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SAC-OCDMA system performance using MDW signature codes with different photodiodes: A comparative study

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Abstract – *This paper demonstrates a performance comparison for spectral amplitude coding optical code division multiple access (SAC-OCDMA) using different detectors at different transmission distances. The single photodiode detection (SPD) technique is used to reduce phase induced intensity noise (PIIN). Modified double weight (MDW) codes are used as signature codes. Simulation results show that the system using avalanche photodetector (APD) achieves 10 km longer transmission distances than that using PIN at both 1Gbps and 2 Gbps, with enhanced bit error rate (BER).*

Keywords: Avalanche photodiode, Bit error rate, Modified double weight code, Multiple access interference, Single photodiode detection.

1.0 INTRODUCTION

Over the past several years, optical code division multiple access (OCDMA) has received a great interest as it does not depend on time or frequency at transmitter [1]. OCDMA has several advantages for implementation of the local area network such as low delay, high capacity, potential security and the possibility of accommodating a large number of simultaneous users [2]. Though, it has the disadvantage of the multiple access interference (MAI), which degrades its performance. It is caused by the non-ideal orthogonal property of optical codes and exists when multiple users share the same medium using the same time and frequency for transmitting concurrent data streams [3, 4]. The presence of PIIN, which is related to MAI due to the overlapping of the spectra from different users, also affects the system performance [5].

Recently, the spectral amplitude coding-optical code division multiple access (SAC-OCDMA) technique is used with codes that have a fixed in-phase cross correlation to reduce the MAI. A detection technique like modified-AND subtraction is used in the receiver to reduce PIIN in incoherent SAC-OCDMA systems. Its function is to split the received spectrum of the decoded signals into two parts: one to the upper decoding branches and the other to the AND decoder through an attenuator. The SPD detection technique needs only one photodetector leading to a cheaper receiver and shot noise reduction [6]. Furthermore, the performance of SAC-OCDMA can be enhanced by utilizing APD. The APD available gain makes it more sensitive as compared to the PIN photodiode [7].

In this paper, we used an SAC-OCDMA system with MDW codes that have fixed in-phase cross correlation with SPD detection technique because of its simplicity as it uses a single photodiode. The impact of APD in the performance of SAC-OCDMA system is investigated and compared with PIN. The performance is discussed according to system BER. A comparison when using APD or PIN detectors is performed at different transmission distances and different bit rates.

The remainder of paper is organized as follows. In Sec. 2, a review of the system description is presented based on MDW code. The SPD detection technique is explained in Sec. 3. Section 4 is devoted to the system simulation model. The obtained results are illustrated and discussed in Sec. 5. This is followed by the main conclusions in Sec. 6.

2.0 MDW CODE CONSTRUCTION

MDW is the enhanced version of double weight (DW) code. The MDW code weight can be any even number greater than 2 and can be constructed using the following steps [8]. MDW code can be represented by using a K×N matrix. In MDW codes structures, the K rows and N columns represent the number of users and the minimum code length, respectively. A basic MDW code, H_1, is given by a 3×9 matrix, as [8]

Step 1:

$$H_0=\begin{vmatrix} 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \end{vmatrix} \qquad (1)$$

Step 2:
From the basic matrix, a larger number of K can be achieved by using a mapping technique as [8]

$$H_1=\begin{vmatrix} 0&0&0&0&0&0&0&0&0&0&0&0&0&1&1&0&1&1 \\ 0&0&0&0&0&0&0&0&0&0&1&1&0&0&0&1&1&0 \\ 0&0&0&0&0&0&0&0&0&1&1&0&1&1&0&0&0&0 \\ 0&0&0&0&1&1&0&1&1&0&0&0&0&0&0&0&0&0 \\ 0&1&1&0&0&0&1&1&0&0&0&0&0&0&0&0&0&0 \\ 1&1&0&1&1&0&0&0&0&0&0&0&0&0&0&0&0&0 \end{vmatrix}$$

$$= \begin{vmatrix} 0 & H_0 \\ H_0 & 0 \end{vmatrix} \qquad (2)$$

An MDW code with weight of 4 denoted by (L, 4, 1) for any given code length L, is related to the number of users K through [8]

