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A COMPARATIVE ANALYSIS OF AN OCDMA SYSTEM BASED ON SINGLE-PHOTO-DIODE (SPD) AND SPECTRAL DIRECTION DETECTION (SDD) SCHEMES

[1]SARAH G. ABDULQADER, [2]HILAL A. FADHIL, S. A. ALJUNID
School of computer and engineering, university Malaysia perlis, perlis, 01000, MALAYSIA
E-mail: [1]eng.saragassan@gmail.com, [2]hilaladnan@unimap.edu.my

ABSTRACT

Abstract: In this paper, a comparative study to evaluate the performance of spectral-amplitude coding optical code-division multiple-access (SAC-OCDMA) systems based on single photo-diode (SPD) detection and spectral direct detection (SDD) schemes. In our work, we utilized Modified Double weight (MDW) code as one of the SAC codes for evaluated both detection techniques. The results characterizing the bit-error-rate (BER) of 10-12 with respect to the data rate show that the SDP offers a significant improved performance for long haul applications over SDD technique. Furthermore, the SPD detection has higher signal –to-noise ratio (SNR) than SDD technique utilizing different types of optical filters. Finally, for the same quality of service (QoS) for a bit error rate (BER) of 10-12 and data rate of 622 Mbps, SPD allows higher transmission distance of 30 km than SDD technique.

Keywords: *OCDMA, PIIN, MAI, SDD, SPD.*

1. INTRODUCTION

Optical Code division multiple access (OCDMA) is an access strategy in which data from multiple users are transmitted concurrently over the network and differentiated with signature code based on specific detection. However, OCDMA system offers many advantages such us asynchronous traffic, does not required network protocol and is well-suited for network applications involving bursty traffic as well as when high bandwidth with low bit-error rate (BER) is required [1-2]. In OCDMA system different approaches have been proposed for its implementation, one of these approaches is called Spectral amplitude coding (SAC). The SAC approach is simpler based on incoherent technique intensity modulation with direct detection, while coherent techniques are based on modulation and detection of optical phase [2-3]. Many codes have been proposed for SAC-OCDMA system [4-6]. However, among the popular one is Modified Double weight (MDW) code as this type of code possesses ideal cross-correlation properties with shorter code length compared with other SAC codes [7]. The main factor of performance degradation in SAC-OCDMA is the multiple access interference (MAI). In SAC-OCDMA system MAI is solely a function of the in-phase cross-correlation values among the address sequences. If the cross-correlation among the address sequences is high, then the phase intensity induced noise (PIIN) between codes sequences increased. However, to suppress the effects of PIIN, Single photo-diode (SPD) and spectral direction detection (SDD) technique have been proposed for SAC-OCDMA system [8-9]. In this paper, the performance analysis of this system is based on SPD and SDD detection schemes as both detectionsused only single photo-diode at the receiver side rather than other SAC detection schemes which composed of two photo-diodes connected electrically in opposition (such as balanced detection technique and AND detection technique [9-11]). Moreover, both SPD and SDD schemes offer cost-effective and less system complexity compared with other types of SAC detection techniques. In this paper, we use the MDW code to compare the performance of SPD and SDD detection schemes. The rest of the paper is organized as follows: In Section 2, we introduce system design based on Modified Double Weight (MDW) code. In Section 3, we presented SPD and SDD detection techniques. In section 4, simulation results are analyzed and investigated. Finally, the conclusion is given in Section IV.

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2. SYSTEM DESIGN

2.1 Sections and Subsections

The code structure is based on Modified Double –Weight (MDW) code families for SAC-OCDMA systems. The MDW codes have a large number of weight can be developed based on double weight (DW) code of weight two. The MDW code possesses ideal cross-correlation properties and exists for every natural number [7]. However, the MDW code weight can be any even number that is greater than 2. Moreover, the MDW codes can also be represented by using a (K×N) matrix as shown in Figure 1. The details of code structure and code parameters have been presented in [7].

