Performance Analysis of DS-OCDMA Using Novel Multi-level Periodic Codes

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Abstract: **In this paper we present a theoretical simulation that evaluate the performance of direct-sequence optical code-division multiple-access (DS-OCDMA) system, using a novel periodic optical encoder applied to fiber-to-the-X (FTTX) passive optical network (PONs). We investigate the performances in terms of signal to noise ratio (SNR) and bit error rate (BER) in the presence of multiple access interference (MAI) and an additive white Gaussian noise (AWGN). Three groups of parameters were considered in this work: the number of users, the parameters related to the encoder and the parameters of the receiver.**

Keywords: direct-sequence optical code-division multiple-access (DS-OCDMA), fiber-to-the-X (FTTX), passive optical network (PONs), periodic optical encoder.

I. INTRODUCTION

Among all the different means of high capacity networks, optical code division multiple access (OCDMA) has received significant attention in recent years because of its several attractions such as asynchronous multiple users access, privacy and security in transmission [1].

OCDMA techniques allow numerous signals from different users to occupy the same single mode optical fiber transmission channel, optimizing the use of the wide available bandwidth. The key components of OCDMA systems consist of the encoder and the decoder that perform all-optical code generation and data recognition, respectively.

A code or sequence of pulses referred to as "chips" is attributed to each user to encode its data bits. The encoded data are then broadcasted into the network and are only recognized by the matched decoder. Depending on the coding approach, various OCDMA technique implementations have been proposed. These are temporal encoding, which is also known as direct-sequence encoding (DS-CDMA) [2], spectral phase and/or amplitude encoding [3], [4], two-dimensional (2-D) encoding [5], and hybrid encoding [6].

Most encoders/decoders of the OCDMA systems are implemented with fiber Bragg gratings (FBGs) because of their ready integrability, compactness, and low fabrication cost. In the direct detection DS-OCDMA system considered here, the encoder is achieved with a new periodic coding scheme [7], that has been previously proposed for FTTX monitoring, and to the best of our knowledge never explored for data coding/decoding.

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.

In the work reported here, we focus our attention on the signal to noise ratio (SNR) and bit error rate (BER) performances of the DS-OCDMA system, whereas we studied the effect of the parameters of the receiver used and the size of the network, on the system performance when applied to FTTX-PON architecture.

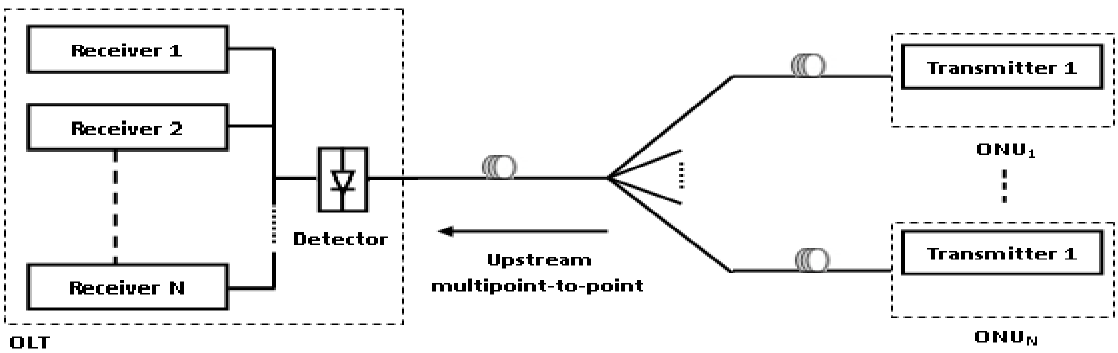

Figure 1: Direct Sequence OCDMA system

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 multilevel periodic codes and their properties. In the fourth section we evaluate the performance of the proposed system through the signal to noise ratio (SNR) and the bit error rate (BER), assuming additive white Gaussian noise (AWGN) channel.

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 (Fig. 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) [7], 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 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, and T_s is the transmitted pulse duration.

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. In the case of multilevel periodic codes (ML-PC), the total power for any code with weight w [7] 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,….,w the level of ρ_j can be derived as:

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

s is the power coupling ratio which determines the amount of power coupled to the ring encoder proposed in [7]. It was shown in [7] 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)

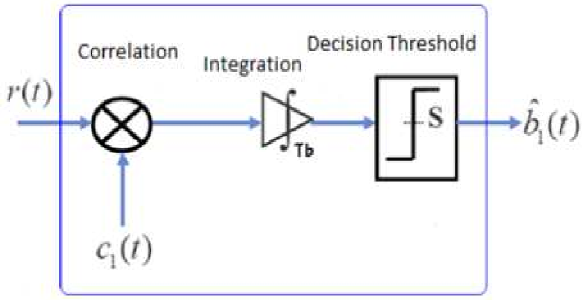

Figure 2: Conventional Correlation Receiver for user 1

is the superposition of signals transmitted by the N users:

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

At the 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 (Fig. 2).

