ALL OPTICAL TUNABLE 2D-ENCODER / DECODER FOR WAVELENGTH HOPPING OPTICAL CDMA SYSTEMS

M.MeenaKshi, Anand Venkataraman, R. Kumar, Pradeep Rajan, E.Manushanth, G.Geetha

Department of Electronics & Communication Engineering
College of Engineering, Guindy
Anna University, Chennai - 600025
meens68@yahoo.com

ABSTRACT
A novel all optic tunable 2D encoder / decoder for a wavelength hopping Optical CDMA system utilizing Fiber Bragg Gratings and Reconfigurable Delay Lines, is proposed and analysed in this paper. The system is simulated with different 2D coding schemes and the BER estimated using a simplified Importance Sampling methodology. The results show the capacity improvement achieved in the 2D- OCDMA system proposed.

Key words: Optical Code Division Multiple Access (OCDMA), Strain Tunable Grating (STG), Re-configurable Delay Line (RDL), Binary Superimposed Grating (BSG), Importance Sampling (IS).

1. INTRODUCTION
In the recent years, Optical Code Division Multiple Access (OCDMA) is getting more attention owing to the utilization of the enormous fiber bandwidth to provide several advantages like security, network scalability and so on with a simple architecture. In a conventional one-dimensional OCDMA, the code is spread in time. Each user is allocated a unique codeword. The codewords used are orthogonal to one another. They should have very high auto correlation peak and very low off-peak auto correlation and cross correlation. Though the signal is spread in time, all users transmit in the same wavelength. Hence the resource utilization becomes very poor. In the hybrid scheme (WDMA + CDMA), the cardinality of the system is less [1]. In the two-dimensional (2D) OCDMA system, the signal is spread in both time and wavelength. The code is a 2D array, in which the rows represent the wavelength spread and the columns represent the time spread. Each row of the code is transmitted in a particular wavelength. The cardinality of the system is greatly increased. The block diagram of an all-optic 2D OCDMA system is shown in Figure 1. An all-optic encoder / decoder is an essential block in the realization of this system. In this paper, a novel implementation for the tunable encoder / decoder is proposed and its performance is analysed by simulation.

2. ALL-OPTIC TUNABLE ENCODER / DECODER

The proposed all-optic tunable 2D encoder and decoder architectures are shown in Figure 2 and Figure 3 respectively. Their realization is based on Strain tunable Fiber Bragg Gratings (FBGs) and Reconfigurable Delay Lines (RDLs). The incoming data externally modulates a broadband source to give a pulse over the chip period. The encoder consists of a series of FBGs with RDLs in between. The weight of the spreading code determines the number of FBGs to be used. In all the 2D coding schemes considered the (1,1)
position of the code is always ‘1’. So the first wavelength is reflected without any delay. The subsequent wavelengths are given the required amount of delays as demanded by the code and the outputs from all the FBGs are combined using a combiner. The functioning of the decoder is similar to the encoder, except that the various delays are reversed. The aim of the decoder is to bring the bit power spread in different wavelengths to the same point in the time scale. Thus the wavelengths that are delayed most in the encoder are delayed the least in the decoder and vice-versa.

3. SYSTEM SIMULATION & EVALUATION

3.1 Simulation Models

The broadband optical source is simulated as an array of laser sources with wavelength spacing of 1.1 nm, starting from an initial wavelength of 1550 nm. Each cavity of the laser array is modeled by solving the large scale, coupled, first order differential rate equation [2] which describes the inter-relationship of the photon density, carrier density and optical phase within the laser cavity. A fourth order Runge Kutta algorithm is used to solve the coupled rate equation. For the simulation of FBGs, the characteristic curve of the Binary Superimposed Grating (BSG) [3], shown in Figure 4 is used. The RDL is modeled as a loss and delay introducing device. The single mode, dispersion unshifted fiber is simulated using its attenuation and dispersion characteristics.

The hopping wavelengths corresponding to the chips are selected by the FBGs and the inter chip intervals are achieved using RDLs. The serial method of implementation reduces the tuning range of RDLs. The use of strain tunable FBGs and the RDLs affect only the call setup time, but not the communication speed. The Avalanche PhotoDiode (APD) is modeled using the Webb, McIntyre and Conradi model [4] by acceptance rejection method. The thermal noise due to receiver electronics has been modeled as a zero mean Gaussian process. The multiple access interference is modelled as in [5]. The outputs of different blocks of the system are shown in the Figures 5, 6, 7 and 8. The figures show the successful performance of the proposed 2D encoders and decoders in spreading and despreading of input data.
Figure 5. Output of the Laser array

Figure 6. Output of the 2D–OCDMA encoder; GMWEPC; 3 wavelengths; \( p_1=p_2=2; \) \( i_1=i_2=1; \) Sample data [101100]

Figure 7. Output of the 2D–OCDMA decoder

Figure 8. Output of the APD
Sample Data [101100]