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

3.0 SPD DETECTION TECHNIQUE

The structure of SAC-OCDMA receiver using MDW code is illustrated in Fig. 1. The received signal is decoded by a decoder having the same spectral response of the encoder [6]. The remainder of the signal from the decoder is then transmitted to the subtractive decoder (s-decoder) to cancel out signals with mismatched signatures, i.e., interferers. The s-decoder contains only frequency bins from different interferers. After optical subtraction, the output from the s-decoder is either zero for active user or λ for interferers. This technique can be implemented using low cost uniform FBGs to decode the received signal. This implies that, the interference signals are cancelled in the optical domain before the conversion to the electrical domain. Consequently, the new SPD scheme alleviates both PIIN and MAI in the optical domain.

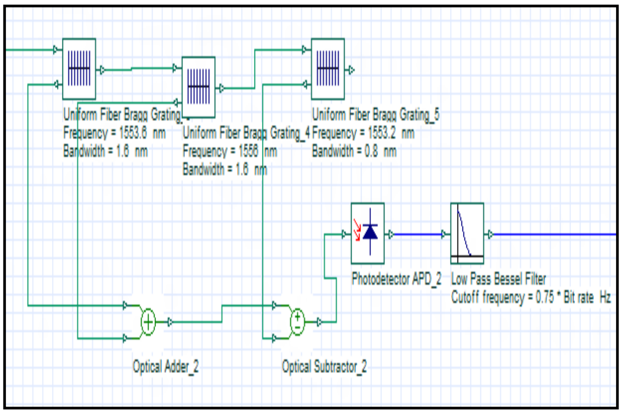


Figure 1: SPD detection technique.

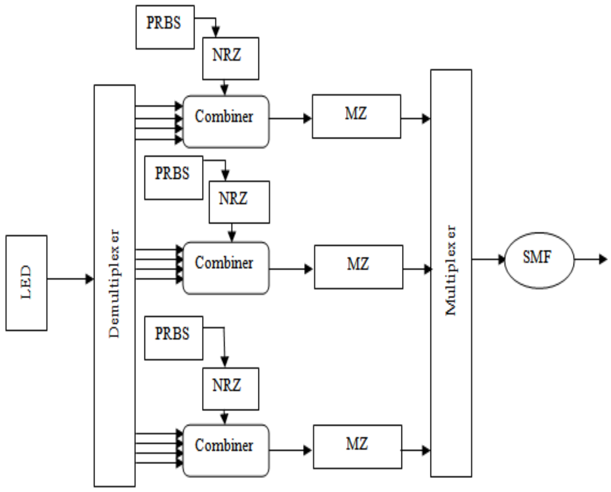
The logical representation of interferences cancellation using MDW code, as an example, is shown in Table 1.

Table 1: Logical representation of interferences cancellation.

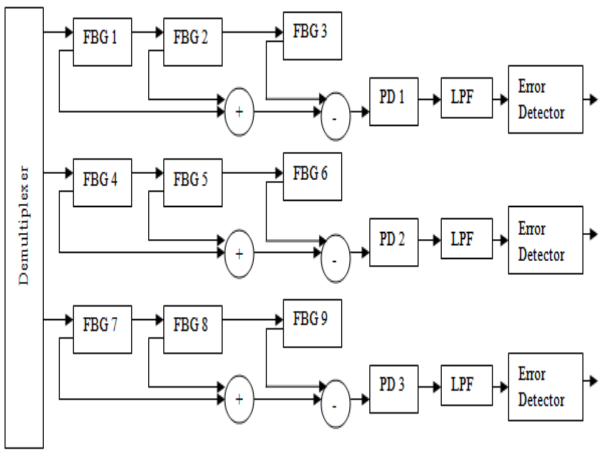
Detection tracing	Cancelled interference codes
User 1 (Decoder)	110110000
First interference of user 1 (X)	011000110
Second interference of user 1 (Y)	000011011
(Decoder × X)	010000000
∑(X × Decoder)	1
$\overline{\text{Decoder}}$	001001111
(X × Y)	000000010
S-Decoder = $\overline{\text{Decoder}}$ × (X × Y)	000000010
(X × S-Decoder)	000000010
∑(X × Decoder) –∑((X × S-Decoder)	1 – 1 = 0

