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Comparison between a conventional receiver (RC) and conventional receiver with limiting device (RC-LO) for a DS-OCDMA link using OOC codes

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Abstract

This article presents the performance of an incoherent optical connection CDMA with direct sequence (DS-OCDMA) by using an orthogonal optical codes (OOC) [1][2]. The influence of the multiple access interference will be studied in the case of a conventional receiver (RC) and Conventional receiver with limiting device (RC-LO).The comparison between both types of receivers enables us to evaluate the performance of the studied system.

*Keyword: Optical CDMA – (DS-OCDMA) - Orthogonal Optical Codes OOC - The Multiple Access interference (MAI) - Conventional receiver (RC) - Conventional receiver with limiting device (RC-LO)***.**

1. Introduction

The technique of optical CDMA allows the resources and data sharing in the optical telecommunications networks in a simultaneous and asynchronous way. The interest of the optical CMDA lies in the use of a broad band-width on the transmission medium which is the optical fiber.

The transmission of the data in a optical CDMA connection can introduce several limitations, like the multiple access interference (MAI).This last is due to the products of non-zero inter-correlation of the codes used.

The optical CDMA is based on the same basic concepts as the CDMA radio frequency: we assign to each user transmitting data through the transmission medium which is consisted of an optical fiber (figure 1), a sequence of signature or code which makes it possible to identify the receiver recipient.

The optical CDMA allows a simultaneous and random access to the network without need of synchronization, as well as a flexibility of routing of information, with an inherent safety of coding.

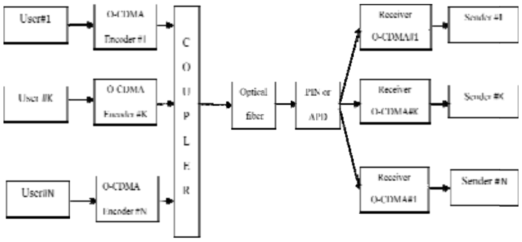

Figure 1 : Synoptic diagram of a CDMA optical transmission

In CDMA technique, the orthogonality of the codes is the significant property to minimize the interferences due to the multiple access of the channel. The Multiple Access interference (MAI) which increases with the number of users and which is related to the properties of inter-correlation of the codes, it is the principal limitation of the performances of an OCDMA system.

The other limitations with the application of the CDMA to optics, certain are due to the nature of the channel (chromatic dispersion), others to the operating of the electronic, optical and optoelectronic components (band-busy, non-linearity, noises of the photo detector, etc.).

2. Incoherent Optical CDMA with Direct Sequence (DS-OCDMA)

In a DS-OCDMA system, the temporal spreading out is performed by multiplying directly a sequence of code signature with the data to be transmitted.

The coded data of each user are sent simultaneously via the same fiber.

In the reception, the multiplexed receiver receives the signal with the sequence addresses of the recipient (code signature) and the desired signal is spread out then formatted via an integrator for decision-making (correlation) (Figure 2).The other signals which do not have the good sequence signature or which are desynchronized are perceived as being noise. This noise which constitutes one of the principal limitations of this technique of access is commonly called the multiple access interference (MAI).

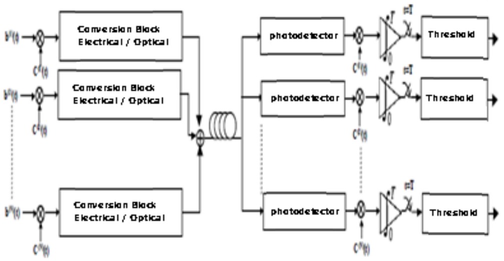

Figure 2: System of transmission DS-OCDMA with electric Coder/decoder **[3][4]**

In an approach of optical CDMA in non-coherent light, we measure the energy of a transmitted signal and not its amplitude and its phase. The optical intensity being a positive or null quantity, the sequences of codes are unipolar sequences, therefore the conditions to satisfy are as follows:

