Investigation of OCDMA System Performance Against the effect of Dispersion & MAI

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Abstract

This paper presents the effect of dispersion and Multi Access Interference (MAI) of optical fiber on the Bit Error Rate (BER) performance of a Direct Sequence Optical Code Division Multiple Access (DS-OCDMA) network by means of intensity modulation and ORC. By using Mat lab simulations, Signal-to-Noise Ratio (SNR) versus Received Optical Power (ROP) of an OCDMA transmission system can be evaluated with a so-called 7-chip m-sequence for different numbers of system users. This can be done for the ROP versus BER for various lengths of single mode optical fiber by taking into consideration the dispersion effect in the optical fiber. Mat lab simulations can be performed in order to illustrate the reduction of the dispersion index gamma, or to visualize different scenarios, e.g., what amount of transmitted power is required in order to obtain a BER of 10-9 when the length of the optical fiber is in-creased.

Keywords: *Access codes, code-division multi-access, BER, SNR, DS-OCDMA, ROP, optical fiber communication.*

I. INTRODUCTION

Our main objective in paper is to analyze Optical Code Division Multiple Access (OCDMA) networks. We analyze the main causes for Multiple Access Interference (MAI) which may reduce the performance of OCDMA networks. We also analyze the limitations that occur due to dispersion in OCDMA networks. Dispersion can also reduce the performance of the passive optical network.

Furthermore, we present in this paper our simulations results for BER versus received power for a multiple users system. We present the simulation results of the effects of Dispersion for various scenarios, e.g. different received optical power for multiple users and various optical fiber lengths in OCDMA Systems.

Development of the optical fiber communications technology has evolved rapidly in order to achieve larger transmission capacity and longer transmission distances [11]. Nowadays, OCDMA systems are highly interesting as they offer several sought-after features such as Asynchronous accesses, privacy, secure transmissions and ability to sup-port variable bit rates and busy traffic and provide high scalability of the optical network [3]

In OCDMA, one great feature is that all subscribers can access the network asynchronously. In this case, a great advantage is that neither conversion of optical to electrical signals is needed nor use of timing devices is required. Current research on OCDMA focuses on direct time spread OCDMA, spectral encoding-decoding, pulse-position modulation OCDMA, asynchronous phase encoding OCDMA and frequency hopping OCDMA [5]. However, in [5] chromatic dispersion of fiber is not considered. Chromatic dispersion can reduce system performance and occurs when increasing the inter-chip interference and decreasing the receiver optical power.

Intensity modulation with direct detection On-Off Keying (OOK) OCDMA and Pulse Position Modulation (PPM) OCDMA systems are analyzed in [1]. The capacity of these networks is limited because the number of signature sequences available with good correlation properties for a given sequence length is small [2]. Furthermore, recent developments in coherent OCDMA encoders/decoders allow for the efficient separation of large number of simultaneously users providing thus a feasible solution for low-cost applications in multi-user Local Area Networks (LAN) environments [6].

In this paper, the analysis is carried out for direct sequence OCDMA system with intensity modulation and direct detection sequence inversion keyed receiver [13] considering both MAI and chromatic dispersion. OCDMA is one promising candidate for the next generation broadband multiple access technique due to full asynchronous transmission, low latency access as well as soft capacity on demand [14].

MAI may be seen as a kind of noise. The MAI noise is minimized in this work by using the so-called m-sequence signature code. In case of practical OCDMA

network applications, the capacity of asynchronous multi-user access is essential [14].
In addition, an aspect of dispersion, namely the limitation of the OCDMA system is also presented here. The main focus of this work is to do research on what can be done in order to reduce the dispersion & MAI of the OCDMA network such as to obtain a given BER.
Optical code-division multiple-access (O-CDMA) is an attractive technology since it potentially provides flexible, robust, and asynchronous communications in access networks. CDMA schemes are categorized as implementing the code through the optical field and relying on coherent detection, or through time slots and wavelengths with reliance on incoherent detection. Coherent schemes are susceptible to coherent beat noise that occurs when the correctly decoded signal temporally overlaps with the multiple access interference (MAI) from other users [1].So recent implementations of coherent O-CDMA resort to timing coordination between users, ranging from complete bit-level synchronization [2] to time slot assignment within the bit [3]. Another approach uses very long spreading codes to minimize the amplitude of the MAI while keeping users asynchronous; however, only ten of 512 possible codes deliver adequate bit-error-rate performance (BER< 10^{-9})[4]. In-coherent schemes are less susceptible to coherent interference [5], but due to time slot allocation, are difficult to implement and less spectrally efficient with increasing data rates and time slots.
A single mode fiber is used for high-bit-rate transmission in low-loss-transmission windows but dispersion is an important impairment that degrades overall system performance of an optical communication system [7].
The major limitation in transmission medium is Group velocity dispersion (GVD) and non-linearity due to optical Kerr effect and their distribution over propagation direction, which degrades the system performance. Hence it is of utmost importance to compensate for the pulse spreading due to GVD and non-linearity [8].

