Performance of OCDMA systems with new spectral direct detection (SDD) technique using enhanced double weight (EDW) code

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ABSTRACT

This paper investigates the performance of enhanced double weight (EDW) code for spectral-amplitude-coding OCDMA (SAC-OCDMA) system using a newly proposed spectral direct detection (SDD) technique. EDW is the enhanced version of double weight (DW) code that possesses ideal cross-correlation properties and weight which can be any odd number greater than one. The theoretical and simulation results show that the proposed new spectral direct detection technique improves the performance compared to the conventional complementary subtraction technique.

1. Introduction

In optical CDMA systems, the detection process affects the design of transmitters and receivers. In general, there are two basic detection techniques namely coherent and incoherent detections. While coherent detection refers to the detection of signals with knowledge of the phase information of the carriers, incoherent detection refers to the case without such knowledge. Alternatively a system consisting of unipolar sequences in the signature code is called incoherent system, while a system that uses bipolar codewords is called a coherent system. Because incoherent detection does not need phase synchronization, hardware complexity of the system is reduced. This is the main reason why we have chosen incoherent detection in this research.

In an incoherent CDMA system, each user is assigned a distinct codeword as its address signature based on the spectral amplitude only. When a user wants to transmit data bit one, it sends out a codeword corresponding to the address signature of the intended receiver. At the receiver, all the codewords from different users are correlated. If a correct codewords arrives, an autocorrelation function with a high peak results. For incorrect codewords, cross-correlation functions are generated and they create Multiple Access Interference (MAI). MAI can be reduced by using subtraction technique. The most common subtraction technique is the Complementary subtraction technique, which is also known as balanced detection technique [1,2].

In most researches [2–5], complementary method has been used at the receiver side to recover the original signal. In this paper, we will compare the complementary technique with a new detection technique known as spectral direct detection (SDD). It will be shown in this paper that SDD reduces the receiver complexity and provides a better performance than the complementary subtraction technique. Enhanced double weight (EDW) code [8] was used in the study, although it can also be applied to other codes.

2. Spectral direct detection technique

Fig. 1 illustrates the implementation of SDD whereby only one pair of decoder and detector is required as opposed to two pairs in the complementary subtraction techniques. There is also no subtraction process involved. 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 (non-overlapping chips) to be directly detected by the photodiode as in normal intensity nodulation/direct detection scheme.

This technique has successfully eliminated the MAI because only the wanted signal spectral chips in the optical domain will be filtered. It is possible because, the code properties posses one clean signal chip for each of the channels. Subsequently, the

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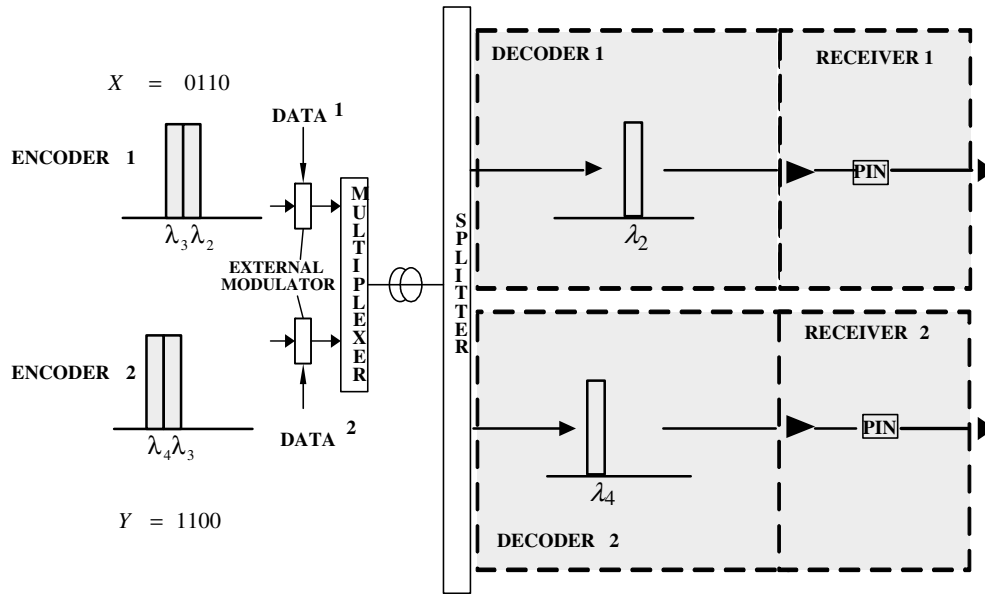E-mail address: feras@vlsi.eng.ukm.my (F.N. Hasoon).

