Proceeding of the 1st ICEENG conference, 24-26 March, 1998. AC3- 471

MILITARY TECHNICAL COLLEGE
CAIRO-EGYPT
ICEENG 98
FIRST INTERNATIONAL CONF. ON
ELECTRICAL ENGINEERING

Spectral Code Division Multiplexed System Using Optical Orthogonal Signalling

*KAMEL M. HASSAN **TAHER M. BAZAN ***SAID M. SAAD

ABSTRACT

In this paper, we present a proposed scheme for improving the performance of the optical code division multiple access system (CDMA). This system works based on spectral encoding of noncoherent sources. The proposed scheme depends on using the orthogonal signalling in place of ASK format. A new design of optical mask is presented in order to minimize the nonflatness effect of the spectral shape of the optical source on the system performance. Analysis study on the required accuracy of the designed mask on the performance improvement has been presented.

I-INTRODUCTION

Since the optical fiber communication systems have been used, several multiplexed techniques were proposed to increase the channel capacity with maximum fidelity. CDMA has recently used in optical communication and the idea has been reported by Salehi in 1989 [1-2]. The encoding processing is done in time domain using optical orthogonal codes. In 1993, Kavehrad et al introduced a new technique which is based on spectral encoding (frequency encoding: FE) of noncoherent optical source to achieve a system for code division multiplexing [3]. Weiner had efficiently used the basic apparatus used in the scheme proposed by Kavehrad before for high-resolution femtosecond pulse shaping [4]. This new technique is characterized with supplying very high channel capacity (several giga bits per second) and independent spreading gain of the modulation bandwidth if it is compared with that system using the encoding process in time domain [5]. For this FE-CDMA, the scheme presented by Kavehrad et al is suffering from several drawbacks such as a 3-dB loss inherent to this system as well as it suffers from the effect of the nonflatness of the LED's spectrum which results in uneven performance for each subscriber channel. Our calculations showed that there are some subscribers will suffer from very strong crosstalk especially when Hadamard code is used in the previous system. The paper is structured as follow:- Section II presents the basic features of Hadamard code and the way of its generation where this code gives the possibility of using orthogonal signalling in our scheme and consequently it is possible to overcome the 3-dB loss in the traditional system. In section III, we present the construction of the used transceiver set. Through this section, the descriptions of the transmitter and the receiver as well as the design of the optical mask are explored. The calculations and results of the signal to interference ratio (SIR) as an indicator of the system performance are explored in section IV .The calculations include the SIR for the traditional scheme with m-sequence code as well as Hadamard code. These results are compared with what we have obtained in our proposal. Finally the main conclusions in section V.

*Assoc.professor , Dpt. of Electrical Engineering and computer, Higher Technology Institute, Ramadan 10th City.
** Graduate student, Egyptian Armed Forces ***Assoc. professor, Egyptian Armed Forces.

II-HADAMARD CODE

The Hadamard code is obtained by selecting any row of a Hadamard matrix except the row which contains all 1's (first row). The Hadamard matrix is related to a Walsh transform, which forms an orthogonal set, defined over the integers [0,1]. A code of length N can be obtained from N×N Hadamard matrix (H) where $N = 2^r$ and r is any positive integer number. For illustration, we take r =3, it gives a 8×8 H matrix as shown

$$H = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 & 1 & 1 & 0 \end{pmatrix}$$

Let H(k,n) be an element in the i^{th} row and j^{th} column in H matrix.

$$H(k,n) = \sum_{k=0}^{N-1} (-1)^{\sum_{r=0}^{r-1} p_r(k).q_r(n)} \qquad k,n \leq N \qquad (1)$$

Where the argument of $p_r(r)$ and $q_r(r)$ are written in gray code [6]. Note that each "-1" will be replaced by "0". Thus, Hadamard matrix has the property that any row differs from any other row in exactly N/2 positions.