Optical fiber transmissions have two fundamental shortcomings: transmission angles and bandwidth limitations. Furthermore, impurities and the phenomenon of glass absorption also create losses in optical fibers.

Losses occur in optical fibers mainly when the fiber is bended at an angle. As a result, the light can leak out from the cladding. There are three windows of wavelengths used in optical communications. In addition, losses are also related to the wavelength. For instance, the 850 nm wave-length has a loss of 4-5 dB/km. For the 1310 nm wavelength, the loss is 3dB/km and for 1550 nm wavelength the loss is 1 dB/km.

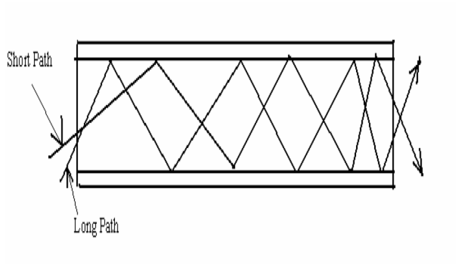

Figure 1: Light path in optical fiber

The loss depends on the light paths because light may have different paths within an optical fiber. Figure 1 illustrates the loss for different light paths.
There are two types of attenuation: intrinsic and extrinsic. The intrinsic attenuation occurs when there is absorption of the ultra-violet and infrared light. In the 0.2-2 µm range, the resonance of ultra violet and infrared light cannot be absorbed in optical fibers. As a result, the impurities of the optical fiber must be also taken into consideration.
From 1.23-1.4 µm range, the OH ions in the optical fiber are responsible for the attenuation (illustrated in Figure 2). The wavelength range of 1.26-1.62 nm is more suitable for optical transmission because, in this case, the attenuation of signal is 0.5dB/km. Furthermore, intrinsic attenuation consists of Raleigh scatterings due to variations of n. The attenuation due to Raleigh scattering is sketched in the dashed line in Figure 2. Extrinsic attenuation appears when the light path is bending or due to micro impurities from the manufacturing process.

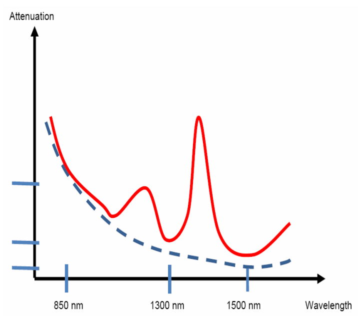

Figure 2: Attenuation of light in single mode

Figure 2 illustrates the attenuation of three wavelength windows. These windows are the following: 850 nm, 1300 nm and 1500 nm. The attenuation (measured in decibels (dB)) for the 850 nm, 1300 nm and 1500 nm window is 3.5 dB, 0.4 dB and 0.2 dB respectively.
In our paper we used the 1500 nm wavelength. In the above figure there are two lines. One solid line and one dashed line. The solid line illustrates the typical shape which is followed in the 1990's. The dashed line shows the actual shape of the attenuation of the single mode fiber.
Chromatic Dispersion: There are several reasons for the reduced performance of optical fiber communications.

Chromatic dispersion is such an effect which can reduce the performance of passive optical networks. Chromatic dispersion is the combinations of mainly two factors: dispersion of material and dispersion of the waveguide. Mathematically we can write

$$D_T=D_M+D_{WG}$$

Where D_T denotes the total dispersion, while D_M and D_{WG} defines the material and the waveguide dispersion respectively [7]

Chromatic dispersion is the effect of pulse spreading (or broadening) and can reduce the integrity of a received signal unless appropriate dispersion modules are included in the optical communication system [7].

Simulated results of the power at the input and output of the optical fiber are shown in Figure 3 [8].

