Performance Analysis Of Optical Interleave Division Multiple Access Using Solitons

Surendra Kr Sriwas[1], M K Shukla[2] , R Asthana[3] ,J P Saini[4]
1,4,BIET,Jhansi ,2,3,HBTI,Kanpur
surendrasriwas@gmail.com

***Abstract*— In this paper, we investigated a technique to establish optical fibre interleave division multiple access communication system for long distance and high capacity using Solitons. Group Velocity Dispersion (GVD) causes most pulses to broaden in time as they propagate through an optical fibre. however , a particular pulse shape known as Solitons takes advantage of nonlinear effects in silica, particularly self phase modulation (SPM) resulting from the Kerr nonlinearity, to overcome the pulse-broadening effects of GVD. Interleave Division Multiple Access is a multiple access technique that employs user specific interleavers for distinguishing the signals from different users. This is different from conventional code division multiple access schemes in which different signature sequences are used to distinguish users.**

***Keywords*— IDMA, Gaussian pulse, Solitons pulse, GVD.**

I. INTRODUCTION

Optical interleave-division multiple-access (OIDMA) scheme inherits the advantage of both Optical system and IDMA technique**.** It is discussed in the paper that the transmission of a Gaussian pulse is not a very good idea as it broadens with distance and degrades the system by increasing the BER. Finally Solitons based OIDMA based system is proposed which can provide very effective solution for the transmission of the very high bit rate in optical system with very less error rate.

Optical fibre is used for long distance and high bandwidth. To utilize the efficient bandwidth, Code Division Multiple Access (CDMA) technique is used in optical fibre. CDMA is mainly limited by multiple access interference (MAI) and Inter Symbol Interference (ISI). Interleave Division Multiple Access (IDMA) is the new technique which mitigate the disadvantage of CDMA. In IDMA scheme, the user-specific interleavers are designed which are unique for each user. In addition to it, for better performance iterative chip by chip multi-user detection technique is also employed in the system. The use of IDMA in optical fibre enhances the performance of the system which is shown in the result.

The objective of this paper is to use Solitons in Optical IDMA system to reduce the Group Velocity Dispersion (GVD) causes most pulses to broaden in time as they propagate through an optical fibre. This paper organized as follows: Section II presents the Basic of IDMA, Optical IDMA and System model. Section III shows the Basic of Solitons9 and its importance in OIDMA. Simulation results are discussed in Section IV. At last conclusion is presented in section V.

II. OPTICAL IDMA

The interleave based multiple-access scheme are used for high spectral efficiency, improved performance and low receiver complexity. This scheme relies on interleaving as the only means to distinguish the signals from different users and hence it has been called interleave-division multiple-access (IDMA). The use of IDMA in Optical domain plays an important role for enhancing the performance. The block diagram of OIDMA is shown in figure:1.

In figure 1, the upper portion displays the transmitter structure of the optical IDMA scheme with K simultaneous users. Low-rate code *C* is used to encode the input data sequence $\boldsymbol{d}_k$ of user-*k*, which generates a coded sequence $\boldsymbol{c}_k = [c_k(1)\ldots\ldots c_k(j)\ldots\ldots c_k(J)]^T$, where *J* is the frame length. The elements in $\boldsymbol{c}_k$ are called coded bits. Coded sequence $\boldsymbol{c}_k$ is permutated by an interleaver π_k, which produces $\boldsymbol{x}_k = [x_k(1)\ldots\ldots x_k(j)\ldots\ldots x_k(J)]^T$. The elements in $\boldsymbol{x}_k$ is referred to as "chips"[2, 3].

