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Design and Performance Analysis of a Novel 32-User Spectral Phase-Encoded system operating at 4.5 Gb/s for Fiber-Optic CDMA Networks

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ABSTRACT

Multiple access techniques are required to meet the demand for high-speed and large-capacity communications in optical networks, which allow multiple users to share the fiber bandwidth. Optical code-division multiple-access (O-CDMA) is receiving increased attention due to its potential applications for broadband access networks. We analyze a new technique for encoding and decoding of coherent ultra short light pulses. In particular, we discuss the temporal pseudo noise bursts generated by spectral phase coding of ultra short optical pulses.

This paper describes a performance analysis of Spectral Phase Encoding optical code-division multiple-access scheme based on wavelength/time (W/T) codes for time spreading and random phase codes. We have studied the optical simulator Encoding/Decoding at different fiber lengths & gain in terms of Quality factor (Q) and Bit Error Rate (BER) performance. We derive the bit error rate (BER) and QoS as a function of data rate, number of users, receiver threshold and we discuss the performance characteristics for a NRZ data modulation format. We find that performance improves dramatically with optical attenuator .Ultra short light pulse CDMA could provide tens to hundreds of users with asynchronously multiplexed, random access to a common optical channel. The system supports 32 users while maintaining bit-error rate (BER) < 10−11 and required QoS for the correctly decoded signal at 2.5 Gbits/s bit rate.

Keywords: **BER, ISD, MAI, OCDMA, OOC, PSO, QoS.**

I. INTRODUCTION

Due to economic advantages, maturing technology, and high information capacity, single-mode fiber- optic transmission media will be embedded in future telecommunications networks. A desirable feature for these future optical networks would be the ability to process information directly in the optical domain for purposes of multiplexing, demultiplexing, filtering, amplification, and correlation. Optical signal processing would be advantageous because potentially it can be much faster than electrical signal processing and because it would obviate the need for photon-electron-photon conversions. Several new classes of optical networks are now emerging [1]. For example, code-division multiple access (CDMA) networks using optical signal processing techniques were recently introduced [2]-[3]. CDMA is a type of spread spectrum communications [4] in which multiplexing is achieved by assigning different, minimally interfering code sequences to different user pairs. In fiber optic CDMA, users communicate by imprinting their message bits upon their own unique code, which they transmit asynchronously (with respect to the other transmitters) over a common channel. A matched filter at the receiver end ensures that data are detected only when they are imprinted on the proper code sequence (see Fig. 1). This approach to multiplexing allows transmission without delay and handles multi-access interference (contention) as an integral part of the multiplexing scheme.

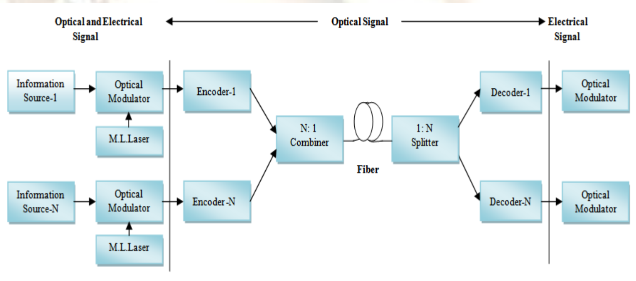

Fig. 1 Block diagram of Optical CDMA Network

In coherent OCDMA, encoding and decoding are performed either in time domain or in spectral domain based on the phase and amplitude of optical field . In coherent time spreading (TS) OCDMA, where the encoding/decoding is performed in time domain. In such a system, the encoding is to spread a short optical pulse in time with a phase shift pattern representing specific codes. The decoding is to perform the convolution to the incoming OOC using a decoder,which has an inverse phase shift pattern as the encoder and generates high level auto-correlation and low level cross correlations.

II. NUMERICAL SIMULATION

The encoders use delay line arrays providing delays in terms of integer multiples of chip times. The placement of delay line arrays and the amount of each delay and phase shifts are dictated by the specific of the signatures. PSO matrix codes are constructed using a spanning ruler or optimum Golomb ruler is a (0,1) pulse sequence where the distances between any of the pulses is a non repeating integer, hence the distances between nearest neighbors, next neares neighbors, etc., can be depicted as a difference triangle with unique integer entries.