4.0 NETWORK SIMULATION SETUP

The transmitter and the receiver of three users SAC-OCDMA using MDW code as signature codes with SPD detection technique are presented in Figs. 2(a) and (b), respectively. Here, the transmitter consists of one LED which is sliced to nine wavelengths using wavelength division multiplexing (WDM) to generate the OCDMA codes. The information signals are generated from the pseudo random bit generator (PRB) with the non-return-to-zero (NRZ) line coding before being modulated with the codes using an external Mach Zehnder (MZ) modulator.



(a)



(b)

Figure 2: Block diagram of three users SAC-OCDMA (a) transmitter using MDW code (b) receiver using SPD detection.

The SAC-OCDMA receiver uses SPD detection techniques. In SPD detection technique, fiber Bragg gratings (FBGs) use the same bandwidth but with different Bragg wavelengths to decode the signal. The photodetector (PD) is used to convert the optical signal to an electrical one. The resultant signal is filtered by a fourth order Bessel low pass filter, which is used to reject noise and interference components that lie outside the information signal spectrum.

Table 2 shows the center wavelength and optical bandwidth for FBGs of each user, where FBG1, FBG2, FBG4, FBG 5, FBG7 and FBG8 represent the decoder and FBG3, FBG6 and FBG9 represent the s-decoder.

Table 2: FBGs wavelengths and bandwidth used in simulation.

FBG	Bragg wavelength (nm)	Bandwidth (nm)
FBG1	1550.4	1.6
FBG2	1552.8	1.6
FBG3	1555.6	0.8
FBG4	1551.2	1.6
FBG5	1555.2	1.6
FBG6	1553.2	0.8
FBG7	1553.6	1.6
FBG8	1556	1.6
FBG9	1550.8	0.8

When the PIN detector is used, the mean optical power reaching the photodetector, when the desired user is active, is given by [9]

$$P_{User} = \frac{4\ S\ B_0}{L} \tag{4}$$

where S is the received power spectral density at PD and B_0 is optical bandwidth portioned into logical frequency bins of width B_0/L.

This is changed when APD detector is used and becomes

$$P_{User} = \frac{4\ S\ G\ B_0}{L} \tag{5}$$

where G is the average internal gain of the APD.

The PIIN expression for unpolarized thermal light source when a PIN detector is used can be expressed as [9]

$$\sigma_{PIIN}{}^2 = \frac{4\ S^2\ B_e\ B_0}{L} \tag{6}$$

where B_e is the electrical bandwidth.

When an APD photodiode is used, and according to the work of H. M. R. Al-Khafaji et al. [10], the PIIN becomes

$$\sigma_{PIIN}{}^2 = \frac{4S^2G^2B_eB_0}{L} \tag{7}$$

The variance of shot noise, when using PIN and APD is, respectively, given by [11]

$$\sigma_{sh}{}^2 = 2eB_eR < P_{User} > \tag{8}$$

$$\sigma_{sh}{}^2 = 2eB_eR_{APD}G^{2+x} < P_{User} > \tag{9}$$

where R is the responsivity of photodiode and the parameter x equals to 0.7 for InGaAs APD [12].

The signal to noise ratio (SNR) can be written as [9]

$$SNR=\frac{(P_{User})^2}{\sigma_{PIIN}{}^2+\sigma_{th}{}^2+\sigma_{sh}{}^2} \tag{10}$$

Based on the Gaussian distribution approximation, the BER is given by [13]

$$BER = \frac{1}{2}\,\mathrm{erfc}\left(\frac{\sqrt{SNR}}{2}\right) \tag{11}$$

where erfc is the complementary error function.

