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LETTER

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Improving spectral efficiency of SAC-OCDMA systems by SPD scheme

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Abstract: This letter presents a single photodiode detection (SPD) as an effective technique for eradicating both multiple-access interference (MAI) and phase-induced intensity noise (PIIN) in spectral-amplitude coding optical code-division multiple-access (SAC-OCDMA) systems. Mathematical analysis and simulation experiments are used to investigate the spectral efficiency (SE) of SAC-OCDMA systems utilizing different detection techniques. Results show that the SPD technique significantly enhances the SE compared to AND as well as modified-AND subtraction detections.

Keywords: SAC-OCDMA, single photodiode detection (SPD), spectral efficiency (SE), MAI, PIIN

Classification: Fiber optics, Microwave photonics, Optical interconnection, Photonic signal processing, Photonic integration and systems

References

[1] S. B. Ahmad-Anas, M. K. Abdullah, M. Mokhtar, and S. D. Walker, "Multiple access interference elimination with enhanced chromatic dispersion tolerance in SAC OCDMA," *IEICE Electron. Express*, vol. 5, no. 16, pp. 617–623, Aug. 2008.

[2] H. M. R. Al-Khafaji, S. A. Aljunid, and H. A. Fadhil, "Improved BER based on intensity noise alleviation using developed detection technique for incoherent SAC-OCDMA systems," *J. Modern Optics*, vol. 59, no. 10, pp. 878–886, June 2012.

[3] F. N. Hasoon, S. A. Aljunid, M. D. A. Samad, M. K. Abdullah, and S. Shaari, "Spectral amplitude coding OCDMA using AND subtraction technique," *Applied Optics*, vol. 47, no. 9, pp. 1263–1268, March 2008.

[4] F. N. Hasoon, M. K. Abdullah, S. A. Aljunid, and S. Shaari, "Performance of OCDMA systems using a complementary subtraction technique," *J. Optical Networking*, vol. 6, no. 7, pp. 854–859, July 2007.

[5] M. Rochette, S. Ayotte, and L. A. Rusch, "Analysis of the spectral efficiency of frequency-encoded OCDMA systems with incoherent sources," *J. Lightwave Technol.*, vol. 23, no. 4, pp. 1610 –1619, April 2005.

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1 Introduction

With the accelerated demand for high-speed broadband services, optical code-division multiple-access (OCDMA) has emerged as a popular candidate for access networks in view of several beneficial features, including simultaneous and asynchronous access to the network, soft capacity on demand, and secure transmission. Spectral-amplitude coding (SAC) is an attractive OCDMA technique for alleviating MAI. This is accomplished by using a subtraction detection technique at the receiver side with fixed in-phase cross-correlation codes [1]. Economical broadband sources such as light-emitting diodes (LEDs) are well-suited candidates for SAC-OCDMA systems. The occurrence of PIIN resulting from the incoherence of such broadband light sources is the dominant source of performance decay in SAC-OCDMA systems [2]. Recently, the authors proposed the modified-AND subtraction detection technique to reduce PIIN and MAI in incoherent SAC-OCDMA systems by dividing the spectrum of the decoded signals [2]. The modified-AND subtraction detection technique has the same receiver complexity as the AND detection technique [3], but offers enhanced system performance. Both of these techniques use balanced detection, composed of two photodiodes connected electrically in opposition, where the output signal is proportional to the power difference between the two optical inputs. Therefore, it would be advantageous to design a low complexity detection technique employing a single photodiode rather than two. In this work, enhanced double weight (EDW) codes are used as the signature sequences for SAC-OCDMA systems [4]. EDW codes are characterized by unity cross-correlation ($\lambda = 1$), the ideal cross-correlation value. For a weight of three ($w = 3$), the code length L is related to the number of users K through:

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

Following Introduction to this work in Section 1, Section 2 describes the SPD technique. Next, SE analysis of SAC-OCDMA system based on SPD technique with EDW code has been undertaken in Section 3, followed by discussions of the theoretical and simulation results. Finally, the conclusions of this letter are stated in Section 4.

