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Research paper

Impact of multifarious design architectures of convolutional encoders on efficiency of O-IDMA at zero dispersion wavelength

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Abstract

Optical interleave division multiple access is a protrusive, obvious and flashy technology used in modern era mobile and wireless systems. Inter-leavers play a major role for estimating the performance of OIDMA system. In present article tree and random inter-leavers are incorporated in OIDMA system one by one and their qualitative comparison has been evaluated. Low rate convolutional encoders having various design topologies by varying number of adders and memory elements are used in coding section. Due to multifarious design architecture of encoders hamming distance (d_{free}) alters for each case. Those architectures which has maximum d_{free} will produces minimum BER (bit error rate). In present paper that optimum architecture which produces minimum BER has been determined for both tree and random inter-leaver cases.

Keywords: *Bit Error Rate; Convolutional Code; Constraint Length; Optical Inter-Leave Division Multiple Access (O-IDMA); Processing Gain; Random and Tree Inter-Leaver.*

1. Introduction

Some basic requirements and needs of modern communication systems is to reduce the size, curtail the power requirement, shortens the bandwidth invigorate security issues and bankrupt interference. To fulfil these demands various technique has been invented such as DSSS (direct sequence spread spectrum), FHSS (frequency hopping spread spectrum), CDMA (code division multiple access), OFDM (orthogonal frequency division multiplexing) etc. [1-2]. CDMA technologies based on user separation with the help of distinct PNS sequences, is a protrusive one which mitigates cross cell interference in a noisy environment. But when traffic intensity (number of users) is drastically increasing multiuser detection problem arises which reduces throughput. Reason, behind this is due to large number of PNS sequences their cross correlation should not be exactly zero which produces multiple access interference at the output and degrade the quality of transmission [3-4]. To overcome this problem an alternative approach of IDMA has been proposed which is similar to CDMA in principle of PNS sequence multiplication.
The difference between CDMA and IDMA is that in IDMA only one PNS is multiplied to all the users [5-7]. The user distinction is done with the help of inter-leavers. Inter-leaver is the mechanism by which data is re-arranged by known deterministic pattern. To improving the quality transmission several types of inter-leavers like random, tree and helical etc. are invented.
In the present work for analysis purpose tree and random inter-leaver are selected and their qualitative comparison has been evaluated. In block diagram of IDMA system the coding section embedded the convolutional encoder. Design of convolutional encoder is based on memory elements and combinational circuits. Basically we are using D flip flops as memory elements and adders (Ex-OR) gates as a combinational circuit. By increasing the memory elements or by increasing the adder will change the code rate and hamming distance. Hamming distance is inversely proportional to bit error rate. So as design topology of encoder changes by either varying adder or memory element the quality of transmission is affected.
In this paper, Section 2 define the block diagram of optical interleave division multiple access (O-IDMA). Section 3 described the process of interleaving. Convolutional coding, an architecture of convolutional encoder by varying memory elements and Ex-OR Gates are explained in Section 4. Section 5 shows the simulation result and their discussion. Conclusion and future scope are discussed in Section 6.

2. Optical IDMA system

The block diagram of proposed IDMA system containing transmitter and receiver are shown in figure 1. There are k different users depicted as b_1, b_2.........b_k. For sending the user signal error free in communication channel, in first step channel coding is done. The first block indicates channel coder [9-10]. I have used low rate convolutional coder for coding purpose. After coding all the users are spreaded with same PNS code. Spreading introduces security and interference rejection capability in the system. All the spreaded coded user signals are passed through π_1, π_2....... π_k, k user specific inter-leavers. Interleaving enhanced error detection and correction capability of a code and also inherit the multiuser detection capability of users in noisy environment. After interleaving signals are converted from electrical to optical domain. For optical conversion we have taken 1550nm zero dispersion wavelength of optical source which is Laser diode [11-12]. Optical channel parameter is

selected properly and at the receiving side optical to electrical conversion has been carried out. For optical detection we have used high responsivity higher gain Avalanche photo diode. Since responsivity is wavelength dependent so APD characteristics is selected accordingly.
In receiver side (in figure 2) the noisy, interference signal goes to the chip match decoding process and transferred to the elementary signal estimator (ESE) for user recognition. In ESE different sets of anticipated noise patterns are already stored and their cross-correlation, autocorrelation, auto-covariance, cross-covariance among other user signals are presented in memory and its impact on incoming signal are checked chip by chip LLR (long likelihood ratio) is the prime component for distinguishing the particular user. If any misdetection occurs user specific inter-leavers are connected in feedback path to properly check, correct and identify the particular users.

