# Successive Interference Cancellation for Optical CDMA Systems: Fundamental Principles

TAWFIG ELTAIF[a*], HOSSAM M. H. SHALABY[b], SAHBUDIN SHAARI[a], MOHAMMAD M. N. HAMARSHEH[c]
[a]Photonics Technology Laboratory (PTL), Institute of Micro Engineering and Nanoelectronics,
Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, MALAYSIA
[b]Elect. Eng. Dept, Fac. of Engineering, Alexandria University, Alexandria 21544, EGYPT.
[c] Dept. of Telecommunication Engineering (TCE), Fac. of Information Technology, Arab American
University, Jenin, P.O. BOX 1 : 240 Jenin, P.O. Box 2 : 13 Zababdeh, PALESTINE
*tefosat@ieee.org

*Abstract:* - In this paper successive interference cancellation (SIC) based on optical code division multiple access (O-CDMA) systems has been investigated. SIC scheme refers to a family of low complexity multi-user detection (MUD) methods for direct sequence CDMA systems. Performance of optical CDMA system is influenced by multiple access interference (MAI) resulted from the overlapping between the users. This kind of noise is became a primary concern in optical CDMA systems. To overcome this problem, we applied successive interference cancellation technique to a spectral amplitude coding (SAC) system that uses modified quadratic congruence (MQC) codes as signature sequence codes, taking into account the effect of all major noise sources, such as phase-induced intensity noise (PIIN), shot noise, and thermal noises. Furthermore, in SIC scheme we have taken into account the impact of imperfect interference cancellation. The system is analyzed for two cases: same effective power for all the users and different effective power from each user. We have successfully shown that under ideal effective power the SIC/SAC optical CDMA systems have potential to suppress the intensity noise and mitigate multiple access interference. Hence, using SIC/SAC cancellation scheme, the system can accommodate much more number of users as compared to the one without cancellation. Further, under ideal power the system using SIC scheme with direct sequence encoding (SIC/DS) shows much lower BER performance as compared to the one without cancellation (i.e. conventional receiver) or to SIC/SAC cancellation scheme. Hence, much more number of users can be accommodated by SIC/DS receiver system. Furthermore, SIC/DS scheme still shows much lower BER performance as compared with SIC/SAC scheme under different effective power.

*Key-Words:* - Optical code division multiple access (O-CDMA); successive interference cancellation (SIC); spectral amplitude coding (SAC); multiple access interference (MAI); modified quadratic congruence (MQC).

## 1 Introduction

The code division multiple access (CDMA) systems permit multiple users to simultaneously access the same transmission medium with no waiting time. In optical code division multiple access (O-CDMA) systems, the public codes used is unipolar sequences instead the bipolar code words like wireless communication. That is related to the optical signal is equivalent to the instant power which is nonnegative. On the other hand we can say code sequences developed in wireless communication filed, which are usually unipolar, can not be directly used in incoherent optical CDMA technique because optical intensity signals can not be negative. This means, that codes based on +1/−1 signals, which are used in wireless CDMA system, cannot be applied in optical system. A good optical CDMA code has much more 0's than 1's in each codeword, while a well-correlated (+1/−1) sequence typically has about the same number of +1's and –1's. Many codes have been produced and applied for optical CDMA systems; in 1989 Chung produced optical orthogonal code (OOC) [1], which became a public code used in optical CDMA systems, and some codes inspired from OOC [2-3]. Prime sequence code families like, modified prime code (MPR) [4], modified quadratic congruence codes (MQC) [5], and modified frequency hopping codes (MFH) [6-8], Hadamard codes [9] have been tested in this technique also. KS (Khazani-Syed) [10] code which is a unified code construction based on DW and MDW codes [11].

Performance analysis of such systems with various receiver structures was the subject of many articles such as Salehi and Brackett [12] have used an optical hardlimiter. Double optical hardlimiters placed before and after the optical correlator have been proposed in [13]. Lin and Wu in [14] have proposed a synchronous OCDMA system with an adaptive optical hardlimiter placed after the correlator receiver, they show the performance can be improved, compared with system with double hardlimiter. Recently one technique inspired by radio frequency communications, which is called multi-user detection (MUD) technique which typically employed in optical CDMA [15], to improve the capacity and overall throughout of the system, and it is known that optimum multi-user detection (MUD) has a much better theoretical performance than conventional detection [16]. Inspired of MUD we have been introducing the successive interference cancellation (SIC) [17]. In [18-21] we have analyzed SIC scheme with optical orthogonal codes (OOC) codes, modified prime codes, Hadamard codes and modified quadratic congruence codes using OOK modulation, it is found that the proposal of SIC receiver is effectively cancelled MAI and significantly BER performance improves at each stage of cancellation process. However, the results of this analysis show that the system with SIC cancellation scheme has much lower bit error rate (BER) performance as compared with the one without cancellation [18-21].

