Hybrid Communication System applying electric CDMA over optical WDM

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Abstract – The purpose of this work is to describe and demonstrate a new concept of a hybrid communication system, which consists of applying electrical CDMA on a system using optical WDM. Each user has a unique orthogonal CDMA code and modulates an electrical carrier (e.g. QPSK) prior to the data directly modulating an optical carrier. Thus, it is possible to add several data channels in a optical fiber, over the same or different optical carriers, and recover the information associated to each of the channels. With this approach we can avoid the use of optical filters at reception, making the system more flexible and robust.

Index Terms – CDMA, PON, RoF, WDM.

I. INTRODUCTION

In recent years we have seen the growing importance of optical solutions in telecommunications systems, e.g. the use of Wavelength Division Multiplexing (WDM). In such systems, multiple optical carriers are used to transmit data in a shared medium, the optical fiber, increasing the total bit rate transmitted. At reception, optical filters are needed to select each channel before the signal is converted to the electrical domain, in the photodiode, and allow the data recovery.

Alternatively, we propose the use of Code Division Multiple Access (CDMA) associated to each channel, making its data recovery possible, after detection, without using optical filters. Each user has a unique orthogonal CDMA code modulating an electrical carrier (e.g. QPSK). This electrical signal is used to directly modulate one or several lasers. Thus, we can have the several channels over one or multiple optical carriers, sharing the same optical fiber. With this approach, we can avoid the use of optical filters making the system more flexible (e.g. changes in channel spacing) and robust (e.g. variations of the central frequency of the optical carriers).

II. CODE DIVISION MULTIPLE ACCESS

Code Division Multiple Access is a shared medium access technique and a 3GPP specification that is widely used in countries like Korea, Japan, U.S.A. and all over Europe as part of an effort of standardization in third generation (3G) communications systems 1. This technique allows multiple accesses by assigning to each data channel a unique coding sequence so that a shared medium can be used in the same time slot and frequency. The spreading operation increases the signal's bandwidth and should only be used if enough bandwidth is available. The signal's power spectrum is spread by a factor called the spreading factor (SF). It is defined as B_t/B_i, where B_i and B_t are, respectively, the signal's original and after spreading bandwidths. The most used orthogonal codes, also called channelization codes, in third generation systems are based on the orthogonal variable spreading factor (OVSF) technique. The use of this technique allows the change of SF, maintaining the orthogonal properties between the codes. These codes (also called Walsh-Hadarmard codes) are obtained as shown in figure 1:

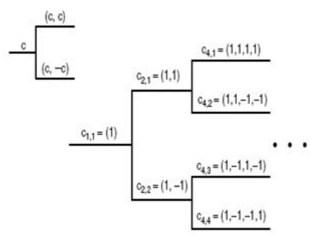

Figure 1 – Spreading Codes tree 1.

III. PERFORMANCE ASSESSMENT

The overlap of information from different connections leads to a multilevel signal. So, it is clear that a typical simple quality factor (Q) analysis cannot be performed. To analyze this type of signal, another approach must be made, which should consider the different transitions between the m+1 levels of the signal (from m signals present and added). Considering each state that results from coding, each transition will have an associated eye diagram (for example, if 3 signals are added, there would be 4 possible levels, corresponding to 6 transitions and 6 different eye diagrams) as shown in figure 2**:**

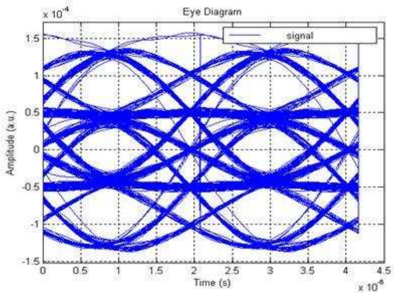

Figure 2 – Multilevel Eye diagram.