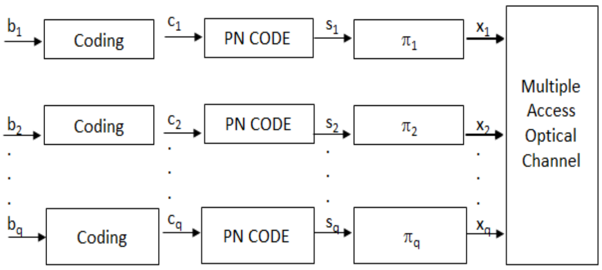

Fig. 1: The IDMA Transmitter Structure.

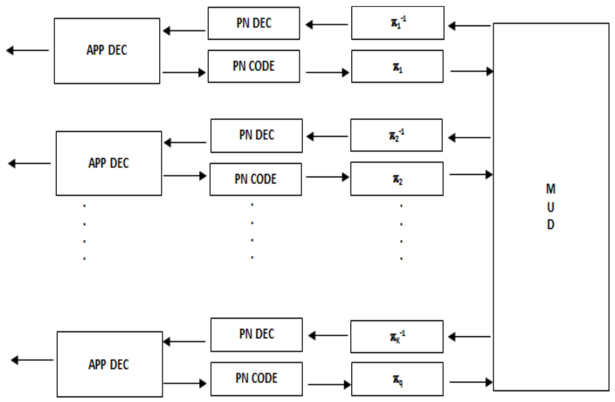

Fig. 2: The IDMA Receiver Structure

3. Inter-leaver

Interleaving is technique of rejumbling the ordering of a data stream in a one to one specific permutation and combination which should be deterministic [13-14]. It is a practical approach to enhances the error detection and correction ability of a code. The basic work of each inter-leaver is to construct a long block code from small memory convolutional codes as long code can approaches the Shannon's capacity limit. It spreads out burst of errors into small errors which is easily distinguishable. Due to scrambling or rearranging bits it increases the uncorrelated data so enhances the code free hamming distance or reduces the numbers of code words with small distances so overall improves the BER.
A very common inter-leaver which scrambles the data bit with any random permutation is known as random inter-leavers. It requires larger memory spaces so used on that place where no storage crisis. Tree inter-leaver is a modified, organized form of random inter-leaver where initially two randomly selected master inter-leavers are taken. These inter-leavers possess orthogonal property having zero cross correlation. All the other inter-leavers are made of combinations of these two, arranged like a tree and users are put on tree branches according to certain rule [15-16]. For example, consider 14 users we have selected two master random inter-leavers. According to number of users levels of tree is chosen which is denoted by L. Each user is arranged in tree branch with maximum distance 2L (L=1,2). In present example L is selected as (1 & 2) which makes maximum distance as 2 & 4. In the given tree 1 & 2 users are treated as master random inter-leavers. In the first level L = 1 upper branch contains odd number users that is 3, 5 & lower branch 4, 6 that is even number of users are arranged with maximum distance 2. In the next higher level (L = 2) users are arranged with maximum distance (2L) 4 that is upper branch contains users [7], [11] [9-13] & lower branch having [8, 12], [10,14]. If number of users are more than 14 then level is increases as 4L, 8L etc.

4. Convolutional coding

Convolutional coding is significant coding technique that is used in error correction [17]. Generally, convolution encoder is made up of combination of flip-flops and logic gates, D- flip-flops as its peculiar shifting property are commonly used in encoder hardware design. Constraint length depends on number of shift registers used in encoder. Normally constraint length is one ahead of number of registers used in encoder. Ex-OR gates are used in design of encoder to produce uncorrelated code-words. Convolutional codes are designated as [X Y Z] where X stands for number of output bits, Y stands for input bits and Z indicates number of memory elements inherit by encoder. The ratio between Y and X is termed as code rate [Y/X] [18]. As the number of Ex-OR gates are increasing the outputs bits X increases makes the code rate as ½, 1/3 & ¼ etc. with fixed number of input bits Y = 1.

