

Eight User, 4Gb/s, Spectral Phase-Encoded OCDMA System in time domain for Metropolitan area Network

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Abstract: In optical code division multiple access (OCDMA) system, many users share the same transmission medium by assigning unique pseudo-random optical code (OC) to each user. OCDMA is attractive for next generation broadband access networks due to its features of allowing fully asynchronous transmission with low latency access, soft capacity on demand, protocol transparency, simplified network management as well as increased flexibility of QoS control and enhanced confidentiality in the network. Hence, in this paper, we proposed a technique using spectral phase encoding in time domain for eight users. This technique is proved to be much effective to handle eight users at 4 Gb/s bit rate for Metropolitan area Network (MAN). Results indicate significant improvement in term Bit Error Rate (BER) and very high quality factor in the form of Quality of Service (QoS). In our analysis, we have used Pseudo Orthogonal (PSO) codes. The simulations are carried out using OptSim (RSOFT).

Keywords: MAI, OCDMA, OOC, PSO, QoS, BER, PON, ISD, CD.

1 INTRODUCTION

OPTICAL code division multiple access (OCDMA), where users share the same transmission medium by assigning unique pseudo-random optical code (OC), is attractive for next generation broadband access networks due to its features of allowing fully asynchronous transmission with low latency access, soft capacity on demand, protocol transparency, simplified network management as well as increased flexibility of QoS control [1~3]. In addition, since the data are encoded into pseudo-random OCs during transmission, it also has the potential to enhance the confidentiality in the network [4~6]. Figure 1 illustrates a basic architecture and working principle of an OCDMA passive optical network (PON) network. In the OCDMA-PON network, the data are encoded into pseudo random OC by the OCDMA encoder at the transmitter and multiple users share the same transmission media by assigning different OCs to different users.

At the receiver, the OCDMA decoder recognizes the OCs by performing matched filtering, where the auto-correlation for target OC produces high level output, while the cross-correlation for undesired OC produces low level output. Finally, the original data can be recovered after electrical thresholding. Recently, coherent OCDMA technique with ultra-short optical pulses is receiving much attention for the overall superior performance over incoherent OCDMA and the development of compact and reliable en/decoders (E/D) [7~12]. 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 instead of its intensity.

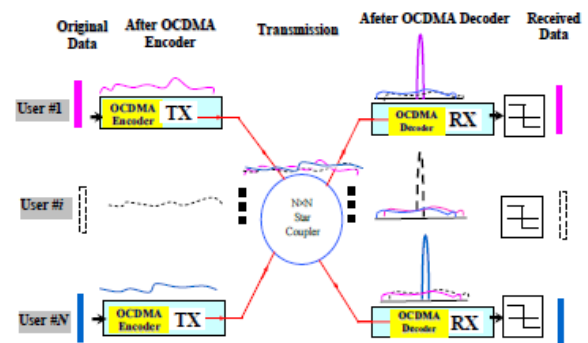


Fig.1. Working principle of an OCDMA network

In coherent time spreading (TS) OCDMA, where the encoding/decoding are 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 a specific OC. The decoding is to perform the convolution to the incoming OC using a decoder, which has an inverse phase shift pattern as the encoder and generates high level auto-correlation and low level cross-correlations.

2 SIMULATION SET-UP

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,

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next nearest neighbors, etc., can be depicted as a difference triangle with unique integer entries. 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:

$$\begin{aligned} \text{ISD} &= \frac{(\text{throughput})}{(\text{bandwidth required})} \\ &= \frac{(\text{cardinality} \times \text{data rate})}{\left(\frac{1}{T_b}\right)(\text{bandwidth expansion})} \\ &= \frac{(n \times r \times R)}{(R)(CD)} \\ &= \frac{n \times r}{(CD)} \end{aligned}$$

The enhanced cardinality and ISD, while preserving the OOC property, are general results of the ruler-to-matrix transformation.