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

Fig.1 The basic MDW code with code length (N=9), weight (W=4), and an ideal in-phase cross correlation

Figure 1 shows that we can increase the number of user from 1 to 3 while the weight is still fixed at 4. An MDW code with weight of 4 denoted by (N,4,1) for any given code length N, can be related to the number of user K through:

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

3. OCDMA DETECTION TECHNIQUE

In OCDMA systems, the detection schemes affect the design of transmitter and receivers. In this sub-section two basic detection techniques, namely single photodiode detection (SPD) and spectral direct detection (SDD) techniques are presented and analyzed. However, these types of detection are incoherent whereas the uniploar sequences in the signature code are called an incoherent system. A system that uses bipolar code words is called coherent system. Since coherent is phase sensitive, the use of such techniques will of course be more difficult than our proposed system.

3.1 Spectral Direct Detection (SDD) technique

The setup of the proposed system using SDD detection is shown in Figure 2. This figure illustrates the implementation of the MDW code using a spectral direct detection technique (SDD). Only one pair of decoder and photo-detector is required [9]. This is achievable for the simple reason that the information is assumed to be adequately recoverable from any of the chips that do not overlap with any other chips from other code sequences. Thus the decoder will only need to filter through the clean chips at the MDW codes; these chips are directly detected by a photodiode as in a normal intensity modulation/ direct detection scheme. This technique has successfully eliminated the MAI because the only wanted signal spectral chips at the data segment in the optical domain will be filtered. This is possible because the code properties possess one clean signal chip for each of the channels at the MDW code [7]. Subsequently, the PIIN is suppressed at the receiver, thus the system performance is improved. It is also important to note that the whole code spectrum still needs to be transmitted to maintain the addressing signature [12].

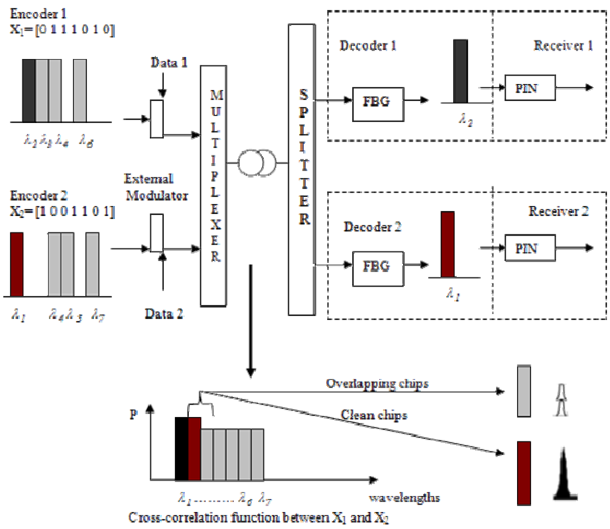

Fig.2 Proposed SDD Technique Based On MDW Code

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3.2 SPD detection technique

The proposed SAC-OCDMA receiver diagram of this technique is shown in Figure 3. The received optical signal is decoded by the decoder, which has an identical spectral response to the intended encoder for the data to be received. 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 output from the s-Decoder is either zero power unit for active user or cross-correlation power unit for interferers. The proposed technique can be performed using inexpensive optical Gaussian filter to decode the received signal. Moreover, other types of filters such us Fiber Bragg Grating (FBG) and thin film filters are also used as the main part in the corresponding SPD implementations. After optical subtraction, the output is either code weight power unit for active user or zero power units for interferers. This implies that the interference signals are suppressed in the optical domain before the conversion of the signals to the electrical domain, as a result, the proposed SPD scheme alleviates both PIIN and MAI in the optical domain [11]. Moreover, the two interference signals at the optical subtractor are assumed to be equal and cancel each other out. However, practically, the interference signals differ slightly at the optical subtractor and results in a small amount of optical power to reach the photodiode. The main advantage of using the SPD is that the cancellation of the interference signals in the optical domain allows the use of only a single photodiode rather than two photodiodes as in typical subtraction detection schemes [10]. This reduces the amount of optical-to-electrical conversion and shot noise generated at the receiver part. The proposed detection technique can also be implemented with any fixed in-phase cross-correlation SAC codes with differ spectral chips distribution of the s-Decoder, depending on the structure of the SAC codes itself. Finally, after the desired signal is detected by a photodiode, the data-carrying electrical signal is low pass-filtered by a Bessel-Thompson filter [2].

