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Hybrid optical CDMA and DWDM system implemented under the influence of non-linear effects

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ABSTRACT

A hybrid optical CDMA-DWDM system accommodating 12 optical CDMA users carried by 5 DWDM wavelengths at a data rate of 60Gb/s/wavelength with channel spacing of 0.4nm is implemented under the effect of four-wave mixing (FWM). It was found that the FWM effect could be minimized by the use of CDMA technology, where the energy of each bit is spread over the optical sequence code. Over a distance of 105.075km, significant performance of all optical CDMA users in terms of the BER is achieved. The results reveal that the inter-symbol interference (ISI) can be mitigated when the interval of optical signature sequence code is squeezed into 25% of the bit duration.

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1. INTRODUCTION

As data transmission get more and heavier, the need of high rate transmission technology is increasing, the target is a high speed capacity transmission technology. Utilizing the bandwidth of the optical fiber to meet the users demand for high-speed communications such as high speed internet, data exchange like audio and video, images, High Definition Television (HDTV) through network, is one of the main challenges. WDM technology enables efficient usage of fiber capacity by dividing the bandwidth into different wavelength sets, where each wavelength supports communication between a pair of end nodes. Different wavelengths are multiplexed at the transmitter side and carried simultaneously over the same physical fiber. At the receiving end, they are de-multiplexed and each wavelength is directed to the designated receiver. Due to the unique properties of Optical Code Division Multiplexing Access (Optical CDMA) technology such as fully asynchronous access capability, high security and soft capacity, it has been widely researched.

To make full use of the huge bandwidth offered by optical fiber and soft capacity properties of optical CDMA, the convergence of optical CDMA and DWDM can be regarded as a new competitive option for the future optical access network. However, it's well known that in WDM, the maximum allowable transmitted power channel is limited due to nonlinear phenomenon known as four-wave mixing (FWM) effect. The physical origin of FWM is from the third order nonlinear susceptibility of optical fiber, where there are three wavelengths propagate, hence, fourth intermodulation product is produced. On the other hand, multiple access interference (MAI) is the big problem facing the researchers in optical CDMA area, which is caused by the overlapping signaling between the users. Few researches of hybrid systems have been

conducted in the literature [1-8]. However the effect of FWM has not been addressed yet. In fact FWM effect has been widely investigated in purely WDM systems [9-21].

In this paper, an optical CDMA-DWDM hybrid system with spacing 0.4nm is proposed to increase the capacity of the network and reduce the FWM effects. Zero cross correlation (ZCC) code is used as a signature sequence code, which has good properties in terms of auto and cross correlation [22]; hence the MAI can be reduced. On the other hand, the nonlinear effect of FWM, which degrades the signals in DWDM system, can be reduced by CDMA technology. To obtain the useful information for practical system design, the hybrid system has been tested with different values of transmitted power while dispersion compensating fiber (DCF) is used in the transmission line to compensate the dispersion. The paper is organized as follows; section 2 provides a description of the proposed hybrid system, while section 3 presents the analysis of FWM in the hybrid system, where section 4 is devoted for the results and discussions and the conclusion is drawn in section 5.