Let $X = (x_0, x_1, x_2, \ldots, x_{N-1})$ and $Y = (y_0, y_1, y_2, \ldots, y_{N-1})$ are two different Hadamard codes having i and j rows respectively . The periodic crosscorrelation is defined by:

$$\theta_{XY}(i,j) = \sum_{c=0}^{N-1} x_c y_c \qquad (2)$$

Let $\overline{X}$ be the complement of the code word X whose elements are $\overline{x_c} = 1 - x_c$, the periodic crosscorrelation between $\overline{X}$, Y is

$$\theta_{\overline{X}Y}(i,j) = \sum_{c=0}^{N-1} \overline{x}_c y_c \qquad (3)$$

for this code , the following conditions are satisfied :

$$\theta_{XY}(i,j) - \theta_{\overline{X}Y}(i,j) = 0 \qquad (4)$$

$$\theta_{X\overline{Y}}(i,j) - \theta_{\overline{X}\overline{Y}}(i,j) = 0 \qquad (5)$$

Achieving these equations prevents the interference of the adjacent subscribers completely i.e., it will lead to an infinite SIR. A proof of these equations is given in the appendix. Equation (4) allows the rejection of the sequence Y while equation (5) states the possibility of the rejection of the sequence $\overline{Y}$. This possibility represents a unique feature of the Hadamard code, where we can use orthogonal signalling in place of the usual ASK formats. This permits to get back the inherent 3-dB loss in the traditional system proposed by [3] as will be shown later.

M-sequence:

It is one of the most used sequences in FE-CDMA systems. We have estimated the performance of the traditional system using this sequence for comparison with what was obtained using our proposed scheme. The m-sequence can be considered one of the different classes of pseudonoise sequence. The length of m-sequence over [0,1] is given by

$$N = 2^{m} - 1 \qquad m = 3,4,5,\ldots \tag{6}$$

Some properties of m-sequence are: (a) The number of m-sequences (versions) of a given length is equal to $\frac{1}{m}\phi(2^{m}-1)$ where $\phi(k)$ is the number of positive integers less than k and relatively prime to k.(b) The number of ones in a sequence is greater than that of zeros by one bit .For a 32 bit code, there are 16 ones and 15 zeros. (c) A modulo-2 addition of m-sequence with a phase shifted replica of itself results in another replica with a phase shift different from either the original [7]. The m-sequence satisfies equations (2), (3), (4) only and a simple software has been used to generate any versions of m-sequence for different lengths.

III-THE TRANSCEIVER CONSTRUCTION

The typical transceiver is shown in Fig. 1.

