EVALUATION OF TIME-DOMAIN OCDMA PERFORMANCES USING GAUSSIAN MODEL FOR AN OPTICAL AMPLIFIED CHANNEL

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Abstract: The performances of time-domain Optical Code Division Multiple Access (OCDMA), using Gaussian model for the optical amplified channel, are evaluated. The interest of spectral spreading to take benefit of low cost optical filtering conditions is point out and the simultaneous effects of Multi Access Interferences (MAI) and optical noises on the optical detection are demonstrated.

To generate OCDMA information sequences, Optical Orthogonal Codes (OOC) and Prime Sequences (PS) are investigated.

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Introduction: The need of faster and more reliable communication systems has been felt these last years and the sharing of the huge optical bandwidth between users needs appropriate access techniques. In order to meet these requirements, Optical Code Division Multiple Access (OCDMA) presents an attractive solution.

OCDMA allows to each user a specific codeword (so called code sequence) to modulate its own data sequences. The resulting coded sequences of the various users, are superposed, transmitted via the optical amplified channel and at least, detected by the suitable receivers.

To determinate the performances of optical CDMA systems associate to threshold and multiuser detection techniques, a Poissonian model [1-3] of the optical channel were previously suggested. However, these configurations do not take into account the amplification noises introduced by today optical amplified channel. In the other hand, the noises and interferences met on the OCDMA channel were separately considered. Indeed, when the Multi Access Interferences (MAI) are introduced [4], the optical noises are neglected and reciprocally.

The aim of this paper is to estimate the performances of time-domain OCDMA technique by using a realistic optical amplified Gaussian channel model and introduces MAI and optical noises generated during the signal transmission and amplification. Moreover, the simultaneous effects of MAI and optical noises on the detection are evaluated.

CDMA technique permits random and asynchronous users emission. The performances evaluated here are considered for the worst case in an OCDMA system using optical codes, which is the synchronous users emission.

In Section II, definitions of appropriate optical codes: Optical Orthogonal Codes (OOC) and Prime Sequences (PS), used in our applications, are given. In Section III, a realistic optical Gaussian channel model associate to OCDMA is detailed and the different parameters that characterize this channel are proposed. The results and performances are discussed in Section IV. The last Section gives further remarks and the conclusion of this paper.

Optical Codes: Because of the specificity of the direct detection optical channel, the optical signal phase is not preserved during a transmission. In these conditions, it is difficult to use bipolar orthogonal sequences usually detected by a coherent detection. Optical codes were conceived to solve these problems. These codes are represented by quasi-orthogonal sequences that tolerate low cross-correlations that turning in MAI. Specific Optical Orthogonal Codes (OOC) [5-6], and Prime Sequences (PS) [7-8] are such codes examples.

A family of optical codes is represented by *(N, L, ω)* where *N*, *L* and *ω* are, respectively, the maximum number of users that are multiplexed by this code group, the length of a code sequence and its weight. OOC are characterized by these parameters and tolerate a maximum cross-correlation peak equal to 1.

In the same way, PS are represented by (*N=p*, *L=p_*, *ω=p*) where *p* is a prime number. These sequences are more efficient than OOC since they present a better multiplexing capacity. For example, when OOC present (4,57,4) code words, PS present (5,25,5) code words.

Moreover, PS fulfill an important information theory rule, witch specify that code sequences are correctly conceived if the signal generated by coded data sequences superposition have an equiprobable occurrence of "0" and "1" chips. Indeed, as it is demonstrated in [9], PS gives:

$$\begin{cases} p_s(0) = 0.6 \\ p_s(1) = 1 - p_s(0) = 0.4 \end{cases} \tag{1}$$

$p_s(0)$ and $p_s(1)$ are the apparition probabilities of chips "0" and "1" in a superposed coded sequences generated by PS. Consequently, in the following OCDMA model, PS are affected to each user to generate data coded sequences.

The proposed optical amplified channel model: Figure 1 shows the optical amplified channel model associated to OCDMA. A quasi-equiprobable sequence is generated by the superposition of coded data sequences using PS as codewords. This signal is transmitted, amplified by the optical channel and filtered. The detector recovers the coded data sequence. The signal, at the input of the detector [10], has a mean photocurrent value equal to:

$$\bar{i} = GR\overline{P} \tag{2}$$

and three principal noise components are introduced; signal against noise beating:

$$\sigma_{S-N}^2 = 4RS_N \bar{i} B_e \tag{3}$$

with

$$S_N = F(G-1)\frac{h\nu}{2} \tag{4}$$

noise against noise beating:

$$\sigma_{N-N}^2 = 2mR^2 S_N^2 \left(B_o - \frac{B_e}{2} \right) B_e \tag{5}$$

and thermal noise. The different parameters that characterize the optical amplified channel are given in Table 1.