2 Single photodiode detection (SPD) scheme

A structure of the SAC-OCDMA receiver for this technique is indicated in Fig. 1. The received optical signal is decoded using the same spectral response as that intended to the encoder. The detected output from the decoder is either w power units (P.U.) for active user or λ P.U. for interferers. The remainder of the signal from the decoder is then transmitted to the subtractive decoder (s-Decoder) to cancel interfering signals of different codes. The s-Decoder contains only frequency bins from the different interferers represented logically in Table I. The output from the s-Decoder is either zero P.U. for active user or λ P.U. for interferers. This technique can be realized by using budget fiber Bragg-gratings (FBGs) to decode the incoming

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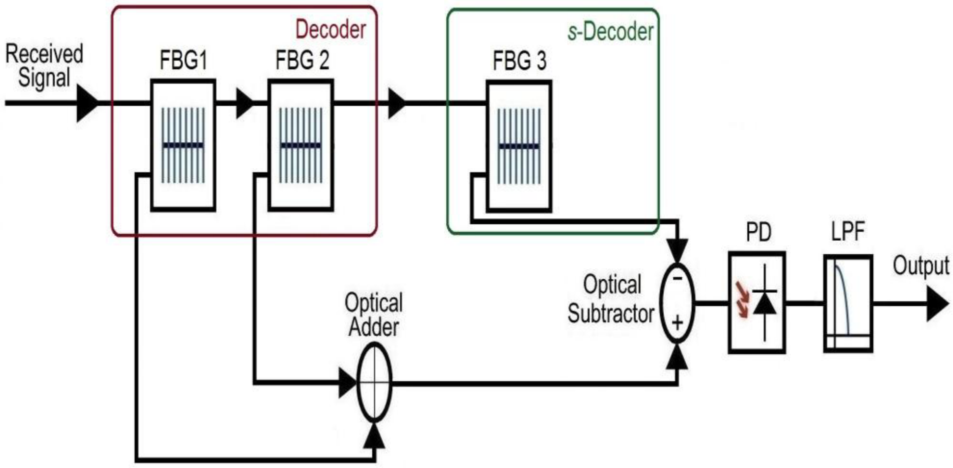

Fig. 1. Schematic diagram of SPD technique.

Table I. Logical representation of interference cancelation for EDW code.

	Code words
Main User (DEC)	{ 1 1 0 1 0 0 }
1st Interfering User (I_1)	{ 0 1 0 0 1 1 }
2nd Interfering User (I_2)	{ 0 0 1 1 0 1 }
($\mathrm{DEC} \bullet I_1$)	{ 0 1 0 0 0 0 }
$\sum(I_1 \bullet \mathrm{DEC})$	1
$\overline{\mathrm{DEC}}$	{ 0 0 1 0 1 1 }
$(I_1 \bullet I_2)$	{ 0 0 0 0 0 1 }
$s\text{-DEC} = \overline{\mathrm{DEC}} \bullet (I_1 \bullet I_2)$	{ 0 0 0 0 0 1 }
$(I_1 \bullet s\text{-DEC})$	{ 0 0 0 0 0 1 }
$\sum(I_1 \bullet s\text{-DEC})$	1
$\sum(I_1 \bullet \mathrm{DEC}) - \sum(I_1 \bullet s\text{-DEC})$	$1 - 1 = 0$

signal. After optical subtraction, the output is either w P.U. for active user or zero P.U. for interferers. This indicates that the interfering signals are eliminated in the optical domain before their conversion to the electrical domain. Canceling interfering signals in the optical domain permits a single photodiode to be used instead of two. This distinguishes the SPD from other detection techniques. The SPD technique may be generalized for any fixed in-phase cross-correlation codes with a simple modification in the spectral distribution of the s-Decoder. After the desired signal is detected by a photodiode (PD), the transmitted information are restored and low-pass filtered to reduce out-of-band high-frequency noise.

3 Spectral efficiency (SE) analysis and results

The mean optical power reaching the PD when the desired user is active

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is [5]:

$$\langle P_{User} \rangle = S\left[\int_0^{B_o} H_E(v) H_D(v) dv\right]$$
$$\langle P_{User} \rangle = S\frac{B_o}{L}\sum_{i=1,E=D}^{L} c_E(i) \bullet c_D(i)$$
$$\langle P_{User} \rangle = \frac{SB_o}{L}w = \frac{3SB_o}{L} \tag{2}$$

where S is the received power spectral density level at photodiode, B_o is the optical bandwidth partitioned into logical frequency bins of width B_o/L, $H_E(v)$ and $H_D(v)$ are the encoder and decoder transfer functions, respectively. These functions are spectral representations of the filters. They are made of bins of a given spectral width that are fully transmissive or fully opaque, and $c_E(i)$ and $c_D(i)$ denote the ith element of the encoder and decoder code words, respectively.