Alternative optical CDMA systems occupy spectral amplitude coding (SAC) get more attention by the researchers since this scheme multiple access interference (MAI) can be completely eliminated. SAC optical CDMA system was first investigated by Kavehrad and Zaccarin in 1995 [22]. Fig. 1 shows the principal structure of this technique. It was shown that the system can cancel multiple access interference (MAI) by using code sequences with fixed in phase cross correlation, but the phase–induced intensity noise (PIIN) in spectral amplitude-coding system limits significantly the system performance.

Many codes have been proposed to suppress the intensity noise and mitigate MAI. One code has been introduced in [23] based on the theorem of block designs. It has been found that the intensity noise can be effectively suppressed by using this code and, hence, a higher signal-to-noise ratio (SNR) results. The higher SNR is in fact due to the higher ratio of the autocorrelation peak to the fixed in-phase cross correlation as compared with -sequence or Hadamard code [22]. However, no clear code construction approach was presented in [23]. In [5-8] series of new codes for each prime number based on the quadratic congruence (QC) codes in [24] have been proposed. It has been shown that these new codes have similar properties with the former code in [23].

In recent years fiber Bragg grating (FBG) has been used to implement the encoder and decoder for optical CDMA systems. The transmitter and receiver structure for an SAC technique based on FBGs has been proposed in [5] using some of prime codes taking into account the effect of PIIN, shot noise, and the thermal noise. The concept of this system with FBG is simple, where the transmitter sends a pulse only when the bit is “1”, otherwise no optical pulse is sent. In the transmitter side two FBG’s are needed, where the optical pulse passes through the first FBG’s groups and correspondent spectral components are reflected. Hence the second FBG’s groups are used to compensate the round trip delay of different spectral components. The received signal will be reflected back from the FBG’s $A(v)$, and as well as it’s complementary $\overline{A}(v)$ will be getting out from the other end of the grating group [5].

In [25] we have showed our proposed receiver structure for optical CDMA technique, combining both of FBG/SAC, and SIC. We consider the proposed receiver for the entire system, and just send the detected signal to each receiver. In this case we would not need power amplification, since we have power splitting once. The concept of this system with FBG is simple, where the transmitter sends a pulse only when the bit is "1", otherwise no optical pulse is sent. In the transmitter side we need two FBG's, where the optical pulse passes through the first FBG's groups and correspondent spectral components are reflected. Hence the second FBG's groups are used to compensate the round trip delay of different spectral components. The received signal will be reflected back from the FBG's $A(v)$, and as well as it's complementary $\overline{A}(v)$ will be getting out from the other end of the grating group. The system shows that the proposed system offers significant improvement in terms of bit error rate and system capacity (number of users).

In the ideal spectral amplitude coding some assumption should be taken, source spectrum is ideally flat over a bandwidth of $v_o + \Delta v/2$, where $v_o$ is the central optical frequency and $\Delta v$ is the optical source bandwidth in hertz (spectral width), and should be identical for each user as shown in Fig 1.

In this paper, we compare the performance of both a SIC scheme and a hybrid SIC/SAC scheme. We show that SIC optical CDMA system has a much lower BER performance as compared with SIC/SAC in both cases of same and different effective power for each user.

The rest of this paper is organized as follows. Section 2 is devoted for the description of the system architecture and the discussion of its basic principles. The performance comparison between receiver structures is given in Section 3. In Section 4, we present our theoretical results with more discussion taking into consideration the interference effect, Shot and thermal noise, and PIIN noise. Finally the conclusion is given in Section 5.

