Interference Mitigation Using Successive Interference Cancellation in Optical CDMA Systems

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: - Performance of optical code division multiple access (O-CDMA) system is influenced by multiple access interference (MAI) resulted from the overlapping between the users. To overcome this problem, successive interference cancellation (SIC) scheme is applied to O-CDMA systems. In this paper we apply successive interference cancellation technique to a spectral amplitude coding (SAC) system that uses modified quadratic congruence (MQC) codes as signature sequence codes. The system is analyzed for two cases: same effective power for all the users and different effective power from each user. It is 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).

1 Introduction

Spectral-amplitude-coding (SAC) OCDMA system was first investigated by Kavehrad and Zaccarin in 1995 [1]. 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 [2-4]. We have proposed the successive interference cancellation (SIC) technique to suppress MAI in optical CDMA systems [5]. This technique was analyzed with optical orthogonal codes (OOC), modified prime codes, and modified quadratic congruence codes. 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 [6-8]. 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.

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.1. Each bit of data received is be split and detected by a complementary scheme [1]. 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 [5-8].

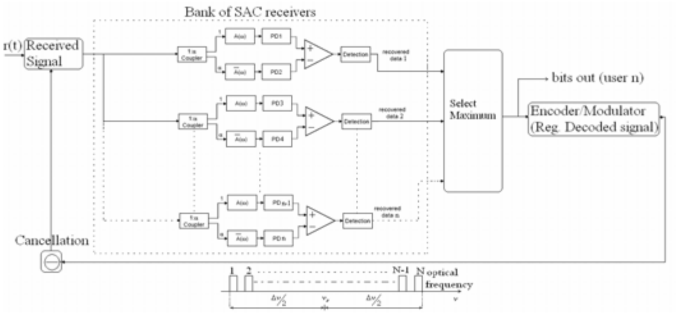

Fig.1 SIC/SAC receiver scheme.

3 Performance Comparison

SIC scheme based on direct sequence (DS) optical CDMA systems analysis is simple. The MQC code, length is $p^2 + p$ and its weight is $(p+1)$. This allows a total number of users $N=p^2$. The received signal at the receiver can be written as follows:

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

Where; $P_{er(n)}$ is the signal strength of the n^{th} user; $b_n(t)$ is the bit sequence of n^{th} user; $c_n(t)$ is the spreading chip sequence of the n^{th} user; $n(t)$ is the noise signal (thermal noise); and τ_n is the time delay of the n^{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^{th} cancellations we get:

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

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:

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

In eq (2), 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 [5-8].

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. Detailed analysis of the SIC/SAC cancellation scheme can be found in [9].The SNR ratios for both SIC/DS and SIC/SAC systems are listed in table 1. in this table 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, Δv is the encoded optical bandwidth in Hertz; N is the number of active users. The responsivity of the photodetector is given by $\Re = \eta e / h v_c$, where η 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. Therefore, the probability of error after the j^{th} cancellation can be estimated using the Gaussian approximation $BER_{j+1} = Q\left(\sqrt{SNR_{j+1}}\right)$.

The parameters used in our calculation are listed in table 2. In Fig. 2 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 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. 3 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. 4 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.

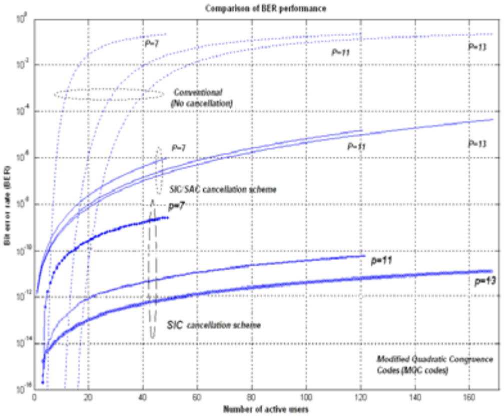

Fig.2 Comparison of BER performances under ideal effective power (-20dBm).

In Fig. 5, 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.

Table 1 SNR Equations of Cancellation Schemes.

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

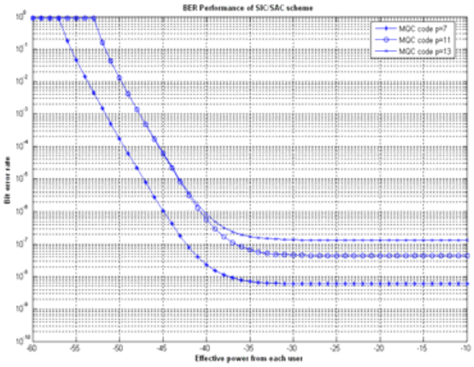

Fig.3 BER versus effective power when number of active users is 49, 121, and 169.

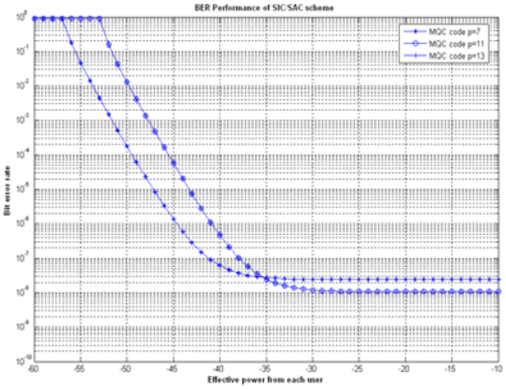

Fig.4 BER versus effective power when number of active users is 49.

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.

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

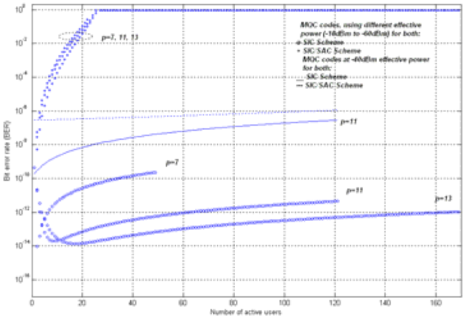

Fig.5 Comparison of BER performances under different effective power per user.

4 Conclusion

In this paper, we proposed to mitigate multiple access interference (MAI), and suppress the intensity noise using successive interference cancellation with spectral amplitude coding (SIC/SAC) for optical CDMA system. The system has been tested with MQC codes, 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.

Reference:

[1] 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.

[2] 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.

[3] 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.

[4] Z. Wei, H. M. Shalaby, and H. Ghafouri-Shiraz, "Proposal of a Novel Code for Spectral Amplitude-Coding Optical CDMA Systems," *IEEE Photon. Technol. Lett.*, 14, No. 3, 2002.

[5] T Eltaif, H M H Shalaby and S Shaari, "A Novel Successive Interference Cancellation Scheme in OCDMA System", in *Proc.ICSE2006,* pp 299 – 303, Kuala Lumpur, (2006).

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

[7] T Eltaif, H M H Shalaby, S Shaari, and 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.

[8] 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.

[9] 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.