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Optical CDMA system parameters limitations for AND subtraction detection scheme under enhanced double weight (EDW) code based on simulation experiment

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The work in this paper is a simulation experiment performed by a computer program to determine the OCDMA system parameters limitations. The system was built up with LED light source in the transmitter with filters to construct the code where the receiver is constructed based on AND-subtraction detection scheme. The system was designed to be compatible with the enhanced double weight (EDW) code, passive optical network (PON), P2P network connection and fiber to the home (FTTH) topology. Five system parameters were considered in this work: the number of users, the transmission distance, the bitrate, the chip spacing and the transmitted power. Optisys 6.0 software program was used as a simulator; the simulator considered the entire practical effects in the system, like nonlinearities, attenuation in the fiber and dispersion. This paper shows that for sufficient system performance parameters (BER $\leq 1\times10^{-9}$, $Q \geq 6$) the system can stand for the maximum number of 3 users, the maximum distance of 21 km and the minimum chip spacing of 0.2. The system also shows that it cannot work for any number of users or any distance without the amplifier.

Keywords: optical code division multiple access (OCDMA).

1. Introduction

Multiple access techniques are required to meet the demand for high-speed, large--capacity communications in optical networks, which allow multiple users to share the fiber bandwidth [1].

Optic code division multiple access (OCDMA) scheme is considered to be a viable multiple-access technique for future all-optical networks. This is mainly due to the availability of excess bandwidth in a fiber-optic medium whereby CDMA technique takes advantage to construct a redundant signaling scheme in order to establish an asynchronous and robust multi-access system for the number of users [2].

OCDMA schemes may be classified according to the choice of coherent versus incoherent processing, coherent (mode-locked pulses) versus incoherent (*e.g.*, amplified spontaneous emission (ASE) and light-emitting diode (LED)) broad-band optical source and encoding method (time-domain versus frequency-domain, amplitude versus phase). Schemes based on incoherent processing (summing of optical powers) and broad-band incoherent (noise) sources are generally the easiest to implement but offer relatively poor performance.

In all types of optical code division multiple access (OCDMA) systems, spectral amplitude-coding (SAC) systems have received more attention in recent years since multiuser interference can be eliminated when a code with fixed inphase cross correlation is used [3, 4]. The elimination for MAI occurs at the receiver side depending on what detection technique is used. In general, there are three detection techniques for SAC-OCDMA systems; direct detection technique, complementary detection technique [5] and AND-subtraction technique [6]. At the receiver side, the selection of the detection technique depends on the used code to get the maximum system performance. So far many codes had been proposed for OCDMA system. The codes showed different system performance under different detection techniques: like MQC and EDW for complementary technique by [7, 8], respectively and DW EDW for AND subtraction technique by [6, 9], respectively. However, the work in this research paper is directly related to AND-subtraction detection technique under the EDW code; the EDW code and the AND-subtraction technique will be briefly discussed later on.

2. Enhanced double weight (EDW) code

EDW code can be represented by using a $K \times N$ matrix. In EDW codes structures, the matrix K rows and N columns represent the number of users and the minimum code length, respectively. The basic matrix H_1 for EDW codes consists of $K_1 \times N_1$ a matrix whose size depends on the value of code weight W, as given below

$$K_1 = W \tag{1}$$

$$N_1 = \sum_{j=1}^{w} j \tag{2}$$

From the basic matrix, a larger value of K can be achieved by using a mapping technique:

$$H_i = \begin{bmatrix} 0 & H_1 \\ H_1 & 0 \end{bmatrix} \tag{3}$$

where $i = 2, 3$ ... is the mapping sequence of the codes.

The mapping sequence, i (together with W), determine the value of user K and code length N:

$$K = i \times W \tag{4}$$

$$N = i \times \sum_{j=1}^{w} j \tag{5}$$

The resulting matrix will consist of a chip-combination sequence of 1, 2, 1, 2, ... (alternating 1 and 2) for the columns (counting from leftmost). A chip-combination is defined as the summation of the spectral chips (1's and 0's) for all users (or rows) in the same column.