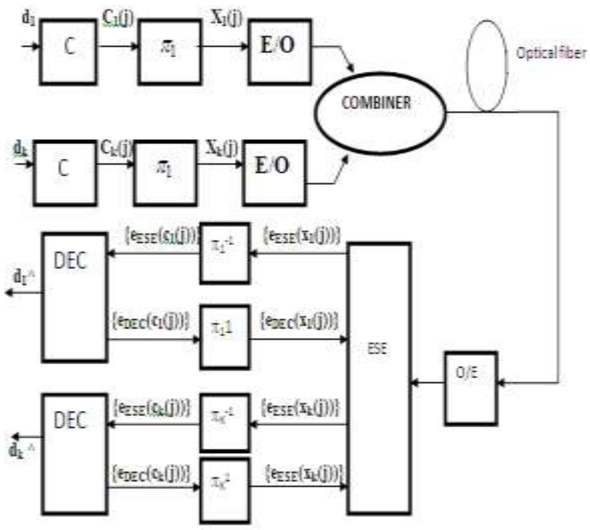

Fig.1. Optical IDMA System Showing Transmitter and Receiver Structure

The key principle of IDMA is employment of user-specific interleavers $\{\pi_k\}$ for the purpose of user separation. It is assumed that the interleavers are generated randomly and independently. Interleavers are used to disperse the coded sequences so that the adjacent chips are approximately uncorrelated, which makes chip-by-chip detection process easy.

After the user-specific interleaver generation, electrical to optical converter (E/O) is used to get optical pulses. The electric field of mode locked laser can be given as [10],

$$\boldsymbol{E}_{MLL} = \boldsymbol{e}^{iwot} \sum_{k=0}^{K-1} \boldsymbol{e}^{ik(\Delta w)t} \quad (1)$$

where K is the number of modes in the mode locked laser, and Δw is the channel spacing between two consecutive modes in the mode locked laser. Now the output of MLL is modulated with interleaved data $x_k(j)$ which is usually a simple OOK modulation. Then the transmitted data can be written as:

$$\boldsymbol{E}_{MLL} \boldsymbol{X}_k(j) = \boldsymbol{X}_k(j) \boldsymbol{e}^{iwot} \sum_{k=0}^{K-1} \boldsymbol{e}^{ik(\Delta w)t} \quad (2)$$

where $x_k(j) \in (1,0)$.

In Figure 1 lower portion shows optical IDMA receiver. At the receiver front we used optical detectors (P-I-N or avalanche photo detector (APD). Optical detectors must have a wide bandwidth and sharp response to achieve the high bit-rate which is required by such a system. Resposivity of PIN diode can be given as:

$$\mathrm{R} = \frac{\mathrm{I_p}}{\mathrm{P_0}} \quad (3)$$

where I_p is the photocurrent (mA), P_o is the average light power (mW).

Quantum efficiency can be given as :

$$\eta = \frac{\mathrm{I_p} hc}{\mathrm{qP_0} \lambda} \quad (4)$$

The probability that a specified number of photons are absorbed from an incident optical field by a PIN detector over a chip interval with T_c is given by a Poisson distribution. The average number of absorbed photons over T_c is shown as

$$\lambda_s = \frac{\eta P_0}{hf} \quad (5)$$

where λ_s is the photon absorption rate, P_0 is the received laser power, η is the quantum efficiency, h is Planck's constant ($6.628*10^{-38}$J/s), and f is the optical frequency, q is the electron charge ($1.6*10^{-19}$C)[9].After APD, receiver consists of an elementary signal estimator (ESE) and K *a* posteriori probability (APP) decoders (DECs) [2-4,14]. The outputs of the ESE and DECs are extrinsic log-likelihood ratios (LLRs) about $\{x_k(j)\}$ defined below

$$\mathrm{e_{ESE}}(x_k(j)) \equiv \log\left(\frac{P_r(x_k(j)=+1)}{P_r(x_k(j)=-1)}\right) \quad (6)$$

$\mathrm{e_{ESE}}$ (x_k (j)) be the extrinsic *a posteriori* log-likelihood ratios (LLRs) generated by the DEC for user-*k*. For each *k*, we rewrite (1) as [1]-[4]:

$$\mathrm{r(j)} = \mathrm{h_k} x_k(j) + \xi_k(j) \quad (7)$$

where

$$\xi_k(j) \equiv r(j) - h_k x_k(j) = \sum_{k' \neq k} h_{k'} x_{k'}(j) + n(j) \quad (8)$$

Denote by E(·) and Var(·) the mean and variance functions, respectively. We list the CBC detection algorithm as follows (with initialization $e_{\mathrm{DEC}}(x_k(j)) = 0$, $\forall\, k, j$) [2].