2. SYSTEM DESCRIPTION

The operational block diagram of the proposed hybrid system is shown in Figure 1, where there are *M* continuous wave distributed feedback lasers (DFB) to generate *M* wavelengths with wavelength spacing of 0.4nm, each followed by an external modulator drives by sinusoidal signal, which used to create a periodic train of return to zero (RZ) pulses, then each wavelength split into *N* outputs ports, each represents one user's data, where an external modulator is driven by an electrical NRZ data source used to impose the modulation by blocking the zero bits. The NRZ data is the pseudo-random binary sequence (PRBS) with a length of $(2^9 - 1)$ at the bit rate of 5 Gbps. The modulated data of each user is then encoded by a unique code of Zero Cross-correlation (ZCC). The *N* encoded users' data are combined together by an optical combiner, where the same optical sequence code will be used for all the other wavelengths. Finally, all the *M* wavelengths multiplexed by WDM multiplexer and sent over single mode fiber. In addition, dispersion compensating fiber (DCF) is used for dispersion compensation, and preamplifier used to composite the loss. Each wavelength/channel can accommodate *N* optical CDMA users; where each user is encoded by a unique optical code and the same code can be reused for other wavelengths. So, the proposed hybrid system is capable of accommodating $M \times N$ users. ZCC sequences used as signature code for the optical CDMA users, where there are *N* zero cross-correlation sequences that can be generated; each sequence code has a weight *w* and a length F_m, where the length of the ZCC sequences is $F_m = 2^m(w^2 + w)$, *m* is the mapping process [22]. As mentioned that a splitter is used to split one wavelength into *N* outputs and each n^{th} output is modulated by 5Gbps then encoded by time delays to correlate the desired code. In order to mitigate the ISI, the sequence code interval must be squeezed into less than bit duration.

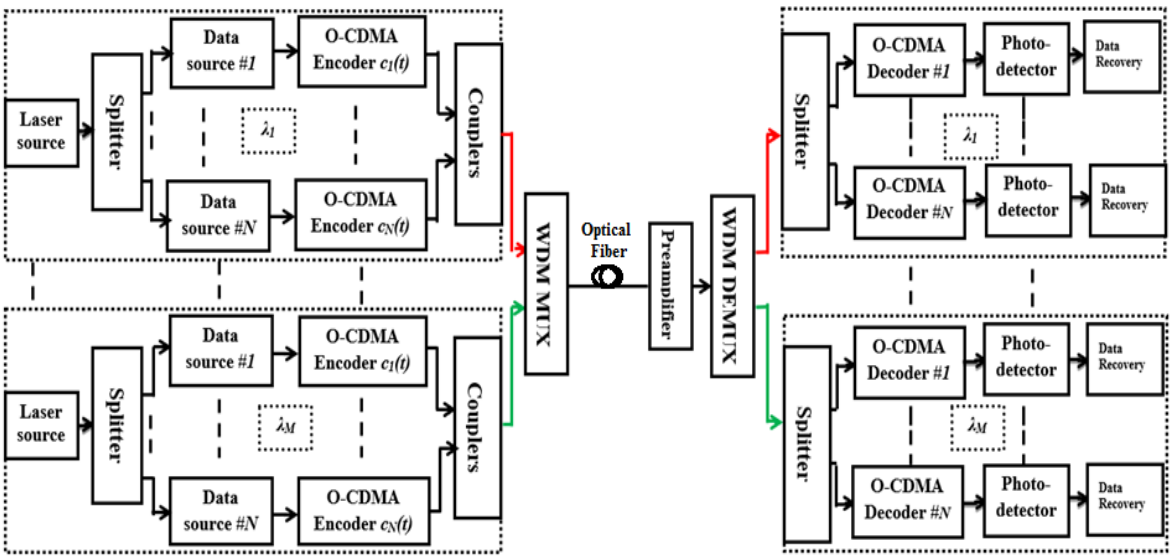

Figure 1. Block diagram of the hybrid system

3. FWM IN THE OPTICAL CDMA-DWDM HYBRID SYSTEM

FWM phenomenon takes place, whenever three different wavelengths propagate inside the fiber. They interact with each other and generate new wavelengths that may coincide with the original wavelengths; the FWM power in the hybrid system due to the interaction of frequencies f_p, f_q and f_r can be expressed as in [23]:

$$P_{pqr} = \frac{\eta}{9}(d\gamma)^2 P_p P_q P_r \left[\frac{(1-e^{-\alpha L})^2}{\alpha^2}\right] e^{-\alpha L} \quad (1)$$