In this work, the EDW code with the weight of three is used as an example. The basic EDW code denoted by (6, 3, 1) is shown below:

$$H_1 = \left| \begin{array}{cc|cc|cc} 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \end{array} \right| \tag{6}$$

An EDW code with weight of 3 denoted by (N, 3, 1) for any given code length N, can be related to the number of users K through the following equation [10]:

$$N = 2K + \frac{4}{3}\left[\sin\left(\frac{K\pi}{3}\right)\right]^2 \left\{ \frac{8}{3}\left[\sin\left(\frac{(K+1)\pi}{3}\right)\right]^2 + \frac{4}{3}\left[\sin\left(\frac{(K+2)\pi}{3}\right)\right]^2 \right\} \tag{7}$$

3. AND subtraction technique

In this technique, the receiver design will be as in Fig. 1 [6]. The spectral amplitude signal at the receiver side will be split into two branches – the upper branch will have

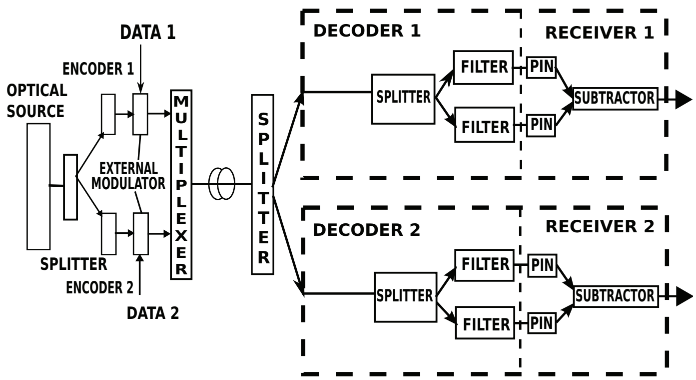

Fig. 1. Two users OCDMA system architecture using AND subtraction technique.

the match decoder for X and the lower branch will have the interfered chips from different users. The result after the subtraction operation will exclude the MAI and subtract the created PIIN in both photodetectors.

T a b l e 1. Design components setup.

LED	
Wavelength	1550 nm
Bandwidth	20 nm
Power	16 dBm
Single mode fiber (SMF)	
XPM	Enabled
SPM	Enabled
FWM	Enabled
GVD	Wavelength dependent
Dispersion slop	0.11 Ps/nm^2/km
Attenuation	0.25 dB/km
Mach–Zhinder	Default
Optical filter	
Bandwidth	Variable
Insertion losses	0 dB

Photodetector	
Responsivity	0.85 A/W
Electrical subtractor	Default
Low pass Bessel filter	
Cut-off frequency	0.75 × bit rate
Pseudo random bit sequence generator	
Bit rate	Variable
NRZ pulse generator	
Amplitude	1 arb.u.
Rise time	0.05 bit
Fall time	0.05 bit
Power (splitter, combiner)	
Branches	Variable
Flat gain EDFA	
Gain	3 dB
Noise figure	4

