Parallel Interference Cancellation in DS-OCDMA System Using Novel Multilevel Periodic Codes

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Abstract— **In this paper, we introduce the optimization of Bit Error Rate (BER) in parallel cancellation of multiple access interference (PIC) using a novel periodic optical encoder applied to fiber-to-the-X (FTTX) passive optical network (PONs) with a direct sequence optical code division multiple access (DS-OCDMA) system. The principle of this structure of receiver consists to reduce the output error in the data received. The performance of our system is analyzed in a synchronous network using multilevel periodic codes (ML-PC) and the results are compared with those for different receivers.**

Keywords- direct-sequence optical code-division multipleaccess (DS-OCDMA); fiber-to-the-X (FTTX); passive optical network (PONs); multilevel periodic codes (ML-PC); parallel interference cancellation (PIC).

I. INTRODUCTION

Direct-sequence code-division multiple access (DS-CDMA) [1] is currently the subject of much research as it is a promising multiple access capability for third and fourth generations mobile communication systems.

In Direct Sequence transmission, the user data signal is multiplied by a code sequence. Mostly, binary sequences are used. To obtain better performance than those obtained by the detection single-user, multiuser detection has been investigated for links OCDMA [2][3].

Indeed, this type of detection, already used for the radio CDMA has proven its efficacy in reducing the impact of interference on performance [4].

The advantage of the multiuser detection over single-user detection is the knowledge of codes of undesired users that evaluates more precisely the interference present in the received signal. Consequently, the data are better detected.

In this paper, we present a parallel cancellation method (called PIC) developed for radiofrequency systems, applied to the direct sequence optical CDMA system, the spreading codes considered here are achieved with a new periodic coding scheme [5], that has been previously proposed for FTTX monitoring, and to the best of our knowledge never explored for data coding/decoding. The receiver studied here is constituted by a limiter optical device placed in front of a PIC structure.

Our study is done when the direction of data transmission is the uplink direction, from Optical Network Unit (ONU), to Optical Line Termination (OLT). Using the DS-OCDMA technique for the upstream, would provide necessary bit rate, dispensing of synchronization for this track. The bit error rate (BER) performances were reported in the case of an optical synchronous incoherent DS-OCDMA system using multilevel periodic codes (ML-PC) when applied to FTTX-PON architecture.

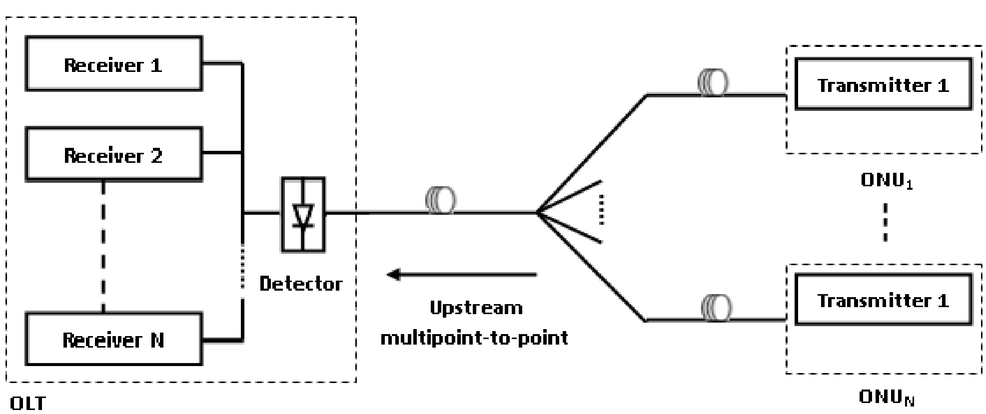

Figure 1. Direct Sequence OCDMA system

In this paper we compared the efficacy of the receptor PIC with the conventional correlation receiver (CCR), and then with their amelioration which is the parallel interference cancellation with an optical limiter (called HL+PIC), we deduce the superiority of HL+PIC structure not only in performance but also in regards to feasibility.