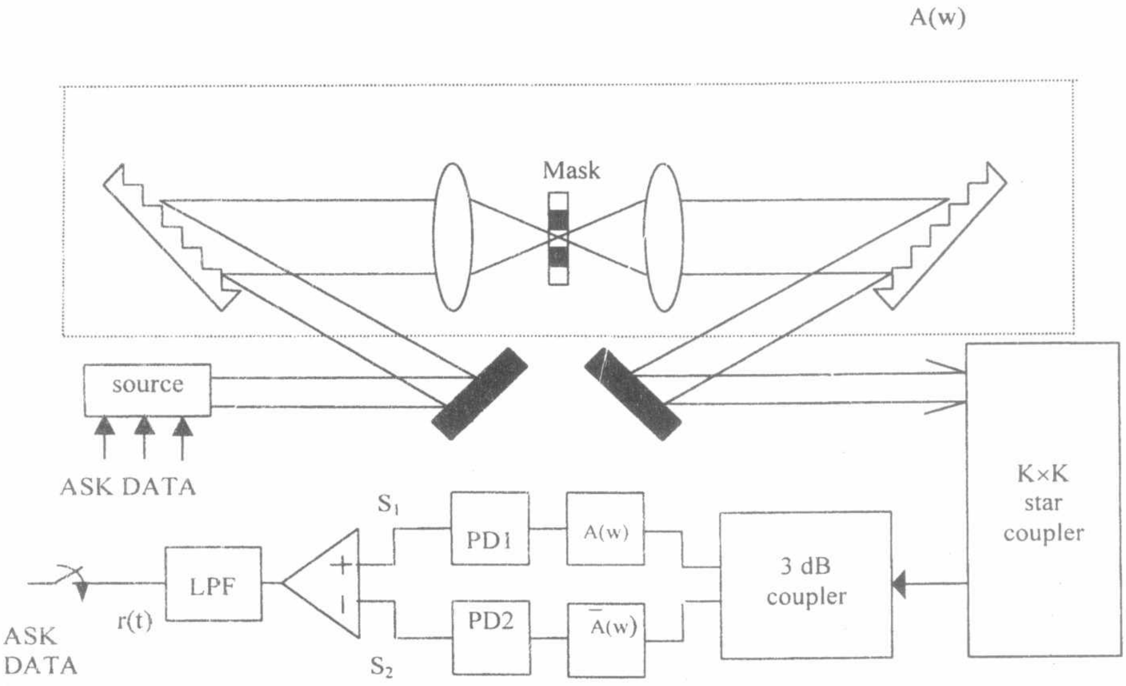

Fig.1. The traditional transceiver system.

The optical source (LED) is intensity modulated according to the incoming binary data then, the optical beam is spatially dispersed within a diffraction grating into optical frequency components.

A nondispersive lens focuses these components. A fixed spatial mask with a certain pattern (for example X) which the transmission through it either "0" or "1". This mask allows the transmission of a certain spectral components and inhibits the others according to its pattern. The second lens and grating reassemble the transmitted spectral components into a single beam, which is sent to all subscribers (receiving ends) via a passive star coupler. The received signals is passed through a 3-dB coupler where there are two arms. The upper arm contains a mask of pattern (X) and the lower one with ($\overline{X}$) pattern. The receiver output r(t) will be either "S" or "0" according to the transmitted data from the corresponding subscriber. If a signal comes from a desired subscriber (with X pattern), then r(t) = S output where the outputs of the upper arm (s_1) and the lower arm (s_2) are "S" and "0" respectively On the other hand, if any other signal comes from undesired subscriber (it would be coded with Y pattern), r(t)= 0 where s_1 and s_2 are identical as equation (4) states.For orthogonal signalling, the same transceiver set will be used except that the traditional mask is replaced with a programmable mask which will be controlled by the information data. The proposed transmitter is shown in Fig. 2.

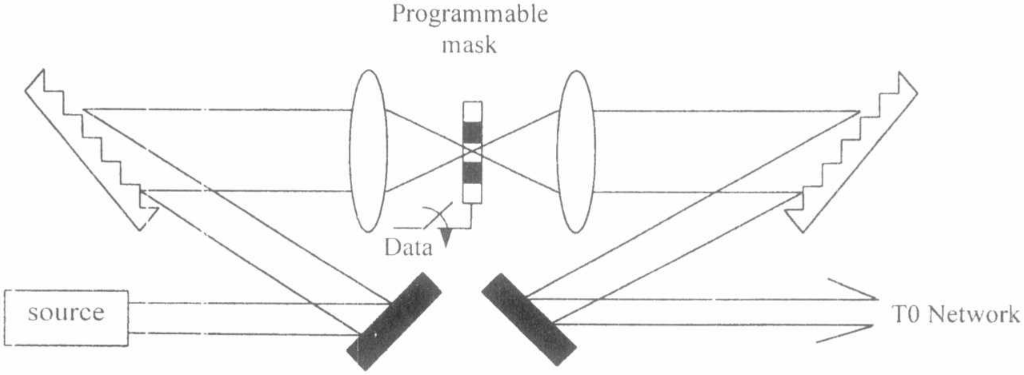

Fig. 2.The proposed transmitter.

In this scheme, the noncoherent optical source will be switched on all the time .The programmable mask will be switched between two states (X) and ($\overline{X}$) according to the transmitted symbols one's and zero's respectively. At the receiving end, for the corresponding subscriber, when symbol one is received, r(t)= S output. On the other hand, when symbol zero is received, r(t)= -S output .So.the difference signal strength between transmitted "one" and "zero" will be 2S. This compensates the 3-dB loss. When any other signal from undesired subscriber will be received, where Y code is used, the output of the receiver will be always zero. This is because equation (4) is valid for symbol "1" while for symbol "0" equation (5) is satisfied and this is achieved only for Hadamard code.The nonflatness of the optical source leads to the loss of the required complete orthogonality. Hence, equations (4)&(5) are not satisfied. This will result in a strong interference from the adjacent subscribers. In general, there are three approaches to minimize the effect of the nonflatness. First, reducing the frequency spectrum length which will be more flatter (near the center of the spectrum). This solution will restrict the number of the used subscribers as well as result in lower performance as it is clear from our calculations in section IV. The second one is to equalize the LED spectrum, up to some degree, by using Acousto-Optical Tunable Filter. This will suffer from power loss which has a bad effect on the detection error probability.

