APD GAIN EFFECT ON SAC-OCDMA SYSTEM USING MODIFIED-AND DETECTION TECHNIQUE

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ABSTRACT

This paper investigates the avalanche photodiode (APD) gain effect on spectral-amplitude coding optical code-division multiple-access (SAC-OCDMA) system using a modified-AND subtraction detection in comparison to the conventional AND detection scheme. Analytical results are presented to investigate the APD gain impact on the bit-error rate (BER) performance. In addition, we confirm the influence of the APD over the positive-intrinsic-negative (PIN) photodiode on the system performance using data transmission simulations.

Keywords: *SAC-OCDMA, modified-AND subtraction detection, phase-induced intensity noise (PIIN), APD, PIN photodiode*

1. INTRODUCTION

In recent years, optical code-division multiple-access (OCDMA) has gained increased interest due to its varied, advantageous features such as asynchronous access ability, enhanced information security, and cost efficiency [1, 2]. Even so, multiple-access interference (MAI) decays the performance and capacity of conventional OCDMA systems, which is its major disadvantage [3]. Of all the OCDMA techniques, spectral-amplitude coding (SAC) warrants close attention owing to its ability to restrain MAI when using a suitable detection approach, as well as the availability of cost-effective broadband sources such as light-emitting diodes (LEDs) [3]. However, despite having major advantages, these sources are thermal in nature, and so, suffer from phase-induced intensity noise (PIIN) [4]. PIIN depends on the number of interfering users, and the performance cannot be enhanced by increasing the transmitted power. Of late, the modified-AND subtraction detection technique has been suggested for eradicating the influences of PIIN and MAI in incoherent SAC-OCDMA systems by dividing the spectrum of the decoded signals [5].

The performance of OCDMA systems can be enhanced by utilizing APD. In high-speed receivers, APD is attributed to their high optoelectronic gain [6]. It internally multiplies the primary signal photocurrent before it enters the input circuitry of the following amplifier. The gains that are available in APD make it extremely sensitive compared to PIN photodiode [7]. Due to this, investigating the impact of APD gain with different SAC-OCDMA receivers is important.

In this study, modified double-weight (MDW) codes are used as the signature codes for SAC-OCDMA systems [8]. Following the Introduction, the work is structured as follows. Section 2 provides a detailed explanation of the modified-AND subtraction detection technique. Next, in Section 3, we focus on performance analysis followed by the discussion of the results. Finally, Section 4 presents the conclusions based on the findings described in this paper.

2. MODIFIED-AND SUBTRACTION DETECTION

The SAC-OCDMA receiver diagram of this technique is shown in Figure 1 [5]. The received optical signal is split by splitter 1 into two parts: one to the upper decoding branches and the other to the AND decoder through an attenuator. The

attenuator ensures that the interference signal has an equivalent power incident on each photo-detector in the case of an inactive user. The decoder filters are placed in a parallel configuration. This structure divides the spectrum of the decoded signals. Note that both splitters (splitter 1 and splitter 2) and the attenuator could be replaced by a single coupler with an appropriate coupling ratio in order to achieve a more cost-effective receiver. The decoder has a spectral response matched to the active user, whereas the AND decoder has overlapped bins from different interferers. These overlapped bins can be represented mathematically by AND operation between the active user and interferers [9]. The photo-detector is composed of two photodiodes (PD and s-PD) which are connected electrically in opposition. The output signal is proportional to the power difference of the two optical inputs. In the presence of an interferer, the difference between the two signals is canceled. The output signal is then low-pass filtered to reduce the out-of-band high-frequency noise.
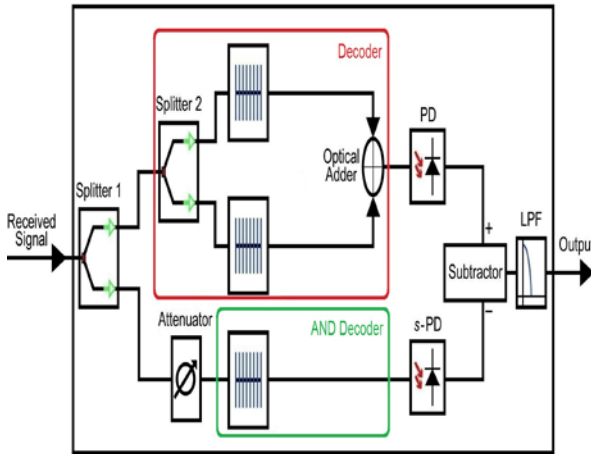

Figure 1 Modified-And Subtraction Detection.