The CBC algorithm

$$E(x_k(j)) = \tanh(e_{DEC}(x_k(j))/2) \quad (9a)$$

$$\mathrm{var}(x_k(j)) = 1 - (E(x_k(j)))^2 \quad (9b)$$

$$E(\xi_k(j)) = \sum_{k' \neq k} h_{k'} E(x_{k'}(j)) \quad (9c)$$

$$\mathrm{var}(\xi_k(j)) = \sum_{k' \neq k} |h_{k'}|^2 \, \mathrm{var}(x_{k'}(j)) + \sigma^2$$

(9d)

$$e_{ESE}(x_k(j)) = \frac{2hk}{\mathrm{var}(\xi_k(j))}(r(j) - E(\xi_k(j))) \quad (9e)$$

After the APP decoding in the DECs is performed to generate the LLRs $\{e_{\mathrm{DEC}}(x_k(j)),\ \forall\, k, j\}$. Then go back to (9a) for the next iteration [2][14].

III. SOLITONS IN OPTICAL FIBER CHANNEL

For long transmission of signal in an optical fiber, the distortion is an important parameter. The dispersion mechanism in a fiber causes optical signal pulse to broaden as they travel along a fiber. If this pulse travels sufficiently far, they will eventually overlap with the neighboring pulses, thereby creating errors in the receiver output. Therefore the signal distortion mechanisms limit the information carrying capacity of a fiber.

All optical pulse is monochromatic since it excites a spectrum of frequencies. The spectral spread of an optical source $\Delta\nu$, which emits power in a wavelength band $\Delta\lambda$, is given by the relation

$$|\Delta\nu| = \left(\frac{c}{\lambda^2}\right)|\Delta\lambda| \quad (10)$$

This is important, because in an actual fiber a pulse is affected by both the Group Velocity Dispersion (GVD) and the Kerr nonlinearity. This is particularly significant for high intensity optical excitations. In addition, when a high intensity optical pulse is coupled to a fiber, the optical power modulates the refractive index seen by optical excitation. This induces phase fluctuations in the propagating wave, thereby producing a chirping effect in the pulse as shown in figure 2. The consequences are that the instantaneous optical frequency differs from its initial value ν_0 across the pulse. This is because phase fluctuations are intensity dependent, different parts of pulse undergo different phase shifts. This effect is known as frequency chirping, in this the rising edge of pulse experiences a red shift in frequency(towards higher frequencies), whereas the trailing edge of pulse experiences a blue shift in frequency(towards lower frequencies). Since the degree of chirping depends on the transmitted power, SPM effects more pronounced for higher-intensity pulses.

When high intensity pulse transverses a medium with a positive GVD parameter β_2($\equiv d^2\beta/d\omega^2$ determines how much a light pulse broadens as it travel along the optical fiber) for the constituent frequencies, leading the part of pulse is shifted towards a longer wavelength (lower frequencies), so that speed in that portion increases. Conversely, in the trailing half, the frequency raises so the speed decreases. this causes the trailing edge to be further delayed. Consequently, in addition to a spectral change with distance, the energy in the centre of the pulse is dispersed to either side, and the pulse eventually takes on a rectangular wave shape. These effects will severely limit high-speed long distance transmission if the system is operated in this condition.

On the other hand, when a narrow high intensity pulse transverse a medium with a negative GVD parameter for the constituent frequencies, GVD counteracts with the chirp produced by SPM. now GVD retards the low frequencies in the front end of the pulse and advances the high frequencies at the back. the result is that the high intensity sharply peaked Soliton pulse changes neither its shape nor its spectrum as it travels along the fiber. Soliton pulse energy is sufficient strong and maintained its shape as it travels along the fiber. In a standard optical fiber, there is a zero dispersion point around 1310 nm. For wavelength shorter than 1310 nm β_2 is positive, and for longer wavelengths it is negative. Therefore, Soliton operation is limited to the region greater than 1310nm.