4.1. Architecture of convolutional encoder by varying memory elements

In designing technology of convolutional encoders flip flops decides the constraint length of encoder. In present work initially we have taken two memory elements with constraint length L = 3 & fixing the number Ex-OR gates 2. This is the basic network topology of convolutional encoder having code rate [1/2] shown in figure 3. Now by fixing the Ex-OR gates two then number of memory elements are increasing 4 (L = 5) & 6 that is (L = 7) respectively shown in figure 6 and figure 7. In figure (6) for (1, 2) code rate possible optimum trellis are 23, 35 in octal number representation [010011,011101] which decides the feedback mechanism of encoder. The optimum trellis [23, 35] are taken from [reference-18 convolution coder chapter-10] which contains tabular form of all possible trellis combination for different code rates and constraint lengths. Similarly, in figure 7 L is increased as 7 that is 6 memory elements are connected with code rate ½ and possible trellis are selected as [171 133] that is [001 111 011, 001 011 011] in octal number and encoder feedback are setting accordingly. Going on same logic the multifarious encoders are designed for code rate 1/3 and coder rate ¼ respectively. The combination of trellis is selected from [convolutional coder chapter 10 Ref. 18]. Theoretically as the number of memory elements is increasing accuracy and error detecting capability should be increased, but due to increasing number of flip flops delays of flip flops might come in pictures which decreases the speed of system.

4.2. Architecture of convolutional encoder by varying Ex-OR gates

In this section memory elements are fixed and Ex-OR gates are changed that is code rates are varying by fixing the flip-flops in encoder [19]. In basic network connection of figure-3 where only 2 adders and 2 flip-flops, Ex-OR gates are added one by one making figure (4) code rate (1, 3) and figure (5) code rate (1, 4) for fixed L = 3. The possible network trellis for figure 4 is 3[5, 7 7] and figure 5 is 3[5, 7 7 7]. The encoder design and feedback connection are used according to trellis. Similar logic has been applied for fixed L = 5 and fixed L = 7 respectively and possible network architecture is shown in figures 8, 9, 10 and 11. In reference 18 the table is formed for various code rates (1, 2), (1, 3), (1, 4) and constraint length (L =3, 5, 7). In the table, optimum trellis structure depending on d_{free}, which is prime factor for deciding error correcting capability of code, is shown. The encoder design chosen on basis of that table, so BER for different architectures of convolutional encoder has been observed on that basis.

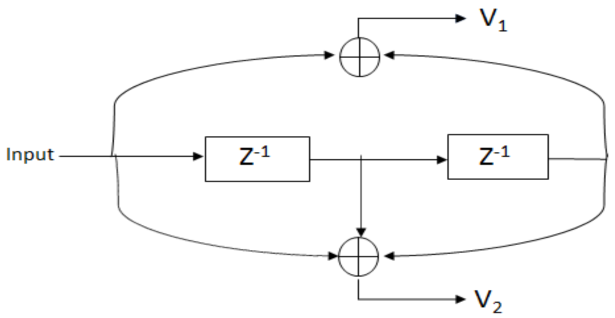

Fig. 3: Convolutional Encoder [1,2], 2 – Ex-OR gates Network Topology [3(5,7)].

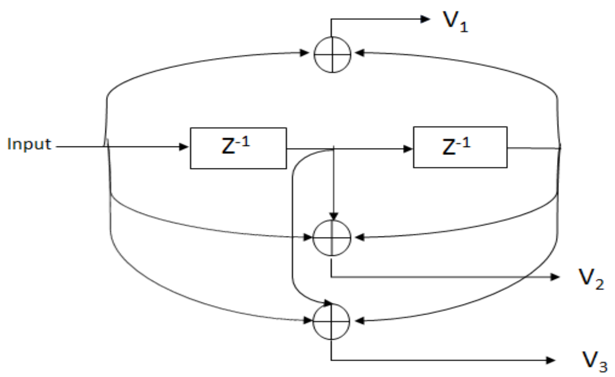

Fig. 4: Convolutional Encoder [1,3], 3 – Ex-OR Gates Network Topology [3(5,7,7)].

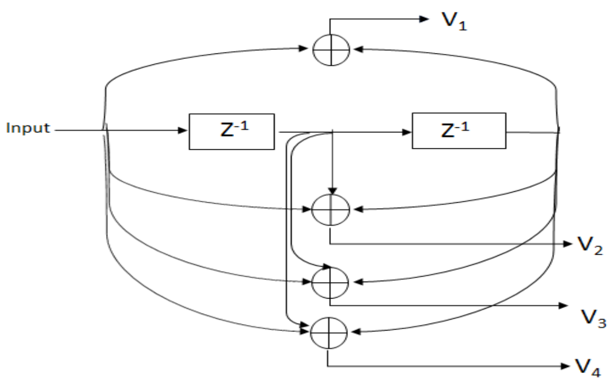

Fig. 5: Convolutional Encoder [1,4], 4 – Ex-OR Gates Network Topology [3(5,7,7,7)].