This paper is organized as follows: In the second section, we present the description of the DS-OCDMA system. In the third section we introduce the principle of the parallel interference cancellation structure and their improvement. In the fourth section, we evaluate the performance of the proposed system through the bit error rate (BER).

II. SYSTEM MODEL

In a DS-OCDMA system, users transmit binary data equiprobable and independently in an optical fiber. Differentiation of users is done by multiplying the data by a code (Figure 1). This code should be specific to each user, so that we can extract the data by comparing the received signal with the desired user code.

The codes studied in this paper are the multilevel periodic codes (ML-PC) [5], which are determined by the length of the silent intervals separating the multilevel pulses, i.e, its period. The codes length of the i^{th} customers (l_{ci}) is related by the silent period between the subpulses and is given as:

$$l_{ci}=p_i w T_s c \quad (1)$$

where c is the speed of light, $p_i=l_i/cT_s$ is an integer number that determines the length of the i^{th} encoders ring l_i, Ts is the transmitted pulse duration and w is the weight of the code (c_i).

In DS-OCDMA system the data of active users are spread by multiplication with the code sequence, and at the output of the encoder the k^{th} user signal is obtained as:

$$S_k(t)=a_k b_k(t) c_k(t) \quad (2)$$

a_k The power level at the output of encoder and b_k is the data transmitted by the k^{th} user. In the case of multilevel periodic codes (ML-PC), the total power for any code with weight [4] is:

$$P_t = \sum_{j=1}^{w} \rho_j \quad (3)$$

ρ_j is the j^{th} subpulse power level generated by the encoder. The first subpulse power level ρ_1 is equal to $\rho_1=s^2$. . For j=2,…., the level of ρ_j can be derived as:

$$\rho_j=(1-s)^2 s^{j-1}+(1-s)\,\rho_{j-1} \quad (4)$$

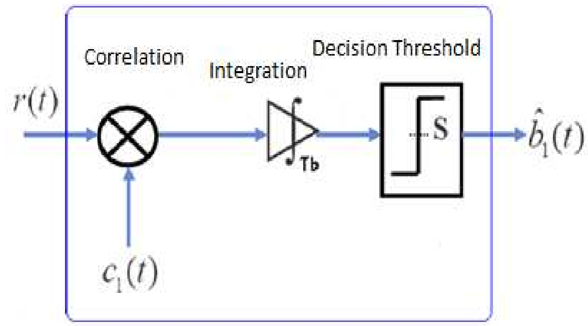

Figure 2. Conventional Correlation Receiver for user 1

s is the power coupling ratio which determines the amount of power coupled to the ring encoder proposed in [5]. It was shown in [5] that the interval of s between 0.5 and 0.6 gives good distribution for the power between the subpulses with cumulative power that depends on the weight w.

Finally, at the input of the receiver, the signal S(t) is the superposition of signals transmitted by the N users:

$$S(t) = \sum_{k=1}^{N} S_k(t-\tau_k) \quad (5)$$

A) *Principle of conventional correlation receiver*

The conventional correlation receiver (CCR) is the simplest receiver in a DS-OCDMA system, the principle of this receiver is the estimation of the power contained in the chips unit code, to compare thereafter to the decision threshold. It provides three functions:

- Multiplying the received signal by the code of the desired user. This step, equivalent to the realization of a mask between the received signal and the code sequence, can retain only the power present in the chip unit code,
- Integration of the signal obtained on the bit time: This step evaluates the total power present on the signal previously obtained during the interval of a bit time. This step provides the value of the decision variable.
- Decision making by comparison to a threshold: comparing the decision variable with the decision threshold used to obtain the estimated data.

Assuming that the user # 1 is the desired user, the decoding part of the DS-OCDMA system is performed by correlation (Figure 2).

B) *Principle of parallel interference cancellation receiver*

In a structure with parallel cancellation, all undesired users are detected at the same time using the conventional receiving systems.