1)- The function of autocorrelation $Z_{C_K C_K}(l)$

$$Z_{C_K C_K}(l) = \sum_{j=0}^{L-1} C_j^{(k)} . C_{j+l}^{(k)} = \begin{cases} W \\ \le h_a \end{cases} \qquad (1)$$

2)- The function of inter-correlation $Z_{C_K C_P}(l)$

$$Z_{C_K C_P}(l) = \sum_{j=0}^{L-1} C_j^{(k)} . C_{j+l}^{(P)} \le h_c \quad \forall l \qquad (2)$$

3. **Orthogonal Optical Codes OOC [1][2]**

The Codes OOC were developed by Salehi in 1989 [1][2]. These codes are composed of unipolar continuations E = {Cj} characterized by four parameters (L, *W*, *ha*, *hc*):

- L is the length of the sequence.
- *W* is the weight of the code, which represents the number of chips with "1".
- *ha*, *hc* are respectively the constraints of auto and inter correlation.

Let x and y representing the sequences of codes used by two users. The condition relating to the auto-correlation is written then:

$$|AC_{xx}(l)| = \left|\sum_{n=1}^{L} x_n . x_{n+1}\right| = \begin{cases} W & pour \quad l=0 \\ \le h_a & pour \quad 1 \le l \le L \end{cases} \qquad (3)$$

The value of n indicates the position of chip of the beginning of the sequence; and the condition of inter-correlation is:

$$|CC_{x,y}(l)| = \left|\sum_{n=1}^{L} x_n . y_{n+1}\right| = \{\le h_c \quad pour \quad 0 \le l \le L \qquad (4)$$

Let us consider L $_{\min}$ and N $_{\max}$ as being, respectively, the minimal length of a sequence of code OOC and the maximum number of users who is possible to multiplex by the same family of code. These two values are determined by the equations according to:

$$L_{\min} \ge N.x\left(\frac{2x^2}{x+1} - 2W + x + 1\right) + \frac{2W}{x+1} - 1 \quad avec \quad 0 < x < W - 1 \qquad (5)$$

$$N_{\max} \le \left\lfloor \frac{L-1}{W(W-1)} \right\rfloor \qquad (6)$$

The symbol $\lfloor x \rfloor$ represents the lower integer value to x. The demonstrations of these two expressions are detailed in [**5**]. It should be noted that the precedents equations are also valid for the traditional OOC [**1**], with the condition of taking in the precedent equation a value of $X = W - 1$, which gives:

$$L_{\min} \ge N.W.(W-1) + 1 \qquad (7)$$

4. The Systems of Reception of an Optical Connection CDMA to Sequence Direct (DS-OCMA)

4.1 Conventional Receiver (RC) [6]

If we use a conventional receiver for the reception, the decoding part of the DS-OCDMA system is carried out by correlation, designating the user to carry out this operation, by supposing that the user n°1 is the desired user (figure 6).

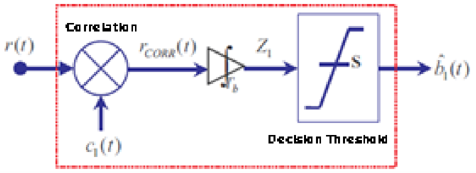

Figure 6 : Diagram of a conventional receiver of the user n°1

The received signal r*(t)* is multiplied by the code of the desired user $C_1(t)$:

$$r_{corr}(t) = r(t).C_1(t) = \left(\sum_{K=1}^{N} b_K(t).C_K(t)\right).C_1(t) \quad (8)$$

$$r_{corr}(t) = b_1(t).C_1(t) + \sum_{K=2}^{N} b_K(t).C_K(t).C_1(t) \quad (9)$$

The signal $r_{corr}(t)$ is then integrated over a time bit T_b in order to obtain a variable of decision Z_1 which is compared with the value of the threshold S of the comparator. At exit, the decided data is $\hat{b}_1(t)$.