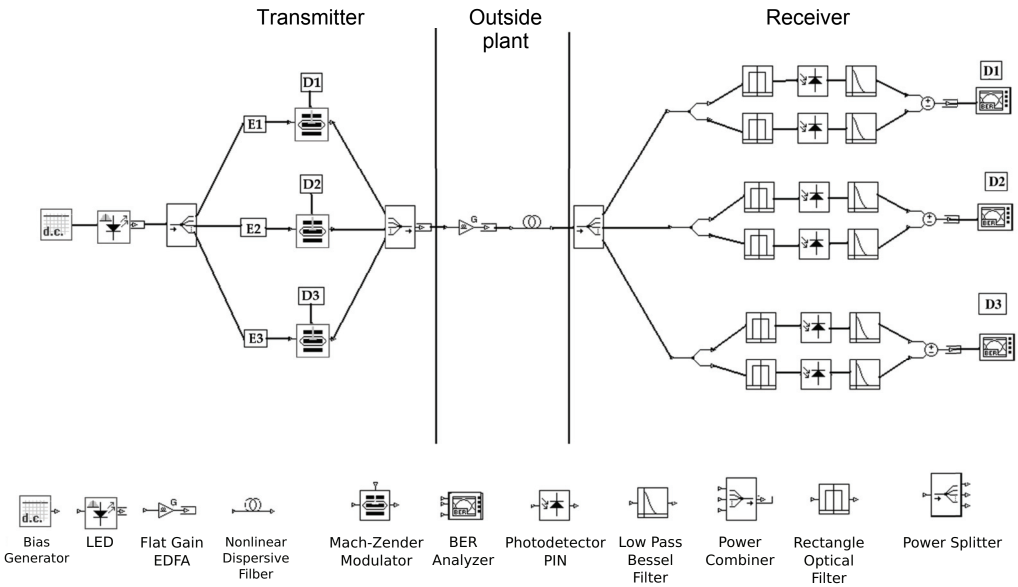

Fig. 2. Simulation setup for the OCDMA system with AND detection technique.

4. Simulation design and setup

Figure 2 shows the OCDMA system design for a simulation experiment where each component in the design was setup according to Table 1.

5. System performance

5.1. Bitrate

The general proposed designs in Fig. 2 were configured using the data in Tab. 1 with source power 16.8 dBm, distance 10 km, number of active users 3, EDFA amplifier gain 10 dB and chip spacing 0.8 nm. The bitrate changed as follows: 466 Mbps, 622 Mbps, 1.25 Gbps, 2.5 Gbps, 10 Gbps. These changes show system performance as in Figures 3 and 4.

Figure 3 shows that in respect of Q factor the system can work sufficiently until 1.5 Gbps with Q factor (7.2) where the BER is (1.59×10^{-13}), as presented in Fig. 4.

5.2. Distance

Figures 5 and 6 show that the maximum distance the system could stand for is 47 km at bitrate 622 Mbps and 21 km at bitrate 1.25 Gbps. The systems were configured using data in Tab. 1 with source power 16.8 dBm, number of active user 3, EDFA

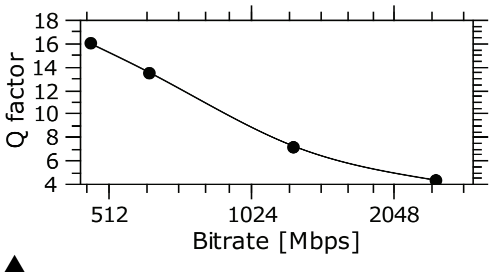

Fig. 3. Q factor *vs*. bitrate.

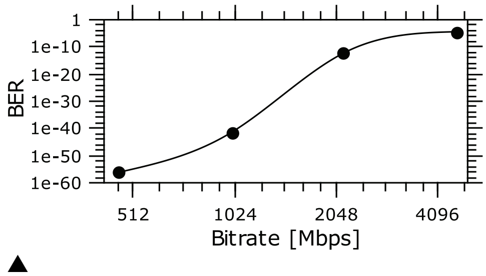

Fig. 4. BER *vs*. bitrate.

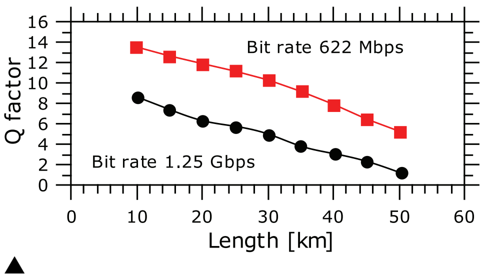

Fig. 5. Q factor *vs*. distance

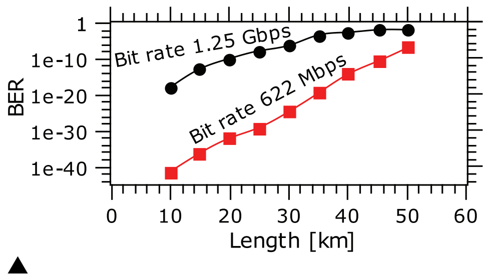

Fig. 6. BER *vs*. distance.

