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A New Scheme for OCDMA using 2D Codes and Differential Detection

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***Resumo* –É proposto um novo sistema de CDMA óptico com codificação dos pulsos no comprimento de onda e no tempo. São usadas duas polarizações ortogonais possibilitando uma codificação e descodificação simples de dois canais independentes e detecção diferencial. O sistema resultante tem um limiar de decisão constante e nulo e portanto tem um desempenho superior a um sistema com detecção directa.**

***Abstract* – A new optical system with wavelength-encoding/time-spreading Optical Code Division Multiple Access (O-CDMA) is proposed. Using orthogonal polarizations we can have a simple encoding and decoding of two independent channels and achieve differential detection. The resulting system has a constant null decision threshold and therefore a superior performance when compared with a system with direct detection.**

I. INTRODUCTION

Existing optical fiber communications systems are been based upon Time Division Multiplexing (TDM) and Wavelength Division Multiplexing (WDM). First Optical Code Division Multiple Access (O-CDMA) systems employed only time [1,2,3] or frequency to code information [4]. The performance of Optical Orthogonal Codes (OOCs) using time was analyzed in [2,3]. What has been proposed several times in the literature is a 2D scheme which comprises both wavelengths and time as a way to code the data pulses [5].

This codification allows a high number of network users, but data Bit Error Rate (BER) degrades very rapidly with the increasing number of users. Theoretical analysis of O-CDMA systems has shown that Multi-User Interference (MUI) is the main reason for performance degradation [4]. There are several multiple access schemes nowadays in optical systems, and the most popular is an hybrid one whose properties are located between the ones of DS-CDMA and FH-CDMA, which can be implemented with Fiber Bragg Gratings (FBG). Meanwhile, this is not a hybrid system in which we have a hop/bit, but a hop/user, i.e. the code is not data independent but user dependent. As is depicted in Figure 1, a broadband source is coded both in frequency and in time by locating and designing correctly the FBG's in the structure. This broadband source can be built recurring to some lasers closely spaced, a multi-wavelength laser or multiple fiber lasers. This is a cost effective way of generating ultra-short pulses to be coded using an O-CDMA scheme.

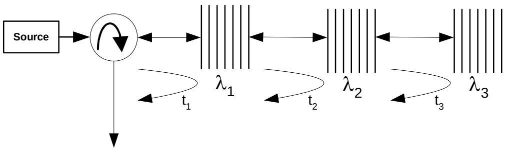

Figure 1 An optical FH-CDMA coder based on FBGs

II. SYSTEM SETUP AND CONFIGURATION

In this work we investigated a system composed of several transmitters and a receiver in a broadcast and select star network. The simulated system is non-coherent and recurs to direct detection. The 2D codes employed are unipolar, so they are not strictly orthogonal to each other. The zeros and ones are sent separately on two orthogonal polarizations and the same 2D code is used to codify both zeros and ones. In the decoder, direct detection is applied to both polarizations and the electrical signal of zeros is subtracted from the ones electrical signal. Considering this, differential detection is achieved for each code. Although in each polarization we have a unipolar 2D encoding, due to differential detection we receive a bipolar signal allowing for a constant threshold (null) independent of the number of users, provided that approximately the same power is present on both polarizations. This is clearly a big advantage because in unipolar OOCs the threshold is dependent on the number of users and the interference.

The pulses of each of the 7 frequencies f_i, i=1..7, are Gaussian and they are generated at a rate of R=1Gbit/s using a Full Width Half Maximum FWHM=1/4/R/7 s, a 10 mW peak power and 100 GHz spacing. The electrical signal is fed to a modulator whose power splits it in two. One of the signals is then inverted in order to have two inverted signals of same amplitude. Both signals are used to separately modulate a Mach Zenhder (MZ). The second signal (zeros) is put into an orthogonal polarization and both (zeros and ones) are fed into an encoder. Using FBG written in highly birefringent (HiBi) fibers, both polarizations are encoded into different wavelengths simultaneously [6]. Note that in order to use the HiBi encoders, extra lasers must be provided with the central frequency shifted ($f_i + \Delta f$). A solution might be the use of broadband sources. A value of $\Delta f = 50$ Ghz was used for the simulation, which can be considered a typical value for HiBi FBGs. Another inherent advantage is that, now, we can differentiate which of the polarizations carry the ones because its frequencies are 50 GHz lower.