Where, η is the FWM efficiency, d is the degeneracy factor, and its value is 1 when $f_i=f_j$, and 2 when $f_i \neq f_j$, γ is the nonlinearity coefficient, L is the transmission length, P_i , P_j , P_k ,are the transmitted power per wavelength/channel, each wavelength is shared with N optical CDMA users, therefore, the transmitted power of each user (e.g., in wavelength p) is $\frac{P_p}{N}$ where the transmitted power per chip is $\frac{P_p}{F_m N}$; F_m is the signature sequence length and α is the attenuation of the fiber. The nonlinearity coefficient is expressed as $\gamma = \frac{2\pi n_2}{\lambda A_{eff}}$, n_2 is the fiber nonlinear refractive index, which is related to the third nonlinear susceptibility x_{111} given by $n_2 = \frac{48\pi^2}{cn^2} x_{111}$, where c, n, A_{eff} and λ, are the vacuum speed of light, the refractive index of the fiber core, the effective area of the fiber core, the vacuum wavelength, respectively. The FWM efficiency η depends on the phase mismatching and can be expressed as:

$$\eta = \frac{\alpha^2}{\alpha^2 + (\Delta\beta)^2}\left[1 + \frac{4e^{-\alpha L}\sin^2(\frac{\Delta\beta . L}{2})}{(1-e^{-\alpha L})^2}\right] \quad (2)$$

The FWM efficiency η takes maximum value 1 when $\Delta\beta$ = 0, where; $\Delta\beta$ refers to the phase mismatch and it can be represented by [23].

$$\Delta\beta = \frac{2\pi\lambda^2}{c}(\Delta f_{ij})(\Delta f_{jk})\left[D_C + (\frac{\lambda^2}{2c})(SD)(\Delta f_{pq} + \Delta f_{qr})\right] \quad (3)$$

where; D_C, SD are the chromatic and slope dispersion, respectively.

4. RESULTS AND DISCUSSIONS

Considering intensity modulation/direct detection (IM/DD) transmission, the proposed hybrid system consists of 5 wavelengths with wavelength spacing of 0.4nm operating at 1559.794nm - 1561.419nm, where each carried 12 optical CDMA user's data. Therefore, 60 optical CDMA users can be accommodated by the proposed hybrid system; the implemented parameters are summarized in Table 1. It has been shown in [24] that the ISI can be mitigated as the interval of the signature optical code is squeezed into 25% of the bit duration; therefore, such interval is considered in our proposed hybrid system.

Figure 2 shows the average BERs versus the transmitted power for the five DWDM channels where each channel carries 12 optical CDMA users at data rate of 5Gb/s/user. The signals are transmitted over 90km of SMF and 15.075km of DCF. According to our previous work [24], the best performance of the proposed system when the transmitted power is 18dBm, beyond this value the system performance significantly decreases because of the effect of the intra FWM. In this work, the amplified spontaneous emission (ASE) is neglected in order to have some insight on FWM effects. The spreading of the energy of the bit over the signature sequence code, the FWM is reduced as the energy is distributed over the set of optical sequence code. Hence, good performance of 60 users is achieved. It can be extracted from the results that the position of weights "ones" in the signature sequence code plays crucial role in increasing the nonlinear tolerance in the hybrid system as the longer the distance between the ones of the code the better the performance. The results also revealed that the hybrid system has its best performance when the transmitted

power is 18dBm. Figure 3 shows the variation of the BERs of random 5 optical CDMA users out of 12 in channel 1 versus the transmitted power. As noted that the BER of user 8 is slightly bigger than those of other users because of the weights' positions in the optical sequence code are close to each other.

In reference [25], the authors proposed hybrid WDM-OCDMA network employing 60 Gb/s non-return to zero/differential quadrature phase shift keying (NRZ/DQPSK) orthogonally modulated data signal operating over 100 km (SMF+DCF), which was capable of supporting 32 users carried by 4 wavelengths. In comparison with reference [25], we managed to implement a hybrid system over 105.075km (SMF+DCF), which is capable of accommodating 60 optical CDMA users carried by only 5 wavelengths with channel spacing of 0.4nm.