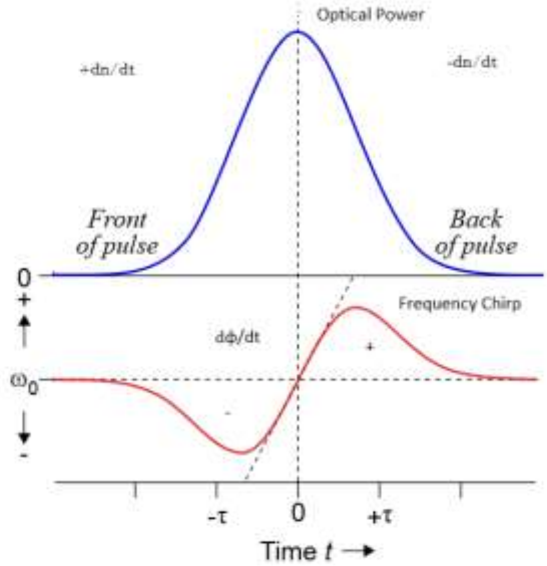

Figure:2 Spectral Broadening of Pulse Due to Self Phase Modulation

For Solitons transmission, it is necessary to consider the Nonlinear Schrodinger(NLS) equation

$$-j\frac{\partial u}{\partial z} = \frac{1}{2}\frac{\partial^2 u}{\partial t^2} + N^2|u|^2 u - j(\alpha/2)u \qquad (11)$$

Here, u(z,t) is the pulse envelope function, z is the propagation distance along the fiber, N is an integer designating the order of the solution, and $\boldsymbol{\alpha}$ representing energy loss.

The solution to equation 10 for fundamental Soliton is

$$u(z,t) = \operatorname{sech}(t)\exp(\tfrac{jz}{2}) \qquad (12)$$

where sech(t) is hyperbolic secant function.

this is bell shaped pulse as shown in figure 3 which is drawn by Matlab.

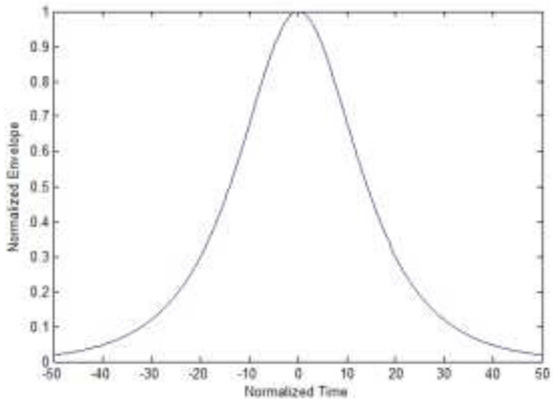

Figure:3 Hyperbolic secant Function

A Soliton pulse has the phase shifts for nonlinear process are

$$d\phi_{nonlin} = |u(t)|^2 dz = sech^2(t) dz \quad (13)$$

and phase shifts for dispersion effect are

$$d\phi_{disp} = \left(\frac{1}{2}\frac{\partial^2 u}{\partial t^2}\right) dz = \left[\frac{1}{2} - sech^2(t)\right] dz \quad (14)$$

The sum of these two terms is a constant. Upon integration, the sum simply yields a phase shift of z/2, which is common to the entire pulse. Since such a phase shift changes neither the temporal nor spectral shape of a pulse, the Solitons remains completely non dispersive in both the temporal and frequency domains.

IV.SIMULATION RESULTS AND DISCUSSION

As in the optical networks distances are large ~100 km to 5000 km, hence for better performance of OIDMA system it is necessary that optical channel does not introduce significant degradation in the signal. However as the signal propagates through the fiber pulse broadens and its peak power gets reduced therefore to compensate such loss in power generally optical amplifiers (EDFA) are placed in the line. These amplifiers amplify the loss of the signal power of the propagating signals but unfortunately add amplified spontaneous noise (ASN) to the signal, hence overall SNR reduces and BER increases.

To enhance the OIDMA system performance Solitons can play an important role because Solitons do not disperse due to nonlinear effects. The simulation of optical IDMA presented in this section, has been performed using MATLAB software.

The transmission of Gaussian Pulse in the Optical Fiber is shown in Figure 4. Here we have observed that the Gaussian pulse is dispersed due to nonlinear effects, as the distance (z in km) increases and the power of the Gaussian pulse decreases significantly. After the distance z = 200 km the power level of Gaussian pulse is not sufficient to transmit in the fiber and the information of the pulse may be lost. At z = 500 km the minimum power of the Gaussian pulse is not sufficient to travel in the fiber. Therefore we conclude that the Gaussian Pulse dispersed due to nonlinear effects which are not suitable for optical fiber communication.

