Analysis of Effect of MAI on an OCDMA System

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ABSTRACT
With the advent of optical CDMA system conventional multiple access techniques such as TDMA and WDMA is losing its interest area of research. This is due to the fact that OCDMA system is more secure and flexible and also provides simplified network management. In this paper the OCDMA simulation model is used to analyze the effect of multiple access interference and wavelength spacing. A detailed analysis of multiple access interference (MAI) which causes a severe degradation in the link performance such as BER and *Q* factor for a temporal OCDMA system is done in this paper. It also reveals that for a good quality of transmission for a temporal OCDMA model shown in this paper, the wavelength spacing should be 0.4 nm.

General Terms
Communication, Security.

Keywords
OCDMA, PSO, MAI, BER, Q factor

1. INTRODUCTION
Telecommunications network uses channel access method to connect different terminals to the same transmission medium in order to share its capacity. The increasing demand of bandwidth has led to the use of Optical network. Three major multiple access techniques are Time Division Multiple Access Technique (TDMA), Wavelength Division Multiple Access Technique (WDMA), Code Division Multiple Access Technique (CDMA) and Optical Code Division Multiple Access Technique (OCDMA). In TDMA single channel is shared by assigning different time slots whereas in WDMA it is done by assigning different wavelengths to different users. In CDMA, all the users occupy the same bandwidth; however they are all assigned separate codes, which differentiate them from each other [1].When CDMA, is applied in the optical system the technique is known as Optical Code Division Multiple Access (OCDMA). This technique proves to be more beneficial than those mentioned above since it also includes the advantages of optical communications. In case of OCDMA, each user signs on a unique digital signature sequence code and transmits the data by using the entire channel bandwidth to the intended receiver [1][2]. OCDMA has an apparent advantage of providing security of data to be transmitted through a transmission medium [3]. It can operate asynchronously without any need of centralized control and packet collision avoidance schemes [4]. It also has an added advantage of providing finite bandwidth to large number of users. The limits on the number of users or access latencies in case of TDMA and WDMA can be resolved by using OCDMA. It creates a soft limit in terms of a number of users, allowing the network to operate at different levels of BER performance. It has been shown that an important advantage of OCDMA systems is that this network easily becomes accustomed to various networking requirements or load conditions, which might not be viable in more rigid WDM based networks. Dynamic networks can therefore benefit from the OCDMA routing [5].Optical CDMA is most suitable to be applied to high speed Local Area Network (LAN) to achieve contention-free, zero delay access, where traffic tends to be bursty rather than continuous [6][7].

In this paper, analysis of the effect of multiple access interference on an OCDMA system is performed in terms of BER and *Q* factor. Also the choice of wavelength spacing of 0.4 nm is justified.

2. OPTICAL CODE DIVISION MULTIPLE ACCESS
The increasing demands for higher speed and advanced services in access networks require a bandwidth of above 50 Mbps for next-generation services to end users. OCDMA over TDMA and WDMA is one of the most promising architecture that can break through the last/first mile bottleneck [5]. OCDMA is a hybrid scheme to combine WDMA and TDMA in such a way that the beneficial characteristics of each technique alleviate the inadequacies of the other. OCDMA supports multiple, asynchronous concurrent users which occupy the same time slots and frequency domain [8]. Each user transmits its unique signature sequence using short optical pulse to transmit bit 1 and a sequence of zeros for no pulse. OCDMA system can be either coherent or incoherent depending on the modulation scheme used to launch the codes into the fiber. Coherent system usually uses phase coding whereas incoherent use amplitude coding. Incoherent method is normally preferred due to its less complex receiver and cost effectiveness [2].

2.1 Optical Codes
Optical codes can be classified as follows [2]:

2.1.1 One dimensional (1-D) codes
One dimensional code can spread in either time (temporal OCDMA) or frequency (spectral OCDMA) domain. Temporal OCDMA is done in time domain by using short optical pulses and delay time where a pulse laser source is intensity modulated by electrical data bits [2]. Spectral OCDMA codes the phase or intensity of the spectral content of a broadband optical signal by using phase or amplitude masks [9].