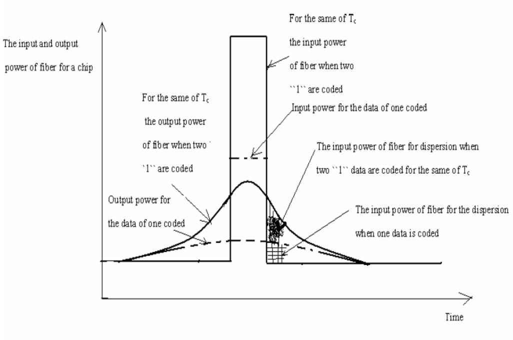

Figure 3: Chromatic dispersion in optical fiber

Here is the power of the optical fiber per chip. From the figure we can see that data is not uniformly changed. The reason for this is that the power is increased when coding of two data streams are superimposed for the same duration in the chip. As a result, more superimposed coded data spreads the available data per chip.

This phenomenon interferes with adjacent chips. For this reason, errors are also in-creased which in turn, reduces optical system performance. Mainly, this effect occurs when multiple users are using the system.

Consequently, we can conclude that data spreading adversely affects the OCDMA sys-tem and shortens the light pulses. In such cases, it is necessary to take into account the fiber dispersion effects and compare them to MAI limitations [8].

Four Wave Mixing: The nonlinear characteristic of the so-called four waves mixing is defined as the product of inter-modulations which, in turn, are the effect of various frequencies at different levels of interactions.

For instance, when three wavelengths, propagate through the optical fiber, they create a fourth wavelength, produced by the incident scattering of the three photons. This mechanism is referred to as a four wave mixing and affects the optical transmission on OCDMA systems.

A photon is defined as the quantum of the electromagnetic field with the unit photon as the light. The photons are regarded as a bundle of discrete packets. When two pump (incident) photons (lights) are annihilated, two new photons are created: the first one is created at the signal frequency, while the other one is created at a complementary frequency called idler [10]. In a WDM context, this resulting power transfer impairs the transmission since it produces crosstalk between the transmission channels [9].

II. Proposed System Description

In this work, the OCDMA system consists of five main sections:

1. Data source (i.e., transmitting computer).
2. Optical CDMA encoder.
3. Optical star coupler: Device that accepts one input signal and is able to output to several. At last, using the PN sequence receiver can receive his desired signal. However star coupler has a loss. But this is very poor.
4. The 4th section is the optical CDMA decoder.
5. Data sink (i.e., receiving computer).

The schematic block diagram of an OCDMA communication system is depicted in Figure 4 and 5, for an OCDMA transmitter and for an Optical Correlator Receiver (OCR) with switched sequence inversion keying, respectively [1].

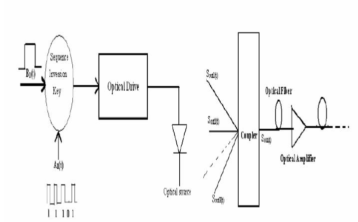

Fig: 4 OCDMA Transmitters

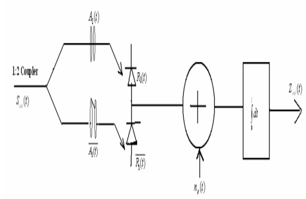

Fig: 5 OCR with switched SIK

In the OCDMA transmitter, every user preserves different signature codes modulated as binary. Data are actually electrical signals sent to the optical drive which converts the electrical signals into optical signals. The encoded signal is further sent to the star coupler. The star coupler used depends on the topology of the network which can be either a LAN or an access network.

In case of a LAN, the star coupler is N: N, while in an access network, the star coupler is 1:N. Further, in OCDMA every user shares the same channel. For this reason, crosstalk which is interference due to multiple accesses is introduced here. In order to reduce this unwanted interference, every user uses various signature sequences.

On the other hand, in the OCR with switched sequence inversion keying, an optical switched correlator is used. Consequently, a bipolar reference sequence is correlated directly with the channel's unipolar signature sequence in order to recover the original data [1].

The unipolar-bipolar correlation is practically realized in an optical correlator, by spreading the bipolar reference sequence into two complementary unipolar reference sequences. In addition, the optical correlator provides unipolar switching functions for de-spreading the optical channel signal [5].

The PIN photodiode is also known as the p-i-n photo-receiver. Here, i is the intrinsic region which is un-doped between the doped regions of n and p. Finally, the PIN photodiode cancels the despreaded signal integrated with the periodic data. This occurs before the detection of the zero threshold voltage.