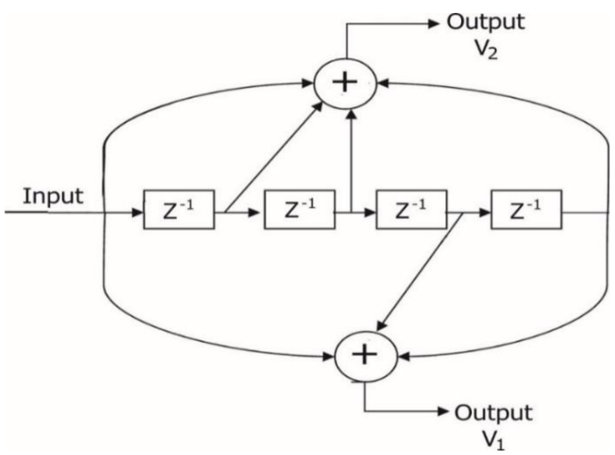

Fig. 6: Convolution Encoder for Constraint Length L=5, L = 5 [23, 35], 4 – Shift Register.

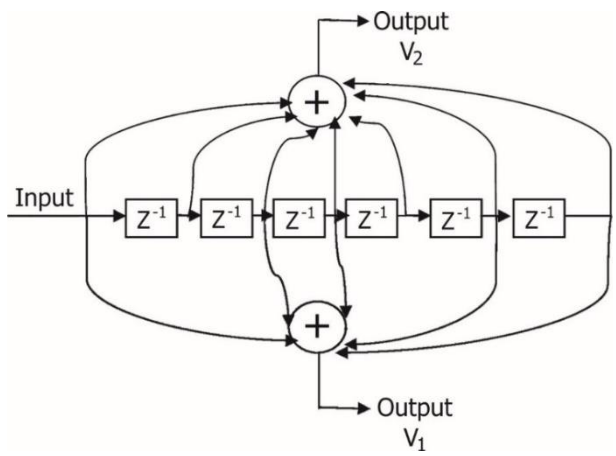

Fig. 7: Convolution Encoder for Constraint Length L=7, L = 7 [171, 133], 6 – Shift Register.

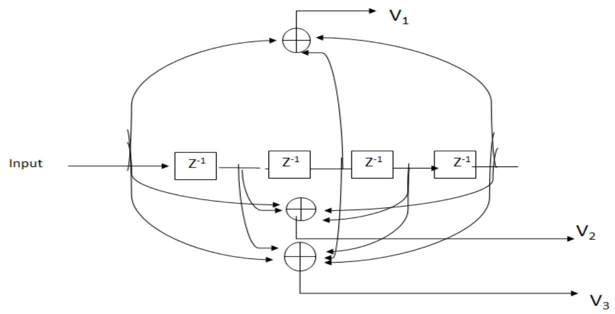

Fig. 8: Convolutional Encoder [1,3], 3 – Ex-OR Gates Network Topology [5(25, 33, 37)].

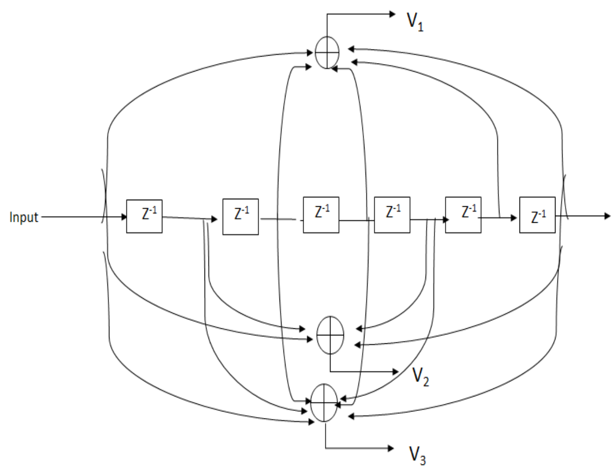

Fig. 9: Convolutional Encoder [1,3], 3 – Ex-OR Gates Network Topology [7(133, 145, 175)].

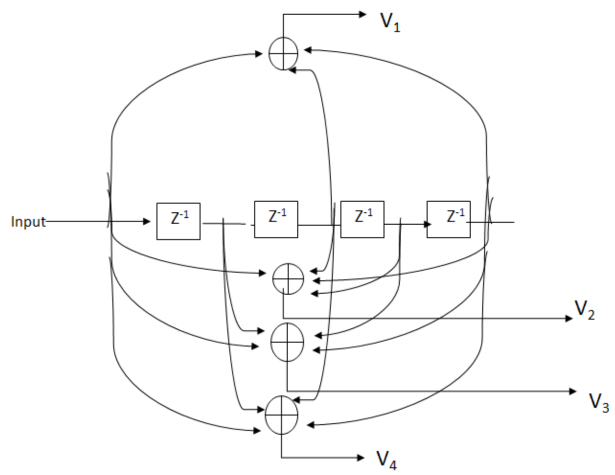

Fig. 10: Convolutional Encoder [1,4], 4 – Ex-OR Gates Network Topology [5(25, 33, 37)].