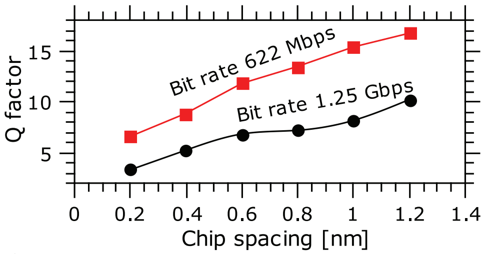

Fig. 7. *Q* factor *vs*. chip spacing.

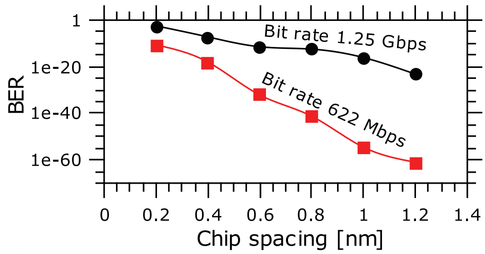

Fig. 8. BER *vs*. chip spacing.

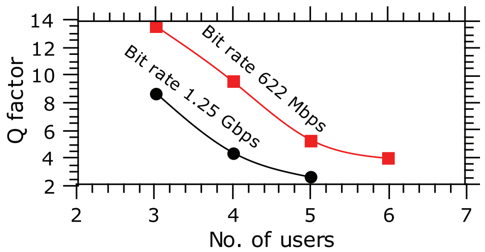

Fig. 9. *Q* factor *vs*. the number of users.

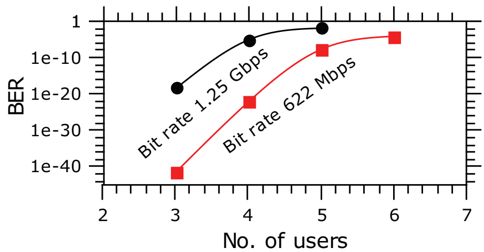

Fig. 10. BER *vs*. the number of users.

amplifier gain 10 dB, and chip spacing 0.8 nm. The distance varied from 10 km to 50 km.

5.3. Chip spacing

Figures 7 and 8 show that increasing the chip spacing gives better system performance. The reason is the code in the transmitter side is constructed using optical filters; these filters give code chips with wide line width which can be compared with chip space itself.

5.4. Number of users

Figures 9 and 10 show how the increment in the number of users effects the system performance at different bitrates. The system was configured using data in Tab. 1 with

T a b l e 2. Maximum and minimum system parameters limitations.

System with light emitting diode (LED) in the transmitter					
	Bit rate [Gbps]	Power [dBm]	Distance [km]	Chip spacing [nm]	Number of users
Maximum bitrate	**1.25**	6.8	10	0.8	3
Maximum distance	1.25	6.8	**21**	0.8	3
Minimum chip spacing	1.25	6.8	10	**0.2**	3
Maximum number of users	1.25	6.8	10	0.8	**3**

source power 6.8 dBm, distance 10 km, EDFA amplifier gain 10 dB and chip spacing 0.8 nm. The bitrate changed as follows: 622 Mbps, 1.25 Gbps, and the number of active users varied from 3 to 9 users. We can see clearly that the system can stand for 4 users; at bitrate 622 Mbps this number is reduced to 3 at 1.25 Gbps.

6. System parameters limitations

The system parameters limitations for minimum and maximum system parameters values at sufficient system performance (BER $\leq 1\times10^{-9}$, $Q \geq 6$) for the simulation proposed designs are listed in Tab. 2.

7. Conclusions

The simulation experiment showed successive implementation for LED power source in OCDMA systems, P2P network connection and FTTH topology. However, this implementation is not absolute but restricted by the system parameters. The simulation showed that for sufficient system performance (BER $\leq 1\times10^{-9}$, $Q \geq 6$) the system can stand for maximum bitrate 1.25 Gbps, maximum distance at 21 km, maximum number of users 3 at maximum bitrate and minimum chip spacing 0.2 nm at maximum bitrate. The system has showed that it cannot work without an amplifier for any number of users at any bitrate or distance.

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