3. PERFORMANCE ANALYSIS AND RESULTS

In this section, we present analytical expressions for the mean optical power and major noises in order to compute the BER performance of SAC-OCDMA system based on modified-AND detection with APDs. As mentioned earlier, MDW codes are utilized as the signature sequences for our SAC-OCDMA systems. MDW codes are characterized by unity cross-correlation, which is the ideal cross-

correlation value. For a weight of four ($w = 4$), the code length is [8]:

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

where L is the code length, and K is the number of users.

The mean optical power reaching PD and s-PD respectively when the desired user is active are given by:

$$\langle P_1 \rangle = \frac{SB_o}{L}\left[\frac{1}{2}N_I + 4\right] \tag{2}$$

$$\langle P_{1S} \rangle = \frac{SB_o}{2L}N_I \tag{3}$$

where S is the received power spectral density level at PD or s-PD, and N_I is the number of interferers which varies in the range $N_I = [0, K-1]$.

After detection, the desired user mean optical power can be written as:

$$\langle P_{User} \rangle = \langle P_1 \rangle - \langle P_{1S} \rangle = \frac{4SB_o}{L} \tag{4}$$

For APDs, Eq. (4) can be rewritten as follows:

$$\langle P_{User,APD} \rangle = \frac{4SGB_o}{L} \tag{5}$$

where G is the average internal gain of APDs.

The simplified expression of PIIN for unpolarized thermal light source can be expressed as follows:

$$\sigma^2_{PIIN,APD} = \frac{3S^2G^2B_oB_e}{4L}[K+7] \tag{6}$$

while the shot noise can be evaluated as:

$$\sigma^2_{sh,APD} = 2eB_e\left[\langle P_1 \rangle + \langle P_{1S} \rangle\right]G^{2+x}\Re_{APD} \tag{7}$$

where the parameter x equals to 0.7 for InGaAs APD [10].

The thermal noise is also given by:

$$\sigma^2_{th} = \frac{4k_BT_nB_e}{R_L} \tag{8}$$

and the signal-to-noise ratio is thus

$$SNR = \frac{\left(<P_{User,APD}>\right)^2}{\sigma^2_{PIIN,APD} + \sigma^2_{sh,APD} + \sigma^2_{th}} \tag{9}$$

Based on the approximation of Gaussian distribution, the BER is given by [5]:

$$BER = \frac{1}{2}erfc\left(\frac{\sqrt{SNR}}{2}\right) \qquad (10)$$

where *erfc* is the complementary error function. Table I illustrates the typical parameters used for our calculations.

Figure 2 shows the variation of the BER versus the number of active users for the modified-AND against the AND detection scheme using APD (with $G = 10$) and PIN photo-detectors. The BER of the SAC-OCDMA system increases when the number of active users increases, mainly due to PIIN. Nevertheless, the modified-AND detection is capable of achieving superior BER performance over the AND detection technique regardless of the type of photo-detector used. Moreover, remarkably, using the APD, the modified-AND is able to sustain better BERs than the PIN photodiode for a larger number of active users compared to the AND detection technique.

The relation between the BER and different values of APD gain G is shown in Figure 3 for $K = 10$. The results reveal that the BER performance decays at high gain values because high APD gains induce increment in PIIN and shot noises as shown in Eq. (6) and (7). It is evident that for the entire range of APD gain, the modified-AND detection demonstrates better BER than the AND detection technique.

We complete this study by simulating three channels of MDW code ($w = 4$) at a transmission rate R_B of 622 Mbps using OptiSystem software (Version 9.0) from *optiwave^{TM}*. Simulations were implemented using one LED sliced into 12 wavelengths. The attenuation and the dispersion coefficients of single mode fiber (SMF) at a wavelength of 1550 nm are 0.25 dB/km and 18 ps/km/nm respectively. APDs with gain of 10 were used. The dark current value was set at 5 nA, and the thermal noise coefficient was 1.8×10^{-23} W/Hz for each of the photodiodes at the detection part.

Figure 4 compares the variation of BER with respect to fiber length for the modified-AND against the AND detection schemes using the APD and the PIN photodiodes. The modified-AND detection shows significant performance enhancement over the AND detection scheme for both APD and PIN photodiodes. The use of the APD is shown to yield better BERs at all fiber lengths compared to the PIN photodiode for both detection schemes.

Table I Parameters Used For Calculations.