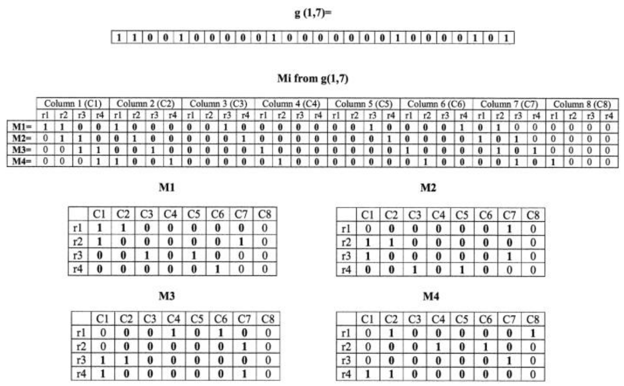

Fig. 2 Constructing the four pseudoorthogonal (PSO) matricesM1. . .M4 from the single optimum Golomb ruler g(1,7).

The ruler-to-matrix transformation increases the cardinality (code set size) from one (1) to four(4) and the ISD (=Cardinality/CD)from 1/26 to 4/32=1/8.The ISD translates to bit/s/Hz when the codes are associated with a data rate and the code dimension is translated into the bandwidth expansion associated with the codes as follows.

$$\text{ISD} = \frac{(\text{throughput})}{(\text{bandwidth required})} \quad (1)$$

$$= \frac{(\text{cardinality} \times \text{data rate})}{\left(\frac{1}{\text{Tb}}\right)(\text{bandwidth expansion})} \quad (2)$$

$$= \frac{(n \times r \times R)}{(R)(CD)} \quad (3)$$

$$= \frac{n \times r}{(CD)} \quad (4)$$

Table 1: The 32 PSO Matrix Codes Interpreted as W/T Matrix Codes

Wave-lengths (W)	Time slots (S)			
	1	2	3	4
λ1	1,9,17,25	1,14,29	19,24,26	1,7,10,11,20,32
λ2	2,10,18,26	2,15,17,30	20,25,27	2,8,11,12,21
λ3	3,11,19,27	3,16,18,31	1,21,26,28	3,12,13,22
λ4	4,9,12,20,28	4,19,32	2,22,27,29	4,13,14,23
λ5	5,10,13,21,25,29	5,20	3,23,28,30	5,14,15,24
λ6	6,11,14,22,26,30	6,21	4,17,24,29,31	6,15,16
λ7	7,12,15,23,27,31	7,17,22	5,9,18,30,32	7,16
λ8	8,13,16,24,28,32	8,18,23,25	6,9,10,19,31	8

The enhanced cardiality and ISD ,while preserving the OOC property,are general results of the rular-to-matrix transformation.We can convert the PSO matrices to wavelength/time (W/T) codes by associating the rows of the PSO matrices with wavelength (or frequency) and the columns with time-slots, as shown in TABLE I. The matricesM1……M32 are numbered 1……..32 in the table, with the corresponding assignment of wavelengths and time-slots. For example, code M1 is (λ1 ; λ1 ; λ3; λ1) and M9 is (λ1,λ4;0;λ7,λ8;0); here the semicolons separate the timeslots in the code. (The codes M1 and M9 are shown in bold numerals.). We focus on codes like M1 because it shows extensive wavelength reuse, and on codes likeM9 because it shows extensive time-slot reuse. It is the extensive wavelength and time-slot reuse that gives these matrix codes their high cardinality and high potential ISD.
Pseudo-orthogonal (PSO) matrix codes [8] are popular for OCDMA applications primarily because they retain the correlation advantages of PSO linear sequences while reducing the need for bandwidth expansion. PSO matrix codes also generate a larger code set. An interesting variation is described ,where some of the wavelength/time (W/T) matrix codes can permit extensive wavelength reuse and some can allow extensive time-slot reuse, for example, an extensive time-slot reuse sequence is used for User 1 (λ1λ3;0;λ2λ4;0). There are four time slots used without any guard-band giving the chip period of 100 ps. Code set for time spreading is mapped as Code1,code 5,code3 and code9 codes are used for time spreading. Code set to apply binary phase shift mapped as M1:{1;0;1;0;1;1;1;1} M2:{1;0;1;1;1;1;1;1}…….M32:{0;0;1;1;1;1;1;0}. (1 represents as a π phase shift, 0 represents as no phase shift)