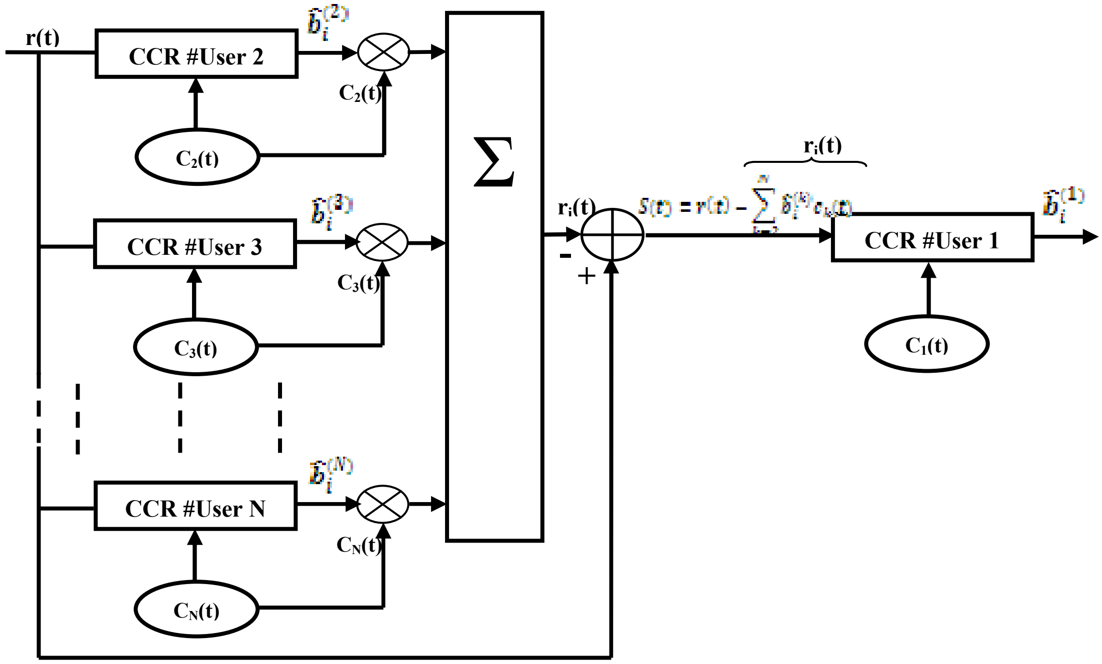

Figure 3. Schematic of the PIC receiver

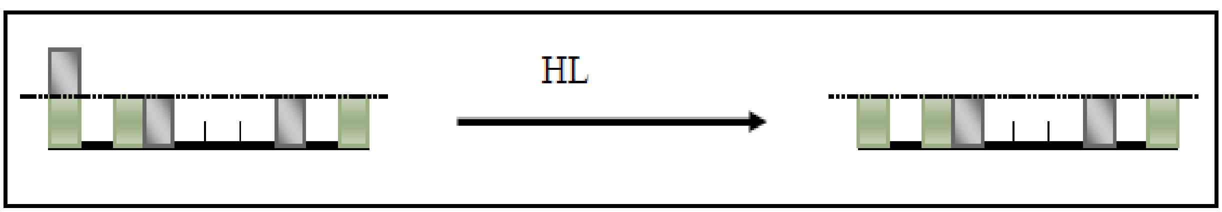

Figure 4. Effect of Hard Limiter on an example of received signal

The parallel interference cancellation receiver has the principle of the reproduction interference from undesired users, to remove it from the total received signal (Figure 3). The PIC requires several steps:

- The detection of data sent by each undesired user is done by the conventional correlation receiver (CCR) with a detection threshold "S_t", at the output of each receiver, we obtain the estimation $\hat{b}_i^{(k)}$ of the data sent by the undesired user # k,
- The second step is to reconstruct the signals transmitted by undesired users by multiplying the estimated data $\hat{b}_i^{(k)}$ by the corresponding code $c_k(t)$,
- We obtain in the third step, the interference term $r_i(t)$ which is actually the sum of the reconstructed signals, then it is subtracted from the received signal r (t): $S(t) = r(t) - r_i(t)$ and as, $r_i(t) = \sum_{k=2}^{N} \hat{b}_i^{(k)} c_k(t)$, then:

$$S(t) = r(t) - \sum_{k=2}^{N} \hat{b}_i^{(k)} c_k(t) \tag{6}$$

- The last step is the detection of the desired user data # 1 from the signal "cleaned" from the interference S(t). This detection is done through a CCR with a decision threshold S_f.

