

# **AND-subtraction detection modified SNR equation for optical CDMA systems in PON applications**

IHSSAN SH. HMUD<sup>1\*</sup>, FERAS N. HASOON<sup>2</sup>, FUAD A. HATIM<sup>1</sup>,  
ALI Z. GHAZI ZAHID<sup>1</sup>, SAHBUDIN SHAARI<sup>1</sup>

<sup>1</sup>Photonics Technology Laboratory, Institute of Microengineering and Nanoelectronics (IMEN),  
Universiti Kebangsaan Malaysia 43600 UKM, Bangi, Selangor, Malaysia

<sup>2</sup>Faculty of Computing and Information Technology, Sohar University,  
Sohar, P.O.Box: 77, PC: 311, Sultanate of Oman

\*Corresponding author: Ihsan\_Hmud@yahoo.com

In this paper, AND-subtraction detection scheme compatible with OCDMA system and EDW code was simulated. The aim of the simulation is to adjust the AND-subtraction detection SNR equation for better accuracy in passive optical network (PON) applications. The simulation is performed by (optisys 06) software. The software considered the entire possible practical effects during implementation, such as dispersion, nonlinear effect of the fiber and attenuation of the fiber. The simulation results compared to the analytical results were based on SNR and BER mathematical equations. The comparison shows that the analytical equation should be modified so that the received power ( $P_{sr}$ ) be more accurate for PON applications.

Keywords: optical code-division multiple access (OCDMA), EDW code, AND-subtraction detection scheme, passive optical networks (PON).

## **1. Introduction**

Motivated by the successful capacity improvement of code division multiple access (CDMA) techniques in wireless communications, many researchers have become interested in the development of optical CDMA systems [1]. The optical code-division multiple access (OCDMA) is a method of sharing the bandwidth of optical fiber among a number of active users in a broadcast local area network [2, 3] where the multiplexing of signals from different users occurs in the optical side as well as de-multiplexing. Using single-mode optical fibers as media has many advantages as it can provide usable transmission bandwidth of 25 THz in the 1.55- $\mu$ m wavelength window. This can support ultrahigh-speed data transmission and networking applications [4], with signals travel at the light speed.

An additional advantage of using fibers is the security because the signal travels through the fiber where no interception or jamming occur. The foundation of OCDMA, as we know it today, started with two technical papers – the one by Prucnal and Santoro (1986) and the other by Weiner, Heritage and Salehi (1988) [5]. After these papers, many studies were conducted to develop the OCDMA technique to be suitable for practical applications, like proposed new codes or detection techniques. Many codes have been proposed for OCDMA, such as optical orthogonal codes (OOC), modified double weight (MDW) and modified frequency-hopping (MFH) codes. However, these codes suffer from various limitations one way or another. The codes' constructions are either complicated (*e.g.*, OOC and MFH codes), the cross-correlations are not ideal or the codes are too long (*e.g.*, OOC) [6]. In this paper, we focused on the EDW code with AND subtraction detection technique. EDW code is an enhanced version of DW code [7]. The EDW code weight can be any odd number that is greater than one. The EDW code can be represented by  $K \times N$  matrix. In EDW codes structures, the matrix  $K$  rows and  $N$  columns represent the number of users and the minimum code length, respectively. The resulting matrix will consist of a chip-combination sequence of 1, 2, 1, 2... (alternating 1 and 2) for the columns (counting from leftmost). A chip-combination is defined as the summation of the spectral chips (1's and 0's) for all users (or rows) in the same column. The EDW code with the weight equal to three can be represented by the following matrix:

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

An EDW code with a weight code equal to three for any given code length  $N$ , can be related to the number of users  $K$  [7]:

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

## 2. AND-subtraction scheme for EDW code

AND-subtraction detection technique under EDW code design is shown in Fig. 1 for a weight code equal to three and users' code sequences: user 1 code sequence =  $0 \ 0 \ \lambda_3 \ \lambda_4 \ 0 \ \lambda_6$ ; user 2 code sequence =  $0 \ \lambda_2 \ 0 \ 0 \ \lambda_5 \ \lambda_6$ , user 3 code sequence =  $\lambda_1 \ \lambda_2 \ 0 \ \lambda_4 \ 0 \ 0$ .