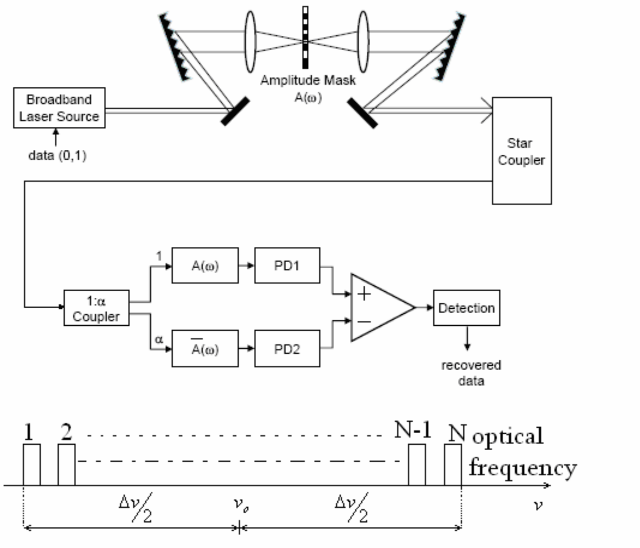

Fig.1 Block diagram of SAC technique

## 2 System Description

In this section we present the function of a SIC scheme and how it works with a SAC technique. In multi user detection (MUD) receiver, the received signal is fed into a bank of SAC receivers, Fig.2. Each bit of data received is be split and detected by a complementary scheme [22]. The main idea of SAC technique that the receiver filters the incoming signal with the same filter (direct decoder, $A(v)$) used at the transmitter as well as its complementary filter (complementary decoder, $\overline{A}(v)$). Hence, the outputs from the SAC filters are detected by the two photodetectors connected in a balanced fashion. After complete detection and demodulation by the user's codes, the strongest user will be selected, regenerated, and subtracted from the original received signal to get a new received signal. Then the strongest received signals are subtracted from the original signal one by one until all users have been detected, and demodulated. The algorithm used in

SIC scheme is summarized as follows (i) Recognize the strongest signal with maximum correlation value; (ii) Decode this strongest signal; (iii) Regenerate the strongest signal using its chip sequence; (iv) Subtract it from the original signal; and (v) Repeat until all interfering signals of users are canceled [17-21].

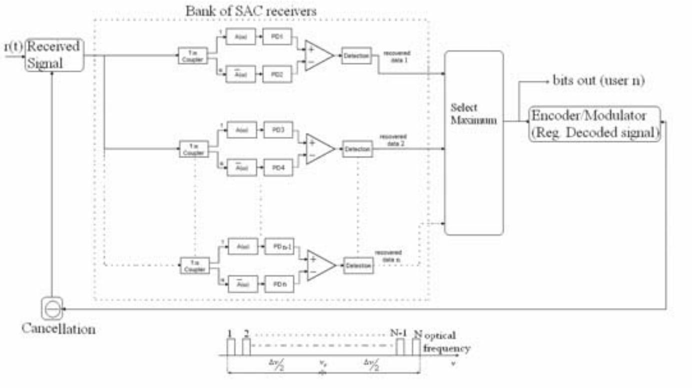

Fig.2 SIC/SAC receiver scheme.

## 3 Performance Comparison

SIC scheme based on direct sequence (DS) optical CDMA systems analysis is simple. In this paper we have theoretically analyzed and presented the SIC scheme more in details on both direct sequence and based on spectral amplitude coding (SAC) optical CDMA systems with modified quadratic congruence (MQC) code. More details of MQC can be found in [5]. The MQC code, length is $p^2 + p$ and its weight is $(p+1)$. This allows a total number of users $N=p^2$. Therefore under the worst case i.e., $\tau_n = 0$, for all $n$, synchronized condition [26], the cross correlation function $I_{xy}$ between any pair of code sequences x and y is given by [5]:

$$I_{x,y} = \begin{cases} p+1; & x = y \\ 0; & x \text{ and } y \text{ are in the same group} \\ 1; & x \text{ and } y \text{ are in different group} \end{cases} \quad (1)$$

The received signal at the receiver can be written as follows:

$$r(t) = \sum_{n=1}^{N=p^2} P_{er(n)} b_n(t-\tau_n) \sum_{i=1}^{p^2+p} c_n^i(t-\tau_n) + n(t) \quad (2)$$

Where; $P_{er(n)}$ is the signal strength of the $n^{\text{th}}$ user; $b_n(t)$ is the bit sequence of $n^{\text{th}}$ user; $c_n(t)$ is the spreading chip sequence of the $n^{\text{th}}$ user; $n(t)$ is the noise signal (thermal noise); and $\tau_n$ is the time delay of the $n^{\text{th}}$ user.

