Comparative Performance of Hybrid SCM SAC-OCDMA System Using Complementary and AND Subtraction Detection Techniques

Ratna Sahbudin[1], Syed Aljunid[1], Mohd Abdullah[1], Mohd bin Abdul Samad[1], Mohd Mahdi[1], and Mahamod Ismail[2]
[1]Department of Computer and Communication System Engineering, Faculty of Engineering, Universiti Putra Malaysia, Malaysia.
[2]Department of Electrical, Electronics and Systems, Faculty of Engineering, Universiti Kebangsaan Malaysia, Malaysia.

Abstract: *This paper presents the comparative performance of two detection schemes based on subtraction detection technique for a hybrid scheme of subcarrier multiplexed spectral-amplitude-coding optical code division multiple access (SCM SAC-OCDMA) system. SAC-OCDMA systems are receiving more attention because of their ability to completely eliminate multi access interference by using code sequences with fixed in-phase cross correlation. On the other hand, the SCM scheme is capable of improving the channel data rate of OCDMA systems. This hybrid scheme is proposed for the benefit of combining the advantages of both schemes. Consequently, the hybrid system is robust against interference and is much more spectrally efficient. Double weight code family is a new code structure used for SAC-OCDMA system. The experimental simulation results show that the proposed new AND subtraction detection technique improve the system performance significantly.*

Keywords: *Hybrid SCM SAC-OCDMA, subtraction detection technique, multi access interference, optical communication system.*

Received April 26, 2006; accepted July 31, 2006

1. Introduction

Optical Code Division Multiple Access (CDMA) systems have received more attention because CDMA allows many users to simultaneously access the channel with a high level of transmission security [1]. However, Multi Access Interference (MAI) is the main reason for performance degradation in optical CDMA especially when large numbers of users are involved. The SAC-OCDMA systems employing code sequences fixed in-phase cross correlation can eliminate MAI by using balanced detection or also known as complementary subtraction detection technique [3, 5, 9].

Several code families have been developed for SAC-OCDMA such as modified quadratic congruence codes [4], M-sequence codes [5], double weight codes [6], etc. Therefore it is desirable to develop a detection technique that provides the MAI elimination capability. In this paper, a new and simple detection technique named AND subtraction is proposed. It is shown in this paper that the technique provides a significantly better performance than the complementary subtraction technique, which in turns allows for longer transmission distance or higher data rate or a larger number of users. The studies were carried out using a hybrid SCM SAC-OCDMA system. A better spectral efficiency can be achieved by using the SCM technique [2].

2. SCM SAC-OCDMA for Point-to-Point System

Figure 1 illustrates the block diagram of the system. The data signals multiply with the assigned subcarrier signals, and then modulated the signals with a distinct codeword using the Optical External Modulator (OEM). The received optical signals are decoded and converted to electrical signals, which then are filtered and demodulated accordingly to recover the original data.

The data are protected by the difference in either the codes or the subcarrier frequencies. Each filter only corresponds to the desired data tuned to its center frequency and with a matching code. Other signals are rejected. Therefore the hybrid scheme is robust against interference and is more spectrally efficient.

3. OCDMA Detection Techniques

In general, there are two basic detection techniques, namely coherent and incoherent [8].

