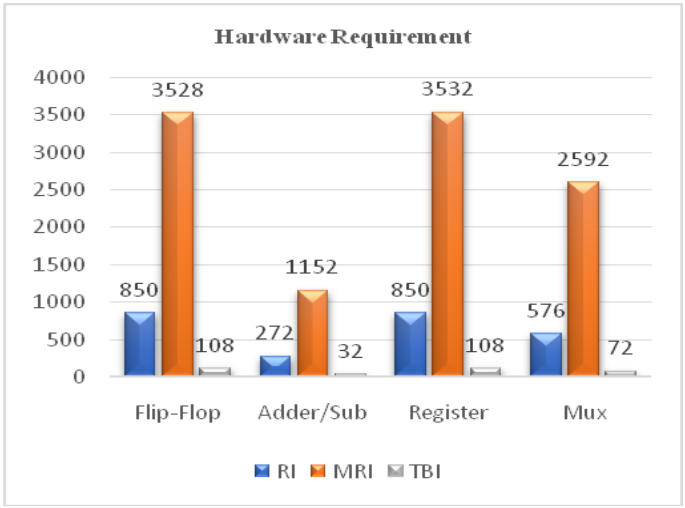

Fig. 10. It compare Hardware requirement for random, master random and tree based interleaver. [12]

3. Result Analysis and Discussion

Efficient bandwidth usage and spectral efficieny, less memory requirement , low complexity and easy design, fast calculation and low cost are some of the basic features of a good interleaver. After analyzing theoretical and simulation results we can differentiate and characterized different interleavers.[9]

a. Memory requirement: among all stated interleaver, random interleaver require maximum memory in order to save randomly generated pattern, then master random, helical and block interleaver which offer better memory requirement then random[39] but treebasedinterleaver and prime interleaver proved to be best interleaver in terms of memory requirement.
b. Bandwith consumption: $1.5x10^{6}$ Hz is the highest bandwidth requirement by random interleaver after that master interleaver which use $0.9x10^{6}$ Hz bandwidth then whe

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have helical and block interleaver with comparatively low bandwith requirement, further treebasedinterleaver which use $0.02x10^{6}$ Hz and least bandwidth requirement is of prime interleaver $0.0001x10^{6}$ Hz.

c. Bit Error rate (BER): 10^{-4} is the highest BER which is offered by random interleaver which slightly reduce in master and helical, comparatively less in block interleaver which is improved in treebasedinterleaver and least $0.2x10^{-4}$ BER is offered by prime interleaver.

d. Complexity: random interleaver is the most complex, this complexity is improved in master random interleaver, helical interleaver and treebasedinterleaver . Less complex interleaver are block and prime interleaver.[15]

e. User Cross Correlation : random, master random and helical interleaver provide very low cross correlation resulting in collision with increase in user. Bl0ck interleaver offer comparatively better performance but treebasedinterleaver and prime interleaver.

4. CONCLUSION

On the basis of theoretical analysis and simulation results IDMA is proven to be most promising and challenging multiple access technique for present and future of wireless communication . By opting proper interleaver interference can be improved even with extended user, high speed data rate can be achieve without compromising the quality of service for multimedia application, with low complixity and less expansive circuits. In this paper we implemented and perform analysis of random, master randon, helical, block, treebased and prime interleaver. In which treebased and prime interleaver proved to be most promising in terms of performance with increase in number users accessing shared channel.

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