

Comparative Analysis of Optical Interleave Division Multiple Access using Helical and Random Interleaver

¹Jwala Prasad, ²Deepak Kumar Singh, ³Ajay Kumar Maurya, ⁴Tushar Srivasatva, ⁵Ravi Prakash, ⁶B. B. Tiwari

¹M. Tech. Student, Department of Electronics Engineering Uma Nath Singh Institute of Engineering and Technology Veer Bahadur Singh Purvanchal University Jaunpur,

^{2,3,4,5,6}Faculty of Department of Electronics Engineering Uma Nath Singh Institute of Engineering and Technology Veer Bahadur Singh Purvanchal University Jaunpur

Abstract- Optical interleave division multiple access (OIDMA) is a protrusive, obvious and flashy technique which is employed in modern era mobile and wireless communication systems. Interleavers play a key role for analyzing the performance of OIDMA system. In this study, helical and random interleavers are incorporated in convolutionally coded OIDMA system one by one and their qualitative comparison has been observed. Low rate convolutional encoders having various design topologies by varying number of adders and memory elements are used in coding section. In the present paper, the convolutional codes of code rate 1/2 and 1/3 as well as fixed constraints length 3 is used and their combined effect on response of OIDMA system has been analyzed. Helical and tree interleaver is considered for analysis purpose and bit error rate with respect to number of users is plotted in graphical as well as tabular manner.

Keywords- Code rate, constraint length, helical interleaver, random interleaver, optical interleave division multiple access (OIDMA).

1. Introduction-

In the modish age the field of communication does not emphasis on power consumption and bandwidth but it also consider the security of data, interference rejection capability, low probability of interception, avoidance of fading problem etc. The challenging aspect is to design the technologies which cope up with the high data rate of multiple users. A latest technology which will suits with all these parameters on optical communication is OIDMA technology which is purely based on interleaving mechanism. Interleaving is just like scrambling of bits to enhance the security as well as error correction capability [1-4].

A Lecture Notes which is based on convolutional codes. This note deals all aspects of convolutional codes like its significance, designing procedure, basic operating principle, trellis diagram decoding process, code tree decoding process, viterbi decoding process etc. A table is also given in this paper which comprises of maximum free distance with various constraints length and code rates [5-8]. The corresponding generators in octal form are also given which is used for convolutional encoder design. Code rate and constraint length specifies that different possible combinations of shift

registers and adders are used in encoder. More number of uncorrelated code words produces larger hamming distance which increases the error detection and correction ability of codes. Constraint length and network topology are the important parameter of the convolutional encoder [9-12].

In this paper, Section 2 define the block diagram of optical interleave division multiple access (OIDMA). Section 3 described the process of random and helical 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. OIDMA 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, \dots, 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. 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 sig signals are passed through $\pi_1, \pi_2, \dots, \pi_k$, 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. 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 [13-17].

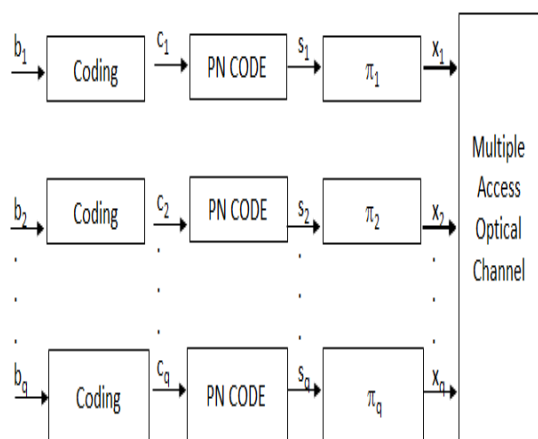


Fig. 1: The IDMA Transmitter Structure.

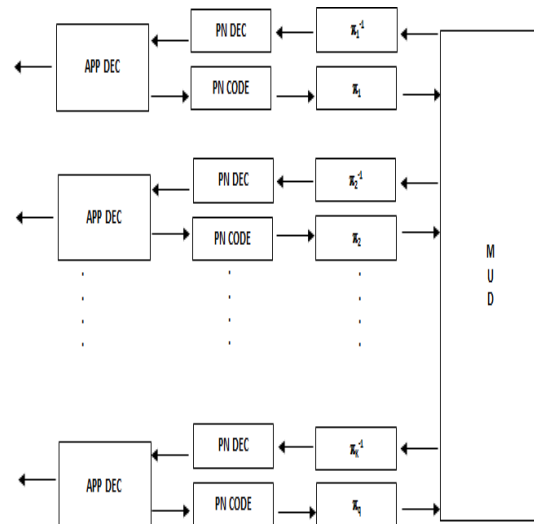


Fig. 2: The IDMA Receiver Structure

3. Interleaver-

Interleaving is technique of rejumping the ordering of a data stream in a one to one specific permutation and combination which should be deterministic. It is a practical approach to enhance 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 [3-4].