In a first approach, Group Velocity Dispersions (GVD) and resulting Inter Symbols Interferences (ISI) are taken into account by a finite extinction ratio *r*. Consequently, a weak photocurrent is introduced in chips "0" and modifies the error probability expression. The signal, at the output of the photo-detector, follows a Gaussian distribution, with mean values for chips "1" and "0", respectively, given by:

$$\begin{cases} \overline{i_1} = GR\overline{P_1} \\ \overline{i_0} = rGR\overline{P_1} \end{cases} \tag{6}$$

and variances equal to:

$$\sigma_{1,0}^2 = 4S_N R\overline{i_{1,0}} B_e + 2mR^2 S_N^2 \left(B_o - \frac{B_e}{2} \right) B_e + \frac{4kT}{R^2 R_L} B_e \tag{7}$$

The expression of the error probability generated by the optical CDMA channel, is given by:

$$\begin{cases} P_e = \sum_{i=0}^{N-1} P_e(i) \binom{N-1}{i} d^i (1-d)^{N-1-i} & \text{where} \quad d = \dfrac{\omega}{2L} \\ P_e(i) = \dfrac{1}{4}\left[erfc\left(\dfrac{m_1 - s}{\sigma_1}\right) + erfc\left(\dfrac{s - m_0}{\sigma_0}\right)\right] & \text{where} \quad s = \dfrac{\sigma_0 \overline{i_1} + \sigma_1 \overline{i_0}}{\sigma_1 + \sigma_0} \end{cases} \tag{8}$$

Results and performances: The error probability of desired user is plotted in Figure 2 as a function of the optical power at the input of the optical amplifier. The simulation results shown in this figure demonstrate the validity of the analytical expression given by equation (8). The effect of the ratio B_o/B_e, which characterize the filtering conditions and determine the necessary bandwidth, is analyzed under amplifier gain condition $G = 30dB$.

It can be seen that a BER lower than 10^{-4} is achieved for standard access, low power level and low cost filtering conditions ($R_b = 155Mbit/s$ $P_1 = -54dBm$ and $B_o/B_e = 100$). This value can easily improved by using low cost Forward Correcting Codes (FEC), like Reed-Solomon FEC [11].

In Figure 3, the effect of multi access users on the BER is depicted. The graphs establish the relation between MAI and optical noises. MAI effects are limited by the noises introduced during the transmission via the optical channel and the upper bound of the associate error probability is limited by the error probability of the optical channel. Indeed, the BER resulting from 29 simultaneous users is identical to the BER obtained for an equiprobable optical sequence, in the same physical condition, without using CDMA. So it is demonstrate that, in our optical model, the effects of MAI on the BER are conditioned and limited by the signal distortions generated by optical noises.

Conclusion: The performances of an Optical CDMA system associated to a Gaussian model of the optical amplified channel are presented. It demonstrates that appropriate time domain optical codes (PS) are used to reduce and control the effect of multi users interferences.

An analytic expression of the error probability is developed. This formulation includes the most important parameters of the optical channel, and arises the effect of filtering conditions by pointing out the benefit of a low optical to electrical bandwidth ratio on the resulting BER. The simulations carried out thereafter confirm the error probability theoretical expression.

In the other hand, our model take into account simultaneously MAI and optical noises generated by the optical channel. It demonstrates that the effect of MAI and optical codes, on the error probability, is directly related to optical noises introduced by the components of the optical channel.

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Figure Captions:

Figure 1: Simplified optical amplified channel model

Figure 2: BER (Theory and Simulation) versus optical power at optical amplifier input. Optical amplifier gain $G = 30\ dB$. Number of simultaneous user $N = 5$.

