

PERFORMANCE ANALYSIS OF AN OPTICAL CDMA COMMUNICATIONS SYSTEM BASED ON FIBER BRAGG GRATINGS

J. I. Marulanda^{*}, P. Torres^{**}

^{*} *Universidad EAFIT Sede Medellín,*

^{**} *Universidad Nacional Sede Medellín*

ABSTRACT

This paper shows simulations of a Fast Frequency Hop Optical Code Division Multiple Access communications system (FFH-OCDMA), using fiber Bragg gratings (FBG) arrays as encoding-decoding devices. Auto and cross-correlation functions of the used codes, and bit error rate (BER) were used as evaluation criteria.

INTRODUCTION

Systems simulation is a powerful tool for feasibility evaluation, especially when complex and expensive systems are involved. We present results of an FFH-OCDMA system performance by weak uniform fiber Bragg gratings (FBG) time response simulations. Error probability function was assumed as Gaussian to evaluate the bit error rate (BER).

A typical CDMA system model is revised in Section I, followed by a description of proposed encoder-decoder device (II and III). Performance of communications systems depends largely on the used codes. This is studied and evaluated in IV. Finally, results and conclusions are discussed.

CDMA SYSTEM MODEL

Let consider a fiber optic CDMA communications system with K active user pairs (transmitter-receiver) in a star architecture [1]. Each bit from k th user is encoded onto a sequence

$$c_k(t) = \sum_{j=1}^L d_{k,j} p_j(t - jT_c), \tag{1}$$

where L is the code length (number of “chips”); $d_{k,j} \in \{0,1\}$ is the j th chip value of the k th user’s code for $1 \leq j \leq L$, and T_c is the chip duration; $p_j(t)$ is the j th chip waveform and corresponds to the FBG time response (Section II). The received signal can be written as

$$r(t) = \sum_{k=1}^K b_k c_k(t - t_k) \tag{2}$$

where $b_k \in \{0,1\}$ is the k th user bit, $0 \leq t_k \leq T_c$ is the time delay of the k th user, and $c_k = [d_{k,1}, d_{k,2}, \dots, d_{k,N}]$ is a vector representing the discrete code form. The incoming signal is filtered at the receiver to obtain the desired information. For example, for $k=1$ and $t=0$, the output per bit duration T is

$$y = \int_0^T c_1(t)r(t)dt = b_1 \int_0^T (c_1(t))^2 dt + \sum_{j=2}^K b_j \int_0^T c_1(t)c_j(t - t_j) dt = b_1 L + MAI \tag{3}$$

where $T = LT_c$ is the information bit duration; multiple access interference (MAI) is the most important system noise source, and its probability function density is approximately Gaussian [2], for a large number of simultaneous users.

BRAGG GRATINGS.

Fiber Bragg gratings (FBGs) are passive devices that reflect specific spectral components from an incident pulse. Length (l) and strength (dn/n_0) determine reflectivity characteristics, where dn is the grating amplitude and n_0 is the effective index of the unmodified core. Strength indicates if the FBG is designed to be weak ($dn/n_0 \approx 10^{-5}$) or very strong ($dn/n_0 \approx 10^{-3}$).

For simulation purposes, we used conventional coupled-mode theory in modeling pulse propagation through fiber gratings [3]. It was considered a weak uniform FBG with $l = 1.0$ cm, $n_0 = 1.452$ and $dn/n_0 = 3 \times 10^{-5}$; 1-ps Gaussian pulse centered at 1550 nm was assumed as input signal, with spectral components between 1549.5 nm and 1550.5 nm. Fig. 1 (a) shows the simulated reflected pulse as a time function; spectral response is represented in Fig. 1 (b), in order to illustrate what fraction of the input spectrum is reflected.

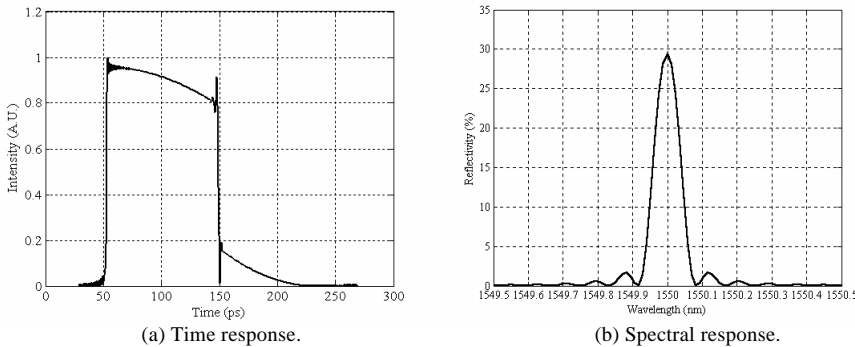


Fig 1. Weak grating responses.

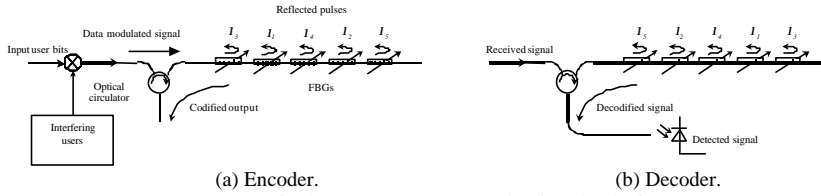
ENCODER AND DECODER.

By using piezo-electric devices, the center frequencies of the Bragg gratings can be changed, effectively changing the hop pattern and therefore allowing for programmable codes. FBGs equally spaced are disposed for coding the bit information from an user; each grating reflect a particular wavelength and the chips are obtained (Fig. 2 a). At the receiver, an identical array to the encoder is disposed in reverse order and then the original information bit is reconstructed (Fig. 2 b). These arrays were simulated “tuning” the reflected FBGs wavelength with Bin’s codes [4].