Thus, each transition will correspond to an error probability and to a transition probability. The transition probability will depend on the number of chips present in levels m and m+1. Therefore, can be given by 2:

$$P_{TRANSITION}\left(Q_n\right)=\frac{2\times N_m \times N_{m+1}}{N_{TOTAL}} \qquad (1)$$

Q_n represents the quality factor associated to transition n. The factor 2 accounts for the bi-directionality of the transitions (from m to m+1 and m+1 to m). With equally probable symbols, the final CER can be given by 2:

$$CER_{TOTAL}=\sum_{n=1}^{N} P_{ERROR}\left(Q_n\right)\times P_{TRANSITION}\left(Q_n\right) \qquad (2)$$

This total CER results from the product of each weight, $P_{TRANSITION}$, of the eyes, by the error probability associated to each eye:

$$P_{ERROR}\left(Q_n\right)=\frac{1}{2}erfc\left(Q_n/\sqrt{2}\right) \qquad (3)$$

CER theoretical analysis presented above is only valid if the resulting signal presents a Gaussian distribution. In order to assess the validity of this assumption, 8 connections were overlapped. The resultant histogram with Gaussian curves superimposed is shown in figure 3, validating the assumption:

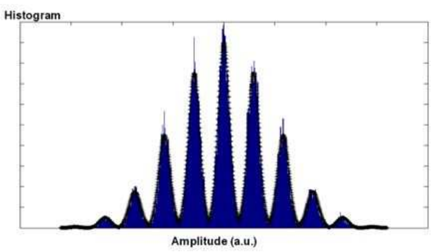

Figure 3 – Multilevel signal histogram. Black line corresponds to equivalent Gaussian curves with adjusted mean, amplitude and standard deviation values.

IV. SIMULATIONS AND RESULTS

In order to simulate the CDMA/WDM system, CDMA coding blocks and optical components were modeled. The data is coded, converted from the electrical to the optical domain using a directly modulated laser (channel spacing of 25 GHz, 1550 nm neighborhood), inserted into an optical fiber and converted back to the electrical domain at the photodiode (PIN). The blocks before the laser represent the electrical data channels, generated as random bit streams, and followed by CDMA codification and QPSK modulation (CDMA block). These electrical signals will directly modulate its dedicated laser, each with its unique optical carrier wavelength. After being added in a span of fiber the signal is detected at a PIN without the use of optical filters. After QPSK demodulation and before the CDMA codification is reversed, CER estimation is performed on the resulting multilevel signal.

The QPSK carrier frequency is 2.2 GHz and the SF used was 8, thus using 8 bit CDMA words. The bit rate is 3.84 Mb/s. All the obtained results were based on the star topology presented in figure 4 (considering for simplicity only two users):

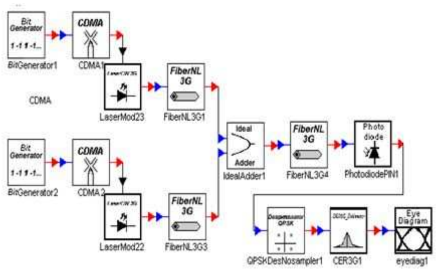

Figure 4 – Simulation Schematic.

In the following we quantify the maximum achievable distance, considering the lasers' chirp effect. The used laser is directly modulated, biased at 70 mA and with a peak-to-peak current (I_{pp}) of 20 mA. The connection to the adder is made using 100 m of standard single mode fiber (SSMF), for each connection, and the length of the SSMF link that connects to the PIN is the variable to study. The obtained CER is presented in figures 5 (a) and (b), respectively for 100 MHz/mA chirp and no chirp, considering 1 mW of mean power for each laser:

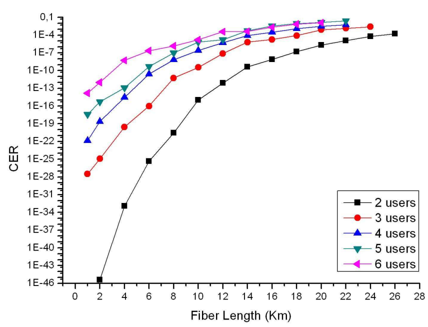

Figure 5a – CER vs. fiber length with Chirp (100MHz/mA) and 1 mW.

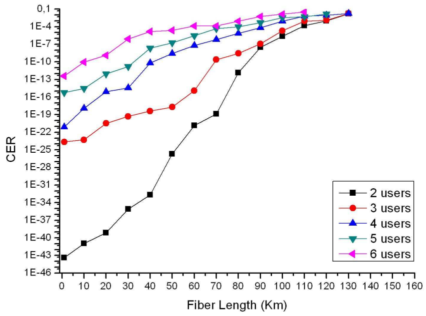

Figure 5b – CER vs. fiber length without Chirp and 1 mW.

Analyzing these results, we confirm that the laser chirp effect introduces a great limitation (LASER chirp will cause instantaneous frequency deviations on the RF carrier, deleterious to the QPSK modulation used). Considering 6 users, with 100 MHz/mA chirp (figure 5 (a)) it's possible to achieve 4 km of fiber with CER below 10^{-9}. Without chirp (figure 5 (b)) it is possible to achieve a fiber length of 20 km with CER lower than 10^{-9}.