$$Z_1^{(i)} = \int_0^{T_b} b_1^{(i)}.C_1(t)dt + \sum_{K=2}^{N} b_i^{(K)}(t).\int_0^{T_b} C_K(t).C_1(t)dt \quad (10)$$

$$Z_1^{(i)} = W.b_1^{(i)} + \sum_{K=2}^{N} b_i^{(K)}(t).\int_0^{T_b} C_K(t).C_1(t)dt \quad (11)$$

If the desired user n°1 sends a data $b_i^{(1)} = 1$, the decisional variable $Z_1^{(i)} = W + I_1$ such as:

$$I_1 = \sum_{K=2}^{N} b_i^{(K)}(t).\int_0^{T_b} C_K(t).C_1(t)dt \quad (12)$$

The term of multiple access interference (MAI) takes any positive or null value according to the values of the data of the other users $b_i^{(K)}$ and of inter-correlation $\int_0^{T_b} C_K(t).C_1(t)dt$

Thus we can conclude that. $Z_i^{(1)} \geq W$, By taking a rule of decoding such as:

$$\begin{cases} si \quad Z_i^{(1)} \geq S \Rightarrow \hat{b}_i^{(1)} = 1 \\ si \quad Z_i^{(1)} < S \Rightarrow \hat{b}_i^{(1)} = 0 \end{cases} \quad (13)$$

We cannot make error of decision on $\hat{b}_i^{(1)}$ when $b_i^{(1)} = 1$ with the condition of having $W \geq S$

If the desired user sends a data $b_i^{(1)} = 0$ the decisional variable $Z_i^{(1)} = I_1 \geq 0$, according to the preceding rule of decoding we can make an error on if $Z_i^{(1)} = I_1 \geq S$ in this case and this more especially as the value of the threshold S is small.

As S is limited to the maximum by the weight W, we can thus conclude that the optimal threshold of the conventional receiver is S = *W.*

In order to better include/understand the impact of the multiple access interference (MAI), we illustrate the procedure of reception in the next figure (Figure 7) for a code OOC of weight W=3 and *ha = hc=1.*

The desired user n°1 sends two bits of 1 data ($b_2^{(1)}$ $b_1^{(1)}$) and two bits of 0 data ($b_4^{(1)}$ $b_3^{(1)}$). The bits are coded and summed with those of the not-desired users. The part of the optical transmission being ideal, the signal summed *e(t)* is the signal received *r(t)* at the entry of the conventional receiver.

The signal r*(t)* is then multiplied by the code $C_1(t)$ of the desired user then integrated over time bit in order to obtain the decisional variable.

Thus whatever is the level S of the threshold of the comparator such as S $\leq W$, the decided data $b_1^{(i)} = 1$, In this case, we do not make an error.

On the other hand, when $b_1^{(i)} = 0$, the next figure (Figure 7) present two examples of interferences:

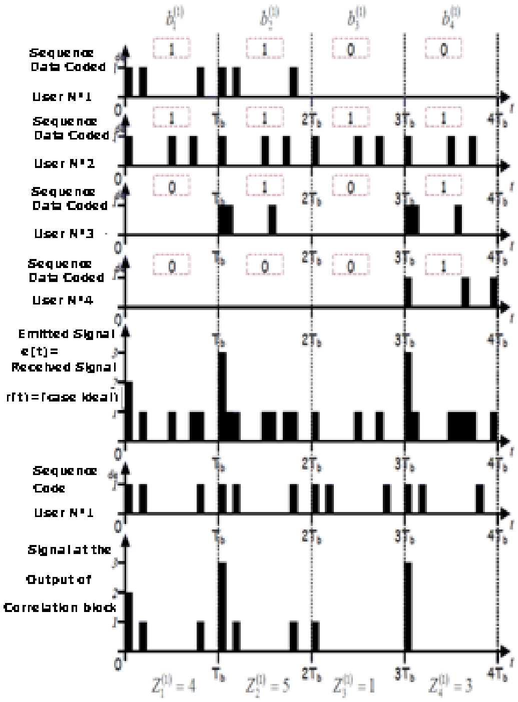

Figure 7: Procedure of emission and acceptance of a DS-OCDMA system for a receiver conventional