2.1.2 Two dimensional (2-D) codes
Two dimensional codes spread both in time and wavelength simultaneously. Wavelength hopping time spreading is a 2-D coding approach in which pulses are placed in different chips across the bit period and each chip is of different wavelength, thus following a wavelength hopping and time spreading pattern [2].

2.2 Technological Barriers
It was also studied that there are many technological obstructions such as thermal noise, shot noise, dispersion and multiple access interference for the transmission of data.

- Thermal noise is the impulsive fluctuation, due to thermal interaction between free electrons and the vibrating ions in a conducting medium [10].
- Shot noise is current arising from the random generation and flow of mobile charge carriers. Shot noise is caused by discrete nature of electrons causing a signal disturbance [11].
- Dispersion is the widening of light pulses on an optic fiber due to different propagation velocities of the pulse components [12].
- Multiple access interference arises from dark pulses from interfering users which replicate the signature sequence of the user [12].

Out of these disturbances multiple access interference has a maximum impact on the link performance. There is a need to analyze and understand its effect on the fiber link performance.

3. OCDMA SYSTEM

The OCDMA system shown in the Fig. 1 [13] basically consists of a transmitter, fiber and a receiver. Modulated laser pulse source and optical encoder are the key components of the transmitter, whereas receiver consists of optical decoder and detector. Data bits transmitted are encoded using a user specific optical code and multiple users are accommodated by assigning different minimally interfering codes to different user pairs [14]. There are a number of different ways to generate the coding sequences to represent each channel; those are prime codes, pseudo orthogonal codes. The block diagram shows OCDMA link with encoding/decoding scheme based on pseudo orthogonal matrix code (PSO) [13]. Each user transmits the encoded data in the network where only one decoder in the receiver matches with the code of the corresponding transmitter. Therefore, only the encoded data bits of one transmitter that is intended for a particular receiver get properly decoded back to the original transmitted format, and the encoded data bits transmitted by all the other transmitters remain as improperly decoded pseudo noise signals, contributing to the decoded signal as multi-access interference (MAI) noise [13] [14].

The link sustains 16 users (chips) at 2.5 Gb/s data rate. There are four time slots having a chip period of 100ps without utilizing any guard band. A dense WDM multi-frequency light source having an input power of 3 mW is created by using four mode-locked lasers. Mach-Zehnder intensity modulator modulates the light with pseudo random binary sequence. This modulated output is then split into four arms and given to four filters centered at different wavelengths. The wavelengths are having a channel spacing of 0.4nm and ranges from 1550nm to 1551.2nm. Delay and inverse delay line arrays provide delay in terms of integer multiples of chip times which are used by encoders and decoders respectively [13]. The position of the delay-line arrays and the amount of each delay are stated by the specifics of the user signatures.