Fig. 1. Implementation of spectral direct detection technique.

phase-induced intensity noise (PIIN) is suppressed at the receiver, thus the system performance is improved. Codes which posses non-overlapping spectra such as MQC [6], MDW [7], and EDW [8] can generally be supported by this detection scheme. It is also important to note that the whole code's spectra still need to be transmitted to maintain the addressing signature. This distinguishes the technique from wavelength division multiplexing (WDM) technologies.

3. System performance analysis

The setup of the proposed EDW [8] system using spectral direct detection technique with two users is shown in Fig. 2.

As mentioned earlier, the main difference of SDD technique compared with the complementary subtraction is at the decoder. With SDD technique, no subtractors are needed at the receivers, thus the number of filters is significantly reduced. This technique will improve the system performance such as in the signal to noise ratio and bit error rate.

Now let $C_K(i)$ denotes the ith element of the Kth EDW code sequence. The code properties for the SDD technique can therefore be written as:

$$\sum_{i=1}^{N} C_K(i)C_l(i) = \begin{cases} W, & \text{for } K = 1 \\ 1, & \text{for } K\text{div}3 = l\text{div}3 \\ 0, & \text{for } k\text{div}3 \neq l\text{div}3 \end{cases} \quad (1)$$

The integration of the power spectral density (PSD) gives,

$$\int_0^\infty G_d(V)\mathrm{d}v = \int_0^\infty \left[\frac{P_{sr}}{\Delta V} \sum_{k=1}^{k} d_k \sum_{i=1}^{N} C_k(i)C_l \left\{ u\left[\frac{\Delta V}{N} \right] \right\} \right] \mathrm{d}V \quad (2)$$

$$\int_0^\infty G_d(V)\mathrm{d}V = \frac{P_{sr}W}{N} + \frac{P_{sr}}{N} \sum_{k=1 k\neq l}^{k} d_k \quad (3)$$

$$\int_0^\infty G_d^2(V)\mathrm{d}V = \frac{P_{sr}^2}{N\Delta V} \sum_{i=1}^{N} \left\{ C_l(i) \cdot \left[\sum_{k=1}^{k} d_k C_k(i) \right] \cdot \left[\sum_{m=1}^{k} d_m C_m(i) \right] \right\} \quad (4)$$

In the above equations, d_K is the data bit of the Kth user that carries the value of either "1" or "0". Consequently, the photocurrent I can be expressed as:
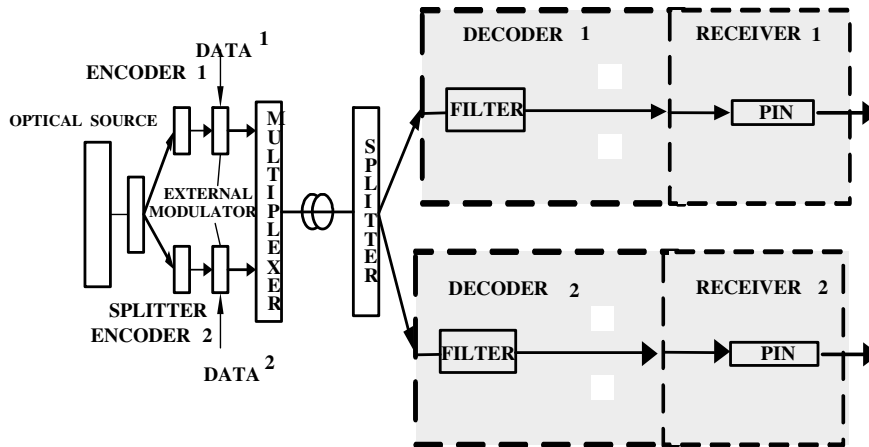

Fig. 2. OCDMA system architecture using spectral direct detection technique for two users.