Once the strongest user has been detected and demodulated, the result is used to regenerate this user. Then the regenerated signal is subtracted from the original signal. In general for the $j^{\text{th}}$ cancellations we get:

$$r_j(t) = r_{j-1}(t) - Z_j \cdot \sum_{i=1}^{P^2+p} c_j(i) \quad (3)$$

After complete detection of all users' signals, the decision variable for the $(j+1)^{th}$ user, where $j^{th}$ refer to cancellation number, can be expressed as:

$$Z_{j+1} = \frac{P_{er(j+1)} b_{(j+1)}}{p} + \frac{1}{p^2}\left[\sum_{n=j+2}^{N=p^2} P_{er(n)} b_n I_{n,j+1}(\tau_{n,j+1}) - \sum_{i=1}^{j} l_i I_{i,i+1}(\tau_{i,i+1})\right] + n_{j+1}(t) \quad (4)$$

In eq (4), the first term refer to the desired user, the second term is MAI of the uncancelled users; and the third term is due to cumulative noise from imperfect cancellation. The negative effects of shot noise, effect of the receiver's dark current, and other sources of noise are neglecting in order to focus only on the interference (i.e., MAI), created by other simultaneous users, in addition, the thermal noise.

Detailed analysis of the SIC scheme can be found in [17-21].

In a SIC/SAC CDMA system analysis, we have to take into account the effect of PIIN noise. In fact it is the dominated noise in SAC techniques. The cross correlation function $I_{xy}$ between any pair of code sequences x and y is given by:

$$\sum_{i=1}^{p^2+p} c_x(i)c_y(i) = \begin{cases} p+1, & x=y \\ 1, & x \neq y \end{cases} \quad (5)$$

$$\sum_{i=1}^{p^2+p} c_x(i)\bar{c}_y(i) = \begin{cases} 0, & x=y \\ p, & x \neq y \end{cases} \quad (6)$$

Assuming that each user has the same power at the receiver, the variance of the photocurrent current can be expressed as [5, 9]:

$$\left\langle i^2 \right\rangle = 2eIB + I^2 B\tau_c + 4K_b T_n B / R_L \quad (7)$$

Where, the first term is due to the effect of shot noise, the second term is due to the effect of PIIN noise, and the last term is due to the effect of the thermal noise, $B$ is the noise-equivalent electrical bandwidth of the receiver, $e$ is the electron's charge, $k_b$ is Boltzmann's constant, $T_n$ is the absolute receiver noise temperature, $R_l$ is the receiver load resistor, $\Delta v$ is the encoded optical bandwidth in Hertz; $N$ is the number of active users, $e$ electron's charge; $I$ average current; $\tau_c$ is the source coherent time, given by[5, 9]:

$$\tau_c = \frac{\int_{v=0}^{\infty} G^2(v)dv}{\left[\int_{v=0}^{\infty} G(v)dv\right]^2} \quad (8)$$

Where $G(v)$ is the one-sided source power spectral density (PSD), expressed as a function of sum of the user's signals at the receiver side as follows:

$$r(v) = \frac{P_{er}}{\Delta v} \sum_{n=1}^{N=p^2} b_n \sum_{i=1}^{F=p^2+p} c_n(i) . \left( \begin{array}{l} u\left[ v - v_o - \frac{\Delta v}{2p^2}(-p^2+2i-2) \right] - \\ u\left[ v - v_o - \frac{\Delta v}{2p^2}(-p^2+2i) \right] \end{array} \right) \quad (9)$$

Where; $P_{er(n)}$ is the effective power at the receiver side, including some losses related to transmission and coupler; $b_n(t)$ is the bit sequence of $n^{\text{th}}$ user; $c_n(t)$ is the spreading chip sequence of the $n^{\text{th}}$ user; and $u(v)$ is the unit step function expressed as :

$$u(v) = \begin{cases} 0; & v \geq 0 \\ 1; & v \leq 0 \end{cases} \quad (10)$$

The received signal is fed to a bank of receivers, one for each user. The sign of the output of the receiver is the corresponding user decision. Detailed analysis of the SIC/SAC cancellation scheme can be found in [25]. The responsivity of the photodetector is given by $\Re = \eta e / h v_c$ , where $\eta$ is the quantum efficiency, $e$ is the electron charge, $h$ is Plank's constant, and $v_c$ is the central frequency of the original broadband optical pulse.

Table 1 SNR Equations of Cancellation Schemes.

| Cancellation Scheme | SNR |
|---|---|
| SIC Scheme | $SNR_{j+1} = \dfrac{\Re^2 P^2_{er(j+1)} \big/ p^2}{\dfrac{\Re^2}{p^2(p^2+p)}[\sum_{n=j+2}^{N=p^2} P^2_{er(n)} + \sum_{i=1}^{j} \Gamma^2{}_i] + 4K_b T_n B \big/ R_L}$ |
| SIC/SAC Scheme | $SNR_{j+1} = \dfrac{\Re^2 \dfrac{P^2_{er}}{p^2}}{\dfrac{eB\Re P_{er}}{(p^2+p)}(2N+p-1-2\sum_{i}^{j}\langle i_i^2\rangle)) + \dfrac{B\Re^2 N P^2_{er}}{2p^2(p+1)\Delta v}[\dfrac{N-1}{p} + p + N - \dfrac{1}{N}\sum_{i}^{j}\langle i_i^2\rangle] + 4K_b T_n B / R_L}$ |

The SNR ratios for both SIC/DS and SIC/SAC systems are listed in table 1. Therefore, the probability of error after the $j^{th}$ cancellation can be estimated using the Gaussian approximation $BER_{j+1} = Q\left(\sqrt{SNR_{j+1}}\right)$.