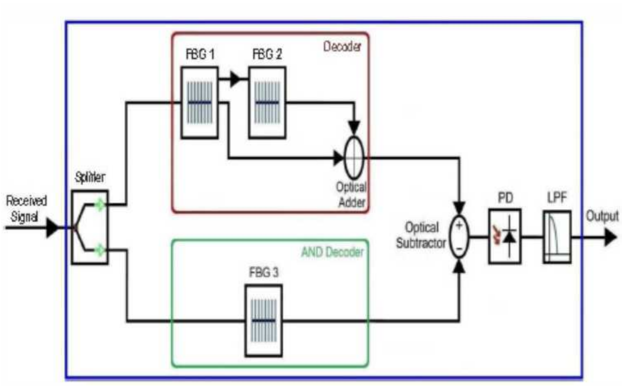

Fig. 3 Proposed SPD Detection Based On MWD Code

The signal-to-noise (SNR) for an electrical signal is defined as the average signal to noise power SNR=[I2/it2] , where it2 is the variance of noise source (note: the effect of the receiver's dark current and nonlinear noises are neglected in the analysis of the proposed system), given by

$$\sigma^2 = \langle i_{shot}^2 \rangle + \langle i_{PIIN}^2 \rangle + \langle i_{thermal}^2 \rangle \qquad (2)$$

Eq. (2) can be expressed as

$$\sigma^2 = 2eBI + I^2 B \tau_c + \frac{4K_b T_n B}{R_L}, \qquad (3)$$

where the symbols used in Eq. (3) bear the following meaning.

- e Electron charge;
- I Average photocurrent;
- I2 The power spectral density for I;
- B Electrical bandwidth;
- K_b Boltzmann Constant;
- T_n Absolute receiver noise temperature;
- R_L Receiver load resistor.
- t_c the coherence time of the source

The formula used to calculate the bit-error-rate (BER) with Gaussian approximation can be expressed as [5,11]

$$BER = P_e = \frac{1}{2} erfc\left(\sqrt{\frac{SNR}{8}}\right), \qquad (4)$$

Where erfc is the complementary error function

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4. SIMULATION RESULTS

Figure 4 & Fig.5 show the average BER for three users against the fiber length at data rates of 622 Mbps and 155 Mbps. It can be seen that the average BER value increases with the increasing of the transmission length. Further, for a fiber length of 70 km the BER are 1×10-23 and 1×10-13 for the SPD and SDD detection techniques, respectively. Moreover, the SDD detection technique allows short transmission in the fiber length as compared with SPD detection technique. However, the SDD technique has a lower BER performance than SPD detection due to the fact the decoder will only need to filter through the clean chips at the MDW codes. Moreover, for the SPD detection technique all chips are detected at the receiver side. Table I shows the system parameters used in the simulation model (Optisystem™), these parameters based on the previously published papers at [3,7,11].

Table 1. System Parameters Used In The Simulation.

wavelength	1550 nm
thermal noise	1.8×10^{-23} w/hz
dark current	5 nA
responsively	1 A/W
optical bandwidth	b_o=3.75 THz
attenuation	0.25 dB/km
no. of user	3
code weight	4
spd filter	FBG, thin film, and Gaussian