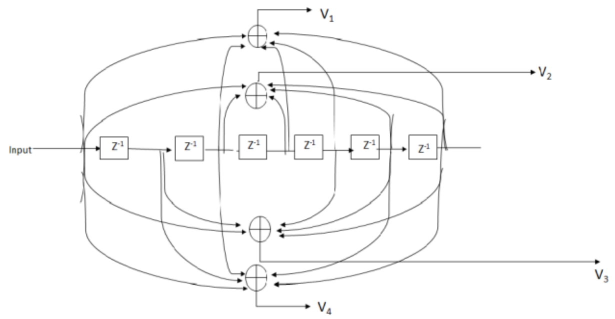

Fig. 11: Convolutional Encoder [1,4], 4 – Ex-OR Gates Network Topology [7(133, 145, 175)].

5. Simulation result and discussion

For finding out the results of this paper MATLAB platform is used. I have implemented the whole IDMA system by programming its various blocks separately and interfaced them for making complete IDMA system. The 1550nm is known as zero dispersion wavelength because at this wavelength chromatic dispersion is equal to the waveguide dispersion. Input parameters are fixed such as data length 512, block length 100, spread length 16. The optical channel is fixed and its parameters such as numerical aperture, fiber length, its dispersion parameter and attenuation are fixed. The optical source has taken as wavelength 1553nm, laser source having power 1m W, Gaussian pulse shape and detector is APD with gain 1000 and fixed responsivity. The results of BER have been calculated for two different inter-leavers random and tree separately. The multifarious architectures of convolutional encoders are connected at the coding section for each inter-leaver and performance of IDMA system has been evaluated in terms of BER. The various tables show the BER result of different convolutional encoder architectures (1, 2), (1, 3) and (1, 4). The number of memory elements has been increased simultaneously with two shift register L = 3, four shift register L = 5 and six shift L = 7 various constraint lengths respectively. Overall for each code rates three tables that is total nine tables are drawn for three different constraint lengths. For three code rates (1, 2), (1, 3) and (1, 4) with varying L = 3, 5 and 7, three graphs (Figure 12, 13 & 14) are plotted showing the comparative study between random and tree inter-leavers.

I have drawn all results in tabular and graphical both form. In table-1 which is drawn for convolutional encoder (1, 2) L = 3 (that is two memory elements and two adders) shows variation of BER with number of users with random inter-leaver a left side and tree inter-leaver on right side. The results show that as number of users increase the BER increases slowly for instance in random case when number of users 120, BER is 1.6280 $\times 10^{-8}$ and reaches 3.776 $\times 10^{-7}$ for 240 users. This increases in BER resembles theoretical concept that as more number of users more ISI and MAI which increases bit error rate. Similar trend obtained for tree inter-leaver also as instance when number of users 120 BER is 1.139 $\times 10^{-8}$ which increases up to 4.195 $\times 10^{-7}$ for 240 users. In table-2 comparative BER for random and tree inter-leavers are shown for (1, 2) convolutional encoder but memory element are 4 that is 2 more than the previous cases shown in figure 6. The observed trends of BER with number of users in tree and random cases fully match with table-1. Due to increasing number of memory elements input bit experience more rigorous testing of errors because more number of output bits are now used to decide the input bit at a time which reduces the BER in this cases. For instance, BER is 1.3020 $\times 10^{-8}$ (120 users random) obtained in this case is smaller than the BER 1.6280 $\times 10^{-8}$ (120 users L =3) case. Same nature of variations is obtained for tree case as BER is 6.510 $\times 10^{-9}$ (120 users L = 5, tree) is improved comparative to BER 1.139 $\times 10^{-8}$ (120 users L = 3, tree) case.

In table-3 the reading of BER are calculated for L = 7 keeping other parameter same. This table also shows the same nature of variations as in two previous cases. Since here six memory element are used in architecture so it gives the best results. For instance, BER is 6.5100 $\times 10^{-9}$ (120 user's random L = 7) which is least error obtained among three tables 1, 2 & 3 for same number of users 120.