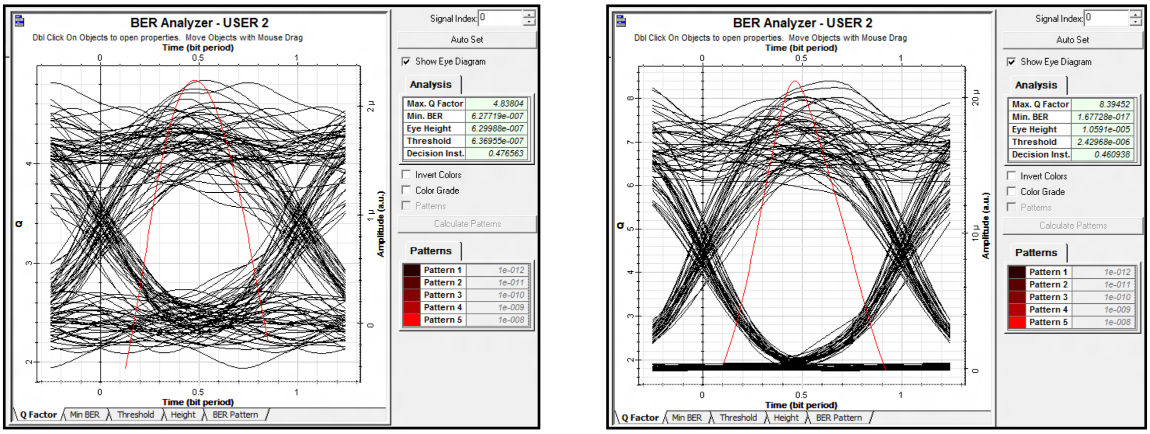
5.0 RESULTS AND DISCUSSION

The network simulation set up shown in Fig. 2 has been simulated using Optisystem (ver. 7.0) with the parameters shown in Table 3.

Table 3: Typical parameters used for simulation [6, 7, 14].

Parameter	Value
LED input power	9 dBm
Signal data	128 PN sequence
Signal format	NRZ
External modulator extinction ratio	30 dB
Bit rate	622 Mbps, 1 and 2 Gbps
FBGs reflectivity	0.99
Fiber dispersion, D	17 ps/nm/km
Fiber attenuation	0.25 dB/km
APD gain	10 dB
Dark current	5 nA
Thermal noise coefficient	1.8×10^{-23}
Low pass filter bandwidth	0.75×Bit Rate
Number of users	3
Code weight	4

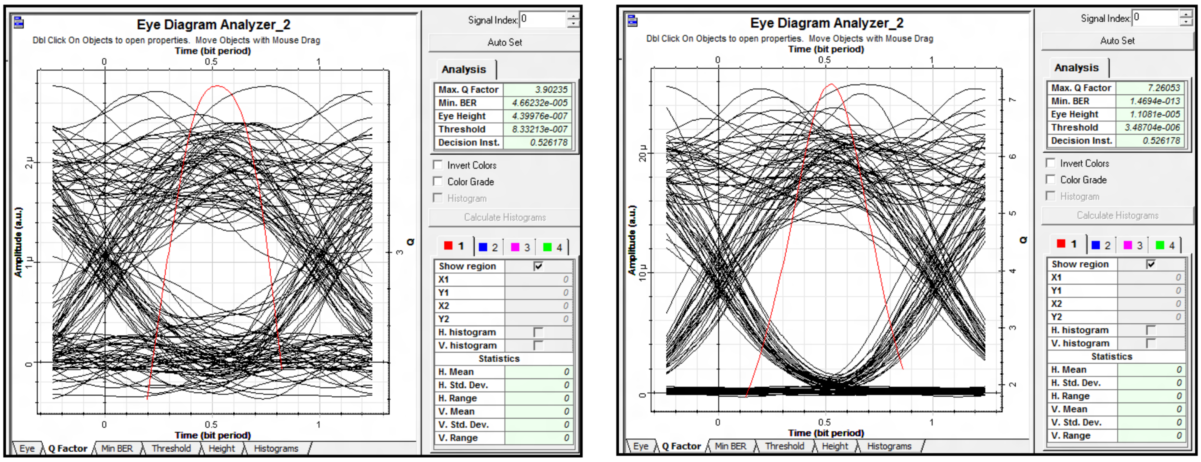
Each user has its own eye diagram. For simplicity, we present a sample for one user of the SAC-OCDMA system that is assigned with MDW code and uses SPD detection technique in the receiver to show the difference in the eye pattern when APD and PIN detectors are used. At a distance of 90 km and a bit rate of 622 Mbps, Fig. 3 (a) and (b) show the eye diagram when PIN and APD are used, respectively. It is clear that, the system when using APD detector performs better with a large eye opening than that when using PIN detector.