3.1. Random Interleaver –Random inter-leaver is the basic inter-leaver which rearranges the data sequence in random nature. Random inter-leaver divides information data sequence of distinct users with distinct pattern. Let us consider the input data sequence 1, 2, 3, 4, 5, 6, 7. The length of sequence is 7. After interleaving this inter-leaver, the inter-leaved sequence is 5, 4, 2, 1, 3, 7, and 6. After that when we apply random de-inter-leaver then the output sequence is obtained which is same as the original data sequence 1, 2, 3, 4, 5, 6, and 7. The procedure for random interleaving is shown in Fig. 3 [3-4].

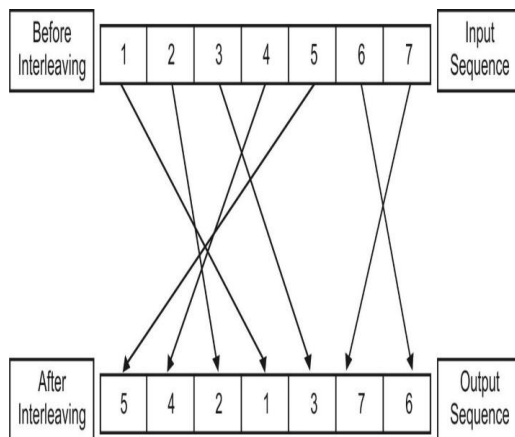


Fig. 3. Random Interleaving

3.2. Helical Interleaver-Helical inter-leaver is designed on the basis of master inter-leaver. This type of inter-leaver is generally designed for modulator and demodulator. Helical inter-leaver is read out the encoded block of data from modulator at the encoder and also decoded this data to demodulate at receiver. Mathematically, helical inter-leaver reading the bits as

$$j = i(n_x + 1) \bmod (n_x n_y) \quad (1) \quad i = \{0, 1, 2 \dots n_x n_y - 1\} \quad (2)$$

Where, the j is the helical index and i is the initial information index. The n_x and n_y are the number of bits in x and y dimension respectively [3-4].

1	*	*
2	5	*
3	6	9
4	7	10
13	8	11
14	17	12
15	18	21
16	19	22
25	20	23
26	29	24
27	30	33
28	31	34
	32	35
		36

Fig. 4. Helical Interleaving

4. Convolutional Coding-

Convolutional coding is significant coding technique that is used in error correction. 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 [6, 10-11].

4.1. Code Rate and Constraints Length-

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 $[Y/X]$. As the number of Ex-OR gates are increasing the outputs bits X increases makes the code rate as $\frac{1}{2}$, $\frac{1}{3}$ & $\frac{1}{4}$ etc. with fixed number of input bits $Y = 1$.

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 5. In figure 5 for (1, 2) code rate possible optimum trellis are 5, 7 in octal number representation $[101, 111]$ which decides the feedback mechanism of encoder [6,11].

The memory elements are fixed and Ex-OR gates are changed that is code rates are varying by fixing the flip-flops in encoder. In basic network connection of figure 4 where only 2 adders and 2 flip-flops, Ex-OR gates are added one by one making figure 6 code rate (1, 3) for fixed $L = 3$. The possible network trellis for figure 6 is $3[5, 7, 7]$. The encoder design and feedback connection are used according to trellis.

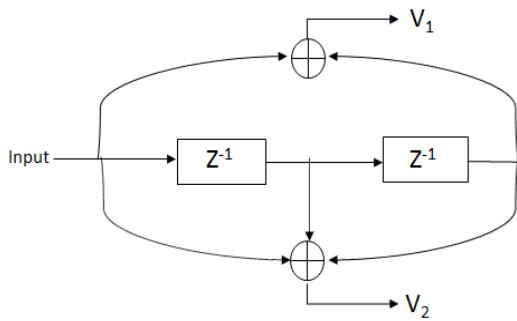


Fig. 5: Convolutional Encoder [1,2], 2 – Ex-OR gates Network Topology [3(5,7)].

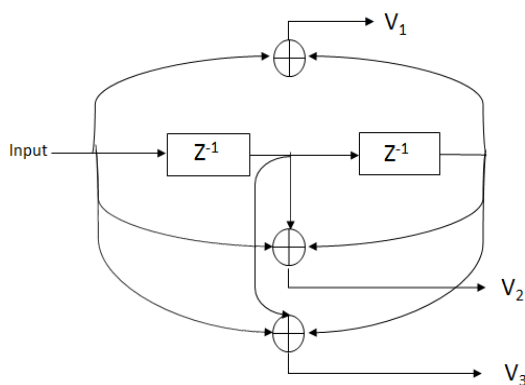


Fig. 6: Convolutional Encoder [1,3], 3 – Ex-OR Gates Network Topology [3(5,7,7)].