Three tables are shown collectively in graph-1 [Figure-12] showing all six BER variations verses number of users with different colors. In all cases BER increases with increasing number of users slowly. Similarly, table 4, 5 and 6 depicts the BER variations for code rate (1, 3) with all other parameters are similar as discussed in table 4, 5 and 6. The observed reading are much improved comparative to code rate (1, 2). The reason behind that in (1, 3) case one more adder is used which produces more uncorrelated bits at the output, with increase hamming distance between code-words causes reduction in BER. This theoretical aspect clearly observed in all results of table 4, 5 and 6. For instance from table-6 BER 1.6276 $\times 10^{-9}$ (120 users, L = 7, random (1, 3) which is smaller than the BER 6.5100 $\times 10^{-9}$ [120 users, random] (1, 2) case. In generally approximately all the readings of (1, 3) code rate is improved as compared to (1, 2) case with some exceptions graphical representation is shown in graph – 2 (Figure-13) of all tabular reading of 4, 5 & 6 collectively.

The table 7, 8 and 9 are drawn for BER verses number of users for code rate (1, 4) keeping other parameters fixed as for graph 1 (figure 12) and graph 2 (figure 13). Here we have used one more adder which introduces more un-correlation between code words. The results obtained in this case is best among all three cases for instance from table-9 the BER is 8.8788 $\times 10^{-10}$ [220 user, random L = 7, code rate (1, 4)] is least compared to BER 4.7940 $\times 10^{-8}$ [220 user, random L = 7, code rate (1, 3)] and BER 3.3290 $\times 10^{-7}$[220 user random L = 7, code rate (1, 2)].

All table are plotted in graphical form with all six BER readings are plotted with different colors. Distinction in colors for random and tree comparison clearly depicts the superiority of tree inter-leaver over random inter-lever approximately in all cases. For instance, from table-9 BER 2.483 $\times 10^{-9}$ [280 user tree, L = 7 code rate (1, 4)] is improved as compared to BER 3.4520 $\times 10^{-9}$ [280 user, random L = 7, code rate (1, 4)].

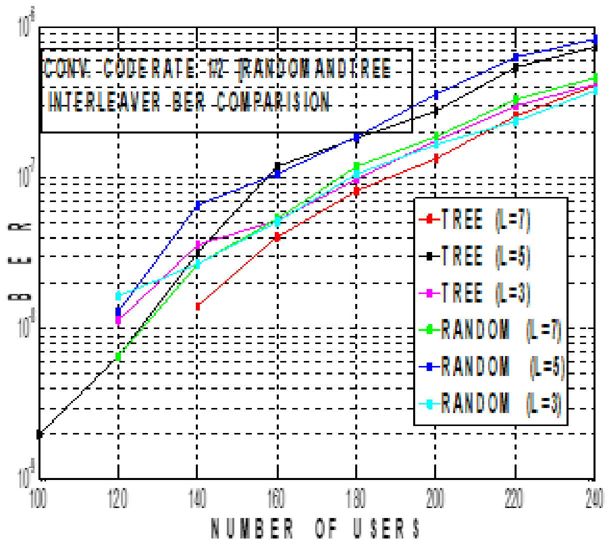

Fig. 12: Bit Error Rate Performance of Random and Tree Inter-Leaver Using Convolutional Code Rate 1/2.

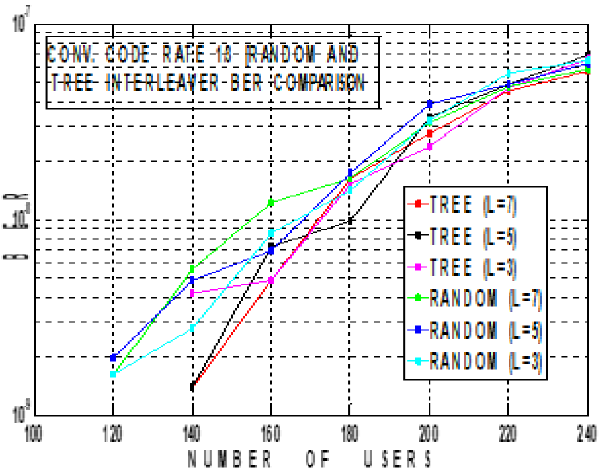

Fig. 13: Bit Error Rate Performance of Random and Tree Inter-leaver using Convolutional Code Rate 1/3.