(a) (b)

Figure 3: Eye diagram for one user of SAC-OCDMA system using MDW code sending bit rate 622 Mbps at 90 km (a) when PIN detector is used (b) when APD detector is used.

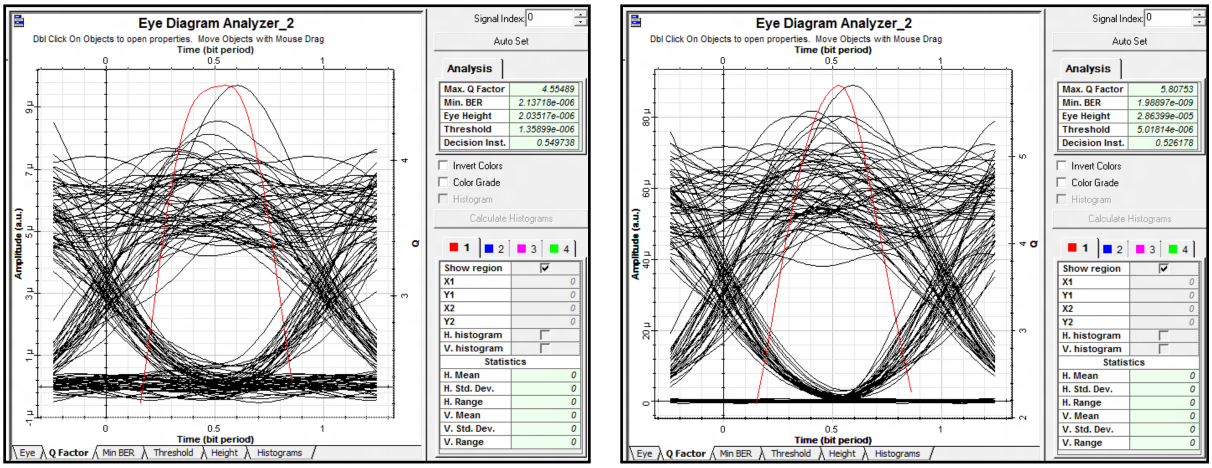
Figure 4 (a) and (b) shows the eye pattern for the same user but at a transmission distance of 50 km and a bit rate of 1 Gbps. It is observed that, the data of the user can be transmitted with a BER of 4.66×10^{-5} and 1.4694×10^{-13} when PIN and APD detectors are used, respectively. Also, the system using APD has a larger eye opening than that of the PIN.



(a) (b)

Figure 4: Eye diagram for one user SAC-OCDMA system using MDW code sending 1 Gbps at 50 km (a) when PIN detector is used (b) when APD detector is used.