The third approach is using a programmable mask in the form of transparent and nontransparent bar. The mask will take one of two forms, one of them is the complement of the other. This will be our choice. The switching between the two forms will be obtained through using the property of special materials to switch between transparent and opaque state [8]. Available technology allows a switching time less than a nanosecond [9]. This gives a data rate of several megabits. Traditionally, the mask bars are equal in width. Here, we propose an equalization technique where the bar's widths are varied to compensate the nonflatness of the source spectrum. Thus, the result will be the transmission of equal powers through each bar. Let Z be the weighting function which is used to equalize the power incident on each bar of the mask from each corresponding frequency bands of the spectrum. Z can be written as

$$Z_i = \frac{1}{\sqrt{2\pi\sigma}} \int_{x_i}^{x_{i+1}} e^{-f^2/2\sigma^2} \, df \tag{7}$$

where $\sigma = B/2.354$, B is the 3-dB bandwidth of the LED assuming that the spectrum takes a Guassian shape . x_i , x_{i+1} are two arbitrary adjacent positions in the spectrum of the source in which the weighting function remains constants for each bar . For the proposed scheme, the center wavelength of the LED (λ) =1.55 µm, the spectral width being encoded ($\delta\lambda$) = 50 nm , the input beam radius (w) = 3 mm , the grating period (d) = 1/1200 lines / mm , the diffraction angle of the central wavelength for Littrow configuration (θ) = 68° and the focal length of the lens = 15 cm .

For N=32, i.e there are 31 subscribers. Our calculations show that the angular dispersion of the grating = 0.1835° / nm . So, one mm of the mask will span a range of 2.0811nm of the spectrum and this implies that the total length of the mask should be equal to 24.02520447mm. Let us define the width of a certain projected frequency band of the optical source spectrum on the mask by the bar width b_w and the fabrication accuracy of its dimension is Δb_w . For equalization, it gives an almost perfect orthogonality if the used accuracy is of order 10^{-6} nm. This is still challenging with the current technology. Through this mask, the performance of the system has been estimated for different available tolerances of the mask's fabrication.

IV- CALCULATIONS AND RESULTS

We evaluated SIR as an indicator of the system performance for both the traditional and proposed system without and with equalization. For the traditional system shown in fig. 1 and using the first approach as mentioned in the previous section, to show the effect of this approach, let us denote a design parameter which will reflects the scaling of the encoded bandwidth by γ . As γ is increased, the encoded bandwidth will be reduced, when γ =1,the encoded bandwidth will be the 3-dB of the source.

SIR has been done without equalization and it can be estimated using the following formula [5],

$$\mathrm{SIR} = \frac{\left(\sum_{i=0}^{N-1} x_i z_i\right)^2}{\sum_{k=1}^{K}\left(\sum_{i=0}^{N-1} x_i x_{i+1} z_i - \sum_{i=0}^{N-1} \bar{x}_i x_{i+1} z_i\right)^2} \tag{8}$$

The results are shown in Fig.3, 4,5 when γ=1.On Fig. 3. SIR (in dB) is plotted versus the subscriber's order for two different versions of m-sequence of length equal to 31.

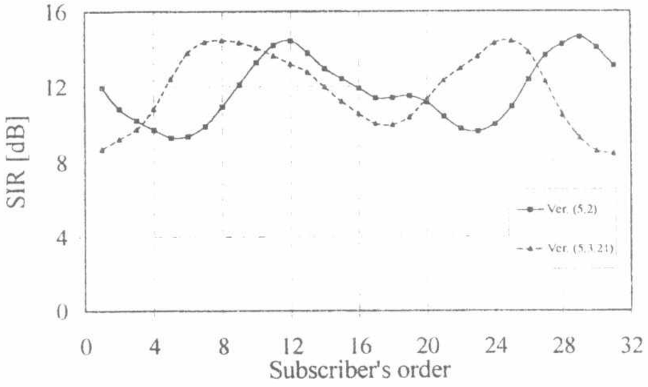

Fig. 3. SIR versus the subscriber's order for two versions of m-sequence when N=31{ (5,2),(5,3,2,1) at γ =1.