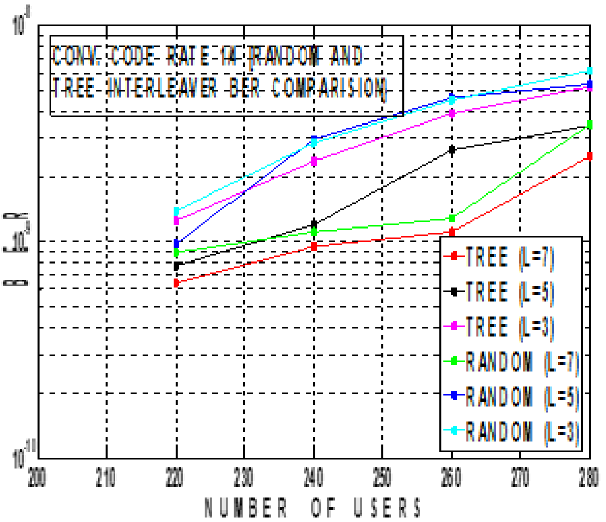

Fig. 14: Bit Error Rate Performance of Random and Tree Inter-leaver using Convolutional Code Rate 1/4.

Table 1: BER for Code Rate (1/2) and Constraint Length L = 3

Conv. Encoder (1, 2), Input Data Length = 512, Pn Sequence Length = 16, Constraint Length = 3			
Random Interleaver		Tree Interleaver	
No. Of Users	Bit Error Rate	No. Of Users	Bit Error Rate
1oo	No Error	100	No Error
120	1.6280×10^{-8}	120	1.139×10^{-8}
140	2.6510×10^{-8}	140	3.627×10^{-8}
160	5.127×10^{-8}	160	5.249×10^{-8}
180	1.0530×10^{-7}	180	9.766×10^{-8}
200	1.6600×10^{-7}	200	1.748×10^{-7}
220	2.3620×10^{-7}	220	3.011×10^{-7}
240	3.776×10^{-7}	240	4.195×10^{-7}

Table 2: BER for Code Rate (1/2) and Constraint Length L = 5

Conv. Encoder (1, 2), Input Data Length = 512, Pn Sequence Length = 16, Constraint Length = 5			
Random Interleaver		Tree Interleaver	
No. Of Users	Bit Error Rate	No. Of Users	Bit Error Rate
1oo	No Error	100	1.953×10^{-9}
120	1.3020×10^{-8}	120	6.510×10^{-9}
140	6.5570×10^{-8}	140	3.209×10^{-8}
160	1.0500×10^{-7}	160	1.196×10^{-7}
180	1.8850×10^{-7}	180	1.834×10^{-7}
200	3.5940×10^{-7}	200	2.744×10^{-7}
220	6.2777×10^{-7}	220	5.362×10^{-7}
240	8.2576×10^{-7}	240	7.438×10^{-7}

Table 3: BER for Code Rate (1/2) and Constraint Length L = 7

Conv. Encoder (1, 2), Input Data Length = 512, Pn Sequence Length = 16, Constraint Length = 7			
Random Interleaver		Tree Interleaver	
No. Of Users	Bit Error Rate	No. Of Users	Bit Error Rate
1oo	No Error	100	No Error
120	6.5100×10^{-9}	120	No Error
140	2.6510×10^{-8}	140	1.395×10^{-8}
160	5.3710×10^{-8}	160	4.028×10^{-8}
180	1.1940×10^{-7}	180	8.138×10^{-8}
200	1.8550×10^{-7}	200	1.348×10^{-7}
220	3.3290×10^{-7}	220	2.575×10^{-7}
240	4.5672×10^{-7}	240	4.085×10^{-7}

Table 4: BER for Code Rate (1/3) and Constraint Length L = 3

Conv. Encoder (1, 3), Input Data Length= 512, Pn Sequence Length = 16, Constraint Length = 3			
Random Interleaver		Tree Interleaver	
No. Of Users	Bit Error Rate	No. Of Users	Bit Error Rate
1oo	No Error	100	No Error
120	1.6270×10^{-9}	120	No Error
140	2.7902×10^{-9}	140	4.1853×10^{-9}
160	8.5449×10^{-9}	160	4.8828×10^{-9}
180	1.4106×10^{-8}	180	1.5191×10^{-8}
200	3.2227×10^{-8}	200	2.3437×10^{-8}
220	5.5930×10^{-8}	220	4.7053×10^{-8}
240	6.4627×10^{-8}	240	6.5918×10^{-8}