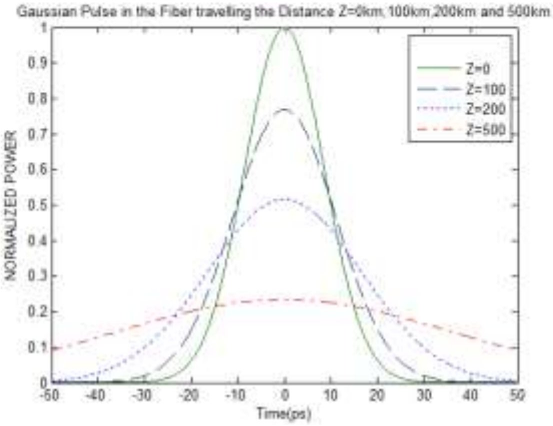

Figure:4 Nonlinear Effects on Gaussian Pulse in the Optical Fiber with different Distances

The Solitons pulse is compared with a Gaussian pulse of the same parameters in Figure 5. It is observed form the figure that they are very much similar in nature. However, it is found in the study that if a Gaussian pulse with properly selected parameters is launched into the fiber, it can be converted into Solitons Pulse easily.

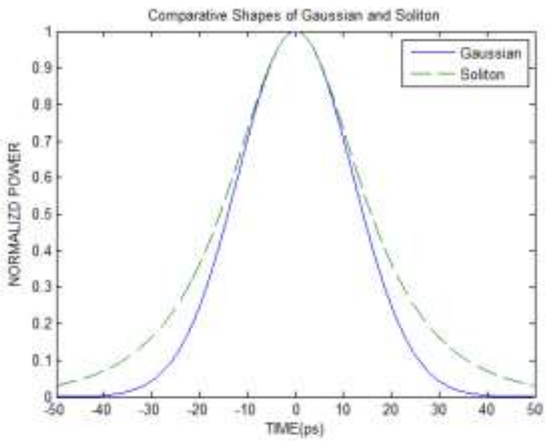

Figure:5 Comparative Shapes of Gaussian Vs Solitons Pulse

The transmission of Solitons Pulse in Optical Fiber with different distances (z) are shown in figure 6. Here we observe that the shape of Solitons pulse does not very with distances due to GVD and it contain almost same shape therefore the transmission through Solitons pulse may give better performance in the OIDMA system.

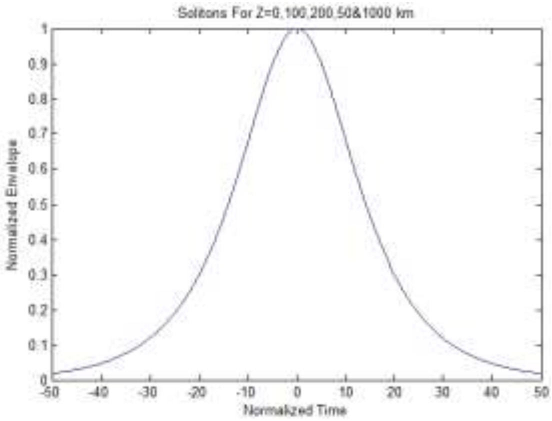

Figure:6 Solitons for Different Distances (Z=0,100,200,500&1000 km) in the Optical Fiber

The Figure 7 shows BER performance of optical IDMA in optical channel with different numbers of simultaneous users. During the simulation, the spreading length is chosen as 16, and the iterative number is set to be 10. The variation is user count has been opted as parameter of performance has been displayed in the figure during performance comparison to OIDMA system. For simulation purpose, the input data for each user is assumed to be same i.e. 2048 bits. Optical fiber has been operated with 155nm wavelength with maximum bit rate of 1Gbps capability. The transmitted power is chosen to be 1mW, while intensity dependent refractive index parameter is $2.35*10^{-20}$. The responsively and efficiency is 0.65, 0.80 has been taken respectively. The input to optical fiber is a Gaussian pulse and ON-OFF keying (OOK) is used for pulse transmission. The simulations have been performed using random interleavers [20].