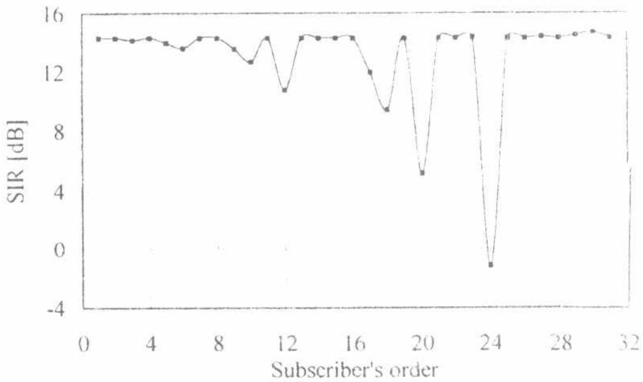

Fig. 4. SIR versus the subscriber's order for Hadamard code of N=32 at γ =1.

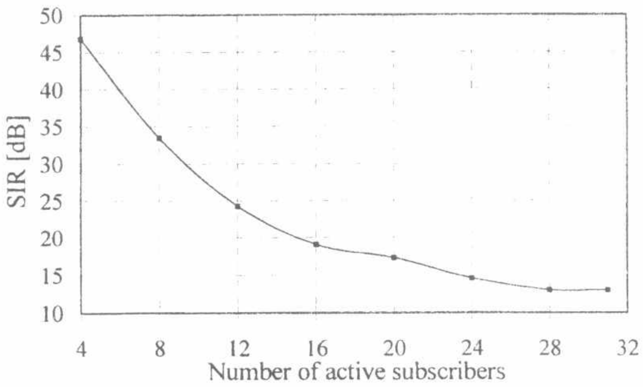

Fig. 5. SIR versus the number of active subscribers for Hadamard code when N=32 at γ =1.

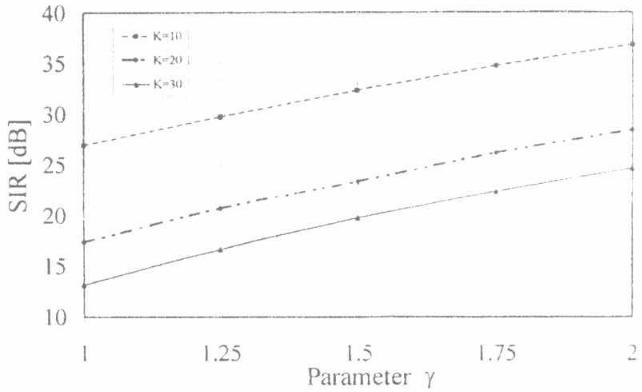

Fig. 6. SIR versus the parameter γ for active subscriber s= 10,20,30

assuming that all the subscribers are active (the worst case). The average SIR (SIR_{av}) is 11.75dB and the maximum variation in SIR between users is 5.33 dB. Another observation is that the SIRs are nearly the same for different versions of the same length. On Fig. 4,SIR is plotted also versus the subscriber's order when using the Hadamard code of length 32 and in the worst case. From this figure, The SIR_{av} is 13 dB and there are 3 subscribers suffering from low SIR and frequently high crosstalk particularly subscriber no. 24 which will be impractical. This is due to presence of 16 consecutive zeros slots around the center of the Hadamard code used by the subscriber no. 24. On Fig. 5,SIR is plotted against the number of active subscribers. As it is expected, the performance of the system decays as the number of active subscribers increase. On Fig. 6, SIR is plotted as a function of γ for different numbers of subscribers. For a certain number of subscribers as γ increases SIR increases but, this improvement of SIR will be on the expense of the required accuracy for the optical mask as well as it increases the detection probability error because the transmitted power of the LED spectrum will be reduced.For the proposed scheme, the new SIR will be written as