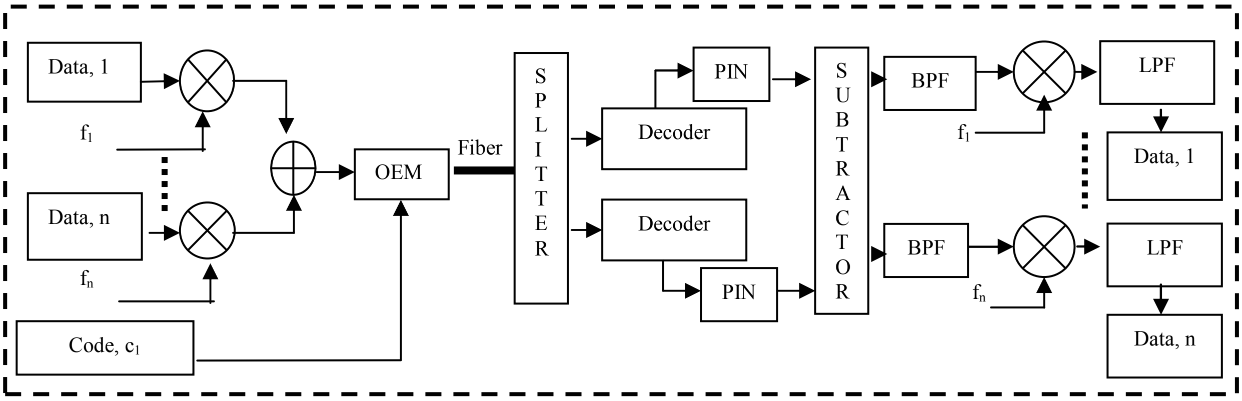

Figure 1. A block diagram for one code of hybrid SCM SAC-OCDMA.

Coherent system uses bipolar codewords whereas incoherent system consists of unipolar sequences in the signature code. Incoherent detection has a less hardware complexity compared to coherent detection because it does not need phase synchronization. In this study, the incoherent detection using subtraction techniques is used. The complementary and AND subtraction detection techniques will be discussed in the following sub-sections.

3.1 Complementary Subtraction Detection Technique

The implementation of complementary subtraction detection technique is shown in Figure 2. The figure shows two different sequences X= (0110) and Y= (1100) are modulated with data and sent to multiplexer. The received signal in *Receiver* is divided into two complementary branches of spectral chips. These two branches of spectral signals are sent to a subtractor that computes the correlation difference.

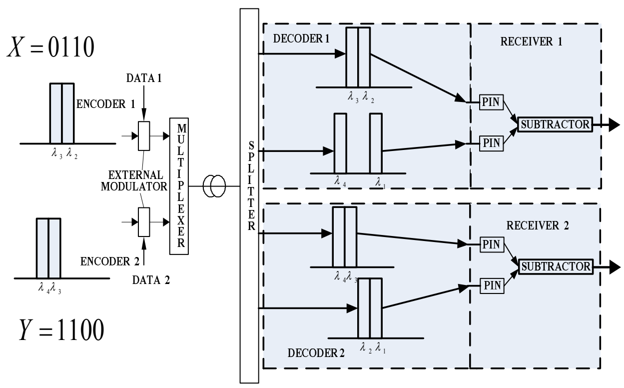

Figure 2. Implementation of the complementary subtraction technique.

The complementary subtraction technique was first proposed by Zaccarin [7]. The cross-correlation is defined as:

$$\theta_{XY}(k) = \sum_{i=0}^{N-1} x_i y_{i+k} \tag{1}$$

where X and Y are the two OCDMA code sequences. The complementary of sequence (X) is given by $(\overline{X})$ whose elements are obtained from (X) by $\bar{x}_i = 1 - x_i$. Let X= 0011 and Y= 0110 and therefore $\overline{X}$ = 1100. The periodic cross-correlation sequence between $(\overline{X})$ and (Y) is similar to Equation 1 and is expressed as:

$$\theta_{\overline{X}Y}(k) = \sum_{i=0}^{N-1} \bar{x}_i y_{i+k} \tag{2}$$

The sequences required are as:

$$\theta_{XY}(k) = \theta_{\overline{X}Y}(k) \tag{3}$$

At the receiver, the photodetectors will detect the two complementary inputs which will be fed to the subtractor whose cross-correlation output, *Z* can be expressed as:

$$Z_{Complementary} = \theta_{XY}(k) - \theta_{\overline{X}Y}(k) = 0 \tag{4}$$

There is no more signal from other users in the intended channel when $Z_{Complementary} = 0$.