5. Simulation Result and Discussion-

To analyze the results of this work, MATLAB software platform is used. I have implemented the whole IDMA system by programming its various blocks separately and interfaced them for making complete OIDMA 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 50, 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 helical separately. The two architectures of convolutional encoders are connected at the coding section for each inter-leaver and performance of OIDMA system has been evaluated in terms of BER.

The tables 1 and 2 show the BER result of different convolutional encoder architectures (1, 2) and (1,

3). The number of memory elements has been fixed with two shift register, $L = 3$ constraint lengths. Overall for each code rates one table that is total two tables are drawn for constraint lengths three. For code rates (1, 2) and (1, 3) with constraints length $L = 3$, two graphs (Figure 7& 8) are plotted showing the comparative study between random and helical 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 helical 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 1.6280×10^{-6} and reaches 7.8532×10^{-5} for 280 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 helical inter-leaver also as instance when number of users 120 BER is 4.5370×10^{-7} which increases up to 1.3420×10^{-5} for 280 users.

In table-2 comparative BER performance for random and tree inter-leavers are shown for (1, 3) convolutional encoder along with memory element 2. The observed trends of BER with number of users in tree and random cases fully match with table-1. For Instance in random case when number of users 120, BER is 1.7592×10^{-7} and reaches 9.8974×10^{-6} for 280 users. Similar trend obtained for helical interleaver also as instance when number of users 120 BER is 2.8631×10^{-8} which increases up to 9.9865×10^{-7} for 280 users.

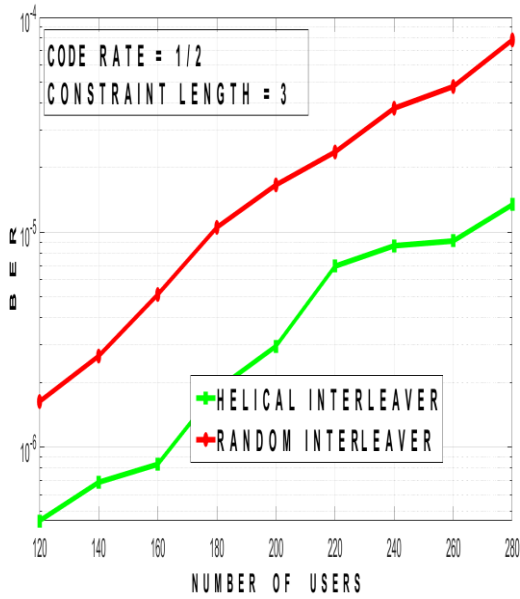


Fig. 7 BER Vs number of users with code rate 1/2 and constraints length 3

Table 1: BER variation for code rate 1/2 and fixed constraint Length 3 for random and helical interleaver (Radius 128)

S. No.	Number of users	BER for Random interleaver	BER for Helical interleaver
1	120	1.6280×10^{-6}	4.5370×10^{-7}
2	140	2.6510×10^{-6}	6.8521×10^{-7}
3	160	5.1273×10^{-6}	8.3129×10^{-7}
4	180	1.0530×10^{-5}	1.8532×10^{-6}
5	200	1.6600×10^{-5}	2.9462×10^{-6}
6	220	2.3620×10^{-5}	6.9460×10^{-6}
7	240	3.7763×10^{-5}	8.6478×10^{-6}
8	260	4.7644×10^{-5}	9.1004×10^{-6}
9	280	7.8532×10^{-5}	1.3420×10^{-5}

Table 2: BER variation for code rate 1/3 and fixed constraint Length 3 for random and helical interleaver (Radius 128)

S. No.	Number of users	BER for Random interleaver	BER for Helical interleaver
1	120	1.75 92×10^{-8}	2.86 31×10^{-8}

		0^{-7}	0^{-8}
2	140	2.93 52×10^{-7}	6.03 56×10^{-8}
3	160	8.05 00×10^{-7}	9.17 83×10^{-8}
4	180	1.45 92×10^{-6}	9.98 61×10^{-8}
5	200	3.17 83×10^{-6}	2.36 32×10^{-7}
6	220	6.28 67×10^{-6}	6.13 08×10^{-7}
7	240	7.10 75×10^{-6}	8.28 75×10^{-7}
8	260	8.39 38×10^{-6}	9.19 62×10^{-7}
9	280	9.89 74×10^{-6}	9.98 65×10^{-7}

6. **Conclusions**-From Table 1 (Fig. 7) and Table 2 (Fig. 8), it is observed that helical interleaver achieves better performance in comparison with random interleaver. When we compared code rate 1/2 to 1/3, code

Fig. 8. BER Vs number of users with code rate 1/3 and constraints Length 3.