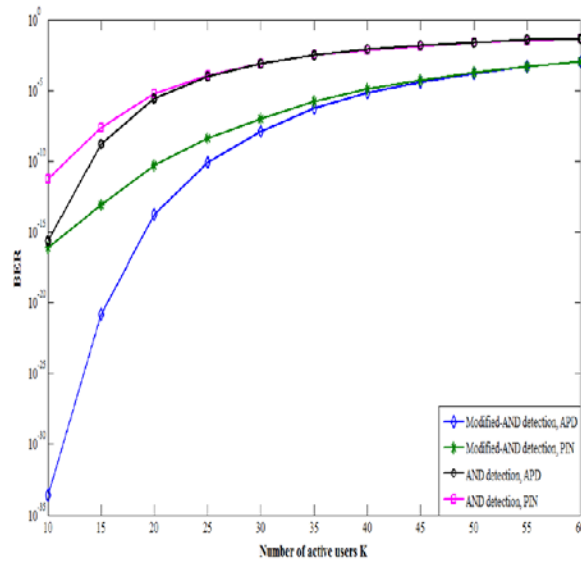|	
Optical bandwidth	$B_o = 3.75$ TH$_z$
Electrical bandwidth	$B_e = 311$ MH$_z$
Data transmission rate	$R_B = 622$ Mbps
Electron's charge	$e = 1.602 \times 10^{-19}$ C
Responsivity of the APDs	$\Re_{APD} = 0.75$
Boltzmann's constant	$k_B = 1.38066 \times 10^{-23}$ JK^{-1}
Receiver noise temperature	$T_n = 300$ K
Receiver load resistance	$R_L = 1030$ Ω

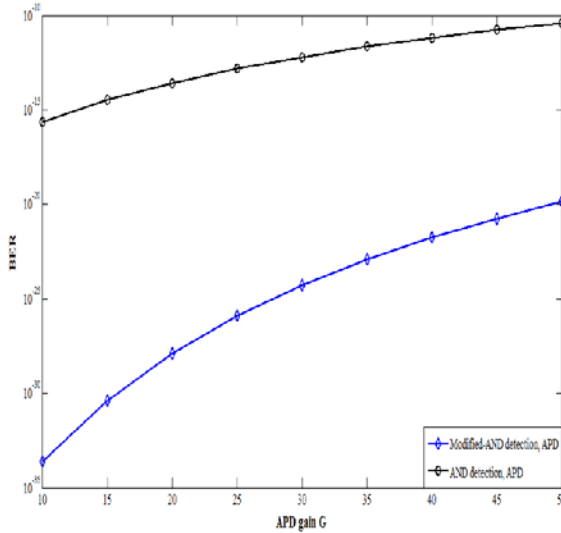*Figure 2 BER versus number of active users for different detection techniques using APD and PIN.*

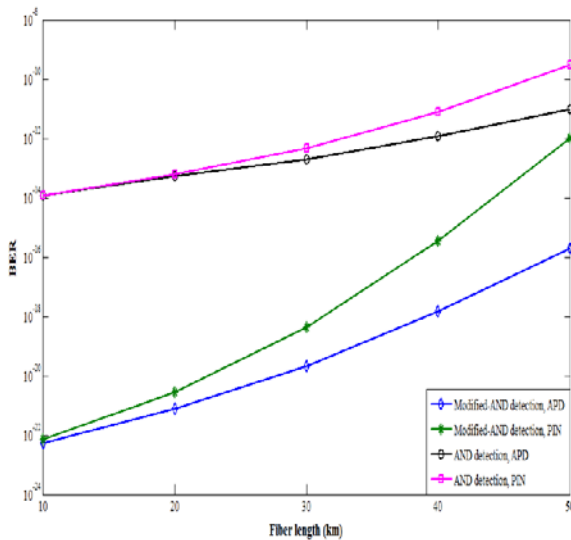*Figure 3 BER versus APD gain for different detection schemes.*

Figure 4 BER versus fiber length for different detection schemes using APD and PIN.

4. CONCLUSIONS

In this paper, the performance of SAC-OCDMA systems using modified-AND detection with APD and PIN photodiodes has been evaluated in comparison to the conventional AND detection scheme. Our results confirm that using APDs with low gain ($G = 10$) have improved the performance of SAC-OCDMA systems. Furthermore, the modified-AND detection is capable of realizing better BER performance than the AND detection

technique. Its usefulness is mainly because of its ability to mitigate both PIIN and MAI. This implies the feasibility of SAC-OCDMA system based on modified-AND detection technique as a candidate for future optical access networks.

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