## 4 RESULTS DISCUSSION

In this section, we present some performance results for our proposed system with typical system parameters as listed in table 2. In Fig. 3 the BER function for the system with and without cancellation has been plotted for the sake of comparison using modified quadratic congruence code (MQC code), with effective power $P_{er} = -20dBm$. It is clear that, SIC/SAC optical CDMA system can suppress the effect of PIIN noise and thus improve the BER performance. However, the figure also shows that our SIC/SAC receiver scheme (i.e. with cancellation) has a better performance than the one without cancellation. It is also shown that the SIC/DS cancellation scheme has better performance than conventional scheme and SIC/SAC scheme. For example by setting the prime number to 7, it is clear that for similar BER performance ($10^{-9}$), less than 10 users can be active with both conventional scheme and SIC/SAC cancellation scheme. However, with SIC/DS cancellation scheme, the number of users can be increased to 25 users giving substantial increase in capacity.

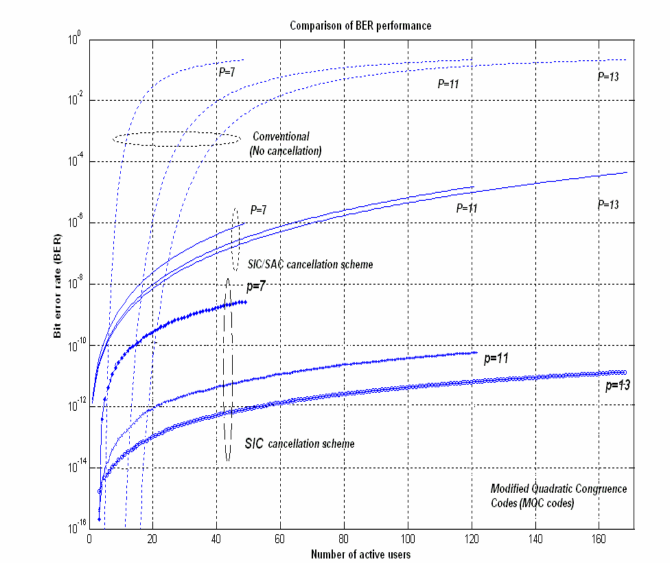

Fig.3 Comparison of BER performances under ideal effective power (-20dBm).

Table 2 Typical Parameters Used For Calculation

| Parameter | Value |
|---|---|
| Operation Wavelength | 193.1 THz |
| PD quantum efficiency | 0.6 |
| Receiver noise temperature | 300 k |
| Receiver load resistor | 1030 Ω |
| Electrical equivalent bandwidth | 80 MHz |
| Line-width of the thermal noise | Δv=3.75 THz |

Fig. 4 shows the bit error rate (for SIC/SAC system) versus number of effective power from each user, when the number of active users using MQC codes is 49, 121, and 169. It is clear that the BER increases when the effective power is less than -35dBm. That is the system with SIC/SAC scheme has much better performance at 49 active users as compared with the one at 121 and 169 active users. This is because the large value of prime number causes large loss, which makes the shot noise and thermal noise affect the system when the effective power is low, and the PIIN noise becomes the main limitation factor of the system when the effective power is large. Also Fig. 4 shows the quick increase of BER when the effective power is less than -35dBm, and the worst system performance when the effective power is less than -52dBm. This comes from the largest power loss, and the system being affected by both the thermal noise and shot noises. Fig. 5 shows the BER versus the effective power from 49 users at different code lengths *(p=7, 11, 13)*. It is clear that at *(p=11, 13)*, the system has the same BER performance which is much better than the system with *(p=7)*. This is because of the few users used with large code length.