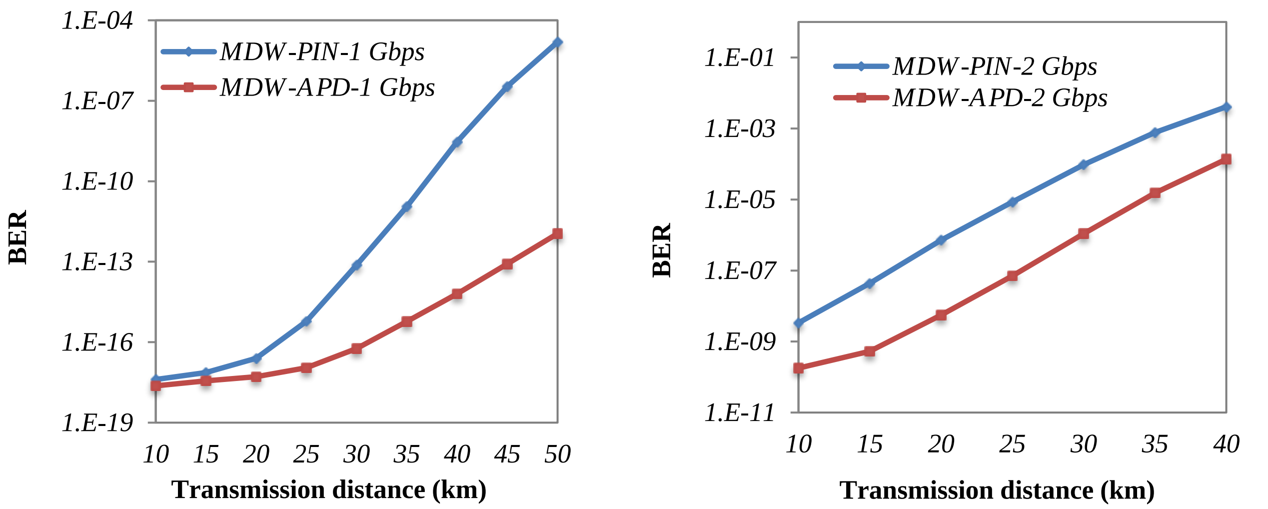
The comparison is repeated at 2 Gbps and 20 km as shown in Fig. 5 (a) and (b). The figures show that data of the system using APD can be received with a BER of 1.989×10^{-9} while the other that uses PIN gives a BER of 2.137×10^{-6}. It must be kept in mind that, at a BER greater than the maximum allowable value of BER (~ 10^{-9}), data will not be clearly received.



(a) (b)

Figure 5: Eye diagram for one user of SAC-OCDMA system using MDW code sending 2 Gbps at 20 km (a) when PIN detector is used (b) when APD detector is used.

The average BER for three users against the fiber length at bit rates of 1 and 2 Gbps are displayed in Fig. 6 (a and b). The data of the system can be transferred at BER ≅10^{-9} as a sample reference. When a PIN photodiode is used, 40 km and 50 km transmission distances are achieved at 1 and 2 Gbps, respectively. It is clear that, the use of APD leads to an increase of 10 km in transmission distance for both bit rates.



(a) (b)

Figure 6: BER of SAC-OCDMA system against the transmission distance with MDW codes using different detectors at (a) 1 Gbps and (b) 2Gbps.

Table 4 summarizes the maximum allowable distance that the data of this system can travel with BER ~10^{-9} when using PIN and APD detectors at different bit rates.

Table 4 Allowable distances for SAC-OCDMA using MDW codes at different bit rates with different detectors

Bit Rate	PIN	APD
1 Gbps	40 km	50 km
2 Gbps	10 km	20 km

6.0 CONCLUSION

The SAC-OCDMA with SPD system is proposed and investigated for different detectors at different transmission distances and different bit rates. MDW codes are used as signature codes of the system. The proposed system eliminates the MAI and PIIN which degrades the system performance. The obtained results show that, the system performance which is related to BER is enhanced when the APD is used and the system achieves 10 km longer transmission distances than that when PIN is used. The proposed system is expected to be an excellent candidate for use in next generation OCDMA networks applications due to low cost and simplicity.

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