The spectral amplitude signal at the receiver side splits into two branches. The upper branch has the signal for user  $X$ , including the overlapped chips between  $X$  and  $Y$  and

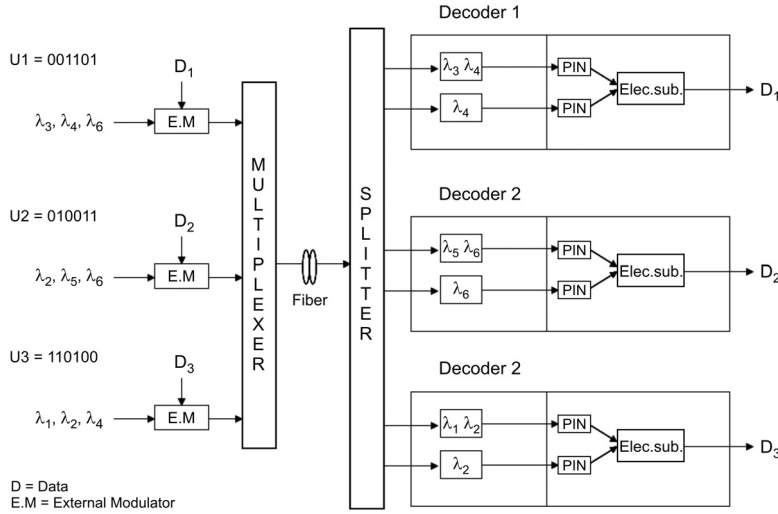


Fig. 1. OCDMA system using AND-subtraction detection technique under EDW code.

the lower branch has the overlapped chips only. These overlapped chips can be represented mathematically by AND operation between  $X$  and  $Y$ .

### 3. Systems setup

#### 3.1. Analytical setup

The design in Fig. 1 was analyzed by [8] with derivation for SNR and bit error rate (BER) equations:

$$\text{SNR} = \frac{\mathfrak{R}^2 P_{\text{sr}}^2 (W-1)^2}{N^2} \frac{P_{\text{sr}} e B \mathfrak{R}}{N} \left[ (2K_B - 4) + W \right] + \frac{P_{\text{sr}}^2 B \mathfrak{R}^2 K W}{2\Delta V N^2} \left[ \frac{2K_B - 4}{W} + W \right] + \frac{4K_b T_n B}{R_L} \quad (3)$$

Using Gaussian approximation, BER can be expressed as [7, 9]:

$$\text{BER} = P_e = \frac{1}{2} \operatorname{erfc} \left[ \sqrt{\frac{\text{SNR}}{8}} \right] \quad (4)$$

Equations (3) and (4) were derived, basing on two assumptions: *i*) each user has equal and fix power at the receiver, equal to  $P_{\text{sr}}$ ; *ii*) the two photodetectors in the reciever side for each user are identical.

T a b l e. Analytical setup.

| Parameters                       | Symbols        | Value                   |
|----------------------------------|----------------|-------------------------|
| Number of users                  | $K$            | Variable                |
| Code length                      | $N$            | Variable                |
| Weight                           | $W$            | 3                       |
| Responsivity                     | $\mathfrak{R}$ | 0.749                   |
| Received power per user          | $P_{sr}$       | $4.41 \times 10^{-5}$   |
| Electrical band width            | $B$            | 311 MHz                 |
| Core matrix number               | $K_B$          | 3                       |
| Boltzmann constant               | $K_b$          | $1.7 \times 10^{-32}$   |
| Absolute temperature             | $T_n$          | 300 K                   |
| Line-width of the thermal source | $\Delta T$     | $3.75 \times 10^{12}$   |
| Thermal load resistance          | $R_L$          | 1030 $\Omega$           |
| Electron charge                  | $e$            | $1.6 \times 10^{-19} q$ |

These assumptions were made to simplify the mathematic derivation which is hard to achieve without it. In this paper, we investigated the system performance analytically through Eqs. (3) and (4), with the parameters setup as in the Table.