C) Amelioration

1) Principle of hard limiter (HL)

The ideal function of the component called "Hard Limiter" (HL) is defined by:

$$g(x)\begin{cases}1 & x \geq 1 \\ 0 & 0 \leq x < 1\end{cases} \tag{7}$$

In practice, this component removes a part of the received power to get at the end a signal which each chip contains a power equal 0 or 1. For example, in Figure 4, we observe that the HL removed a part of the power contained

in the first chip, and left unchanged the rest of the signal. Indeed, the power contained in the first chip of the received signal has a value of 2, while the one in the same chip after the action of HL is 1.

Thus, the HL has eliminated a part of the interference contained in the first chip. On the other side, the chips containing a power equal to 1 before the HL remain unchanged, and those for which the power was zero. As a result, levels 0 and 1 will be unchanged, and levels greater than 1 will be reduced to one. This limitation of the power in each chip reduces the interference, and removes some interference patterns leading to an error.

2) HL+PIC

To improve the performance of the PIC, the detection of undesired users can be achieved by a HL + CCR receiver. Thanks to the limiters placed before the receivers of the undesired users, the data are therefore better estimated so the contribution of these users in the received signal is better evaluated.

III. PERFORMANCE EVALUATION

We will present in this section the algorithm used in our simulation and we will analyze the results.

A) Numerical simulation

At the transmitter of the DS-OCDMA channel, we begin by the generation of periodic codes and then the random generation of bits sent by each user and random selection of N active users among users of the family, afterwards the step of the spreading is done by multiplying the data of the desired user by the corresponding code, subsequently the spreading of data of the undesired users and adding their contribution to the signal of the desired user. Finally, we sum the encoded data and transmit over a channel assumed to be ideal.

At the receiver, we will follow the different stages of the parallel interference cancellation structure described in Section II, and to analyze the performance of this structure multi-user, we will compare it with another receiver such as, the conventional correlation receiver (CCR), and the CCR improved by adding an optical limiter (known as Hard Limiter), and then the improved of PIC (HL+PIC).

B) Analysis of results

The simulation has been carried out in MATLAB to evaluate the BER performance for the parallel interference cancellation (PIC) and compared it with other receivers (CCR, HL+CCR, HL+PIC).

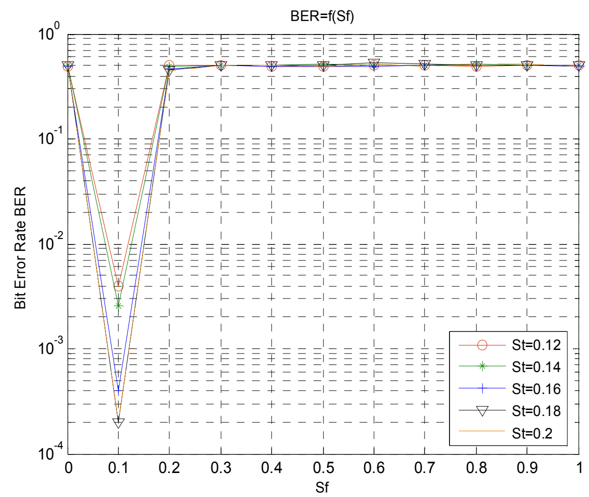

Figure 5. BER versus decision threshold of the undesired users Sf using ML-PC, N=6 Users