SYSTEM PERFORMANCE.

A. *Auto- and Cross-Correlation.* In any CDMA system, the following conditions must be satisfied. Let $c_k(j)$ the j th chip of code c_k , then

- i) the peak of the auto-correlation function



(a) Encoder. (b) Decoder.
Fig. 2. FFH-OCDMA encoder-decoder device.

$$R_m(s) = \sum_{i=0}^N c_m(i)c_m(i-s) \quad -N+1 \leq s \leq N-1 \quad (4)$$

should be maximized for each code, and
ii) the cross-correlation function

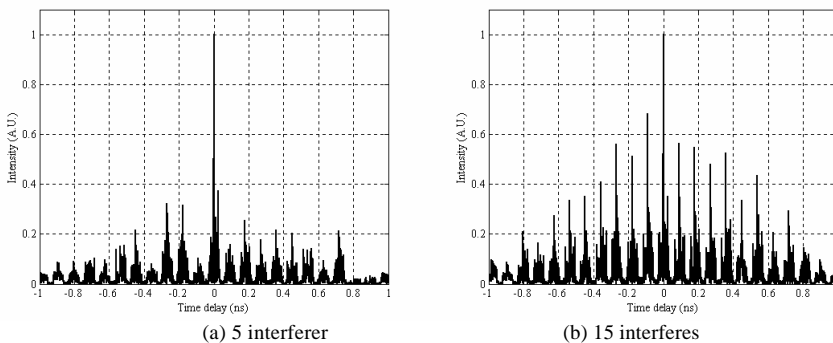
$$R_{m,p}(s) = \sum_{i=0}^N c_m(i)c_p(i-s) \quad (5)$$

of each pair of sequences c_m and c_p should be minimized for all delays s .

For performance evaluation of encoder–decoder, we calculate the auto and cross-correlation functions for different numbers of simultaneous users (Fig. 3). Using the Bin algorithm, we found sequences with $q = 29$ and $d = 8$ (i.e. $L = 12$); generator sequence (9, 13, 11, 12, 15, 10, 20, 16, 18, 17, 14, 19) was chosen. In all cases, auto-correlation has an easily identifiable peak compared to the cross-correlation function, although for 15 interfering users the cross-correlation peaks are significant. This means that the maximum number of active users is roughly equal to half the code capacity. This is consistent with 16 simultaneous users (1 user, 15 interferers) in a system with 29 unique available codes.

B. Error Probability. Codes average variance for the simulated gratings was calculated per

$$s_{m,p}^2 = \frac{1}{2N-1} \sum_{s=-N+1}^{N-1} (R_{m,p}(s) - \bar{R}_{m,p})^2 \quad (6)$$



(a) 5 interferer (b) 15 interferer
Fig. 3. Auto and cross-correlation functions for 1 user and some interferers.

where $\bar{R}_{m,p}$ is the delay-averaged value of the cross-correlation between codes m and p and $N = 29$ available frequencies were used. Error probability was calculated as:

$$P_e = Q(\sqrt{SIR}) \tag{7}$$

where $Q(x) = \frac{1}{2\pi} \int_x^{\infty} e^{-u^2/2} du$, $SIR = \frac{N}{(K-1)s^2}$ for K active simultaneous users and $s^2 = s_{m,p}^2/N$.

Solid line in Fig. 4 is derived assuming ideal reflectivity, and rectangular, disjoint, contiguous chip pulses. The simulated gratings (dashed) use nonideal reflectivity and noncontiguous chip pulses. As it can be seen, the spacing between chip pulses reduces the probability of coincidence between users in an asynchronous transmission system, and reduces the interference contribution leading to better probability of error than a system with contiguous chip pulses.

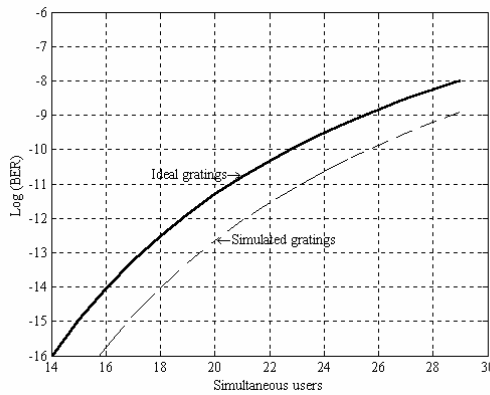


Fig. 4. Probability of error versus number of simultaneous users.

CONCLUSIONS

Evaluated system is a promissory option for fiber communications systems, taking account of its all-optical signal processing and security characteristics. Depending of the number of users, speeds of Gb/s can easily reached, and increasing the spacing between consecutive chips, crosstalk is reduced. For future work, performance simulations with strong and very strong FBGs will be done to evaluate new bounds.

REFERENCES

[1] Azizoglu, M., "Optical CDMA via temporal codes ". IEEE Transactions on Communications, vol 40, No 7, July 1992.
 [2] Fathallah, H. et al, "Passive optical fast frequency-hop CDMA communications system". Journal of Lightwave Technology, vol. 17, no. 3, March 1999.
 [3] Chen, L., "Ultrashort pulse reflection from fiber gratings: a numerical investigation". Journal of Lightwave Technology, vol. 15, no. 8, August 1997.
 [4] Bin, L., "One-coincidence sequences with specified distance between adjacent symbols for frequency-hopping multiple access". IEEE Transactions on Communications, vol 45, No 4, Apr 1997.