In Fig. 6, we compare the BER versus number of users under different effective power per user. It is clear that using different powers for each user in a SIC/SAC system can make the system unstable, and low power dominates on the system performance. The figure also shows the BER performance for SIC/DS scheme using different effective power. It is clear in this figure that the BER curve suddenly changed at 10 active users. On the other hand we can say that, for small number of users $N$, the BER improves as $N$ increases. The question is why BER curve was improved as $N$ increases till it reaches 10 users. First factor comes from dominating of thermal noise on the system because of the different effective power, interference caused between the overlapping optical pulses with the same wavelength, this interference can be a high factor limiting the system performance, because the sharing wavelength carrying different data with different power. Hence, using few users with $(P^2 + P)$ code length (large enough) makes the MAI decreases until certain value of users, after that the MAI increases which affects the system and the BER start increasing.

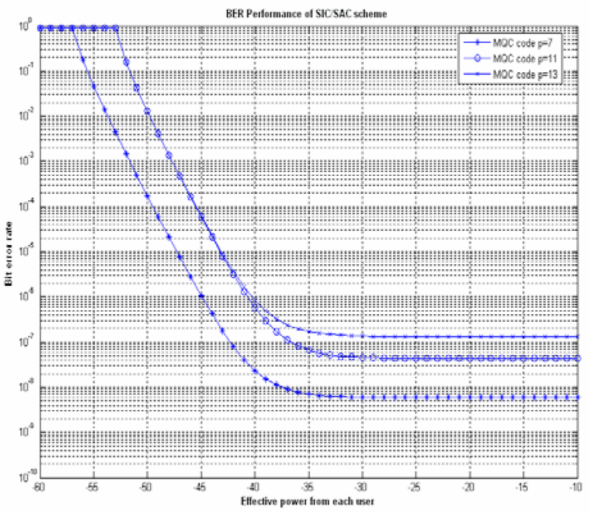

Fig.4 BER versus effective power when number of active users is 49, 121, and 169.

Fig. 7 shows the SIC/SAC optical CDMA system is affect by the intensity noise, shot noise and thermal noise, which become the main limitation factor of the system performance when the $P_{er}$=-30dBm, and the main reason of that came from the large number of prime code, which causes a large power loss at the transmitter part.

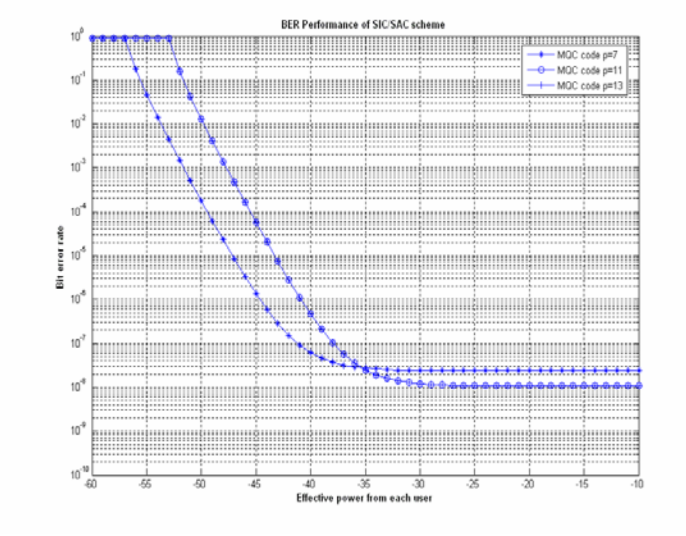

Fig.5 BER versus effective power when number of active users is 49.

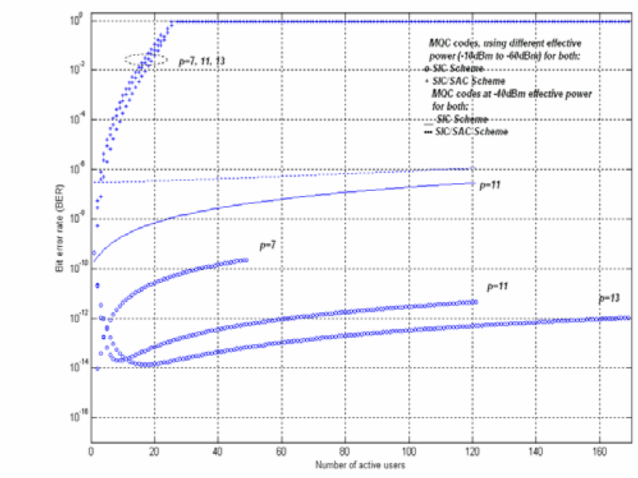

Fig.6 Comparison of BER performances under different effective power per user.