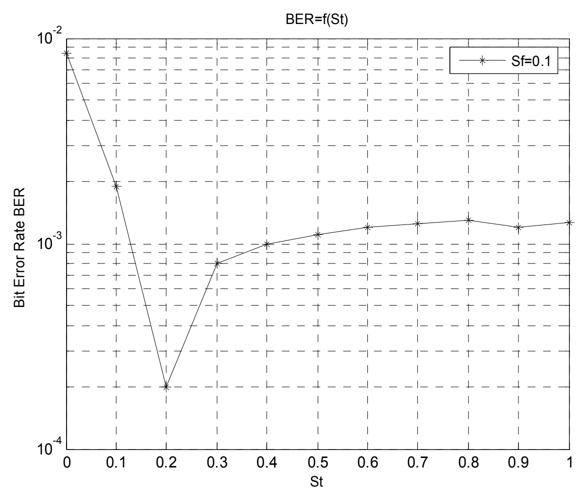

Figure 6. BER versus decision threshold of the desired users St using ML-PC, N=6 Users

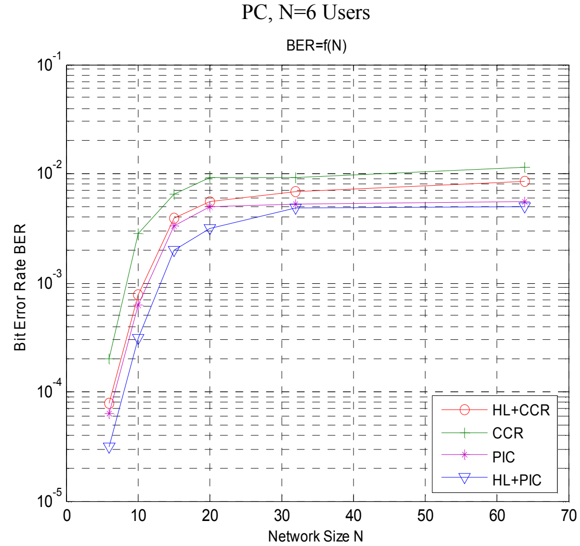

Figure 7. BER versus the network size N

So we must first determine the optimal thresholds (S_t: optimal threshold of the desired user, S_f: optimal threshold of the undesired users) of the PIC receiver.

In Figure 5, we plotted the evolution of the BER of the PIC receivers with ML-PC codes with period p_i, weight w=5, s=0.4 and N=6 users. This performance was evaluated as a function of the S_f and varying S_t between 0.12 and 0.2. From this presentation, we can observe that the best performance is obtained for a decision threshold S_f = 0.1 whatever the value of S_t.

Now, we will fix the value of S_f at 0.1 and we will present in Figure 6, the variation of BER as a function of S_t with the same ML-PC code and N=6 users. So we can look that the best performance is achieved when S_t = 0.2.

We can conclude that the two optimal thresholds are:

- The optimal threshold of the desired user: S_t=0.2,
- The optimal threshold of the undesired users: S_f=0.1,

We worked with the two optimal threshold estimated in the previous figures, and we plotted the variation of the BER as a function of the network size N (Figure 7), with the same ML-PC code. First, we can see that the performance of the four receivers degrade when the number of users increases, but does not exceed $2*10^{-2}$ and that thanks to the use of periodic codes.

Furthermore, we observe that for a given code, the PIC allows a number of active users more important than the CCR or HL+ CCR. Indeed, for a ML-PC code (with period p_i, w = 5 and s = 0.4) and BER = $5.5*10^{-2}$, the PIC allows 64 simultaneous users to communicate, while the CCR and HL+CCR allow only 20 users at most, to be active on the network.

By comparing the four receivers, one can conclude that the best performances are obtained when we work with a HL+PIC receiver and here the BER can achieve $3.125*10^{-5}$ for N = 6 users.

IV. Conclusion

In this paper, we investigated the multi-users detection with the parallel interference cancellation (PIC) structure by comparing it with their amelioration (HL+PIC) and other receivers (CCR and HL+CCR), using a novel coding scheme so called multilevel periodic coding (Ml-PC) for DS-OCDMA system. We studied the characteristics of these codes and investigated their performance in BER. We derived the values for an optimum threshold that minimizes the bit error rate when we use the PIC receiver. In our system, we can achieve almost a BER = $3.125*10^{-5}$ for N = 6 users.

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