We will study the impact of noise on the performance of a DS-OCDMA system using periodic codes by analyzing the CCR receiver in absence of noise and then in the presence of this imperfection:

1st case: In the synchronous case (τ_k = 0) and ignoring the noise term, the only limitation is the multiple access interference (MAI). In this case the received signal r(t) is given by the following relationship:

$$r(t) = \sum_{k=1}^{N} a_k b_k(t) c_k(t) \quad (6)$$

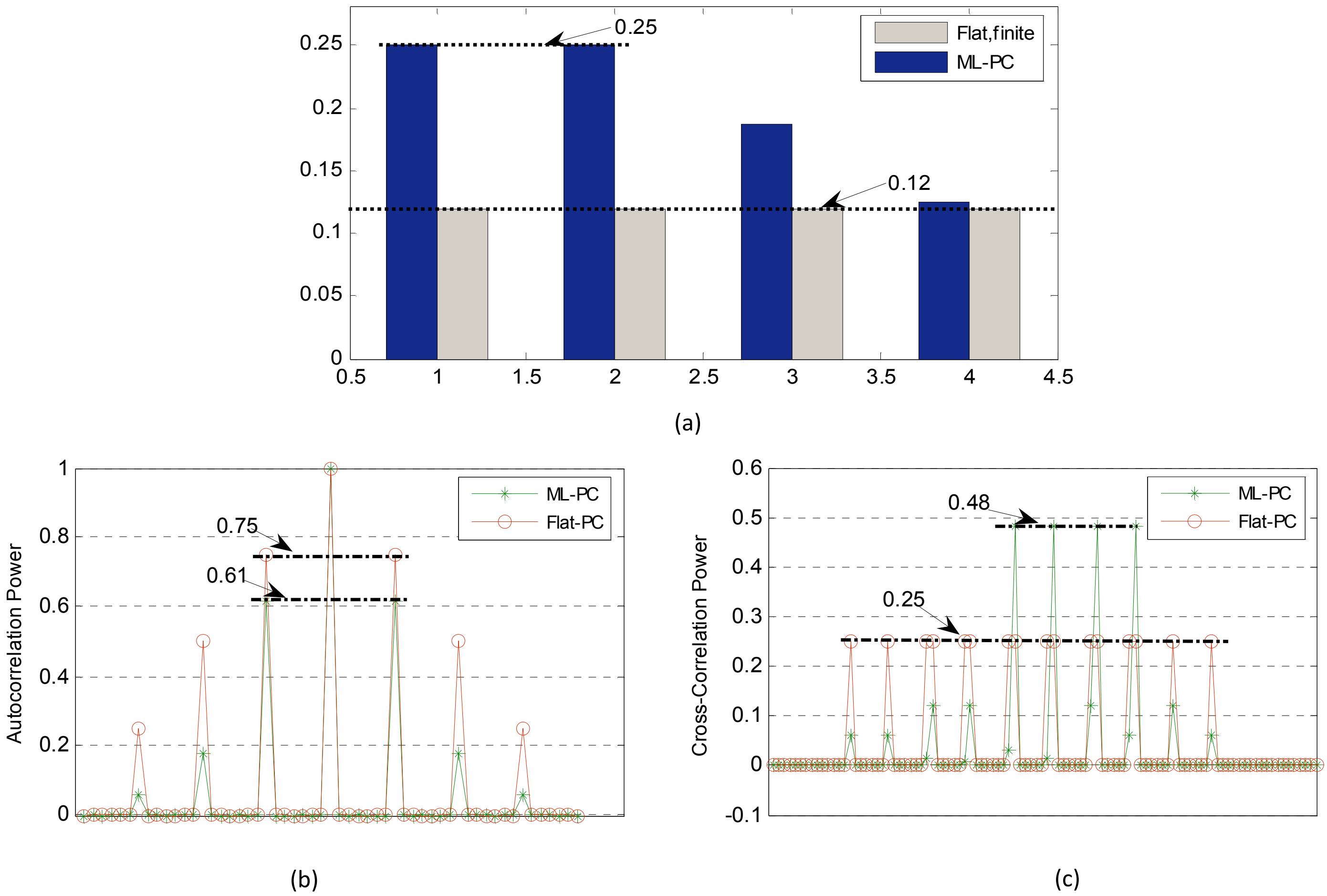

Figure 3 : ML-PC and Flat-PC code properties, (a) flat versus ML-PC code;
(b) Normalized autocorrelation for p=7 and w=4;
(c) Normalized cross-correlation for p1=7, p2=15 and w=4.