$$I = I_{\mathrm{d}} = \Re \int_0^\infty G_{\mathrm{d}}(V)\mathrm{d}v \tag{5}$$

$$I = \Re \frac{P_{\mathrm{sr}}}{N}\left[W + \sum_{k=1 k \neq l}^{k} d_k\right] \tag{6}$$

$$I = \Re \frac{P_{\mathrm{sr}}W}{N} \tag{7}$$

where $\Re$ is the responsivity of the photodetectors given by

$$\Re = \frac{\eta e}{hV_{\mathrm{c}}} \tag{8}$$

Here, η is the quantum efficiency, e is the electron's charge, h is the Planck's constant, and V_{c} is the central frequency of the original broad-band optical pulse. The power of noise sources that exist in the photocurrent can be written as

$$\langle I^2 \rangle = \langle I_1^2 \rangle + \langle I_{\mathrm{th}}^2 \rangle \tag{9}$$

where I^2 is the total noise power; I_1^2 is the shot noise; I_{th}^2 is the thermal noise.

$$\langle I^2 \rangle = 2eB(I_{\mathrm{d}}) + \frac{4K_{\mathrm{b}}T_{\mathrm{n}}B}{R_{\mathrm{L}}} \tag{10}$$

Therefore,

$$\langle I^2 \rangle = 2eB\Re\left[\int_0^\infty G_{\mathrm{d}}(v)\mathrm{d}v\right] + \frac{4K_{\mathrm{b}}T_{\mathrm{n}}B}{R_{\mathrm{L}}} \tag{11}$$

Noting that the probability of sending bit '1' at any time for each user is $\frac{1}{2}$ [6], then Eq. (11) becomes:

$$\langle I^2 \rangle = \frac{P_{\mathrm{sr}}eB\Re}{N}[(K_{\mathrm{B}} - 2) + W] + \frac{4K_{\mathrm{b}}T_{\mathrm{n}}B}{R_{\mathrm{L}}} \tag{12}$$

From (7) and (12), we can get the average SNR as in (13) and (14)

$$\mathrm{SNR} = \frac{(I_2 - I_1)^2}{\langle I^2 \rangle} \tag{13}$$

$$\mathrm{SNR} = \frac{\frac{\Re^2 P_{\mathrm{sr}}^2 W^2}{N^2}}{\frac{P_{\mathrm{sr}}eB\Re}{N}[(K_{\mathrm{B}} - 2) + W] + \frac{4K_{\mathrm{b}}T_{\mathrm{n}}B}{R_{\mathrm{L}}}} \tag{14}$$

Eq. (14) is the general equation used to calculate the signal to noise ratio for the EDW code families. Using Gaussian approximation, the Bit Error Rate (BER) can be expressed as [2,6,9–10]:

$$\mathrm{BER} = P_{\mathrm{e}} = \frac{1}{2}\mathrm{erfc}\left(\sqrt{\frac{\mathrm{SNR}}{8}}\right) \tag{15}$$
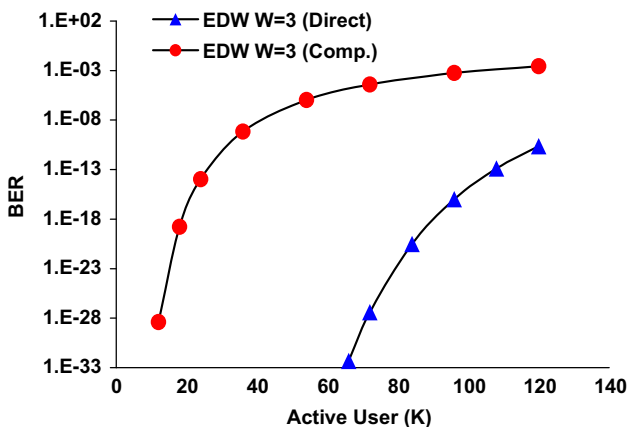
Table 1
System parameter