TABLE 1
THE 32 PSO MATRIX CODES INTERPRETED AS
W/T MATRIX CODES

Wavelengths (W)	Time slots (S)			
	1	2	3	4
λ_1	1,9, 17,25	1,14, 29	19,24, 26	1,7,10, 11,20,32
λ_2	2,10, 18,26	2,15, 17,30	20,25, 27	2,8,11, 12,21
λ_3	3,11, 19,27	3,16, 18,31	1,21, 26,28	3,12, 13,22
λ_4	4,9,12, 20,28	4,19, 32	2,22, 27,29	4,13, 14,23
λ_5	5,10,13, 21,25,29	5,20	3,23, 28,30	5,14, 15,24
λ_6	6,11,14, 22,26,30	6,21	4,17,24, 29,31	6,15, 16
λ_7	7,12,15, 23,27,31	7,17, 22	5,9,18, 30,32	7,16
λ_8	8,13,16, 24,28,32	8,18, 23,25	6,9,10, 19,31	8

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 (λ_1 ; λ_1 ; λ_3 ; λ_1) and M9 is ($\lambda_1, \lambda_4; 0; \lambda_7, \lambda_8; 0$); 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. Four mode-locked lasers are used to create a dense WDM multi-frequency light source. Pseudo-orthogonal (PSO) matrix codes [3] 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 in [1] where some of the wavelength/time (W/T) matrix codes can permit extensive wavelength reuse and some can allow extensive time-slot reuse. In this example, an extensive time-slot reuse sequence is used for User 1 ($\lambda_1 \lambda_3; 0; \lambda_2 \lambda_4; 0$). There are four time slots used without any guard-band giving the chip period of 100 ps. Codeset for time spreading is mapped as C1:{0; $\lambda_2; 0; \lambda_4$ }, C2:{ $\lambda_1; 0; \lambda_3; 0$ }....C8:{ λ_1 ; $\lambda_2; 0; 0$ }. Code set to apply binary phase shift mapped as M1:{ 0;1;0;1;} M2:{1;0;1;0;}....M8:{0;0;1;1;}-(1represents as a π phase shift,0 represents as no phase shift)

TABLE 3
SPE O-CDMA system parameters used for simulation

Parameter	Value
Code weight	6
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 Gbs
Modulation Format	NRZ and RZ
Fiber length	60 km to 120 km
Measurements	Eye diagram, Bit error rate and Quality factor

3 PROPOSED SPE O-CDMA SCHEME

- 1) Lasers (mode locked laser required to produce 4 wavelength signal)
- 2) Encoders consisting of required components like fiber delay lines, PRBS, 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