- A non desired user (n°2) sends in common has a chip with the user n°1; that led $Z_3^{(1)}$ = 1.
- Three non desired users (n°2,3 and 4) in common send a chip with user 1; that led to $Z_4^{(1)}$ = 3.
- In this case, according to the value of the threshold S, one will have:
- if S=1 : $Z_3^{(1)} \geq S$ and $Z_4^{(1)} \geq S \Rightarrow b_3^{(1)}=1$ and $b_4^{(1)}=1 \Rightarrow$ 2 errors
- if S=2 : $Z_3^{(1)} < S$ and $Z_4^{(1)} \geq S \Rightarrow b_3^{(1)}=0$ and $b_4^{(1)}=1 \Rightarrow$ 1 errors
- if S=3 : $Z_3^{(1)} < S$ and $Z_4^{(1)} \geq S \Rightarrow b_3^{(1)}=0$ et $b_4^{(1)}=1 \Rightarrow$ 1 errors.

Even while being placed under the optimum conditions for decision-making (S=W), the multiple access interference can involve errors on the data $b_1^{(i)} = 0$ of the desired user. By using a limiting device at the entry of the receiver, we can reduce the number of these errors.

4.2 Conventional Receiver with Limiting Device (RC-LO) [7]

In order to reduce the error count on a data $b_1^{(i)} = 0$**,** we can limit to the entry of the system of reception the level of the interference due to the not-desired users while placing a component which limits the received power. It is an optical component called «hard- limiter» whose ideal function is defined by:

$$g(x)=\begin{cases} 1 & x \geq 1 \\ 0 & 0 \leq x < 1 \end{cases} \qquad (13)$$

We consider that the effect of this component acts as a normalization of the electric signal amplitude received r(t):

The amplitude of each impulse or chip of duration T_C is chopped with value 1. That means that the contribution in amplitude on a chip, due to the not-desired users whose codes have chip considered in common with the wished user, will be brought back to value 1, therefore the term of interference I_1 will be thus reduced.

Let us take again the preceding example (Figure 8) and examine the detection of transmitted data 0 ($b_3^{(1)}$ and $b_4^{(1)}$). It is noted that as the 3 not-desired users have in common the chip n°0 their codes respective with the wished user, the value of the interference I_1 is reduced to 1.

In this particular case, the errors all are eliminated, if the threshold S is optimal (S = W = 3). However, the codes of the not-desired users can in common have chips with the desired user all with different positions. In this case, the interference I_1 can reach the maximum value W and lead to errors of decisions on $b_i^{(1)} = 0$.

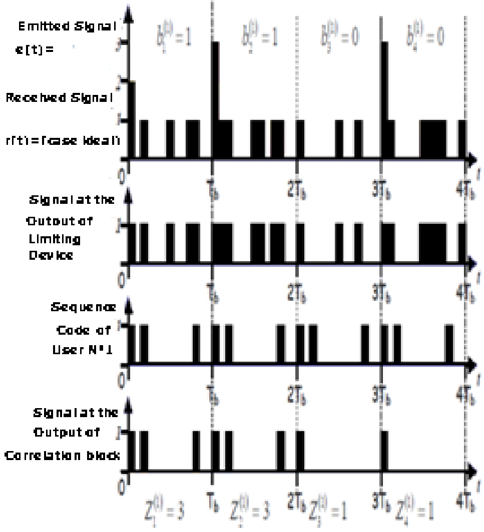

Figure 8 : Application of an optical limiting device in front of the conventional receiver

5. Results of Simulation

It is considered that the degradation of the performances is due only to the effect of the interference of the multiple access (MAI).The calculate of Probability of error (TEB) takes in account the parameters according to:

- The desired user and the user n°1.
- Transmission of the data b_i is equiprobable.
- All the users have the same power in reception.