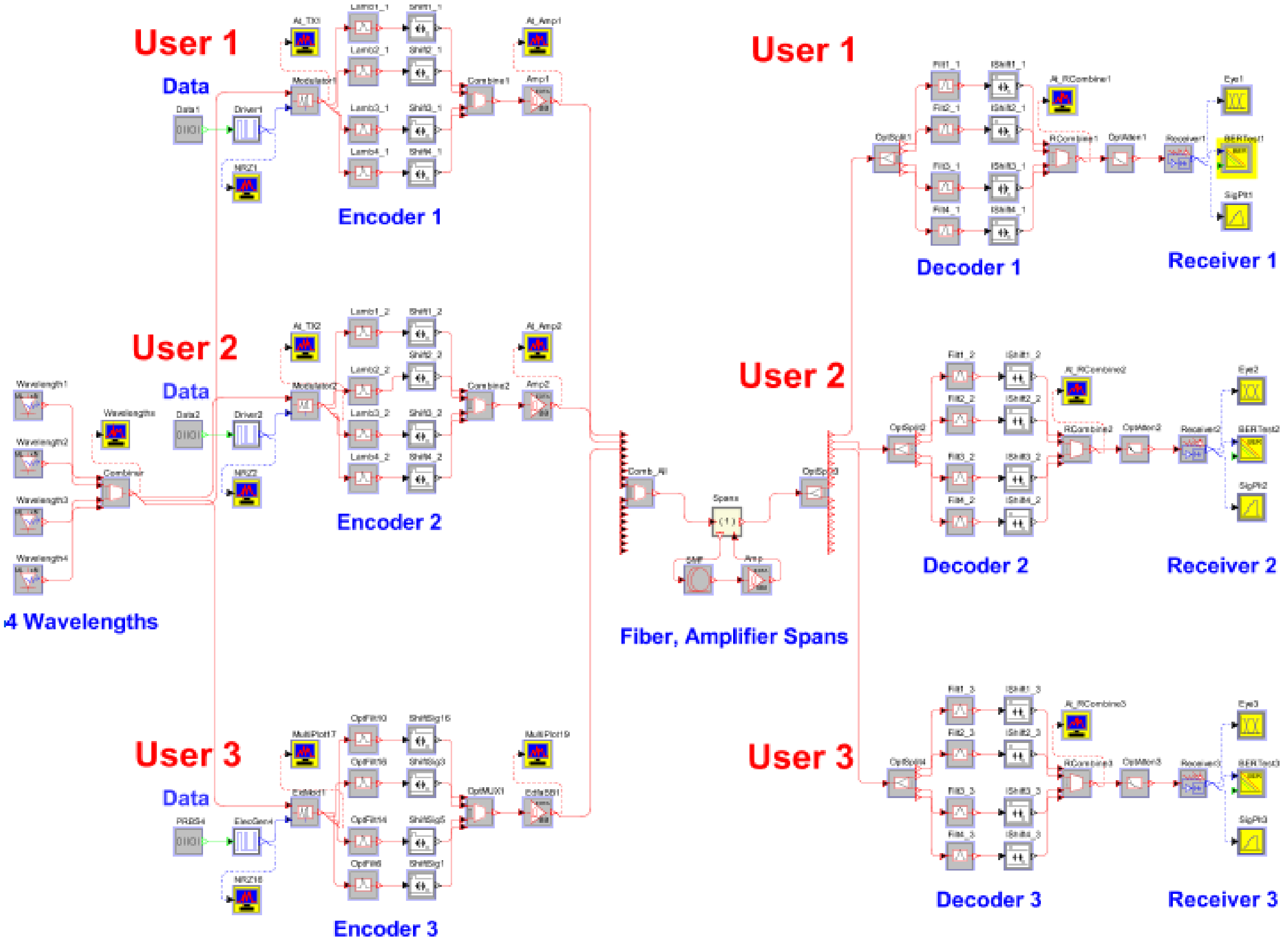

Fig 1: Simulation set up for Temporal OCDMA system for 3 users [13]

$$T_d = n \times \text{chiptime} \times \text{code} \quad (1)$$

The time delay T_d can be represented as [13] [18] given in equation □□□ where *n* is an integer. The encoded data from all users are multiplexed and then passed through a 60 km span of standard single mode fiber (SMF) followed by a loss compensating optical amplifier [13]. Amplifiers can also be used to compensate for the insertion losses due to encoders, multiplexers, de-multiplexers and decoders if needed. The output signal from a fiber span is then passed through splitter/de-multiplexer and routed to the user's decoder [13]. The decoded signal finally appears at optical receiver which is Avalanche photodiode (APD), BER tester and signal analyzer. For simplicity, analysis is only performed for 3 users. The analysis of this system is done, based on the performance parameters such as bit error rate, quality factor and output power.