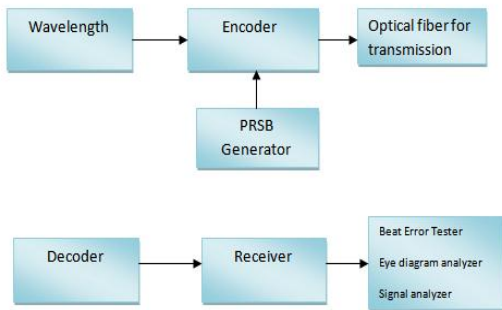


Fig. 2. Schematic Block Diagram for Spectral Phase Encoding Optical CDMA

III Simulation of SPE O-CDMA system one user

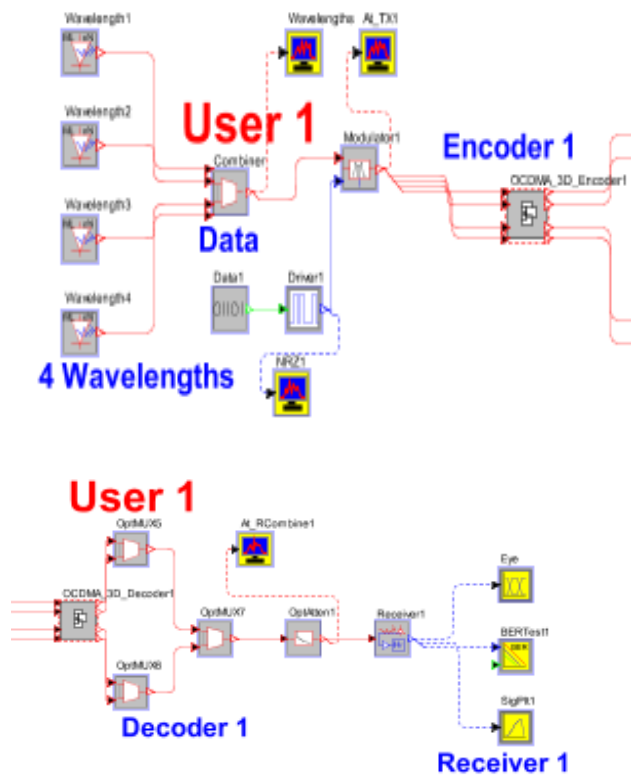


Fig. 3 Simulation setup for Spectral Phase Encoding Optical CDMA system for 1 User

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 0.4 nm wavelength spacing. Four MLL (wavelengths 1 to 4) are used to create a dense WDM multi-frequency light source i.e. carrier signal. This carrier signal is used to modulate the pseudo random bit sequence (PRBS) data of the user. An intensity modulator which is ExtMod is using on-off keying to modulate the

multiplexed 4 wavelengths according to the NRZ electrical data. For analysis, Eye Diagram analyzer, Beat Error tester and Signal analyzer is used.

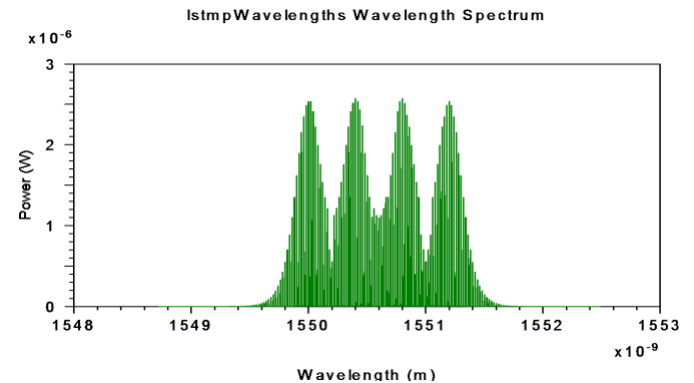


Fig. 4. Wavelength Spectrum for Spectral Phase Encoding Optical CDMA for Eight Users

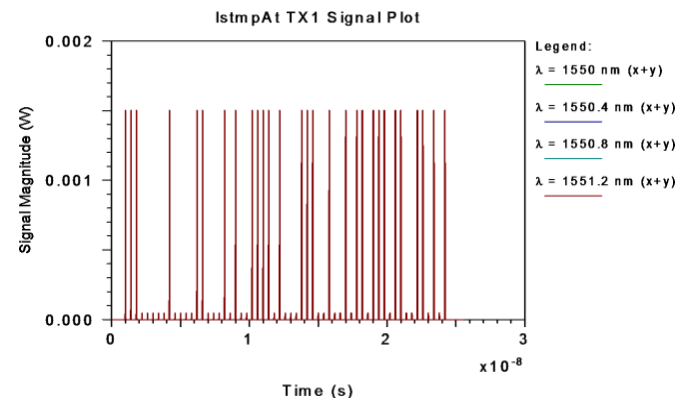


Fig. 5. Modulated data before encoder of User 1

After modulation an encoder is used for encoding the signal. The modulated signals are distributed to the respective encoders, which have been assigned a unique W/T code respective to each encoder. The encoded data from all users are multiplexed by Optical MUX and then passed through a 60 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 OptSplit1 to 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 the decoded signal finally arrives at optical receiver (Receiver), BER Test and Eye Diagram. 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 .