The Performance of OIDMA system using Solitons pulse and Gaussian pulse is shown in figure 7. here we easily observe that the BER of Solitons pulse is far better than Gaussian pulse.

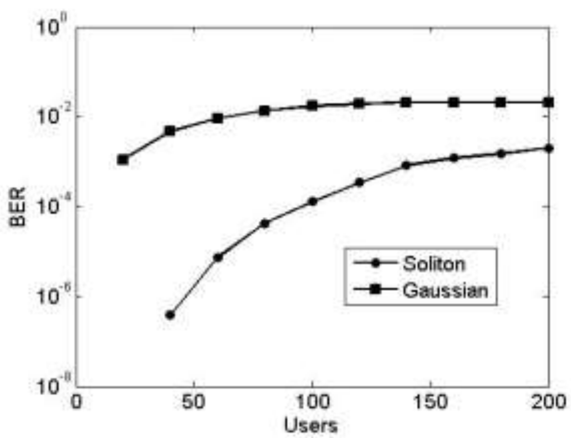

Figure:7 BER of OIDMA System of Solition and Gaussian Pulse with varying number of users

V. CONCLUSION

In this Paper First we have shown the OIDMA System model and explain the importance of IDMA compare over CDMA system. next we have explained the reason to introduce the Solitons pulse in place of Gaussian pulse. further we have shown that the Gaussian pulse is highly dispersed due to GVD and nonlinear effects up to 200 km and it is not suitable for higher distance therefore the introduction of Solitons pulse is required. the trnasmission of the Solitons pulse is Compatable in the optical IDMA System because it is almost same as Gaussian pulse. finally we have transmitted the Solitons pulse in OIDMA system and observed that the Solitons pulse is better for long transmission. the BER for Gaussian Pulse and Solitons Pulse are listed here.

No of Users	BER For Solitons Pulse	BER For Gaussian pulse
20	0	0.0011
40	3.8147e-7	0.0047
80	4.1962e-5	0.0135
120	3.4186e-4	0.019
200	0.0020	0.021

REFERENCES

[1] Li Ping, L. Liu, K. Y, Wu, and W. K. Leung, “On interleave-division multiple-Access,” in Proceeding 2004 of ICC’ 2004. Paris, France.

[2] Li Ping and Lihai Liu, “Analysis and Design of IDMA Systems Based on SNR Evolution and Power Allocation” in the proceeding of Fall 2004 Vehicular Technology Conference, VTC2004 vol:2 pp 1068-1072.

[3] L. Ping, L. Liu, K. Wu, and W. K. Leung, “Interleave division multiple access,” IEEE Trans. on Wireless Communications, vol. 5, no. 4, April 2006 pp. 938- 947.

[4] R. H. Mahadevappa and J. G. Proakis, “Mitigating multiple access interference and inter symbol interference in uncoded CDMA systems with chip level interleaving,” IEEE Trans. On Wireless Communication, vol. 1, no. 4, October 2002.

[5] Govind P Agrawal and Ansers Olsson " Self Phase Modulation and Spectral Broadening of Optical Pulses in Semiconductor lasers Amplifiers " in IEEE Journal of Quantum Electronics Vol.25 No II Nov 1989.

[6] G. P. Agrawal, “Nonlinear Fiber Optics”, 3rd ed. New York: Academic, 2001.

[7] V. Sinkin, R. Holzlohner, J. Zweck, and C. R. Menyuk, “Optimization of the split-step Fourier method for modeling optical-fiber communication systems,” J. Lightwave Technol., vol. 21, Jan. 2003, pp. 61–68.

[8] J. A. C. Weideman, and B. M. Herbst: "Split-Step methods for the solution of the nonlinear Schrodinger equation", SIAM J. Numer. Anal., Vol. 23, 1986, pp. 485-507.

[9] Ching-Chaun Tseng, Li Wang “Application of Advanced Computer Communication and Control Technology for Modern Substations”, IEEE Transition on Power Delivery, 2015.