III. Proposed System Analysis

At the OCDMA transmitter, the SIK (Sequence Inversion Keying) modulated signal is sent to the optical drives through a laser diode. Consequently, the output for users can be mathematically expressed as [3]

$$S_k(t) = \sum_{l=0}^{N-1} P_T B_k(t) \otimes A_k(t - lT_c) \tag{1}$$

In (1), $S_K(t)$ represents the transmitted output pulse shape for different users in single mode fiber while l represents the period of the chip and PT is the optical power of the chip. Furthermore, B_K and A_K represent the user's binary signal and signature codes, respectively. The operator $\otimes$ represents the sequence inversion key modulation so that when A_K is transmitted for "1" A_K is transmitted for "0" respectively. Furthermore, T_C is the pulse interval.In the OCR with switched sequence inversion keying, due to chromatic dispersion of the optical fiber, the output can be expressed mathematically as [3]

$$S_{output}(t) = \sum_{l=0}^{n-1} \frac{1}{\sqrt{\pi\gamma}} e^{-j\left[\left(\frac{1}{\gamma}\right)\left[\frac{(t-lT_c)}{T_c}\right]^2 - \left(\frac{\pi}{4}\right)sign\gamma\right]} * \sin c\frac{(t-lT_c)}{\pi\gamma T_c} \tag{2}$$

Here, γ represents the index of chromatic dispersion of the optical fiber which, in turn, can be expressed mathematically as [5]

$$\gamma = \frac{(\lambda^2)}{(\pi)(c)} D b_c^{\,2} L \tag{3}$$

In (3), γ represents the wavelength of the optical carrier, is the light velocity and is the fiber length. Further, D describes the coefficient of chromatic dispersion of the optical fiber while the rate of the chip is b_c. Consequently, we can state that when the fiber length is increased, the index of chromatic dispersion in the fiber is also increased. The receiver section handles the despreaded signal. The signal is sent to the photo detector and is integrated in the output of the correlator for the i^{th} user. This can be mathematically expressed as [3]

$$Z_i(t) = \frac{RP_R}{2}\int_0^T \sum_{K=1}^{K}\sum_{l=0}^{N-1} B_K(t) S_{out}(t) \otimes A_K(t-lT_c) * \{A_i(t-lT_c) - \overline{A_i(t-lT_c)}\} * dt + \int_0^T n_0(t)dt \tag{4}$$

Here, the photodiode's responsively is given by R, K represents the concurrent number of users, n_0 is the noise of the channel which as seen in the output of the optical correlator. P_R represents the optical received power given by [5]

$$P_R = P_T - P_F \tag{5}$$

In (5), P_T is the transmitted optical power while the loss in the optical fiber is P_f.

The first part of the output signal described by (4) is compensated by considering the mean of the signature code, denoted as *U* while the remaining part represents the noise occurring in the channel due to multiple accesses of the channel, chromatic dispersion and various noises for the spontaneous signal fluctuations in the receiver.

This is described by the variance of the system, denoted as σ^2. The mean of is given by [3]

$$U = \frac{RP_R}{4T}\int_0^T \sum_{l=0}^{N-1} S_{out}(t - lT_c)\,dt \qquad (6)$$

The interference variance due to multiple accesses is given by [15]

$$\sigma^2 = U^2 \frac{2(K-1)}{3N} \qquad (7)$$

The noise of the variance $n_0(t)$, is a combination of thermal noise and noise of the shot power and is given by

$$N_0 = N_{SH} + N_{TH} \qquad (8)$$

The thermal noise N_{TH} and the shot noise of the photo detector are given by [5]

$$N_{TH} = \frac{(4K_B T_r) * B_r}{R_L} \qquad N_{SH} = \frac{2qRKP_R}{4T} \qquad (9)$$

In (9) and (10), KB represents the Boltzmann constant while the bandwidth of the receiver is given by. Further, the temperature of the receiver is and the charge of the electron is *q*. The resistance of the receiver load is denoted.

The SNR and BER of the OCDMA system are given by [1]

$$SNR = \frac{U^2}{\sigma^2 + N_0} \qquad BER = \left(\frac{1}{2}\right) erfc\left(\frac{\sqrt{SNR}}{\sqrt{2}}\right) \qquad (10)$$

IV. RESULT & DISCUSSION

The OCDMA system performance is validated with a rate of $10*10^9$ chips per second. We evaluate the OCDMA system performance by looking at the BER for various users and at the eye diagram penalty for 7 chip m-sequence signature (m-signature chip used in our simulations was 1110010.