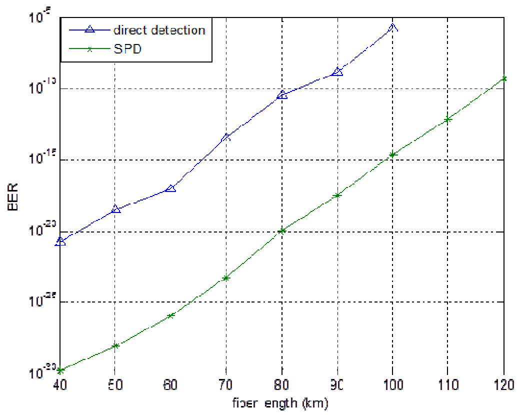


Fig. 4 Bit Error Rates Of SAC-OCDMA Systems Versus Fiber Length At 622 Mbps

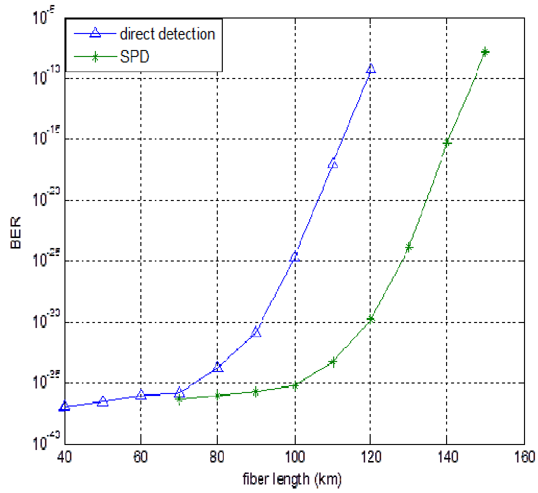
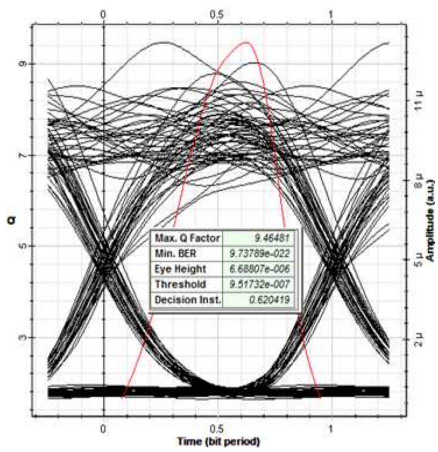


Fig. 5 Bit Error Rates Of SAC-OCDMA Systems Versus Fiber Length At 155 Mbps

Figure 4 shows average BER for three users against the data rate at transmission distance of 70 km. It can be seen that the average BER value increases with the increasing of data rate for both detection techniques. Moreover, for a given data rate at transmission distance of 70km the proposed system using SPD offers better performance in terms of BER than SDD technique. This result indicates that there is a significant improvement in performance or, for a fixed BER, could accommodate a higher data rate for greater capacity. Figure 6 show the eyes diagram for the spectral direct detection technique and SPD, it's clearly shows that the system performance using SPD detection is better than SDD technique.



(a)

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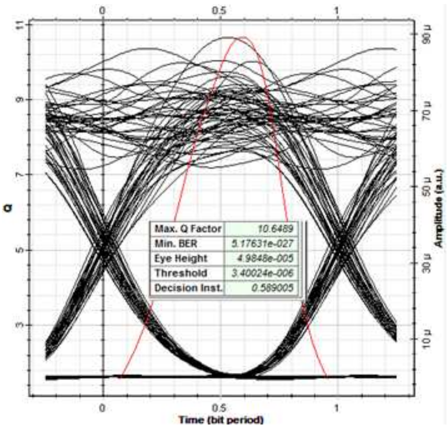

(b)

Fig.6 Eyes Diagram, A) Direct Detection; B) SPD Detection

5. CONCLUSIONS

In this paper, a comparison among two types of detection techniques for spectral amplitude coding OCDMA system have been presented and analyzed. The SPD detection and spectral direct detection (SDD) is performed with single photodiode at the detection segment. It is shown that in order to achieve minimum BER of 10-9; both detection schemes are capable of supporting 155Mbps, 622Mbps, at different BER requirements. The ability of the SPD detection to support services in multimedia applications has been presented, where three active users can be obtained with a proper choice of supportable code weight. The SPD detection always has smaller BER than spectral direct detection even when the transmission distance is long. The PIIN is also an important system limitation which must be reduced. Thus, in an access optical network when the SPD detection is used, PIIN is suppressed significantly and the overall network performance can be improved compared with SDD technique. This proposed technique can be an excellent candidate for use in next generation OCDMA networks applications.

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