Mathematically, the successive operations of the CCR receiver translate into the following expressions:

➢ multiplying the received signal by the code of the desired user gives:

$r_{corr}(t) = \left(\sum_{k=1}^{N} a_k b_k(t).c_k(t)\right).c_1(t)$

$$r_{corr}(t) = b_1(t).c_1(t) + \sum_{k=2}^{N} a_k b_k(t).c_k(t).c_1(t) \qquad (7)$$

➢ the integration of the obtained signal provides the decision variable $Z_i^{(1)}$ of the ith data of user #1 is written as follows:

$$Z_i^{(1)} = \int_0^{T_b} b_i^{(1)}.c_1 dt + \sum_{k=2}^{N} b_i^{(k)} \int_0^{T_b} a_k c_k(t).c_1(t) dt \quad (8)$$

➢ decision making by comparison with a threshold S adhere to the rule decoding follows:

$$\begin{cases} \text{si} \ \ Z_i^{(1)} \geq S \rightarrow \hat{b}_i^{(1)} = 1 \\ \text{si} \ \ Z_i^{(1)} < S \rightarrow \hat{b}_i^{(1)} = 0 \end{cases} \qquad (9)$$

2nd case: We consider in this case that the noises can be assimilated to an additive Gaussian noise. We consider a DS-OCDMA system in the presence of additive white Gaussian noise (AWGN) with variance σ_b^2. In this case the received signal at the input of the CCR is the sum of contributions of all users (MAI) and noise (AWGN):

$$r(t) = \sum_{k=1}^{N} a_k b_k(t) c_k(t) + b(t) \qquad (10)$$

Considering that the desired user is the user # 1, we deduce the decision variable:

$$Z_i^{(1)} = \sum_{k=1}^{N} b_i^{(k)} \int_0^{T_b} a_k c_k(t).c_1(t) dt + \int_0^{T_b} b(t).c_1(t) \qquad (11)$$

For the decision making we will follow the same rule in Equation (9).

III. ML-PC CODE PROPERTIES

The values of auto and cross-correlation of the codes are key parameters for system performance in the presence of multiple users. To calculate this parameters we consider a truncated version of an ML-PC codes as shown in Fig. 3(a) (dark bars) with a weight *w*=4.

For comparison with the ML-PC code (dark bars) we also consider a flat periodic code with weight w=4 (gray bars). Fig. 3(b) shows the autocorrelation function for code having a period p_1=7 for both ML-PC and flat periodic codes. For simplify, we always normalize the autocorrelation main peak to one. In this case we observe a main lobe of one for flat and ML-PC codes. We can also note that similar to the well known prime codes, high out-of-phase sidelobes appear with maximum equal to (w-1) pulses [8]. For flat periodic codes $\frac{(w-1)}{w} = \frac{3}{4} = 0.75$, however, for ML-PC this is 0.61 (the sum of its highest three pulses). High autocorrelation sidelobes are not problematic as pulses are separated by more than sidelobe duration [8].

The cross-correlation function is illustrated in Fig. 3(c) considering codes with periods p_1 = 7 and p_2 = 15. We obtain unitary cross-correlation for flat codes which is $\frac{1}{w} = \frac{1}{4} = 0.25$, and 0.48 for ML-PC codes.

IV. Performance evaluation

A. Signal to Noise Ratio (SNR)

We consider the signal to noise ratio of the spread signal received at the input of CCR. Thus with an additive noise n normally distributed with zero mean and variance equal σ^2, and a total power for any code P_t (in the case of multilevel periodic codes, ML-PC), the SNR is:

$$SNR = 10\log_{10}(\frac{P_t}{\sigma_b^2}) \quad (12)$$

And with a power normalized to 1 (in the case of flat periodic codes, flat-PC) the SNR becomes:

$$SNR = 10\log_{10}(\frac{1}{\sigma_b^2}) \quad (13)$$

B. 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 consider both scenarios: Interference only and Interference plus AWGN. We decoded one of the users and measure the bit error rate.

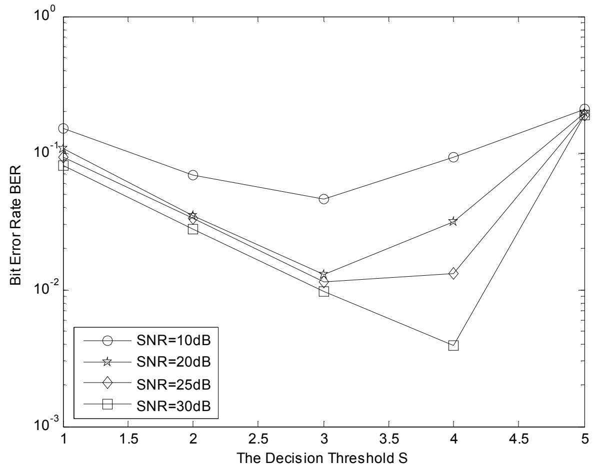

Figure 4 : BER versus decision threshold for different SNR using flat-PC, N=6 Users