Next, the obtained CER is presented in figures 6 (a) and (b), respectively for 100 MHz/mA chirp and no chirp, after increasing the mean power of each laser to 10 mW:

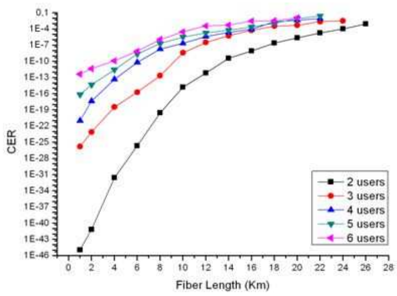

Figure 6a – CER vs fiber length considering 100 MHz/mA chirp and 10 mW.

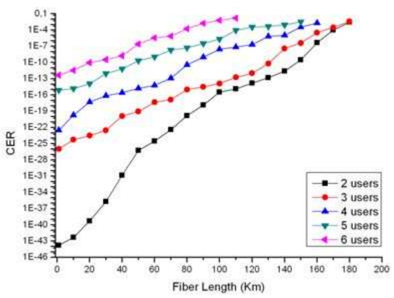

Figure 6b – CER vs fiber length without chirp and 10 mW.

Analyzing these results, we confirm that the main limitation is the LASER chirp effect although some improvements can be observed. With 100 MHz/mA chirp (figure 6 (a)) it is possible to achieve 6 km of fiber with CER below 10^{-9}. Without chirp (figure 6 (b)) it is possible to achieve 40 km of fiber with CER lower than 10^{-9}.

The performance degradation introduced with chirp can be noticed observing figure 7, where we present CER as a function of laser chirp, considering 6 users, 1 mW and 10 mW of mean power per laser and I_{pp}=20mA:

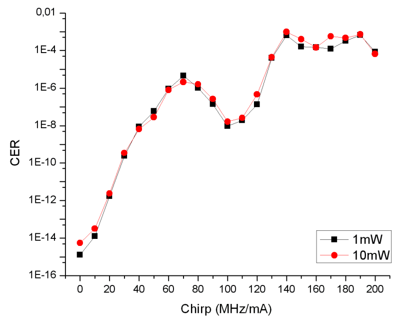

Figure 7 – CER vs. Chirp with 1 mW and 10 mW LASER power.

Also notice from this results, the power fading effect (figure 6), associated to RF propagation over fiber.

The performance degradation induced by increasing the users' Bit Rates (without chirp) can be noticed observing figure 8, where we present CER as a function of the Bit Rate, considering 2 to 6 users, 10 mW of mean power per laser, I_{pp}=20 mA, 1 km of SSMF linking each LASER to the adder and 5 km of SSMF for the link that connects the adders to the PIN:

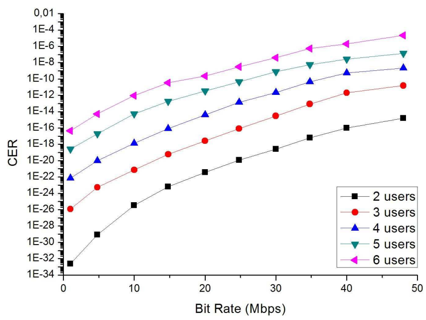

Figure 8 – CER vs Bit Rate (without Chirp and 10 mW LASER power).

As observed, increasing each user's Bit Rate also leads to performance degradation of the system, as expected. Nevertheless, 6x25 Mbps can be achieved for the considered link, with CER below 10^{-9}.

V. CONCLUSIONS

We described a new technique that allows several users to send information over an optical shared medium, combining electrical CDMA and optical WDM. A fiber length of 20 km may be achieved (CER under 10-9), without laser chirp, for 6 data channels (3.84 Mb/s, SF=8) and 1 mW mean power. The achieved distance is lower if we consider chirp, 4 km in the conditions referred. By increasing the LASER's mean power to 10 mW, a fiber length of 40 km may be achieved (CER under 10-9), without laser chirp, for 6 data channels (3.84 Mb/s, SF=8). The achieved distance is lower if we consider chirp, 6 km in the conditions referred. Nevertheless, the proposed concept can be an alternative to traditional WDM demultiplexing, using optical filters, within the mentioned limits (lower number of channels, bit rate, distance), due to its inherent CDMA transparency and robustness.

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