The PIIN expression for unpolarized thermal light source can be evaluated as [5]:

$$\sigma^2_{PIIN} = S^2 B_e \int_0^{Bo} [H_E(v) H_D(v)]^2 dv$$
$$\sigma^2_{PIIN} = S^2 B_e \frac{B_o}{L}\sum_{i=1,E=D}^{L} [c_E(i)]^2 \bullet [c_D(i)]^2$$
$$\sigma^2_{PIIN} = \frac{S^2 B_e B_o}{L}w = \frac{3S^2 B_e B_o}{L} \tag{3}$$

and the signal-to-noise ratio (SNR) is thus

$$SNR = \frac{(\langle P_{User} \rangle)^2}{\sigma^2_{PIIN}} = \frac{3B_o}{B_e L} \tag{4}$$

Based on the approximation of Gaussian distribution, the bit-error rate (BER) is also given by:

$$BER = \frac{1}{2} erfc\left(\frac{\sqrt{SNR}}{2}\right) \tag{5}$$

where *erfc* is the complementary error function.

The general SE (η_S) at a given BER is calculated as:

$$\eta_S = \frac{KR_B}{B_o} \tag{6}$$

Assuming the electrical bandwidth resulting from detection (B_e) is equal to $0.75 \times R_B$, where R_B is the bit rate, and substituting the ratio B_o/B_e from Eq. (4) into Eq. (6), the derived SE expression is

$$\eta_S = \frac{4}{\text{SNR}}\frac{K}{L} \simeq \frac{2}{\text{SNR}} \tag{7}$$

It is shown in Eq. (7) that, as the system SNR necessity becomes more demanding, the SE of the system degrades.

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Fig. 2 denotes the SE against the number of active users for different detection schemes at a BER of 10^{-11}. It may easily be pointed out that the SPD scheme achieves better SE compared to AND as well as modified-AND detection schemes. This is more pronounced as the number of active users increases. The SPD curve crosses $K = 60$ with 22.2×10^{-3} b/s·Hz, while modified-AND detection curve crosses $K = 60$ with 1.3×10^{-3} b/s·Hz. This shows a 12.1 dB SE improvement in case of SPD versus modified-AND detection. With the exception of the SPD scheme, it can be observed that the SE declines with increasing the number of active users. The drop in SE is more prominent for the AND detection compared to the modified-AND detection. The AND detection curve crosses $K = 10$ with 1.9×10^{-3} b/s·Hz, and crosses $K = 60$ with 3.6×10^{-4} b/s·Hz. This shows a 7.2 dB SE penalty for an increase of 50 users.

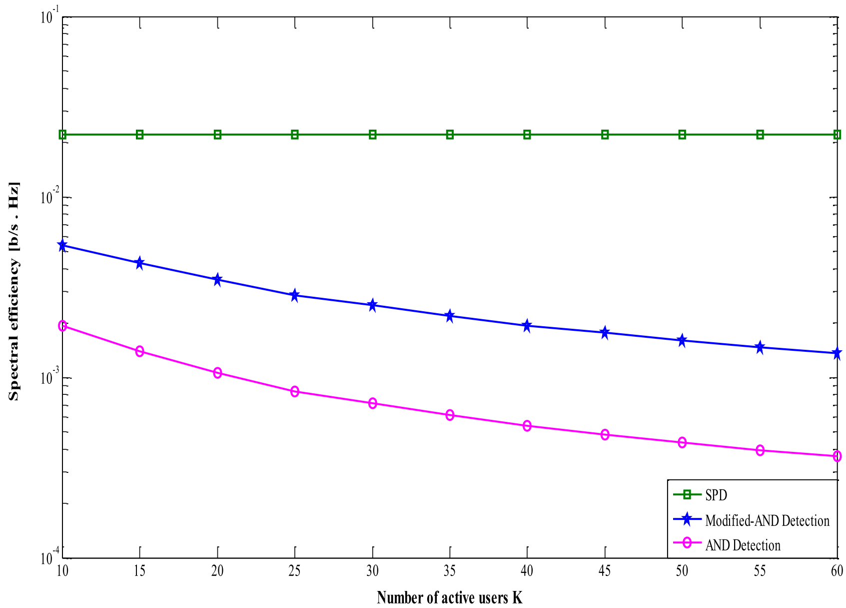

Fig. 2. SE versus the number of active users for different detection techniques at $BER = 10^{-11}$.