III. CODING AND INTERFERENCE

Our goal was to evaluate how many users could we have in a system using only m=7 wavelengths and n=7 time chips. Using well behaved codes, choosing only the codes that have different frequencies at every time chip, we can have at most m codes without interference. Considering a (7x7,3,1) code with weight w=3, maximum out of phase autocorrelation λ_a=1 and maximum cross correlation λ_c=1 gives a total of 56 users [7]. The frequencies are placed in time chips (t_1, t_2, t_4) as in [7]; the first 7 codes are

$$\left(4+a, 2+a, 1+a\right), \quad a = 0, \dots, 6 \tag{1}$$

where the sum is taken modulo m. This is the first block of codes, and since there are 3!=6 permutations, we can have 6 blocks of 7 codes obeying (1) with a different starting vector, which gives us 42 possible codes. We are ignoring some troublesome codes, which need specially designed coders to be implemented, and since MUI doesn't allow us to use all the codes, these extra 14 codes are first discarded. With the 7 codes given by (1), we don't have MUI and so we can use a Gaussian approach to calculate the error probability.

In order to assure a reduced MUI the subsequent codes need to be all from another group, so we pick another element from the permutation of the original vector (4,2,1),

$$\left(2+a, 4+a, 1+a\right), \quad a = 0, \dots, 6 \tag{2}$$

giving another 7 codes. This time, after using a code from another group, MUI is no longer negligible and therefore we cannot recur to the Gaussian approximation to calculate BER.

IV. RESULTS AND DISCUSSION

As a consequence of using differential detection, we achieved a 3 dB gain and a constant null threshold making the receiver easier to build. The codes obtained from (1) produce a constant eye opening of -1.89 dBm with a received peak of -0.944 dBm. The interference noise is not increased when going from 1 to 7 users using this scheme. When adding users from the second group using the block of codes from (2), we realized that MUI degrades the signal very severely. The eye is thus closed with just 6 more codes, rendering the maximum possible codes equal to 12. These results can be seen in Figure 2. This fact occurs due to the fact that these 2D codes are not strictly orthogonal to each other, and although differential detection might reduce MUI slightly, differential detections best achievement is doubling eye opening. This also dramatically improves BER, but one way to have more users is to add more wavelengths and time chips and/or use 2D orthogonal codes. This latter approach is better because we can achieve a better spectral efficiency.

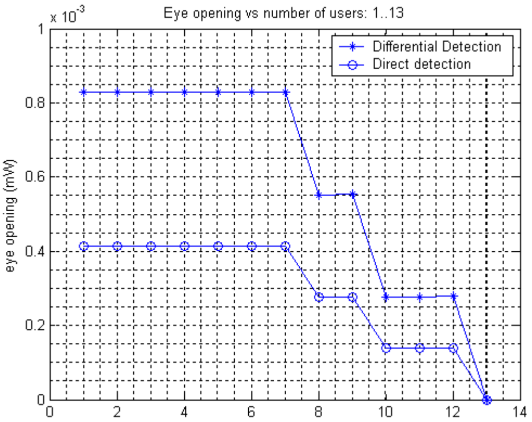

Figure 2 Eye opening in mW

As we expected, from 1 to 7 codes the eye opening is constant and decays drastically with more users from other blocks. This result is only due to MUI (we are not taking into account the fiber linearities and non-linearities). Nevertheless, this gives us an indication on how the error probability degrades with MUI.

The results show that the new implementation offers better results against the typical direct detection techniques and is simpler to implement than other differential detection architectures.

ACKNOWLEDGMENTS

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