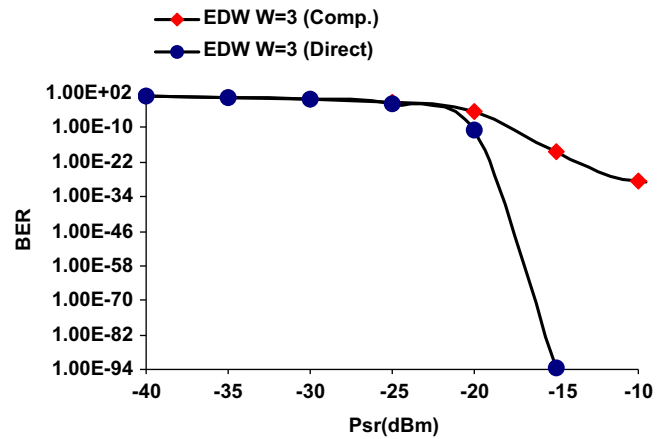|	
PD quantum efficiency	$\eta = 0.6$
Line-width of the thermal source	$\Delta v = 3.75$ THz
Operation wavelength	$\lambda_{\mathrm{o}} = 1.55$ μm
Electrical bandwidth	$B = 80$ MHz
Data bit rate	$R_{\mathrm{b}} = 155$ Mbps
Receiver noise temperature	$T_{\mathrm{r}} = 300$ K
Receiver load resistor	$R_{\mathrm{L}} = 1030\ \Omega$

Fig. 4. BER versus P_{sr} when number of simultaneous users is 1.2.

Fig. 3 shows the bit error rate (BER) versus number of users for SDD and complementary subtraction techniques [8]. The system parameters used to obtain the numerical results are listed in Table 1.

In Fig. 3, it is shown that, the OCDMA system using SDD technique performs better than the system using existing complementary technique. The figure clearly shows that SDD technique supports more users (110 users at BER of 10^{-13}) compared with complementary technique (25 users at BER of 10^{-13}). This is because; with direct technique there is no multiple access interference (MAI) in the receiver side.

Fig. 4 shows the performance of the system using SDD and Complementary techniques at various values of received power P_{sr}. The number of active users in the system is fixed at 12.

It is shown that SDD technique gives a much better performance when the effective received power P_{sr} is large (when $P_{\mathrm{sr}} > -25$ dBm). At the lower values of P_{sr} (when $P_{\mathrm{sr}} < -25$ dBm), the performance of the system for both techniques is nearly the same. It should be noted that although the BER can go down to the values which are practically meaningless (such as 10^{-94}), it does not contradict the objective of this study in comparing the performance of the two detection schemes.

In this analysis, we do not consider any fiber optic non-linear effect such as Four Wave Mixing (FWM), Self Phase Modulation (SPM) and Cross Phase Modulation (XPM) and also the dispersions such as Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD). This however will not affect the comparative analysis between the two techniques as both of them are subjected to the same transmission conditions. However, the results presented in Section 4 below do consider all the factors.

4. Simulation result

A simple schematic block diagram consisting of 2 users is illustrated in Figs. 5 and 6 as an illustrative example (the study was carried out from 4 to 12 users). Each chip has a spectral width of
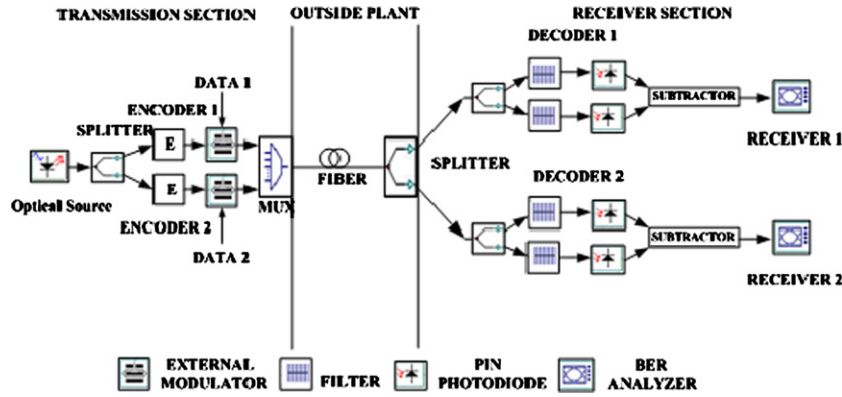

Fig. 3. BER versus number of simultaneous user when $p_{\mathrm{sr}} = -10$ dBm.