The N users of the system have the same flow of data D and are spread out by codes OOC (L, W, 1,1).

After calculation, and by using the precedents formulas, thus we obtain the probability of error (TEB) of a conventional receiver (RC) for the synchronous DS- OCDMA system **[7]**:

$$P_{erc} = \frac{1}{2}\sum_{i=S}^{N-1} C_{N-1}^{i}\left[\frac{W^2}{2L}\right]^{i}\left[1-\frac{W^2}{2L}\right]^{N-1-i} \qquad (14)$$

The same step is used for finds R the probability of error of a conventional receiver with optical limiting device (RC-LO) for the system DS-OCDMA synchronous **[7]** :

$$P_{erc-Lo} = \frac{1}{2}\, C_W^S \prod_{i=0}^{S-1}(1-q^{N-1-i}) \qquad (14)$$

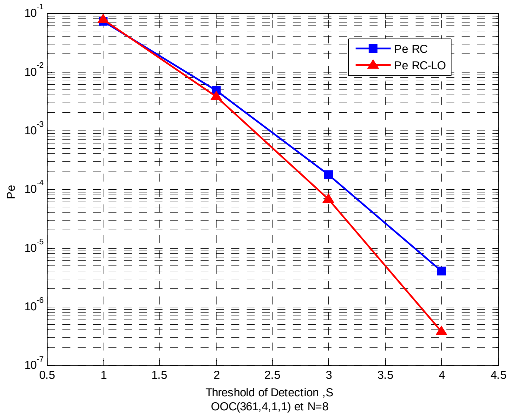

Figure 9: Probability of error P_{erc} and P_{erc-lo} according to the threshold S for code OOC (361, 4,1, 1)

The Figure 9 represents the probability of error for the R conventional receiver (RC) and for R conventional receiver with optical limiting device (RC-LO) according to the threshold of the comparator for code OOC (361, 4, 1,1) with N = 8 users.

It is noticed that the optimal threshold of the conventional receiver with limiting device is unchanged (S=W=4) since the limiting device does not modify the nature of the receiver. It only makes it possible to eliminate certain patterns from interference.

For the case S=1, the two curves of error P_{erc} and P_{erc-lo} are confused, thus the limiting device does not have any effect for this case.

When the threshold S increases and the number of possible patterns for interference generating an interference I_1 equal to S increases (C_W^S), the use of an optical limiting device makes it possible to reduce the number of these patterns by limiting the value of the interference to 1. We thus notes an improvement of the performances with the conventional receiver with limiting device (RC-LO) compared to the conventional receiver (RC) all the more large as S is large.

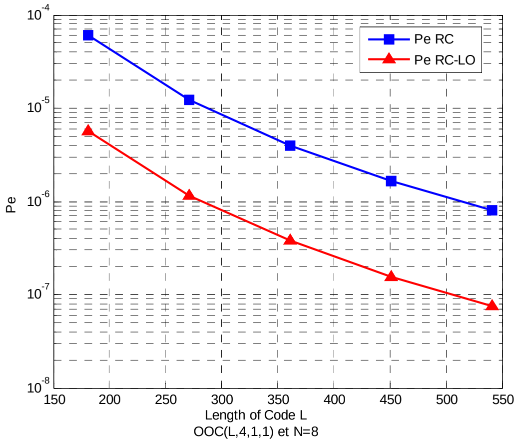

Figure10: The Probability of error P_{erc} and P_{erc-lo} according to the length of the code for OOC (L, 4, 1, 1).

We now compares the two types of receiver S, while varying the length L of code OOC (L, 4, 1,1) for the optimal threshold S = W = 4.We seeks the probability of error P_{erc} and P_{erc-lo} according to the figure above, the receiver with limiting device RC-LO improve the performances compared to conventional receiver RC whatever is the length of the code.