In our simulations we have considered single mode optical fiber at 1550 nm wavelength, with coefficient of chromatic dispersion of 17ps/km-nm and a receiver load resistance of 50 Ω. Table 1 below presents the parameters of the evaluated OCDMA system.

Symbol	Significance	Value
λ	Operating wavelength	1550 nm
b_c	Chip rate	10 G chip/s
Q	Electron charge	$1.6e^{-19}$ c
K	Boltzmann constant	$1.38e^{-23}$ W/K. Hz
T_r	Receiver temperature	300^0 k
R_L	Load resistance of receiver	50 Ω
R	Responsivity of each p-i-n photodiode	0.85 Ω
L	Length of fiber	245.05 km
$P_S dBm$	Received optical power gain	-20
I_{dk}	Dark current	10 nA
N_{th}	Thermal current	1 pA^2Hz^{-1}
D	Coefficient of chromatic dispersion	17 ps/km-nm

Table 1: Simulation parameters

Figure 11, 12 & 13 below presents the system performance for BER versus received optical power (ROP) for 3 and 6 users, 12 and 17 users & illustrates the BER performance versus ROP for up to 23 users

We observe that BER decreases when the ORP and the number of users is increased.

For instance, when we consider a 10^{-5} BER, the ROP is -14.8dBm for 19 users while for 23 users, this becomes -14.2dBm.

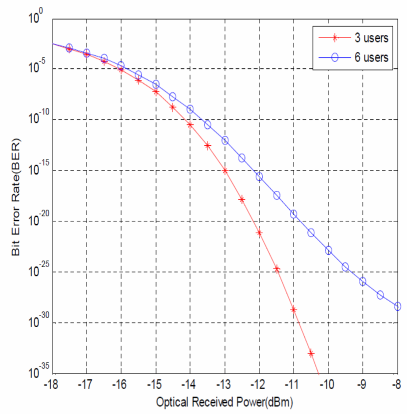

Fig: 11 BER Vs ROP for 3/6 users

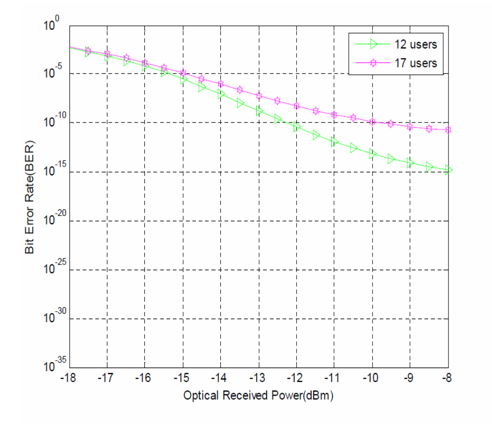

Fig: 12 BER Vs ROP for 12/17 users

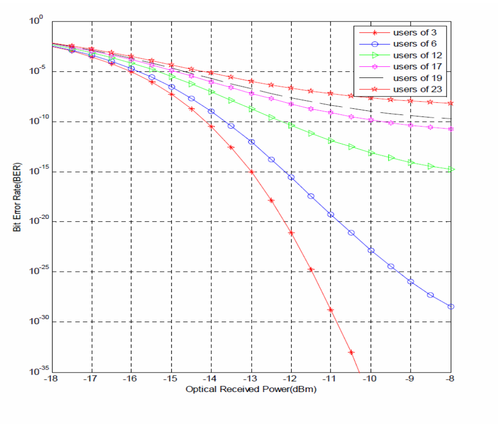

Fig: 13 BER Vs ROP for different users

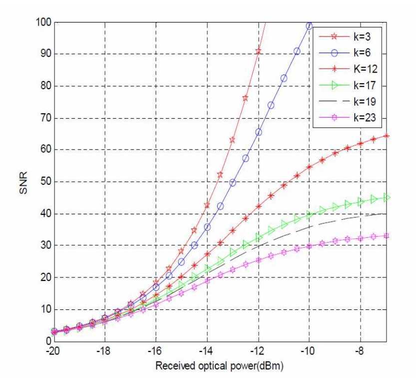

Fig: 14 Performance comparisons -SNR vs. ROP

The eye diagram for the evaluated OCDMA system is also simulated in Mat lab. We used two signal levels in our simulations: signal level 1 and signal level 0. The top line shows the output level of the signal level 1. The bottom line represents the output level of signal level 0.