Rate 1/3 outperforms 1/2. Thus it is verified that helical interleaver with radius $R = 128$ achieves better performance as compared to random interleaver. If radius is doubled it might be produced even better results in further study. It is concluded that helical interleaver using convolutional codes with ODMA is a good approach for 6G communication networks.

References-

[1] Yadav, Anurag; Shukla, Aasheesh. Performance Analysis of IDMA and Coded IDMA System. 5th international conference on computational intelligence and communication

- network2013.https://doi.org/10.1109/CICN.2013.60.
- [2] Sriwas, S. K.; Shukla, M.; Asthana, R.; Saini, J. P. High Speed Detection with Avalanche Photodiode in Optical Interleave Division Multiple Access Scheme. *Indian Journal of Science and Technology*. October 2016 Vol. 9(38),https://doi.org/10.17485/ijst/2016/v9i38/101632.
- [3] Chavan, Pragati N; Jadhav, H. M. Survey on Inter-leavers in IDMA System. *International Journal of Science and Research (IJSR) Licensed Under Creative Commons Attribution CC BY*. December 2014, ISSN (Online), 2319-7064.
- [4] Tiwari, Preeti; Srivastava, Vikash. A Comparative Study: Various Inter-leavers for IDMA Technology. *International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)*. January 2015, Volume 4, Issue 1, 33 ISSN 2278-909X.
- [5] Chung, Y. H., 2007. *Performance and Bandwidth Efficient Interleave-Division Multiple Access Scheme with High-Spread Interleavers*. Division of Electronics, Computers and Telecommunications, Pukyong National University, Busan, Korea. Information, Communications & Signal Processing 6th International Conference.10-13 Dec.
- [6] Maurya A. K., R. Prakash, S.K. Sriwas, P.Kumar, and R.K. Singh, "Impact of code rate and constraint length variation on qualitative performance of IDMA system with random inter-leaver," *Optik - International Journal for Light and Electron Optics* 202 (2020) 163584.
- [7] G. Selvakumar, and M. Shanthi, " IDMA based Communication for Next Generation (4G)," *International Conference on VLSI, Communication & Instrumentation (ICVCI) 2011 Proceedings published by International Journal of Computer Applications® (IJCA)*.
- [8] Á. J. Almeida, A. Shahpari, Z. Vujicic, Y. Sheikhejad, F. Rodrigues, and A. L. Teixeira, "Simplified model for power penalty when using PIN and APD receivers," *Optics Communications*, 392 (2017) 15–19.
- [9] M. Attaran, "The impact of 5G on the evolution of intelligent automation and industry digitization," *Journal of Ambient Intelligence and Humanized Computing*, doi.org/10.1007/s12652-020, 02521-x, Feb. 2021.
- [10] A. Tripathi, S. K. Sriwas, and R. K. Singh, "Performance Evaluation of Sc-IDMA & Of DM-IDMA in Impulsive Media," *International Journal of Engineering and Advanced Technology (IJEAT)*, ISSN: 2249 – 8958, Volume-8 Issue-6, August 2019.
- [11] R. Prakash and A. K. Maurya, "Impact of multifarious design architectures of convolutional encoders on efficiency of O-IDMA at zero dispersion wavelength," *International Journal of Engineering & Technology*, 7 (4) (2018) 6421-6426.
- [12] B. Lin, X. Tang, X. Shen, H. Zhang, Y. Wu, H. Li, and Z. Ghassemlooy, "Experimental Demonstration of IDMA- OFDM for Visible Light Communications," eView by River Valley Technologies, IET Communications, pp. 01-06.
- [13] S. Dhaliwal , N. Singh, and G. Kaur, "Performance Analysis of Convolutional code over Different Code rates and Constraint length in Wireless Communication," *International conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC 2017)*.
- [14] S. V. N. Reddy, C. K. K, and N. Koppala, "Design of Convolutional Codes for varying Constraint Lengths," *International Journal of Engineering Trends and Technology*, Volume4, Issue1- 2013.
- [15] S. K. Sriwas, M. Shukla, R. Asthana, and J. P. Saini, "High-Speed Detection with Avalanche Photodiode in Optical Interleave Division Multiple Access Scheme," *Indian Journal of Science and Technology*, Vol.9(38),DOI:10.17485/ijst/2016/v9i38/101632, October 2016.
- [16] K. Choudhary, and P. S. Sharma, "Interleavers for IDMA Technology: A Comparison Survey," *International Journal of Advanced Research in Computer and Communication Engineering*, Vol. 1, Issue 2, April 2012.
- [17] Tarable, A., Montorsi, G. and Benedetto, S., 2005. *Analysis and design of interleavers for iterative multiuser receivers in coded CDMA systems*. IEEE Trans. Inf. Theory. Vol. 51, No. 5, pp. 1650-1666.