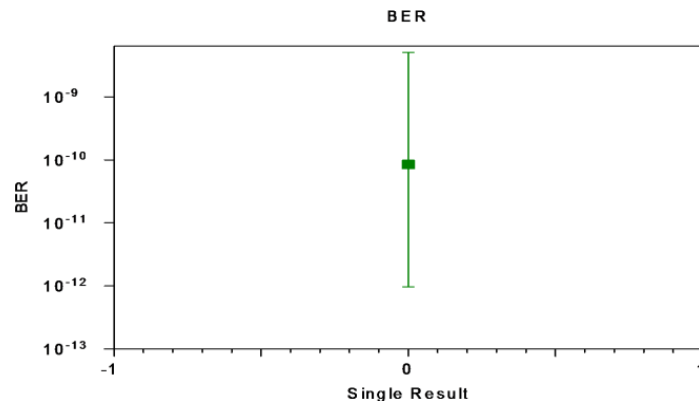


Fig. 6. BER at User 1 Rx for Spectral Phase Encoding Optical CDMA for Eight active Users

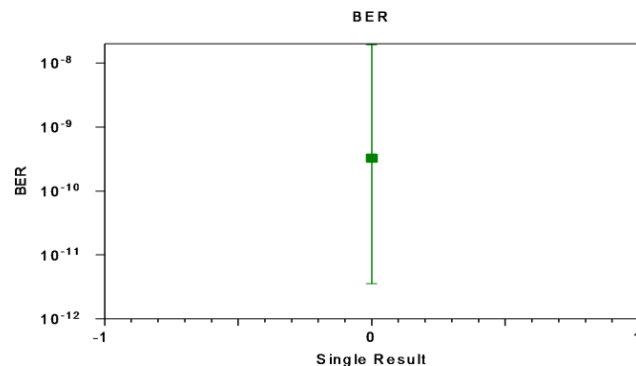


Fig. 7. BER at User 8 Rx for Spectral Phase Encoding Optical CDMA for Eight active Users

Number of Users	BER	Q factor
User1	1.2746e-014	1.7638e+001
User2	6.5483e-013	1.7017e+001
Use3	9.0242e-012	1.6549e+001
User4	8.4236e-011	1.6107e+001
User5	3.2562e-010	1.5816e+001
User6	3.9974e-010	1.5770e+001
User7	4.8900e-010	1.5725e+001
User8	1.8659e-009	1.4554e+001