3.2 AND Subtraction Detection Technique

In AND subtraction technique, the cross-correlation $\theta_{\overline{X}Y}(k)$ is substituted by $\theta_{(X\&Y)Y}$, where $\theta_{(X\&Y)}$ represents the AND operation between sequences X and Y. For code sequences of X= (0011) and Y= (0110), (X AND Y) = 0010. Figure 3 depicts the proposed AND subtraction detection technique.

At the Receiver

$$Z_{AND} = \theta_{XY}(k) - \theta_{(X\&Y)Y}(k) = 0 \tag{5}$$

Equation 5 shows that with AND subtraction technique, MAI or the interference from other channels also can be cancelled out. Comparison between complementary and AND subtraction technique using DW codes is shown in Table 1.

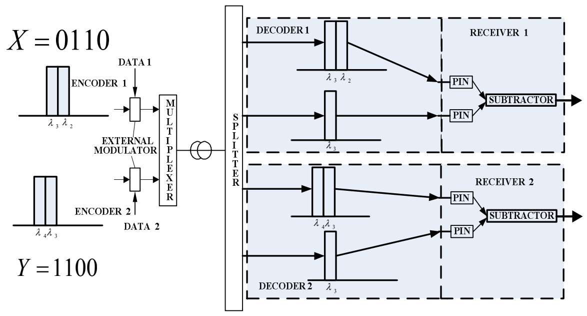

Figure 3. Implementation of the AND subtraction technique.

Table 1. Example of complementary and AND subtraction techniques.

	Complementary Technique				AND Technique			
	$\lambda 4$	$\lambda 3$	$\lambda 2$	$\lambda 1$	$\lambda 4$	$\lambda 3$	$\lambda 2$	$\lambda 1$
X	0	0	1	1	0	0	1	1
Y	0	1	1	0	0	1	1	0
	$\theta_{XY} = 1$				$\theta_{XY} = 1$			
	$\bar{X} = 1100$				$X \& Y = 0010$			
	$\theta_{\bar{X}Y} = 1$				$\theta_{(X\&Y)Y} = 1$			
Z	$Z = \theta_{XY} - \theta_{\bar{X}Y} = 0$				$Z = \theta_{XY} - \theta_{(X\&Y)Y} = 0$			

Therefore, as discussed in the sections 3.1 and 3.2, MAI can be cancelled out by using both techniques. However in term of the architecture, AND subtraction needs less number of filters in the decoder. For example, complementary subtraction detection technique as shown in Figure 2, three filters are required for decoder 1. A filter with the bandwidth twice the chip width for λ_2 and λ_3, and two separate filters for λ_1 and λ_4. Whereas for AND subtraction technique as shown in Figure 3, only two filters are needed for decoder 1. A filter with bandwidth twice the chip width for λ_2 and λ_3, and a filter at the position of the overlapping spectra occurring in the code sequences, that is λ_3.

4. Experimental Simulation Results and Discussion for SCM SAC-OCDMA System

The performance of the system was evaluated using OptiSystem Ver. 4.1, which is widely used for optical fiber simulations. The simulation was carried out for Double Weight (DW) code family with weight equal to 2 for four SCM channels. The bit rate of each channel is 155 Mbps (STM-1). Table 2 shows the DW code with weight equal to 2. The advantages of DW code are easy and efficient code construction, simple encoder-decoder design, existence for every natural number *n*, ideal cross correlation and high SNR. The detailed of DW code families' construction and performances are explained in [6].

Table 2. DW code with weight= 2 and 4 users.

K_{th}	C_6	C_5	C_4	C_3	C_2	C_1
1	0	0	0	0	1	1
2	0	0	0	1	1	0
3	0	1	1	0	0	0
4	1	1	0	0	0	0

The ITU-T G.652 standard single mode optical fiber without any amplifier is employed for a point-to-point optical transmission. The spectral width of each chip was 0.8 nm. The attenuation and dispersion were set at 0.25 dB /km and 18 ps /nm-km, respectively. The nonlinear effects were activated and specified according to the typical industry values to simulate the real environment as close as possible. The performances of the system are characterized by referring to the Signal-to-Noise Ratio (SNR) and eye pattern for the complementary and AND types of detection schemes.