Fig. 5. Simulation setup for the OCDMA system with complementary technique.
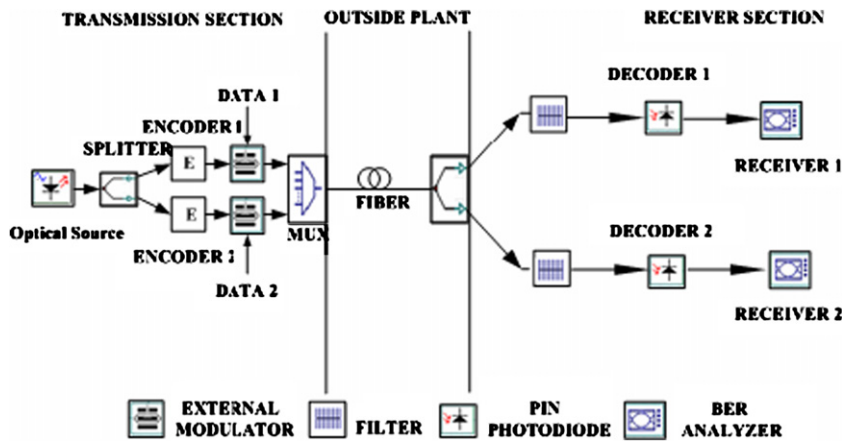

Fig. 6. Simulation setup for the OCDMA system with direct technique.

0.8 nm. The tests were carried out using OptiSystem version 6.0 from Optiwave, an established commercial software at the rates of 622 Mbps, and 1.25 Gbps for 10 km. The fiber used had the values of parameters taken from the data which are based on the G.652 Non Dispersion Shifted Fiber (NDSF) standard. This included the attenuation, group delay, group velocity dispersion, dispersion slope and effective index of refraction, which were all wavelength dependent. The non-linear effects such as the Four Wave Mixing and Self Phase Modulation (SPM) were also activated. At 1550 nm wavelength, the attenuation co-efficient was 0.25 dB/km, and the chromatic dispersion co-efficient was 18 ps/nm-km and the polarization mode dispersion (PMD) co-efficient was 5 ps/$\sqrt{}$km. The transmit power used was 0 dBm out of the broadband source. The noises generated at the receivers were set to be random and totally uncorrelated. The dark current value was 5 nA and the thermal noise co-efficient was 1.8×10^{-23} W/Hz for each of the photodetectors. The performance of the system was evaluated by referring to the bit error rate.

Fig. 7 shows the BER increases as the number of user becomes bigger for the different techniques. The number of users is varied from 4 to 12 at 622 Mbps and 1.25 Gbps bit rates. The effect of varying the number of user is related to the power level of the received power. A larger number of users have higher insertion loss, thus smaller output power. In this particular system, direct technique can support higher number users than the conventional technique because of the number of filters at the receiver is reduced, thus a smaller power loss. Note that the very low BER values are just a measure of the quality of the received signals as calculated by the simulator, although they may not be very meaningful, practically speaking.
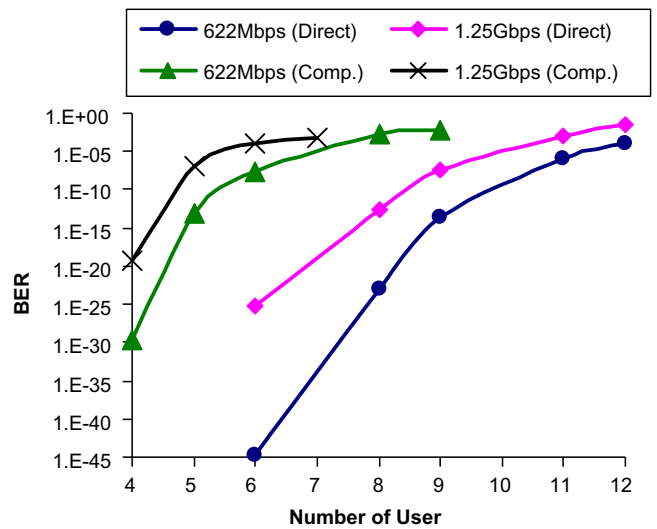

Fig. 7. BER versus number of user for OCDMA system using direct and complementary technique at different transmission rates at 10 km.

5. Conclusion

In this paper, a new detection technique known as Spectral Direct Detection (SDD) has been proposed for SAC-OCDMA systems. The performance was evaluated based on EDW code. The theoretical and simulation results have proved that the new detection technique provides a better performance than the conventional

complementary subtraction technique. This is achieved by virtue of the elimination of MAI and PIIN by selecting only the non-overlapped spectra of the intended code sequence. The overall system cost and complexity of the system can be reduced because of the less number of filters used in the detection process.

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