[10] Katsutoshi Kusume, Gerhard Bauch "IDMA vs. CDMA: Analysis and Comparision of Two Multiple Access Schemes", IEEE Transition on Wireless Communication, VOL.II,NO.I, January 2012.
[11] J. A. Salehi, "Code division multiple-access techniques in optical fiber networks-part I: Fundamental principles," IEEE Trans. Communication, vol. 37, Aug. 1989, pp. 824–833.
[12] J. A. Salehi and C.A.Brackett "Code division multiple-access techniques in optical fiber networks-part II: System Performance Analysis", IEEE Trans. Communication, vol. 37, Aug. 1989, pp. 834–842.
[13] Saeed Mashhadi and J. A. Salehi, "Code division multiple-access techniques in optical fiber networks-part III: Optical and Logic Gate Receiver Structure with Generalized Optical Orthogonal Codes", IEEE Trans. Communication, vol. 54, Aug. 2006, pp. 1457–1468.
[14] M. Aleshams, A. Zarifkar and M. H. Sheikhi," Split-Step Fourier Transform Method in modeling of pulse propagation in dispersive nonlinear optical fibers" in proceeding of CAOL 2005.
[15] Wei Huang and Mohamed H. M. Nizam, "Coherent Optical CDMA (OCDMA) Systems Used for High-Capacity Optical Fiber Networks-System Description, OTDMA Comparison, and OCDMA/WDMA Networking" journal of Lightwave Technology, VOL. 18, NO. 6, JUNE 2000.
[16] L. A. Rusch and H. V. Poor, "Effects of laser phase drift on coherent optical CDMA," IEEE J. Select. Areas Communication, vol. 13, Apr. 1995, pp. 577–591.
[17] K. Kusume and G. Bauch, "A Simple Complexity Reduction Strategy for Interleave Division Multiple Access," in Proceeding of IEEE Vehicular Technology Conference, VTC2006-fall, Montreal, Canada.
[18] Aminata Amadou Garba and Jan Bajcsy, "A New Approach to Achieve High Spectral Efficiency in Wavelength-Time OCDMA Network Transmission" IEEE Photonics Technology Letters, VOL. 19, NO. 3, February 1, 2007.
[19] John M. Senior "Optical Fiber Communication", Pearson Education, 2008.
[20] M. Shukla, V.K. Srivastava, S. Tiwari **"**Interleave Division Multiple Access for Wireless Communication**,"** 'International Conference on Next Generation Communication Systems: A Perspective', "ICONGENCOM 06**"**, J.K. Institute, Allahabad, India, pp. 150-154**,** Dec 9-11, 2006.
[21] M. Shukla, V.K. Srivastava, S. Tiwari **"**Analysis and Design of Tree Based Interleaver for Multiuser Receivers in IDMA Scheme**,"** 16th IEEE International Conference on Networks "ICON 2008", Delhi, India, pp. 1-4, Dec. 13-14, 2008.
[22] M. Shukla, Aasheesh Shukla,, V.K. Srivastava, S. Tiwari "Performance Evaluation of MRC Diversity Scheme for Iterative IDMA Receivers ," Annual IEEE India Conference "INDICON-09", Gandhinagar, Gujrat, India, pp. 1-4, Dec. 18-20, 2009.
[23] M. Shukla, Aasheesh Shukla,, V.K. Srivastava, S. Tiwari **"**Different Designing Factors for IDMA Systems," 1ST International Conference on Computer, Communication, and Control and Information Technology "C3 IT 2009" in Academy of Technology, Calcutta, India, pp. 748-756, Feb. 6-7, 2009.
[24] M. Shukla, V.K. Srivastava, S. Tiwari, "Analysis and Design of Optimum Interleaver for Iterative Receivers in IDMA Scheme," Wiley Journal of "Wireless Communications and Mobile Computing" Vol 9. Issue 10, pp. 1312-1317, 2009.
[24] M. Shukla, Aasheesh Shukla, Rohit Kumar, V.K. Srivastava, Sudarshan Tiwari, "Simple Diversity Scheme for IDMA Communication System," International Journal of Applied Engineering Research, Vol. 4 No. 6, pp. 877-883, 2009.
[25] M. Shukla, M.Gupta Etl "Optical Interleave-Division Multiple-Access Scheme for Long Distance Optical Fiber Communication" ", in Proc. of International Conference on Computational Intelligence and Computing Research "ICCIC 2010" (IEEE), pp. 1-5, Dec. 28-29/ 2010.