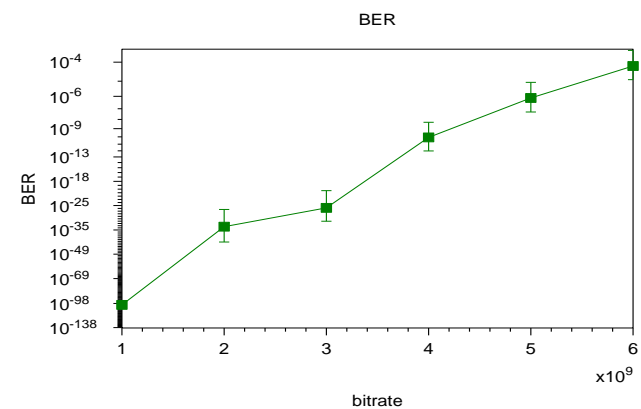


Fig. 8. BER at 1 to 6 Gb/s for Spectral Phase Encoding Optical CDMA for Users 1

4. PERFORMANCE ANALYSIS

TABLE 3
BER AND Q FACTOR FOR 8 USER SPEO-CDMA

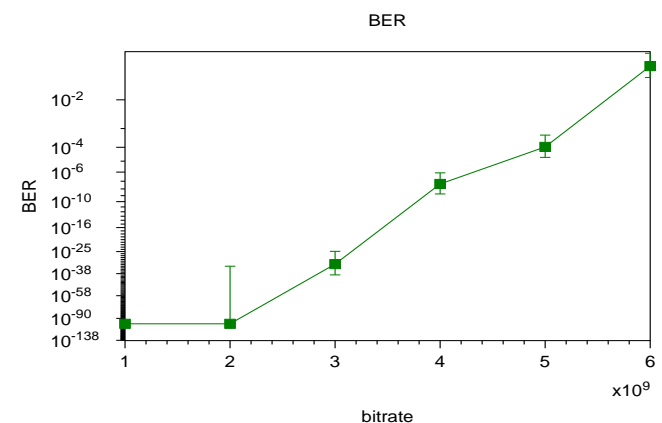


Fig.9. BER at 1 to 6 Gb/s for Spectral Phase Encoding Optical CDMA for Users 8

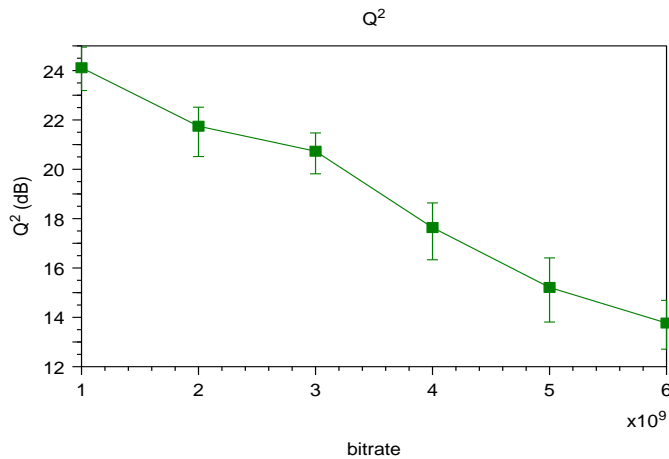


Fig. 10. Q Factor at 1 to 6 Gb/s for Spectral Phase Encoding Optical CDMA for Users 1

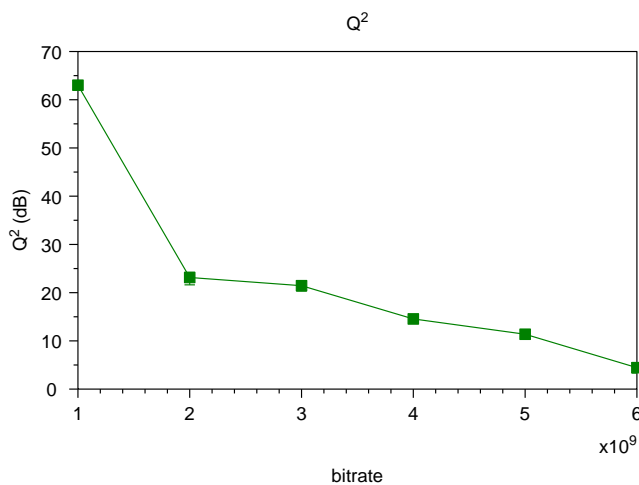


Fig. 11. Q Factor at 1 to 6 Gb/s for Spectral Phase Encoding Optical CDMA for Users 8

Figure 8, 9, 10 and 11 shows performance of spectral Phase Encoding O-CDMA BER and Quality factor.

4. 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 shift reduced the MAI as seen in the bit error rate performance. The overall MAI is reduced which further enhances the QoS. Which overcomes some of the major demerits of O-CDMA and to makes the SPE O-CDMA system more adaptive and has enhanced the performance of the system in terms of reduction in MAI and improvement in Q Factor.

The spectral phase encoding O-CDMA system designed for eight users at 4Gb/s .It has been seen that SPE O-CDMA can accommodate up to eight users at 4Gb/s

.Moreover these results are more realistic as practical impairments have been considered with -15 dB received power and for permissible BER of 10⁻⁹.

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