4. PSEUDO ORTHOGONAL MATRIX CODES

Researchers have proposed and studied different types of codes such as prime codes, optical orthogonal codes etc. The one used in this system is pseudo orthogonal codes because it retains the correlation advantages of PSO linear sequence and avoids bandwidth expansion with the increase in the number of users [15]. Also the spectral efficiency of PSO is better than prime codes. It can be calculated by the formula given below as in [16].

$$\text{Spectral efficiency} = \frac{(\text{No.of users} \times \text{data rate per user})}{\frac{2}{\text{pulsewidth}}} \quad (2)$$

$$\frac{(16 \times 2.5\ \text{Gb/s})}{(2/100\text{ps})}$$

$$=2$$

4.1 Construction of Matrix codes

This technique uses spanning ruler or optimum Golomb ruler sequence. It is a (0,1) pulse sequence where the distances between any of the pulses is a non-repetitive integer, hence the distances between nearest neighbors, next nearest neighbors, etc., can be depicted as a difference triangle with unique integer entries [15].

Fig.2 shows four Golomb ruler sequence with cardinality 4, weight 4, length 26, in order to generate 32 codes. Immediately below there is a table showing the ruler and seven shifted versions with filler zeroes to make up the code dimension (CD) of 32 [15]. The resulting matrix shown in Fig. 3 is orthogonal, because the rows are transposed into columns. It should be noted out that the ruler-to-matrix transformation increases the cardinality (code set size) from 1 to 8 and the information spectral density (ISD) from 1/26 to 8/32, where ISD is given by the formula [15] in equation (3).

g1(4,4)=

1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1

g2(4,4)=

1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0

g3(4,4)=

1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0

g4(4,4)=

1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0

Mi from g1(4,4)

	Column 1 (C1)							
	r1	r2	r3	r4	r5	r6	r7	r8
M1=	1	0	0	0	0	0	0	0
M2=	0	1	0	0	0	0	0	0
M3=	0	0	1	0	0	0	0	0
M4=	0	0	0	1	0	0	0	0
M5=	0	0	0	0	1	0	0	0
M6=	0	0	0	0	0	1	0	0
M7=	0	0	0	0	0	0	1	0
M8=	0	0	0	0	0	0	0	1

	Column 2 (C2)							
	r1	r2	r3	r4	r5	r6	r7	r8
M1=	1	0	0	0	0	0	0	0
M2=	0	1	0	0	0	0	0	0
M3=	0	0	1	0	0	0	0	0
M4=	0	0	0	1	0	0	0	0
M5=	0	0	0	0	1	0	0	0
M6=	0	0	0	0	0	1	0	0
M7=	0	0	0	0	0	0	1	0
M8=	0	0	0	0	0	0	0	1

	Column 3 (C3)							
	r1	r2	r3	r4	r5	r6	r7	r8
M1=	0	0	1	0	0	0	0	0
M2=	0	0	0	1	0	0	0	0
M3=	0	0	0	0	1	0	0	0
M4=	0	0	0	0	0	1	0	0
M5=	0	0	0	0	0	0	1	0
M6=	0	0	0	0	0	0	0	1
M7=	0	0	0	0	0	0	0	0
M8=	0	0	0	0	0	0	0	0

	Column 4 (C4)							
	r1	r2	r3	r4	r5	r6	r7	r8
M1=	1	0	0	0	0	0	0	0
M2=	0	1	0	0	0	0	0	0
M3=	0	0	1	0	0	0	0	0
M4=	0	0	0	1	0	0	0	0
M5=	0	0	0	0	1	0	0	0
M6=	0	0	0	0	0	1	0	0
M7=	1	0	0	0	0	0	1	0
M8=	0	1	0	0	0	0	0	1

Fig 2: Construction of PSO matrices with eight rows and four columns from the set of four optimum Golomb rulers [15] [17]