Table 1. The Performance of the proposed hybrid system

Parameter	Value	Parameter	Value
Number of channels	M = 5	Attenuation for SMF	0.2dB/km
Number of users in each channel	N = 12	Dispersion for SMF	16.75 ps/nm.km
Length and weight of the sequence code	F=24, w=2	Dispersion slope for SMF	0.075 ps/nm^2.km
Input transmitted power to the fiber	18dBm	Cross effective area for DCF	22 um^2
Total channel length	105.075km (90km SMF + 15.075km DCF)	Dispersion for DSF	-100 ps/nm.km
Preamplifier gain	5 dB	Dispersion slope for DSF	-0.45 ps/nm^2.km
Channel spacing	0.4nm	Attenuation for DCF	0.5dB/km
Cross effective area for SMF	80 um^2	Data rate per channel	60Gb/s

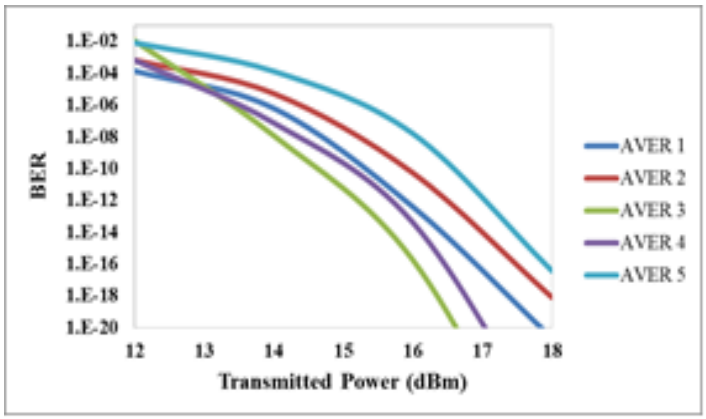

Figure 2. The average BERs versus transmitted power for the five DWDM channels with 0.4nm spacing

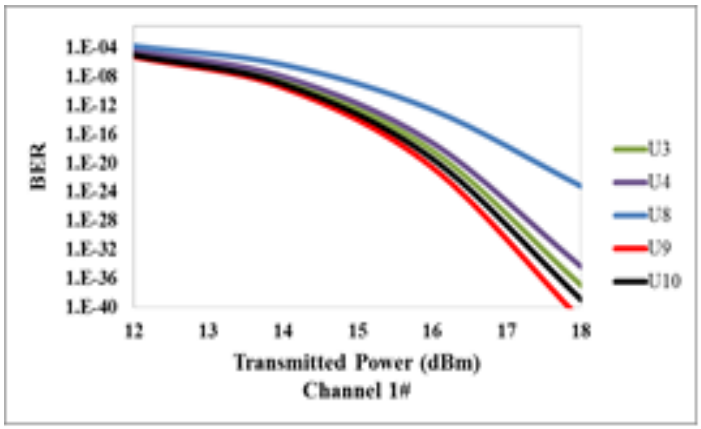

Figure 3. BERs versus transmitted power for 5 random optical CDMA users out of 12 carried in channel 1

5. CONCLUSION

This paper reported a hybrid system of 12 optical CDMA users x 5 DWDM with channel spacing of 0.4nm at 60Gb/s/wavelength. In the proposed system the inter-symbol interference (ISI) is mitigated by squeezing the interval of optical sequence code into 25% of the bit duration, while the multiple access interference (MAI) is minimized due to the use of MD sequence code. The results revealed that the CDMA technology could be used to reduce the effect of FWM in the proposed hybrid system. It is found that the optimum values of transmitted power and transmission distance are 18dBm and 105.075km respectively. In future work, an electro optic phase modulator (EOPM) will be implemented to enhance the nonlinear tolerance of the proposed hybrid system.

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