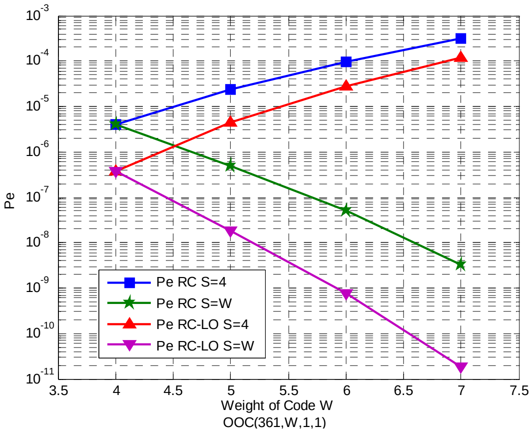

Figure 11: Probability of error P_{erc} and P_{erc-lo} according to the weight of code for one OOC (361, W, 1,1)

Figure 11 above represents the probability of error for the two receivers according to the weight of code OOC (361, W, 1,1) for a number of N=8 users. The conventional receiver with optical limiting device improves the performances whatever is the weight W.

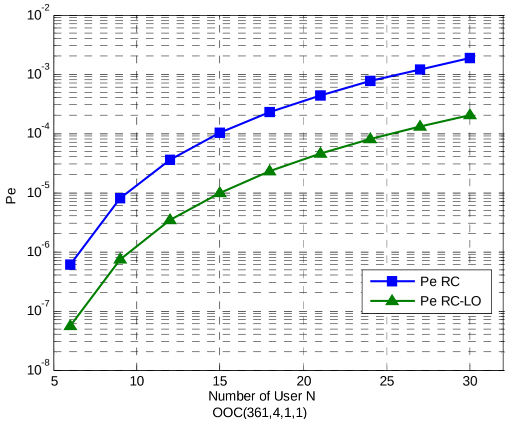

Figure 12: Probability of error P_{erc} and P_{erc-lo} according to the number of users N for OOC (361,4,1,1)

Figure 12 represents the probabilities of error P_{erc} and P_{erc-lo} according to the number of users N for a code OOC (361, 4,1,1).In the two cases, the probability of error increases with the increase of the number of users because of the multiple access interference (MAI).We note that the use of conventional receiver with optical limiting device improves the performances without all the cases.

	conventional receiver (RC)	conventional receiver with optical limiting device (RC-LO)
(L,W)	(1081,9)	(181,4)

The evaluation of the minimal code allowing the obtain of a factor of quality lower than 10^{-9} will be a factor determining in the comparison of the two type of receiver RC and RC-LO

The results are deferred on the table below:

Tableau 1: Minimal codes for one RC and RC-LO with one Q $<10^{-9}$.

N	**RC (L,W)**	**RC-LO (L,W)**
10	(561,8)	(421,7)
15	(1081,9)	(631,7)
20	(1441,9)	(1121,8)
25	(1801,9)	(1401,8)
30	(2161,9)	(1681,8)

According to the table above, we note that the use of a limiting device makes it possible to release the constraint over the length of the code L for a number of users N and a given performance.

However, for the specifications of the optical systems, the constraint over the length L is still not easily realizable.

5. Conclusion

The objective of this study is to minimize our work and to decrease the effect of the multiple access interference (MAI) which presents like a limitation on the data transmission of a DS-OCDMA system. For that we made a comparison between two different systems of reception; a conventional receiver (RC) and a conventional receiver with optical limiting device (RC-LO).

In each case, the error rate (BER) is evaluated according to the length of the code L, of the weight W of the code and number N of users. The results presented showed that:

$$\text{BER (RC)} > \text{BER (RC-LO)} \quad (15)$$

Thus, if we compare the structures for an error rate of reference BER=10^{-9} and for a number of users N=15, we obtain:

We can conclude that the use of a conventional Receiver with optical limiting device (RC-LO) allows us to improve the performances of a system DS-OCDMA.

To still improve the performances of detection, one can apply a method of cancellation of interference, developed for the radio CDMA systems.

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