Table 2: SPE O-CDMA system parameters used for simulation

Parameter	Value
Code weight	8
Channel spacing	0.4 nm
Wavelength	4 at 1550,1550.4,1550.8,1551.2 nm
Chip time	4
Chip rate	1.25E-10
Bit rate	2.5 Gbits/s
Fiber length	60 km to 140 km
Measurements	Eye diagram, Bit error rate and Quality factor

III. PROPOSED SPE O-CDMA SCHEME

1) Lasers (mode locked laser requited to produce 4 wavelength signal) 2) Encoders consisting of required components like PRBS Gen. External Modulator, Multiplexers, 3) Multiplexers 4) Optical fiber of 60 km length 5) De- multiplexers 6) Decoders corresponding to each encoder 7) Receiver etc. 8) BER analyzer 9) Eye Diagram analyzer 10) Signal analyzer.

Multiplot analyzer is used at transmitter and receiver after multiplexer, modulator, driver and optical attenuator for analysis of signal spectrum and eye diagram. Single mode fiber with 60 km span is used.

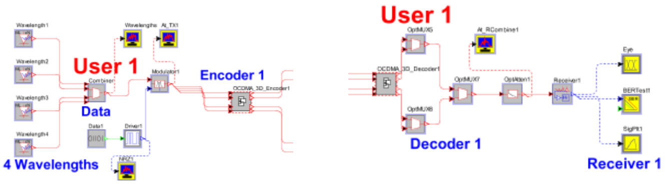

Fig. 3 Simulation setup for Spectral Phase Encoding Optical CDMA system using for 1 User

The simulation setup for Spectral Phase Encoding Optical CDMA is shown in figure 3 .The MLL is used for generating coherent pulses .The wavelengths range from 1550 nm to 1551.2 nm, with 0.4nm wavelength spacing. This four MLL (wavelengths 1 to4) are used to create a dense WDM multi- frequency light source i.e. carrier signal and this carrier signal is used to modulate the pseudo random bit sequence (PRBS) data of the user. An intensity modulator which is Ext Mod is uses on-off keying modulation to modulate the multiplexed 4 wavelengths according to the NRZ electrical data. For analysis, Eye Diagram analyzer, Beat Error tester and Signal analyzer are used.