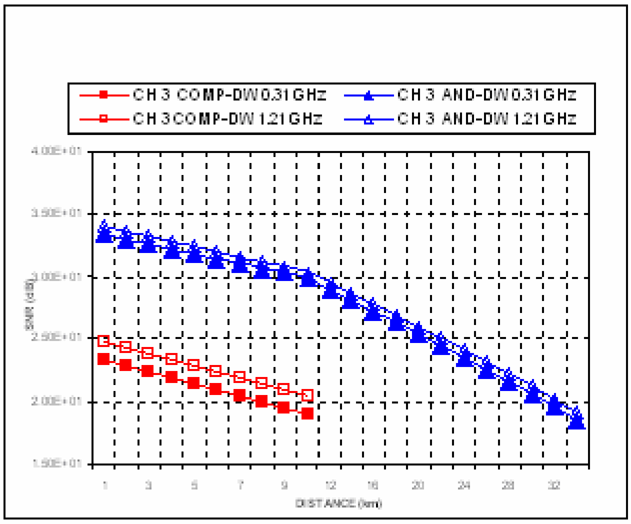

Figure 4. SNR vs. distance for SCM SAC-OCDMA systems using complementary and AND detection technique.

Figure 4 shows the SNR performance carried out against the transmission distance taken at the lowest and highest sub carrier frequencies, 0.31 and 1.21GHz, respectively. It can be seen that SNR decreases with the transmission distance. A longer optical fiber provides a larger dispersion and attenuation thus decreasing the SNR. The results for the SCM SAC-OCDMA system using AND subtraction shows better SNR compared to the complementary subtraction technique. It is found that the system using complementary subtraction technique could perform sufficiently well only up to about 10 km and AND subtraction up to 32 km.

Figure 5 shows the effect of transmitted input power on the system performance taken at the lowest and highest subcarrier frequencies, 0.31 and 1.21 GHz, respectively. The distance of the optical fiber is set at 10 km. Taking the SNR threshold of 20, the system with AND subtraction could perform sufficiently well even when the transmitted power is at -5 dBm whereas for the complementary subtraction the transmitted power should set at 0 dBm or higher.

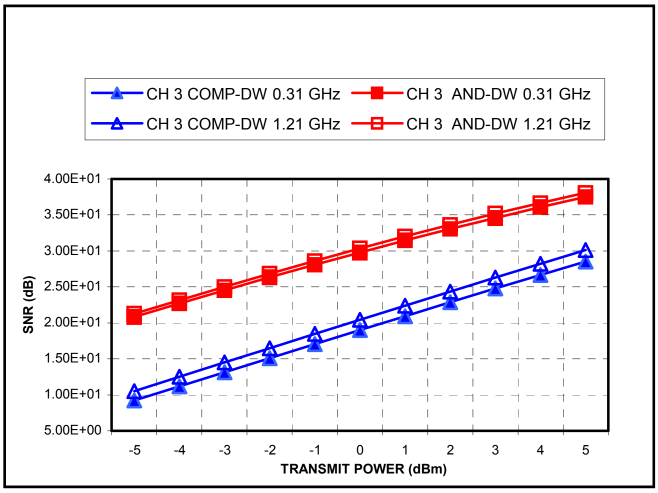

Figure 5. SNR vs. transmit power for SCM SAC-OCDMA systems using complementary and AND detection technique for DW.

Figures 6 and 7 show the results for the SCM SAC-OCDMA with optical fiber length of 15 km using complementary and AND subtraction detection techniques, respectively. The eye patterns show that the AND subtraction detection technique gave a better performance. The BER for complementary and AND subtraction technique were 10^{-7} and 10^{-22}, respectively.

The performance of the SAC-OCDMA system is improved significantly because with less number of filters in the AND subtraction, the total power loss can be reduced. Hence, the overall hybrid SCM SAC-OCDMA system cost and complexity is reduced with less number of filters.