$$\mathrm{SIR} = \frac{(\sum_{c=0}^{N-1} x_c(i) z_c)^2 + (\sum_{c=0}^{N-1} \bar{x}_c(i) z_c)^2}{\sum_{k=1}^{K}(\sum_{c=0}^{N-1} x_c(i) y_c(k) z_c - \sum_{c=0}^{N-1} \bar{x}_c(i) y_c(k) z_c)^2 + \sum_{k=1}^{N-1}(\sum_{c=0}^{N-1} x_c(i) \bar{y}_c(k) z_c - \sum_{c=0}^{N-1} \bar{x}_c(i) \bar{y}_c(k) z_c)^2} \quad (9)$$

Given that the symbols of "1" and "0" are transmitted equally likely, i.e., P(1) = P (0) = 1/2 .First when the used mask is divided into equal bars , i.e. without equalization . The results in Fig. 7 show that almost the same as obtained in Fig. 4. The regain of the 3-dB loss in this system has no effect on the SIR but it will be effective in calculations of the detection error probability. Second, for the equalized mask, our design is depending on the different levels of accuracy for fabricated bars dimension, starting from $\Delta b_w = 10^{-1}$ up to 10^{-6} mm whereas this accuracy increases the equalization is improved and SIR tends to infinity. SIR's have been calculated for different degrees of equalization.

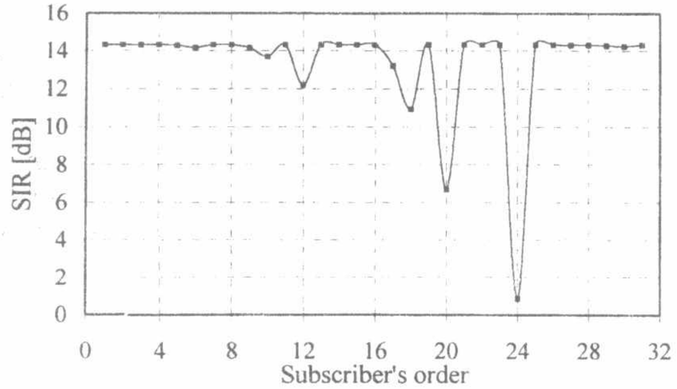

Fig. 7. SIR versus the subscriber's order for Hadamard code when N=32 and without equalization.

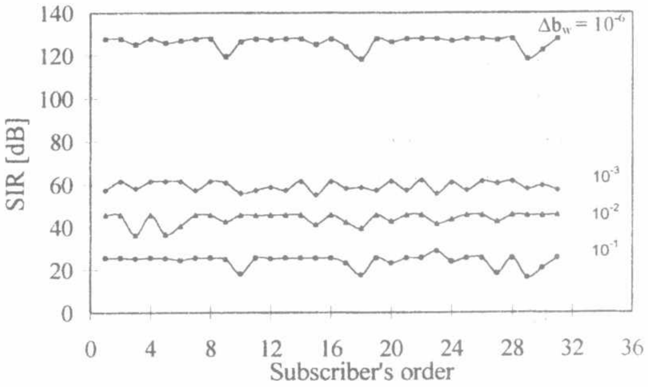

Fig. 8. SIR versus the subscriber's order for Hadamard code when N=32 and with equalization in case of different values of Δb_w .

The results are shown in Fig. 8. The SIR_{av} = 24dB which is nearly double the value of the traditional system in the case of lower accuracy of mask's fabrication (Δb_w = 0.1mm). On Fig. 9., we show the effect of active subscribers on SIR in case of equalization. As expected, SIR's have better values than that obtained in Fig. 5.