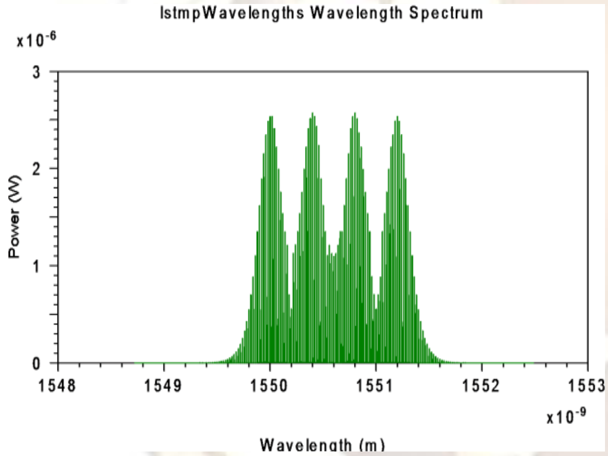

Fig. 4 Wavelength Spectrum for Spectral Phase Encoding Optical CDMA for 32 Users

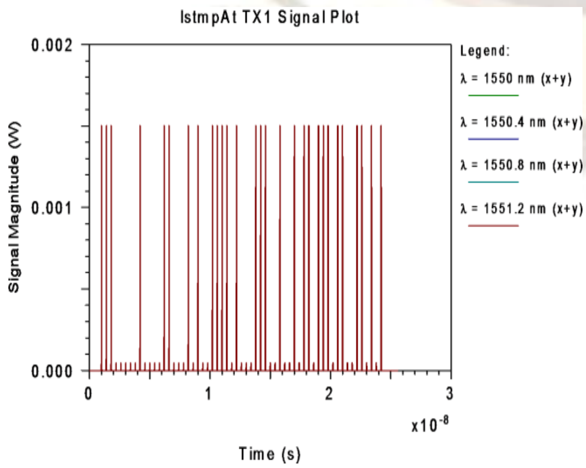

Fig. 5 Modulated data before encoder of User 1

After modulation an encoder is used to encode the signal. The modulated signals are distributed to the respective encoders, which have been assigned a unique W/T code and phase shift code respective to each encoder. The encoded data from all users are multiplexed by Optical MUX and then passed through a 140 km span of standard single mode optical fiber followed by a loss compensating optical amplifier which is OptAmp. The output signal from a fiber span is then passed through OptSplit1to split the signal and routed to the user's decoder. The decoder uses optical filters and inverse delay line arrays providing delays in terms of integer multiples of chip times and inverse phase shifts. The decoded signal finally arrives at optical receiver, BER Tester and Eye Diagram analyzer. Eye diagram analyzer has been used to take the plot of Eye pattern at the receiver end. Bit error rate values for different number of transmitting users have been taken from BER Tester. The system has been redesigned for different number of users. In spite of the use of orthogonal codes, the main effect limiting the effective signal-to-noise ratio of the overall system is the interference resulting from the other users transmitting at the same time, which is called Multiple Access Interference (MAI). MAI is the major source of noise in OCDMA systems.

IV. PERFORMANCE ANALYSIS AND DISCUSSION

Table 3: BER and Quality factor 32 User SPE OCDMA System

User	BER	Quality factor
User1	7.8811E-049	23.310
User4	2.6514E-40	22.436
User8	2.2304E-38	22.212
User12	1.8294E-35	21.85
User16	6.7008E-29	20.902
User20	1.0566E-25	20.353
User24	1.1051E-24	20.163
User28	1.0467E-19	19.093
User32	2.1978E-13	17.198

Table shows BER and Quality factor of SPE O-OCDMA system using optical attenuator at User1 to User 32 . System supports 32 users at 2.5Gbits/s and offers extremely good performance in terms of low BER and high Quality factor.User1 has good Quality factor as compare User 32.