### 3.2. Simulation setup

The system design in Fig. 1 was simulated by Optisys 06 software produced by Optiwave Company, with due consideration for all the practical effects in the fiber, like nonlinearities, attenuation and dispersion. The system was simulated for P2P connection passive optical network and for the fiber to the home (FTTH) topology. CW laser diodes for code construction with 0 dBm power were used in the transmitter side. Data modulation was performed by a Mach–Zehnder external modulator at a bit rate of 622 Mb/s. The transmission channel was NDSF, 10 km long. The decoders in the receiver side were constructed using optical filters.

## 4. System performance and comparison

Under both setups presented above, a comparison in respect to the number of users was performed between the analytical BER equation and the simulated BER at the same bit rate (622 Mb/s), as shown in Fig. 2.

Figure 2 shows two curves: simulation and analytical ones, acting in the same way but with big BER difference between them, for the same number of users. The reasons for this difference are related to the two assumptions the analytical equation is based on. The simulation work showed that the  $P_{sr}$  was not fixed, but was a function of the number of users, where the increase in the number of users resulted in the decrease in the  $P_{sr}$ , as shown in Fig. 3.

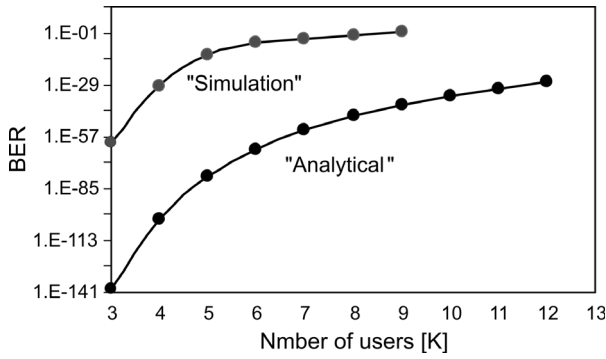


Fig. 2. The number of users via BER.

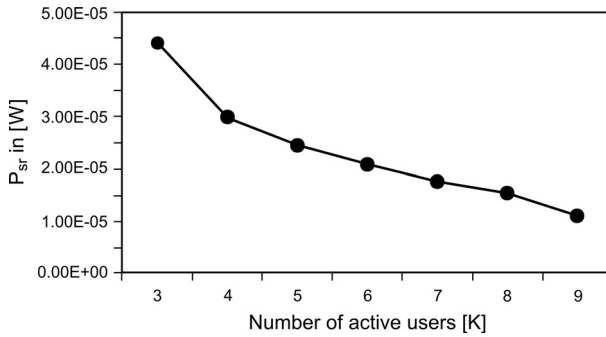


Fig. 3.  $P_{sr}$  via the number of users.

From Figure 3 we can mathematically describe the relation between  $P_{sr}$  and the number of users:

$$P_{sr} = 10^{-(0.144K + 3.997)} \tag{5}$$

where  $K$  is the number of users. Now, by substituting Eq. (5) in Eq. (3)

$$\text{SNR} = \frac{\mathfrak{N}^2 10^{-2(0.144K + 3.997)} (W - 1)^2}{N^2 A} \tag{6}$$

while

$$A = \frac{10^{-(0.144K + 3.997)} eB\mathfrak{N}}{N} \left[ (2K_B - 4) + W \right] + \frac{10^{-2(0.144K + 3.997)} B\mathfrak{N}^2 KW}{2\Delta V N^2} \left[ \frac{2K_B - 4}{W} + W \right] + \frac{4K_b T_n B}{R_L}$$