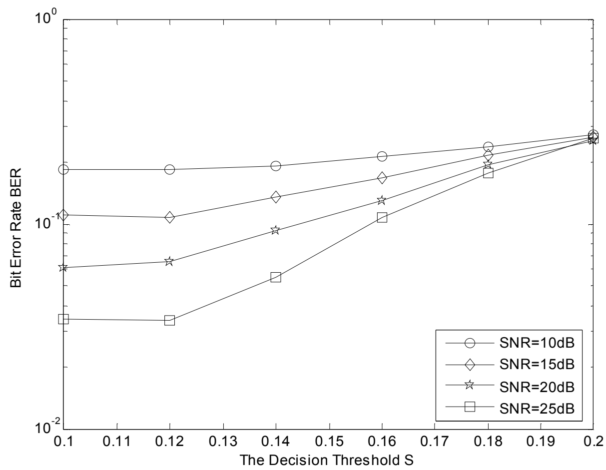

Figure 5 : BER versus decision threshold for different SNR using ML-PC, N=6 Users

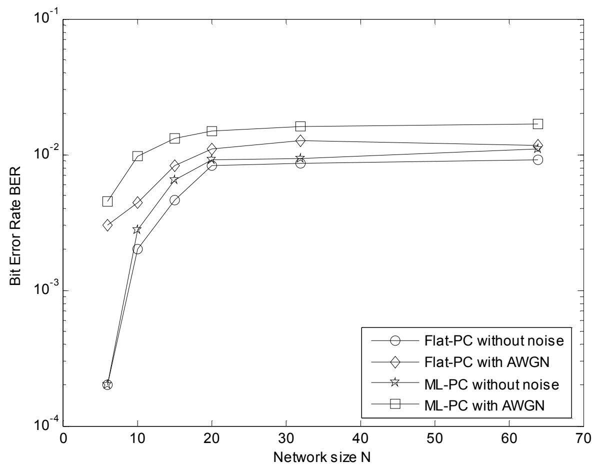

Figure 6 : BER versus network size N

C. Analysis of results

The simulation has been carried out in MATLAB to evaluate the BER performance of the proposed scheme in an AWGN channel.

We plotted in Fig. 4 the evolution of the BER of the CCR receiver in the presence of noise as a function of the decision threshold when we used the flat-PC codes (p_i, w=5) with network size N = 6, and for different SNR (by using Equation (13)).

On the other hand, it can be seen that according to SNR, the threshold for which we obtain the best performance evolves. Indeed, for an SNR equal to 10 dB, the optimal threshold is S_{opt}=3, while from an SNR equal to 30 dB, the threshold is S_{opt}=4. Then, according to SNR, the optimal threshold will be between $\frac{w}{2}$ and w, getting closer to w for a high SNR and moving away from it for a low SNR.

As usual, we will identify the optimal threshold by plotting the evolution of the BER of the CCR receiver in the presence of noise as a function of decision threshold for ML-PC codes with period p_i, weight w=5, s=0.5 and N = 6 (Fig. 5), using Equation (12). We can see also that the optimal threshold S_{opt} is the same whatever the value of SNR, we can define the optimal threshold as follows:

$$S_{opt} = P_t * w = w * \sum_{j=1}^{w}(1-s)^2 s^{j-1} + (1-s)\rho_{j-1} \quad (14)$$

As in our case, we have s=0.5, then P_t = 0.0238
Here: S_{opt} = 0.0238*5 = 0.119 approximately
S_{opt} = 0.12 (as shown in Fig. 5).

In Fig. 6, we worked with the parameters estimated in the previous figures, which are:

- For ML-PC: s = 0.5; S_{opt} = 0.12; SNR = 25dB,
- For flat-PC: S_{opt} = 4 and SNR = 30dB.

We can observe that the impact of AWGN on the performance of system is more clearly in this figure.

It should be noted that although we worked with encoders with low cost manufacturing, installation and operation, we can maintain good performance and a significant in terms of number of users. Then with this type of codes (flat or ML periodic code) we can achieve a BER = $1.4*10^{-4}$.

V. Conclusion

In this paper we proposed novel coding scheme so called Multi-level periodic coding for DS-OCDMA system. We studied the characteristics of these codes and investigated their performance in AWGN.

We derived an expression for an optimum threshold that minimizes the bit error rate. In our numerical simulation we considered conventional correlator only and obtained about 10^{-2} BER for 20 users and close to 10^{-3} for 10 users.

In future work, sophisticated interference cancellation and multiuser detection techniques may highly improve the performance of the system.

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