## 5 Conclusion

In this paper, we proposed to mitigate multiple access interference (MAI), and suppress the intensity noise using successive interference cancellation in both direct sequence and with spectral amplitude coding (SIC/SAC) for optical CDMA system. The system has been tested with modified quadratic congruence (MQC) code, and the system shows a much lower BER performance as compared to the one without cancellation. Further, it is shown that a SIC/DS scheme has a much lower BER performance as compared to the one without cancellation and to SIC/SAC cancellation scheme. Hence, much more number of users can be accommodate by a SIC/DS system. In addition, SIC/DS and SIC/SAC optical CDMA systems have been tested under different effective power from each user, and it is shown that the system with SIC/DS scheme still has a much better performance than the one with SIC/SAC scheme.

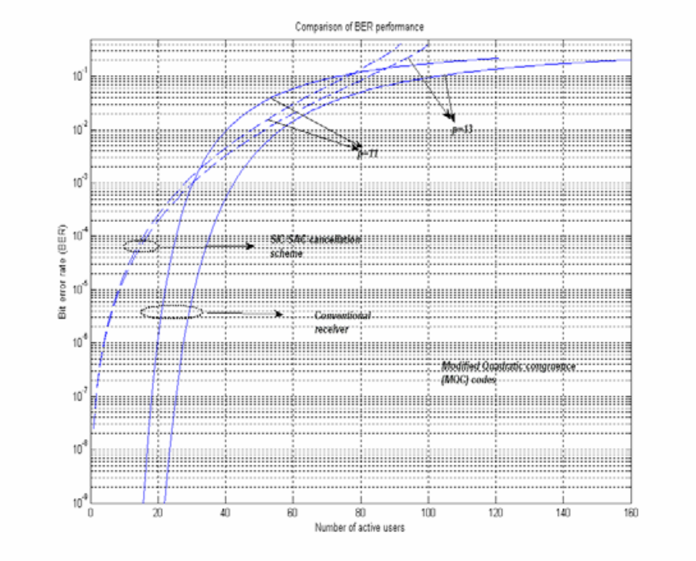

Fig. 7 Comparison of BER at $P_{er}$ = *-30dBm.*

## Acknowledgement

Tawfig Eltaif would like to thank Dr. Menon, P. S of University Kebangsaan Malaysia, Bangi, Selangor Malaysia, for worth ideas and useful suggestions. This work was funded by Malaysian Ministry of Science, Technology and Environment under project UKM-GUP-BTT-07-26-177.

*References:*

[1] F. Chung, J. A. Salehi and V. Wie, “Optical Orthogonal Codes: Design, Analysis and Application,” *IEEE Transactions on Information Theory*, Vol. 35, No. 3, 1989.

[2] E. Shivaleela, K. Sivarajan and A. Selvarajan, “Design of a New Family of Two-Dimensional Codes for Fiber-Optic CDMA Networks,” *IEEE Journal of Lightwave Technology*, Vol. 16, No. 4, 1998.

[3] E. S. Shivaleela, A. Selvarajan, and T. Srinivas, “Two-Dimensional Optical Orthogonal Codes for Fiber-Optic CDMA Networks,” *J. Lightwave Technol.* Vol. 23, 647- 654, Feb. 2005.

[4] W. C. Kwong, P. A. Perrier, and P. R. Prucnal, “Performance comparison of asynchronous and synchronous code-division multiple-access techniques for fiber-optic local area networks,” *IEEE Transactions on Communications*, 39, pp. 1625-1634, (1991).

[5] W. Zou, H. M. H. Shalaby, and H. G. Shiraz, "Modified quadratic congruence codes for fiber Bragg-grating-based spectral-amplitude-coding optical CDMA systems," *J. Lightwave Technol.*, vol. LT-19, pp. 1274-1281, Sept. 2001.

[6] Z. Wei, H. M. Shalaby, and H. Ghafouri-Shiraz, “New Code Families for Fiber-Bragg-Grating-Based Spectral-Amplitude-Coding Optical CDMA Systems,” *IEEE Photon. Technol. Lett.*, Vol. 13, no.8. 890–892, 200.

[7] Z. Wei and H. G. Shiraz, “Proposal of A Novel Code for Spectral Amplitude-Coding Optical CDMA Systems,” *IEEE Photonics Technology Letters,* Vol. 14, no.3. 414–416, Mar. 2002.

[8] Z. Wei and H. G. Shiraz, “Unipolar Codes with Ideal In-Phase Cross-Correlation for Spectral Amplitude-Coding Optical CDMA Systems,” *IEEE Transaction on Communication*, Vol. 50, No. 8, 1209–1212, August 2002.