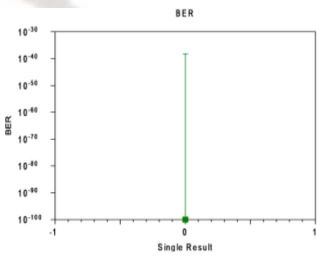

Fig. 6 BER at User1

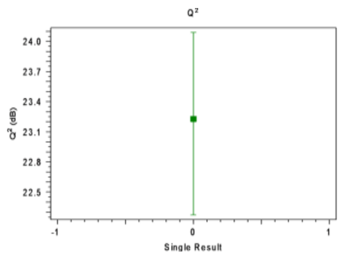

Fig. 7 Quality factor at User1

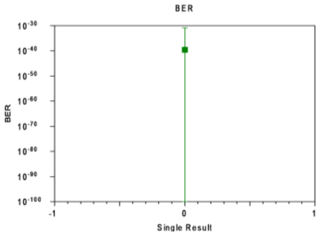

Fig. 8 BER at User4

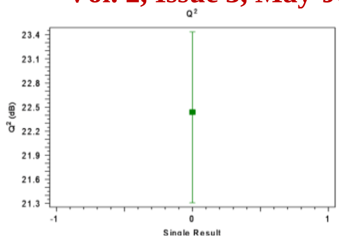

Fig. 9 Quality factor User4

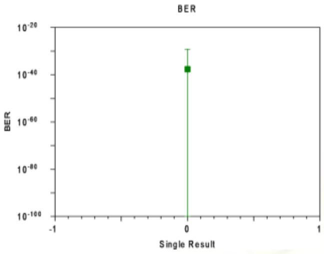

Fig. 10 BER at User8

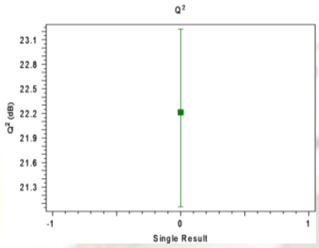

Fig. 11 Quality factor User8

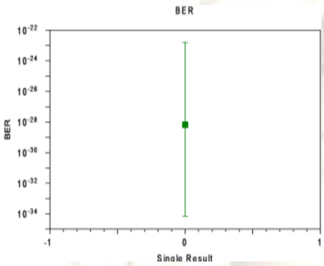

Fig. 12 BER at User16

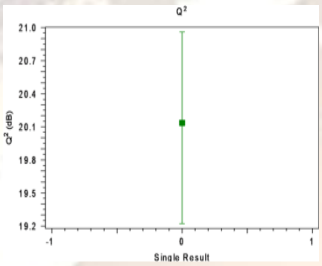

Fig. 13 Quality factor User16

Figure 6 to figure 17 shows BER and Quality factor of User1, User4, User8, User16, User 24 and User32.As numbers of active user's increases Quality factor degrades. Figure 18 shows Quality factor for 32 active users.Results of SPE OCDMA system are more realistic as practical impairments have been considered with -15 dB received power for optical attenuator for permissible BER of 10-9.

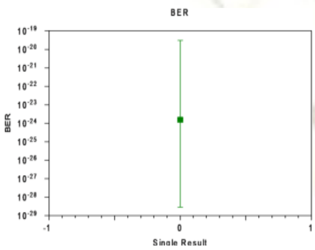

Fig. 14 BER at User24

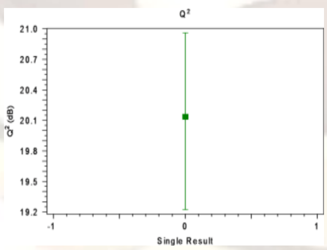

Fig. 15 Quality factor User24

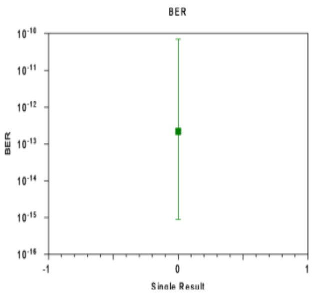

Fig. 16 BER at User32

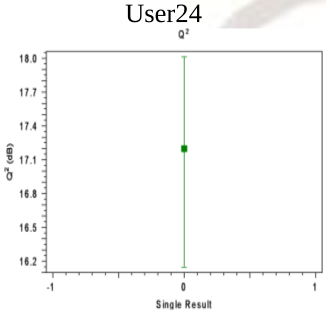

Fig. 17 Quality factor at User32

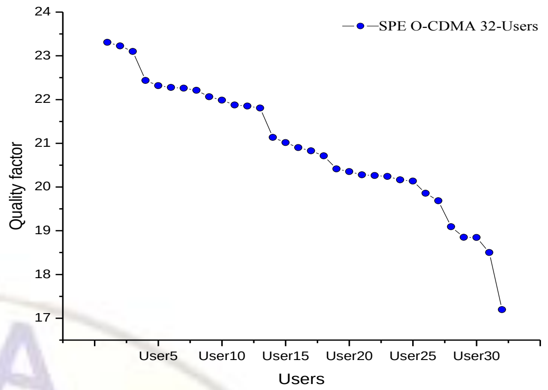

Fig.18 Quality factor for 32-Users

V. CONCLUSION

The multiple access interference effect was also seen at the optical receiver end in optical CDMA which degraded the efficiency of system by increasing bit error rate. Use of spectral phase encoding O-CDMA system reduced the MAI as seen in the bit error rate performance.

The spectral phase encoding O-CDMA system is designed for 32 users at 2.5Gbits/s bit rate using optical attenuator. The performance of 32-User SPE O-CDMA system is analyzed by using NRZ data modulation format, this data modulation format offers extremely good performance. The SPE O-CDMA system has been successfully demonstrated at system capacity of 80 Gbits/s over 140 km of fiber length and -15 dB received power at receiver. This newly designed SPE O-CDMA offers high Quality factor and less Beat Error Rate <10-9 .Moreover these results are more realistic as practical impairments have been considered with -15 dB received power for optical attenuator for permissible BER of 10^{-9} .

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