4.2 BER Evaluation

In high performance and broadband systems like optical fiber systems, the Bit Error Rate (BER) requirement is less than or equal to \(10^{-9}\). To evaluate a BER of \(P_e=10^{-9}\), the conventional Monte Carlo (MC) technique would require \(100/P_e\) independent simulation runs [6] which would prove computationally costly. Hence advanced simulation techniques like Importance Sampling (IS) [6] are required. IS is a variance scaling technique which reduces drastically the number of simulation runs, over the conventional MC technique. In this the decision is made by comparing the received number of electrons ‘\(V\)’ with a threshold ‘\(\gamma\)’. If \(H_0\) and \(H_1\) indicate the hypotheses of a ‘0’ and ‘1’ being transmitted, then \(P_0=P(V \geq \gamma \mid H_0)\) and \(P_1=P(V \leq \gamma \mid H_1)\) indicate the error in ‘0’ and ‘1’ respectively. The average BER is given by,

\[
P_e = \frac{P_0 + P_1}{2}
\]

(1)
Let $f(.)$ denote the unbiased probability density function and $f^*(.)$ denote the biased density, then the ‘weighting function’ of the IS is given by

$$w = \frac{f(.)}{f^*(.)}$$  \hspace{1cm} (2)

If ‘L’ were to denote the length of the sequence and $1i(.)$ denote the error in a ‘1’, then

$$P_1^* = \left[ \sum 1i(.)w(.) \right] / L$$  \hspace{1cm} (3)

Using equation (2) the actual error $P_1$ is calculated from $P_1^*$. In this work, the IS technique is implemented as follows. For evaluating error rate for a ‘0’ transmission, the threshold is first kept at a very low level and the BER is found. This allows more errors to occur. The threshold is then slightly increased and the BER is found again. With this set of co-ordinate points (threshold, BER), the weighting function is determined using the rate of decrease of BER between these two points. The weighting function so obtained is used to estimate the BER corresponding to a still higher threshold and this BER value is compared with the BER obtained from simulation, and suitable corrections are made to the weighting function. This is repeated over many Monte Carlo runs and the weighting function is appropriately determined. The minimum BER corresponding to optimum threshold values, can then be estimated. For evaluating the error rate for ‘1’ transmission, a similar procedure is adopted, but the threshold is initially kept at a very high value and gradually brought down to estimate the weighting function.

4.3 Results and Discussion

The accuracy of the IS methodology used in this work is verified by comparing the BER evaluated by simulation with the theoretical results as shown in Figure 9. The GMWEPC code [7] with $p=7$ is used in the 2D-OCDMA system.

The influence of the APD gain on system performance for a single user is shown in Figure 10. As the mean gain of the APD increases, the BER performance improves up to a certain point. Beyond this, quantum noise dominates and the SNR decreases and consequently the BER performance deteriorates.

In analyzing the coding schemes, 1D Optical Orthogonal Codes (OOC), 2D Generalized Multi-wavelength Prime Codes (GMWPC) and 2D Generalized Multi-wavelength Extended Prime Codes (GMWEPC) [7] are considered. It is observed from Figure 11 that, the 2D schemes surpass their 1D counterparts in performance. For example, for a prime length of 7 and active users of 5, 1D CDMA system has a BER of $10^{-3}$, while the 2D CDMA system has a BER of $10^{-9}$. Also among the 2D coding schemes, GMWEPC outperforms GMWPC by several times. On an average the BER of GMWEPC is 100-1000 times lesser than that of GMWPC for a prime of 7.
4. CONCLUSIONS

A novel all optic tunable 2D encoder / decoder for a wavelength hopping Optical CDMA system utilizing Fiber Bragg Gratings and Reconfigurable Delay Lines, is proposed and analysed in this paper. The modeling and the simulation issues in the design of the novel encoder and the decoder for the use of 2D codes in multi-wavelength OCDMA systems are discussed. In each of the components involved in establishing the link, the associated noises and parameters have been incorporated. While theory associated with the 2D codes have very recently been well established, the novelty lies in the encoder / decoder design, which works totally in the optical domain and performs the job of an optical correlator, thus avoiding electronic correlation which would place restrictions on the communication speed. This scheme has thus enabled the possibility of a very large number of users sharing hundreds of gigahertz of available fiber bandwidth in an all-optic network. The simplified IS methodology adopted to evaluate BERs in the order of $10^{-16}$ is also a highlight of this work.

5. REFERENCES

[1] Guu-Chang Yang and Wing C. Kwong, “Performance Comparison of

Multiwavelength CDMA and WDMA +
CDMA for Fiber-Optic Networks”, IEEE

Performance”, Journal of Lightwave

[3] Ivan.A.Avrutsky, J. M. Xu,
“Multiwavelength Diffraction and Apodization
using binary superimposed gratings”, IEEE

[4] M.C.Jeruchim, P.Balaban and
K.SamShanmugam, “Simulation of

Rusch, “Code performance in multi-rate
CDMA for an optical fiber network”,
Laboratoire de Radiocommunications et de
Traitement du Signal-Rapport annuel

[6] Narayan. B. Mandayam, Behnaam Aazhang,
“Importance Sampling for Analysis of Direct
Detection Optical Communication Systems”,
IEEE Transactions on Communications, Vol.
43, No. 2/3/4, pg 229-239, February/ March/
April 1995.

the Analysis of Multiwavelength Optical
CDMA Communication System using
Extended Prime Codes”, Photonics-
98: International Conference on Fiber
Optics&Photonics, pg 420-423, December
1998.