5. Conclusion

A new AND detection technique based on subtraction technique has been proposed. The performance of the hybrid SCM SAC-OCDMA system with the new AND subtraction technique using DW code family has been presented. The results of the experimental simulation have proved that the new AND subtraction technique provides a better performance than the complementary subtraction technique. The performance of the system improved significantly because the total power loss is reduced as AND subtraction technique requires less number of filters in the decoder.

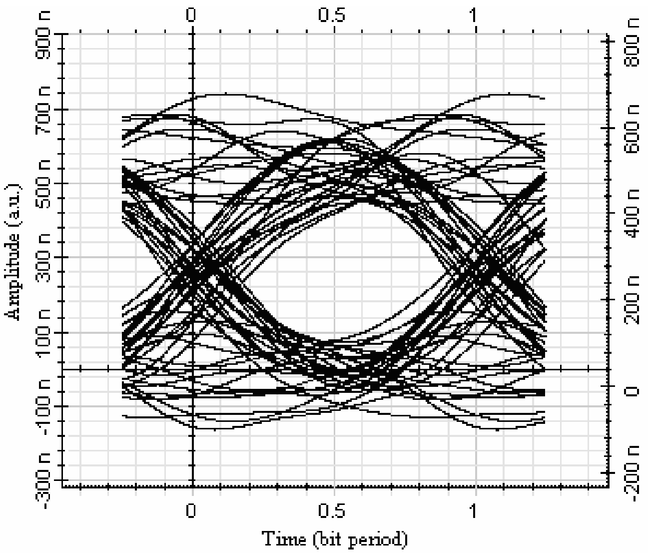

Figure 6. Eye diagram taken at channel 1 with complementary subtraction detection technique, subcarrier frequency of 0.61GHz.

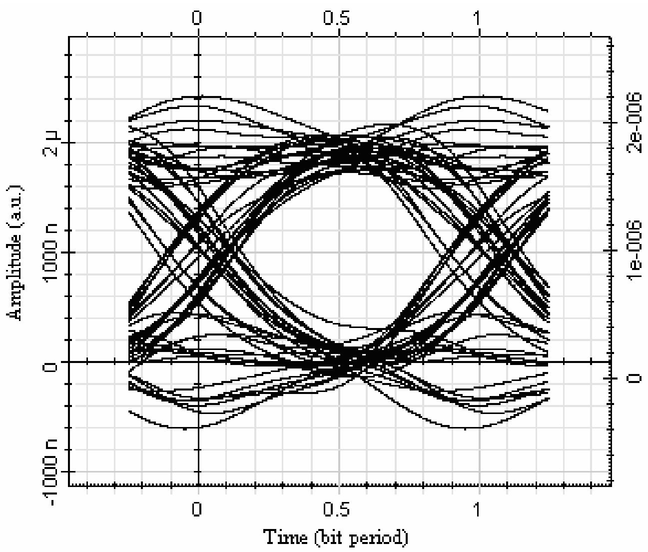

Figure 7. Eye diagram taken at channel 1 with AND subtraction detection technique, subcarrier frequency of 0.61GHz.

References

[1] Aljunid S., Ismail M., Ramli A., Ali B., and Abdullah M., "A New Family of Optical Code Sequences for Spectral Amplitude-Coding Optical CDMA Systems," *IEEE Photonic Technology Letters,* vol. 16, no. 10, pp. 2383-2385, 2004.

[2] Huang J. and Yang C., "Reductions of Multiple-Access Interference in Fiber-Grating-Based Optical CDMA Network," *IEEE Transactions on Communications*, vol. 50, no. 10, pp. 1680-168, 2002.

[3] Huang W., Nizam M., Andonovic I., and Tur M., "Coherent Optical CDMA (OCDMA) Systems Used for High-capacity Optical Fiber Networks-System Description, OTDMA Comparison, and OCDMA/WDMA Networking," *Journal of*

Lightwave Technology, vol. 18, no. 6, pp. 765-778, 2000.