When the eye is “opened” and the line is spiky, it means a better performance of the OCDMA system. On the other hand the eye is “distorted” when dispersion occurs in the system. We evaluated the OCDMA performance by looking at the eye diagram for a chip rate of 10 G chip/s and a coefficient of fiber dispersion of 17ps/km-nm and different indices of chromatic dispersion γ. 35

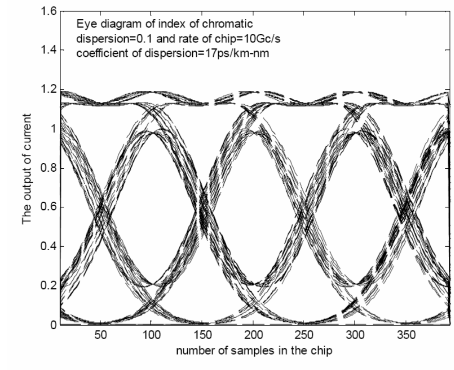

Fig: 15 Eye-diagram - gamma = 0.1

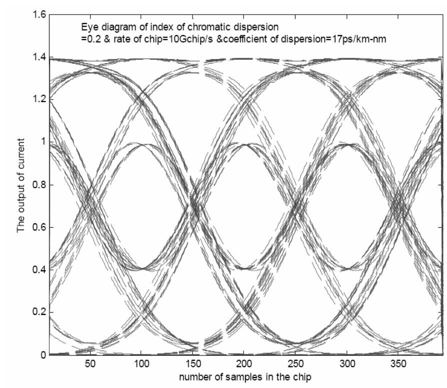

Fig: 16 Eye-diagram

Figure 17 illustrates the eye-diagram of the OCDMA system for a fiber length of 70 km while in Figure 18 the length was set to 85 km. We observed from our simulations that the eye-diagram is more opened for a length of 70 km than in the case of 85 km.

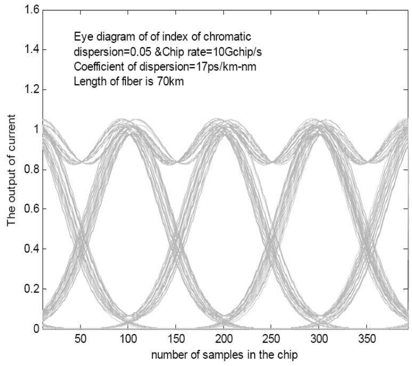

Fig: 17 Eye-diagram fiber length 70 Kms

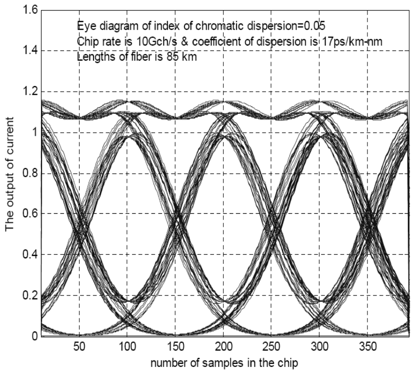

Fig: 18 Eye-diagram fiber length 85Kms

We observed from all our simulations that the eye is more closed for longer fiber lengths with the same index of chromatic dispersion. We also observed that, in order to maintain a better performance of the OCDMA system we need also to reduce the index of the chromatic dispersion of the optical fiber.

We also considered the shot and the thermal noise with MAI. We observed that a higher power of the optical transmitter is required in order to maintain a 10-9 BER for increasing number of users.

We also observed the behavior of the OCDMA system by looking at the eye diagram of the OCDMA network with a coefficient of fiber dispersion of 17ps/km-nm and an index of chromatic dispersion of the optical fiber $\gamma = 0.05$ and when considering different lengths of the optical fiber.

The more closed the eye-diagram is, the worse performance the OCDMA system has. For instance, we found that for an index of chromatic dispersion of 0.05 and a coefficient of fiber dispersion equal to 17ps/km, the eye-diagram is more opened at 70 km than at 100 km.

We noticed also that when the fiber length is decreased, the index of chromatic dispersion of the optical fiber increases. In addition, BER performance degrades due to dispersion effects in the OCDMA system. The BER be reduced by adding the chips while the effect of the chromatic dispersion is reduced by sinking the power of the optical transmitter.

V. References

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