[9] E. D. J. Smith, R. J. Blaikie, and D. P. Taylor, “Performance enhancement of spectral-amplitude-coding optical CDMA using pulse-position modulation,” *IEEE Trans. Commun.*, vol. 46, pp. 1176–1185, Sept. 1998.

[10] R. K. Z. Sahbudin, M. K. Abdullah, Performance Analysis of Hybrid SCM/OSCDM System using the Khazani-Syed (KS) Code, *WSEAS Transactions on Communicatios,* Issue 11, Volume 7, November 2008.

[11] M. K. Abdullah, S. A. Aljunid, S. B. A. Anas, R. K. Z. Sahbudin, M. Mokhtar, A New Optical Spectral Amplitude Coding Sequence: Khazani-Syed (KS) Code, *Proceeding of International Conference on Information and Communication Technology (ICICT '07),* 2007, pp. 266-278.

[12] J. A. Salehi and C. A. Brackett, “Code division multiple-access techniques in optical fiber networks—Part II: Systems performance analysis,”*IEEE Trans. Commun.,* 37, pp. 834–842, (1989).

[13] T. Ohtsuki, K. Sato, I. Sasase, and S. Mori, “Direct-detection optical synchronous CDMA systems with double optical hard-limiters using modified prime sequence codes,” *J. Select. Areas Commun.*, 14, pp. 1897–1887, (1996).

[14] C. L. Lin and J. Wu, “A synchronous fiber-optic CDMA system using adaptive optical hardlimiters,” *J. Lightwave Technol.*, 16, pp. 1393–1403, (1998).

[15] M. B. Pearce and B. Aazhang, “Multiuser Detection for Optical Code Division Multiple Access Systems,” *IEEE Trans. Commun*, 42, no. 2/3/4, pp 1801-1810. (1994).

[16] S. Verdu, “Adaptive Multiuser Detection, ” *in Proceedings of IEEE on International Symposium on Spread Spectrum Techniques and Applications*, pp. 43- 50, Oulu, Finland, (1994).

[17] T Eltaif, H M H Shalaby and S Shaari, “A Novel Successive Interference Cancellation Scheme in OCDMA System”, *in Proceedings of IEEE Conference on*.(ICSE, 2006), pp 299 – 303.

[18] T Eltaif, H M H Shalaby, S Shaari, &M. M. N. Hamarsheh. “Analysis of Successive Interference Cancellation Scheme using OOC code in Optical CDMA Systems,” *in Proc. IEEE. ICACT*. pp 2023-2026. (2008).

[19] T Eltaif, H M H Shalaby, S Shaari, &M. M. N. Hamarsheh. “A proposal of successive interference cancellation scheme in optical CDMA systems,” *optic. Eng. SPIE*. Vol.47. no. 3, 2008.

[20] T Eltaif, H M H Shalaby, S Shaari, &M. M. N. Hamarsheh. ”Performance analysis of successive interference cancellation scheme for optical CDMA systems using modified prime sequence codes,” *in Proceedings of the SPIE*, Volume 6837, pp. 68370Y (2008).

[21] T Eltaif, H M H Shalaby, S Shaari, &M. M. N. Hamarsheh. “Analytical comparison of optical CDMA system with and without successive interference cancellation scheme using modified prime sequence codes,” *Opt. Eng., Proc. SPIE*, vol. 47(9), pp. 095001(1-6), Sept. 2008.

[22] M. Kavehrad and D. Zaccarin, “Optical code-division-multiplexed systems based on spectral encoding of noncoherent sources,” *J. Lightw. Technol.*, vol. 13, no. 3, pp. 534–545, 1995.

[23] X. Zhou, H. M. H. Shalaby, C. Lu, and T. Cheng, “Code for spectral amplitude coding optical

CDMA systems," *Electron. Lett.*, vol. 36, pp. 728–729, Apr. 13, 2000.

[24] Z. Kostic and E. L. Titlebaum, "The design and performance analysis for several new classes of codes for optical synchronous CDMA and for arbitrary- medium time-hopping synchronousCDMA communication systems," *IEEE Trans. Commun.*, vol. 42, pp. 2608–2617, Aug. 1994.

[25] T Eltaif, H M H Shalaby, S Shaari, & M. M. N. Hamarsheh. "Performance analysis of a hybrid fiber Bragg grating-based spectral-amplitude-coding/successive interference cancellation for optical CDMA systems. *Optics Communications*. vol. 282 (2009) 1-6.

[26] J. A. Salehi, "Code division multiple-access techniques in optical fiber networks—Part I," *IEEE Trans. Commun.*, 37, no. 8, 824–842 (1989).