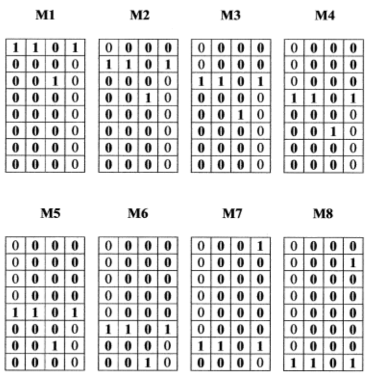

Fig 3: Eight OOC matrices M1 to M8 generated from the optimum Golomb ruler g1(4,4)[15] [17]

4.2 Conversion of PSO Matrix into W/T codes

The matrices can be converted to Wavelength/Time codes by associating the rows of PSO matrices by wavelength and columns by time-slots [14] as shown in the Table1. The matrices M1 to M32 are numbered 1 to 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 (λ_1, λ_4;0; λ_7,$\lambda_8$0); here the semicolons separate the timeslots in the code [14]. (The codes M1 and M9 are shown in bold numerals)

Table 1: PSO Matrix Codes Interpreted as W/T Matrix Codes [15]

Wavelengths (λ)	Time slot (s)			
1	**1**,**9**,17,25	**1**,14,29	19,24,26	**1**,7,10,11,20,32
2	2,10,18,26	2,15,17,30	20,25,27	2,8,11,12,21
3	3,11,19,27	3,16,18,31	**1**,21,26,38	3,12,13,22
4	4,**9**,12,20,28	4,19,32	2,22,27,29	4,13,14,23
5	5,10,13,21,25,29	5,20	3,23,28,30	5,14,15,24
6	6,11,14,22,26,30	6,21	4,17,24,29,31	6,15,16
7	7,12,1523,27,31	7,17,22	5,**9**,18,30,32	7,16
8	8,13,16,24,28,32	8,18,23,25	6,**9**,10,19,31	8

We focus on codes like M1 because it shows extensive wavelength reuse, and on codes like M9 because it shows wide time-slot reuse. It is the extensive wavelength and time-slot reuse that gives these matrix codes their high cardinality and high potential ISD [15].

5. RESULTS AND DISSCUSSION

In this paper we have studied the performance of an OCDMA system having a data rate of 2.5 Gb/s with 3 users. Effect of MAI was analyzed for the link by varying various parameters like:

5.1 Effect of Length and Number of Users

A variation of power with fiber length with the increase in number of users is displayed in theTable 2and Fig 4. For the existing system shown in Fig.1it is observed that beyond 100 km of fiber length the attenuation in the fiber is high for the link with 1 user, 2 users and 3 users. This implies that this link can transmit the data without much degradation in terms of power up to a distance of 100 km.

Table 3 shows the variation in bit error rate (BER), quality factor (*Q*) and power for simultaneous access of channel by different combinations of number of active users. Fig 5 gives the power plot which shows that with the increase in the number of users the output power is increasing.

Table 2: Power vs. Fiber length

No. of Users	Fiber length (km)	Power (dBm)
1	60	-70
	80	-72.96
	100	-79.286
	120	-88.571
2	60	-67.72
	80	-69.54
	100	-73.37
	120	-80.54
3	60	-67.27
	80	-68.63
	100	-71.84
	120	-77.123

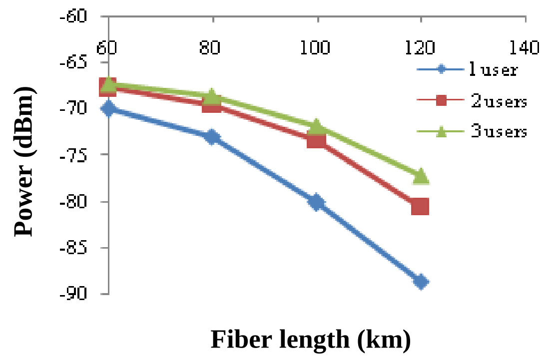

Fig.4: Plot of Power vs. Fiber length

Table 3: Performance parameters of an OCDMA system with MAI

User 3	User 2	User1	BER	*Q* factor (dB)	Power (dBm)
0	0	1	2.50×10^{-10}	15.87	-79.28
0	1	0	5.93×10^{-2}	18.905	-76.43
1	0	0	6.06×10^{-12}	16.623	-76.33
0	1	1	8.36×10^{-17}	18.322	-73.377
1	0	1	2.09×10^{-13}	17.206	-73.377
1	1	1	1.56×10^{-9}	15.454	-71.266