Figure 3: BER versus the number of simultaneous users. $N = 29$, $L = 841$, $\omega = 29$

Table 1: Numerical values of optical amplified channel parameters

Figure 1

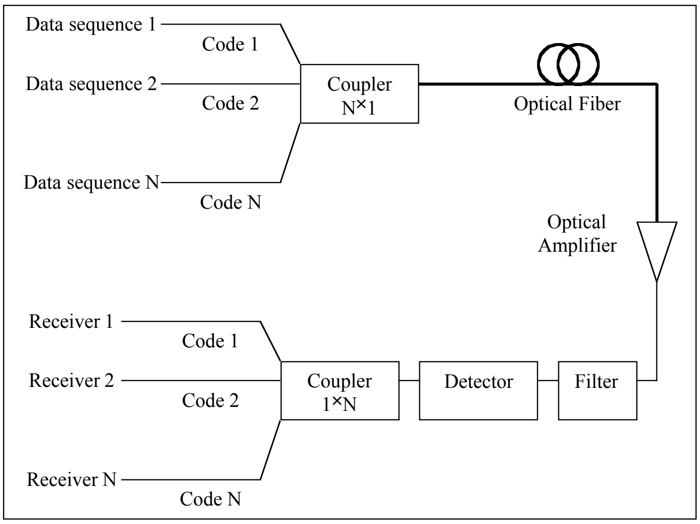

Figure 2

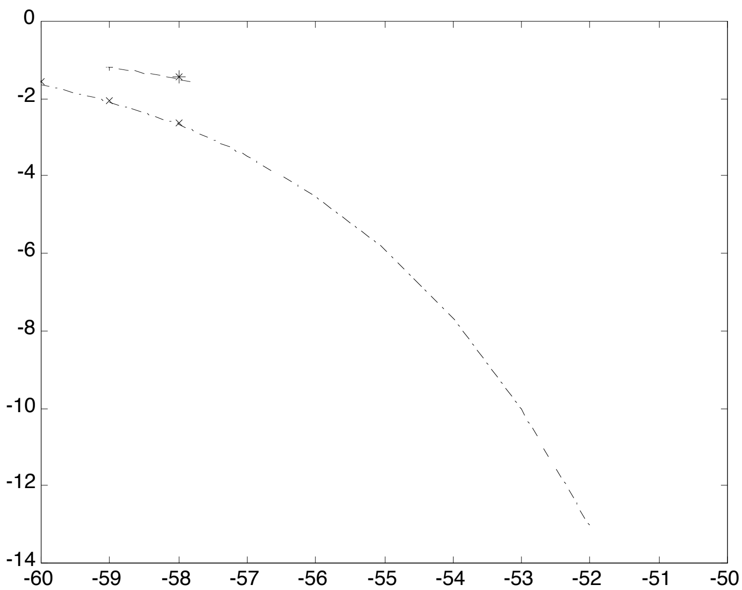

Figure 3

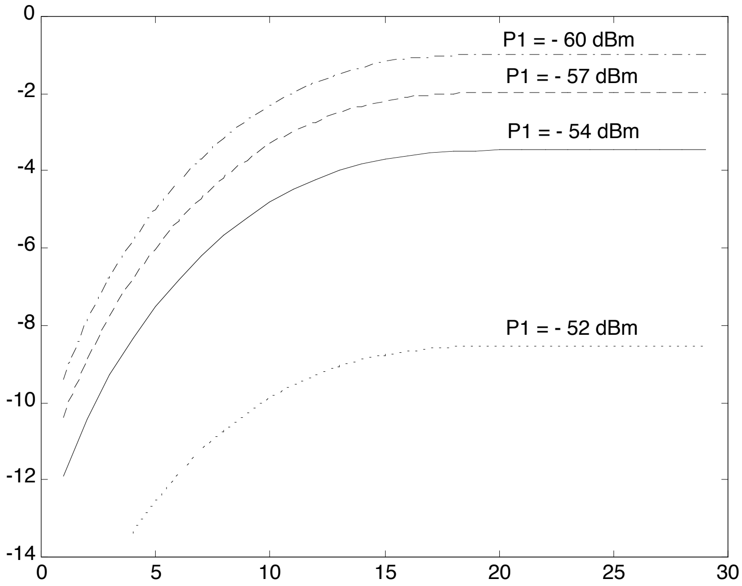

Table 1

Parameters	Symbols	Values
Extinction ratio at the receiver	r	0.1
Photo detector responsivity (A/W)	R	1
Optical noise factor (dB)	F	6
Polarization mode number	m	2
Equivalent temperature (K)	T	600
Boltzmann constant (J/K)	k	1.38×10^{-23}
Load resistance (Ω)	R_L	50
Optical amplifier gain (dB)	G	30
Electrical bandwidth (Mhz)	B_e	80
Optical bandwidth (MHz)	B_o	from 400 to 8×10^5
Optical frequency (Thz)	ν	200
Planck constant (J.s)	h	6.63×10^{-34}
Optical power at the optical amplifier input (dBm)	$\overline{P}$	from –60 to –50