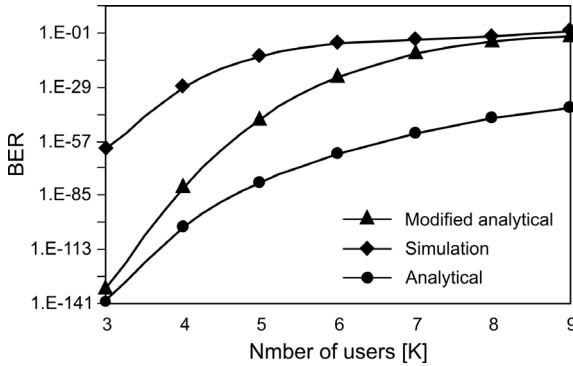


Fig. 4. The number of users via BER.

By applying the analytical setup in Section 3.1 on Eq. (6), the BER will be as in Fig. 4.

Figure 4 shows that the BER difference between the BER analytical equation and simulation. BER was reduced by using the modified equation. When the number of users is less than 5, the difference in BER between the modified and the simulation is still big; which is because of the error resulting from the electrical subtraction operation. However, when the number of users is higher than 7, the two curves start to match each other.

## 5. Conclusions

The system performance comparison between analytical and simulation results shows that the analytical equation should be modified to be more accurate for PON applications. When the number of users is low, the difference in BER is big between the modified equation and the simulation, because the errors resulting from  $P_{sr}$  degradation are small in comparison with the errors resulting from electrical subtraction.

*Acknowledgements* – This work was supported by the Institute of Microengineering and Nanoelectronics (IMEN)/Photonic Laboratory/(UKM).

## References

- [1] HASOON F.N., ABDULLAH M.K., ALJUNID S.A., SHAARI S., *Performance of OCDMA systems using a complementary subtraction technique*, Journal of Optical Networking **6**(7), 2007, pp. 854–859.
- [2] STOK A., SARGENT E.H., *System performance comparison of optical CDMA and WDMA in a broadcast local area network*, IEEE Communications Letters **6**(9), 2002, pp. 409–411.
- [3] STOK A., SARGENT E.H., *Lighting the local area: optical code-division multiple access and quality of service provisioning*, IEEE Network **14**(6), 2000, pp. 42–46.
- [4] JIAN-GUO ZHANG, LIAN-KUAN CHEN, KWONG, W.C., KWOK-WAI CHEUNG, SHARMA A.B., *Experiments on high-speed all-optical code-division multiplexing systems using all-serial encoders and decoders for 2<sup>n</sup> prime code*, IEEE Journal Of Selected Topics in Quantum Electronics **5**(2), 1999, pp. 368–375.
- [5] PRUCNAL P.R., *Optical Code Division Multiple Access Fundamentals and Applications*, CRC Press, Taylor and Francis Group, Edition 1, 2006.

- [6] ANUAR M.S., ALJUNID S.A., SAAD N.M., MOHAMMED A., BABEKIR E.I., *Development of a zero cross-correlation code for spectral-amplitude coding optical code division multiple access (OCDMA)*, International Journal of Computer Science and Network Security **6**(12), 2006, pp. 180–184.
- [7] HASOON F.N., ABDULLAH M.K., ALJUNDI S.A., SHAARI S., *Construction of a new code for spectral amplitude coding in optical code-division multiple-access systems*, Optical Engineering **46**(7), 2007, p. 075004.
- [8] IHSSAN SH. HMUD, FERAS N. HASOON, ALJUNID S.A., SAHBUDIN SHAARI, *Performance of OCDMA system using AND subtraction technique based on EDW code*, Journal of Optical Communications **29**(3), 2008, pp. 178–181.
- [9] ZACCARIN D., KAVEHRAD M., *New architecture for incoherent optical CDMA to achieve bipolar capacity*, Electronics Letters **30**(3), 1994, pp. 258–259.

*Received March 12, 2009*