Table 5: BER for Code Rate (1/3) and Constraint Length L = 5

Conv. Encoder (1, 3), Input Data Length = 512, Pn Sequence Length = 16, Constraint Length = 5			
Random Interleaver		Tree Interleaver	
No. Of Users	Bit Error Rate	No. Of Users	Bit Error Rate
1oo	No Error	100	No Error
120	1.9531×10^{-9}	120	No Error
140	4.8828×10^{-9}	140	1.3951×10^{-9}
160	6.9754×10^{-9}	160	7.3242×10^{-9}
180	1.7361×10^{-8}	180	9.7656×10^{-9}
200	3.9063×10^{-8}	200	3.3203×10^{-8}
220	4.8838×10^{-8}	220	4.8828×10^{-8}
240	6.2165×10^{-8}	240	6.9173×10^{-8}

Table 6: BER for Code Rate (1/3) and Constraint Length L = 7

Conv. Encoder (1, 3), Input Data Length = 512, Pn Sequence Length = 16, Constraint Length = 7			
Random Interleaver		Tree Interleaver	
No. Of Users	Bit Error Rate	No. Of Users	Bit Error Rate
1oo	No Error	100	No Error
120	1.6276×10^{-9}	120	No Error
140	5.5804×10^{-9}	140	1.3951×10^{-9}
160	1.2207×10^{-8}	160	4.8828×10^{-9}
180	1.6276×10^{-8}	180	1.6276×10^{-8}
200	3.1250×10^{-8}	200	2.7344×10^{-8}
220	4.7940×10^{-8}	220	4.5277×10^{-8}
240	5.8735×10^{-8}	240	5.685×10^{-8}

Table 7: BER for Code Rate (1/4) and Constraint Length L = 3

Conv. Encoder (1, 4), Input Data Length = 512, Pn Sequence Length = 16, Constraint Length = 3			
Random Interleaver		Tree Interleave	
No. Of Users	Bit Error Rate	No. Of Users	Bit Error Rate
1oo	No Error	100	No Error
120	No Error	120	No Error
140	No Error	140	No Error
160	No Error	160	No Error
180	No Error	180	No Error
200	No Error	200	No Error
220	1.3756×10^{-9}	220	1.2480×10^{-9}
240	2.8594×10^{-9}	240	2.3562×10^{-9}
260	4.5318×10^{-9}	260	3.9240×10^{-9}
280	6.1462×10^{-9}	280	5.2138×10^{-9}

Table 8: BER for Code Rate (1/4) and Constraint Length L = 5

Conv. Encoder (1, 4), Input Data Length = 512, Pn Sequence Length = 16, Constraint Length = 5			
Random Interleaver		Tree Interleaver	
No. Of Users	Bit Error Rate	No. Of Users	Bit Error Rate
1oo	No Error	100	No Error
120	No Error	120	No Error
140	No Error	140	No Error
160	No Error	160	No Error
180	No Error	180	No Error

200	No Error	200	No Error
220	9.7656×10^{-10}	220	7.7248×10^{-9}
240	2.9652×10^{-9}	240	1.1956×10^{-9}
260	4.6481×10^{-9}	260	2.6483×10^{-9}
280	5.3420×10^{-9}	280	3.4240×10^{-9}

Table 9: BER for Code Rate (1/4) and Constraint Length L = 7

Conv. Encoder (1, 4), Input Data Length = 512, Pn Sequence Length = 16, Constraint Length = 7			
Random Interleave		Tree Interleaver	
No. Of Users	Bit Error Rate	No. Of Users	Bit Error Rate
1oo	No Error	100	No Error
120	No Error	120	No Error
140	No Error	140	No Error
160	No Error	160	No Error
180	No Error	180	No Error
200	No Error	200	No Error
220	8.8778×10^{-10}	220	6.4210×10^{-10}
240	1.125×10^{-9}	240	0.9465×10^{-9}
260	1.2723×10^{-9}	260	1.110×10^{-9}
280	3.4520×10^{-9}	280	2.483×10^{-9}

6. Conclusion and future scope

The various network architectures for convolutional encoders designed with variable number of memory elements and adders combination with optimum feedback connections are tested in OIDMA case with two different type inter-leavers random and tree. All the eighteen different tabular results which are plotted in three graphical view clearly suggest that when large number of memory element are used with more number of adder six memory elements and 4 adders as in figure -12. we find the best result. By comparing the results of tree and random case tree proves its supremacy over random inter-leaver due to its better organized design, low power consumptions as well as low cost. The results might be improved more if it can be tested for code rate (1, 5) with L = 7, 9 etc. But using more gates and memory elements can cause complexity in the network design as well as more delay in IDMA system. Overall it can be concluded that with using optimum network architecture suggested in paper with tree inter-leaver in OIDMA system might be a superior alternative among all existing multiple access technologies in future communication systems.

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