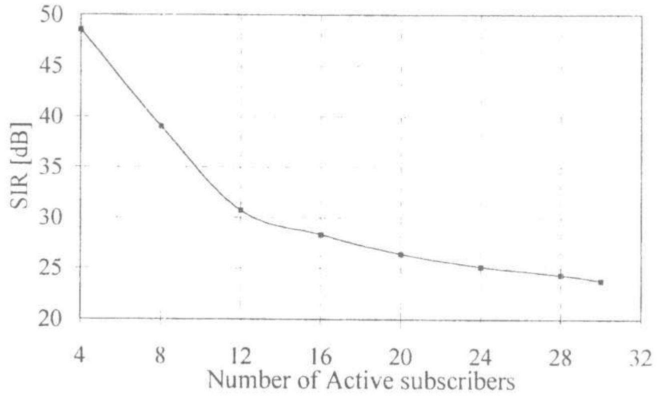

Fig. 9. SIR versus the number of active subscribers for Hadamard code when N=32 with equalization

V-CONCLUSION

Through this work, a modified scheme for FE-CDMA system has been proposed where ASK format is replaced by orthogonal signalling and an equalization technique for the optical mask has been introduced. A significant improvement of the signal to interference ratio (SIR) has been achieved compared to the traditional system. This improvement depends on the degree of tolerance that can be obtained in the mask's dimensions. The detection error probability of the receiver of the proposed system will be also improved as a result of using the orthogonal signalling .The quantitative analysis will be the issue of future work.

APPENDIX

The proof of equation (4) is as follow :

$$\theta_{XY}(i,j) = \sum_{c=0}^{N-1} x_c y_c \text{ which result to } \tfrac{N}{4} \text{ for } i \neq j \text{ and to } \tfrac{N}{2} \text{ for } i = j \;. \qquad (1)$$

The receiver will compute:

$$\begin{aligned}\theta_{XY}(i,j) - \theta_{\bar{X}Y}(i,j) &= \sum_{c=0}^{N-1} x_c y_c - \sum_{c=0}^{N-1}(1-x_c)y_c = 2\theta_{XY}(i,j) - \theta_{XY}(j,j)\\ &= 2(\tfrac{N}{4}) - \tfrac{N}{2}\\ &= 0 \qquad (2)\end{aligned}$$

The proof of equation (5) is as follow:

$$\begin{aligned}\theta_{X\bar{Y}}(i,j) - \theta_{\bar{X}\bar{Y}}(i,j) &= \sum_{c=0}^{N-1} x_c(1-y_c) - \sum_{c=0}^{N-1}(1-x_c)(1-y_c)\\ &= 2\theta_{XY}(i,j) - 3\theta_{XY}(j,j) - N\\ &= 2(\tfrac{N}{4}) - 3(\tfrac{N}{2}) - N\\ &= 0 \qquad (3)\end{aligned}$$

REFERENCES

[1] J.A.Salehi , " Code Division Multiple Techniques in Optical Fiber Networks – part I : Fundamental priciples " , IEEE Trans. Commun. , vol. 37 , pp. 824 - 833, Aug. (1989).

[2] J.A. Salehi and C.A.Brakett , " Code Division Multiple Access Technique in Optical Fiber Networks – part II : System performance " , IEEE Trans. Commun. , vol. 37 , pp. 834 -842 , Aug. (1989).

[3] D. Zaccarin and M.Kavehrad , " Optical CDMA system Based on Spectral Encoding of LED ", IEEE Photon. Technol. Lett. , pp. 479 - 482, Apr. (1993) .

[4] A.M.Weiner et al , " Programmable Shaping of Femtoesecond Optical pulse Shaping by Use of 128 Element Liquid Crystal Phase Modulator ", J. quantum Electron. , Vol. 28, pp. 908-920, Apr.(1992)

[5] M.Kavehrad and D.Zaccarin , " Optical Code Division Multiplexed Systems based on Spectral Encoding of Noncohernt sources " , J. Lightwave Technol. , Vol. 13, pp. 534 - 545, Mar. (1995)

[6] A.Poularikus and s.seely , " Signals and Systems " , PWs publisher , U.S.A , (1995).

[7] R.C.Dixon , " Spread Spectrum System " , John Wiley & Sons (1976).

[8] H.H. Arsenault et al editors," Optical Processing and Comuting", Academic Press, Inc., (1989).

[9] H.A.Mackenzie et al, " The Dynamics of Photonic Switching in Indium Antimonide", Photonic Switching, Proceeding of the First Topical Meeting, (1987).