Moreover, the SE of the mentioned detection schemes is investigated through simulating three channels of EDW code ($w = 3$) using OptiSystem software (Version 9.0) from *optiwave*^{TM}. Simulations are carried out using one LED sliced into 9 wavelengths. The source optical bandwidth is set at 3.75 THz. The attenuation and the dispersion coefficients of a 10 km single mode fiber (SMF) at a wavelength of 1550 nm are 0.25 dB/km and 18 ps/km/nm respectively. The dark current value is set at 5 nA, and the thermal noise coefficient is 1.8×10^{-23} W/Hz for each of the photodiodes at the detection part.

In Fig. 3, interesting eye patterns are used to elucidate the resultant SE from simulation experiments. The SE increases due to the increase in bit rate. This implies that the SE is improved using the SPD, without compromising the BER of the system.

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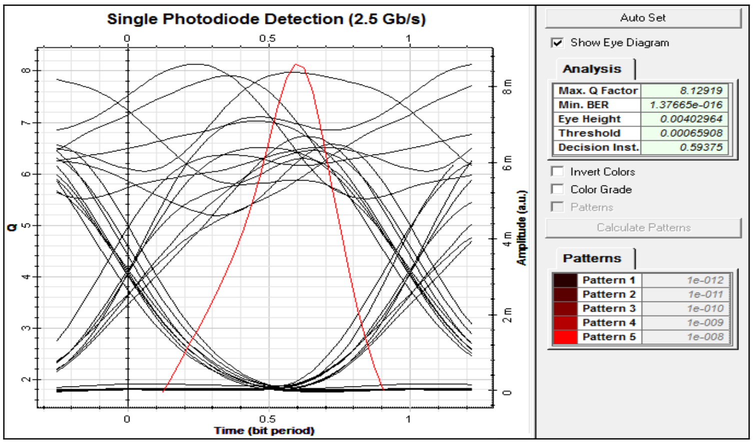
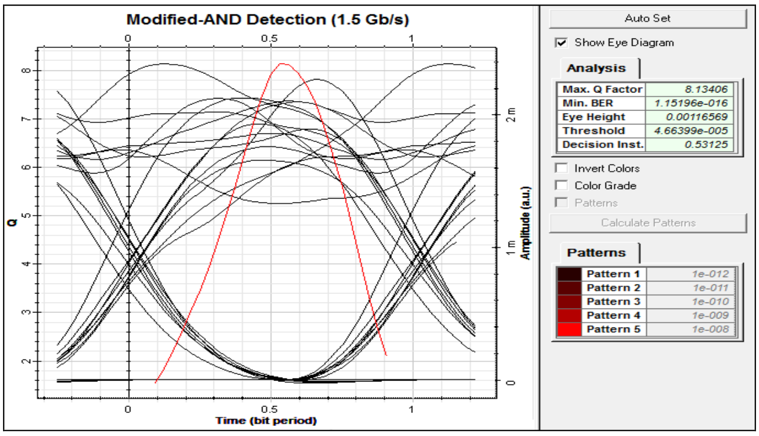
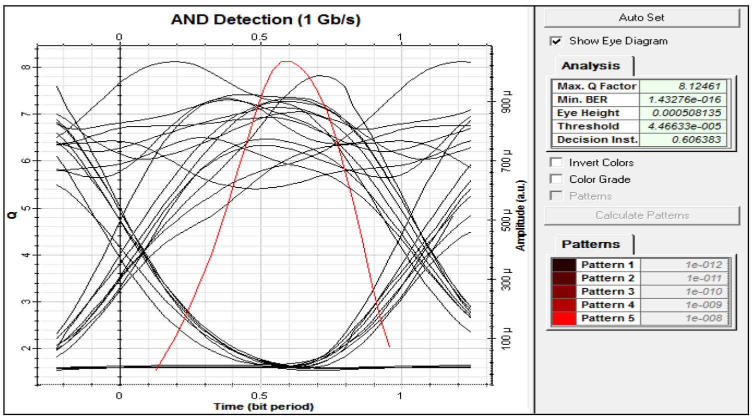


(a)



(b)



(c)

Fig. 3. Eye diagrams for EDW code using (a) SPD, (b) Modified-AND detection, and (c) AND detection.

4 Conclusions

Focusing on PIIN and MAI elimination in SAC-OCDMA systems, this letter shows an effective solution by utilizing the SPD technique. The SE of different detection schemes is discussed. In SAC-OCDMA systems, PIIN suppression is extremely desirable for achieving high SE. Thus, it is concluded that SPD technique is an attractive candidate for future optical access networks.

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