[4] Hui R., Zhu B., Huang R., Allen C. T., Demarest R., and Richards D., "Subcarrier Multiplexing for High-Speed Optical Transmission," *IEEE Journal of Lightwave Technology*, vol. 20, no. 3, pp. 417-427, 2002.

[5] Kavehrad M. and Zaccarin D., "Optical Code-Division-Multiplexed Systems Based on Spectral Encoding of Noncoherent Sources", *IEEE Journal of Lightwave Technology*, vol. 13, no. 3, pp. 534-545, 1995.

[6] Wei Z. and Ghafouri-Shiraz H., "Codes for Spectral-amplitude-coding Optical CDMA Systems," *Journal of Lightwave Technology*, vol. 20, no. 8, pp. 1284-1291, 2002.

[7] Wei Z. and Ghafouri-Shiraz H., "Proposal of a Novel Code for Spectral Amplitude-Coding Optical CDMA Systems," *IEEE Photonic Technology Letters*, vol. 14, no. 3, pp. 414-416, 2002.

[8] Xu L., Glesk I., Baby V., and Prucnal P., "Multiple Access Interference (MAI) Noise Reduction in a 2D Optical CDMA System Using Ultrafast Optical Thresholding," *Lasers and Electro-Optics Society (LEOS'2004), in Proceedings of the 17th Annual Meeting of the IEEE*, vol. 2, pp. 591-592, Nov. 8-9, 2004.

[9] Yang C., Huang J., and Tseng S., "Optical CDMA Network Codecs Structured with M-Sequence Codes Over Waveguide-Grating Routers," *IEEE Photonics Technology Letters*, vol. 19, no. 2, pp. 641-643, 2004.

Ratna Sahbudin received her BSc in electrical engineering degree from Fairleigh Dickinson University, New Jersey, USA, in 1988 and the MSc in RF and communication engineering degree from University of Bradford, UK, in 1992. She is a senior lecturer at the Department of Computer and Communication Engineering, University Putra Malaysia, Malaysia. Currently, she is pursuing the PhD degree in the area of optical communication system at University Putra Malaysia, Malaysia.

Syed Alwee Aljunid is currently an associate professor with KUKUM, Malaysia. He received his BEng with first class honours and PhD from Universiti Putra Malaysia. His research interests include OCDMA and optical communications.

Mohd Abdullah is currently an associate professor and head of the Photonics and Fiber Optic Systems Laboratory, Universiti Putra Malaysia. He obtained his BSc and MSc from University of Missouri at Rolla, USA in 1990 and 1993, respectively, and PhD from Universiti Malaya in 1999. His research interest includes fiber optics devices, non-linear optics, and DWDM and OSCDMA systems. He was awarded the national young scientist award for year 2001 for his various contributions in the field of optical fiber communications. He has successfully filed 9 patents for his inventions and scientific works.

Mohd bin Abdul Samad is a degree holder in electrical engineering from KUiTTHO, Malaysia. Currently, he is a research assistant in the Photonics Laboratory, University Putra Malaysia and also pursuing his master degree in University Kebangsaan Malaysia. His research interest includes optical communications and OCDMA systems.

Mohd Mahdi received the BEng (1st class honors) from Universiti Kebangsaan Malaysia, Bangi in 1996 and immediately joined Telekom Malaysia Research and Development as a research officer. He received his MSc and PhD with distinction from the Universiti Malaya, Malaysia in 1999 and 2002, respectively. He is currently an associate professor at the Faculty of Engineering, Universiti Putra Malaysia. He has authored and co-authored more than 180 technical papers. His research interest includes optical communication devices, systems, optical signal processing and sensors.

Mahamod Ismail is currently an associate professor with the Department of Electrical, Electronics and System Engineering, Universiti Kebangsaan Malaysia. He received the BSc degree in electrical and electronics from University of Strathclyde, UK in 1985, the MSc degree in communication engineering and digital electronics from UMIST, Manchester UK in 1987, and PhD from University of Bradford, UK in 1996. His research interests include mobile communication and wireless networking.