When several users transmit simultaneously their packets at the same wavelengths, their code-words overlap. Due to this overlap of code words, their power will be added. Thus, optical pulses from one code-word may be detected by other receivers tuned to other codes. These errors can be quantified by looking into bit error rate and quality factor of the signal being received.

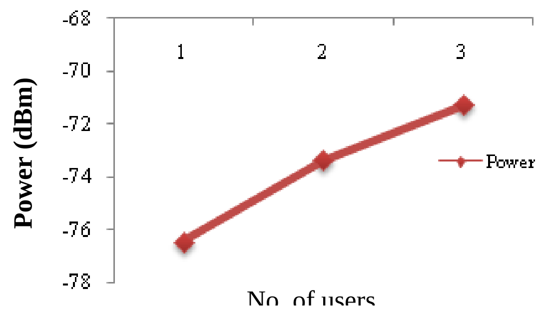

Fig 5: Plot of Power vs. No. of users

5.2 Effect of Wavelength Spacing:

Table 4 shows that the variation of BER and Quality factor with the increase in wavelength spacing. It can be observed that for a band gap of 0.4 nm the link performance is appreciable, i.e. bit error rate is low and quality factor is high. Since with the increase in channel spacing beyond 0.4 nm interference due to other wavelengths causes degradation in link performance. From Table 2, it has been concluded that for a good quality transmission the wavelength spacing that can be used is 0.4 nm. Fig. 6 shows the plot of bit error rate and quality factor with the variation of wavelength spacing.

Table 4: Result of change in Wavelength spacing on link performance

Wavelength spacing (nm)	BER	*Q* factor (dB)
0.2	1.57×10^{-6}	13.37
0.4	1.56×10^{-9}	15.454
0.6	2.35×10^{-6}	13.213
0.8	4.09×10^{-8}	14.589
1	9.13×10^{-8}	14.347
1.2	1.51×10^{-7}	14.189

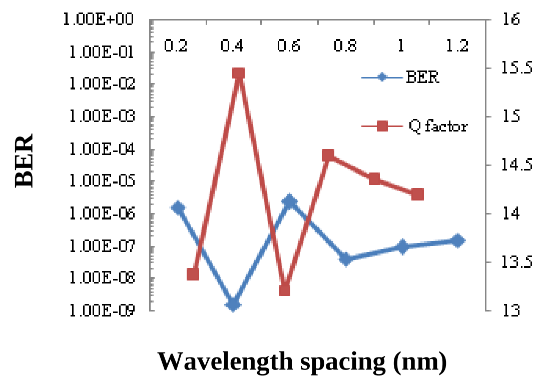

Fig 6: Plot of Wavelength spacing on BER and Q factor

6. CONCLUSIONS

Any multiple access technique, an increase in the number of users gives rise to an interference thereby deteriorating the link performance parameters. The performance of the proposed scheme is investigated for 2.5 Gb/s and 3 users.

It is observed that for small fiber length, parameters such as BER and *Q* factor are tolerable. But as the fiber length is increased these parameters degrade and affect the performance of the system. Also with the increase in the fiber length, due to the dispersion (broadening of the waves), the output power also decreases. Hence primarily in order to get sufficient amount of power required for proper detection of data being transmitted, we have to compromise on the transmission distance by keeping the fiber length small .So a 100 km fiber length is the maximum distance which can be used for transmission for a sustainable performance of the system.

In the proposed system as the wavelength spacing increases, the link performance improves and is the highest at 0.4 nm wavelength spacing and deteriorates thereafter. This justifies the use of 0.4 nm wavelength spacing between the two wavelengths.

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