Mismatch Tolerance in Wavelength Hopping/Time Spreading 2-D Optical CDMA Systems

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Abstract

In this paper, the autocorrelation peak reduction due to wavelength-domain and time-domain mismatches between an encoder and a decoder in wavelength hopping/time spreading (WH/TS) 2-D optical CDMA systems have been analyzed. The tolerance of both wavelength and time-domain mismatches are then obtained through the analysis of the system bit error rate (BER) performance.

Introduction

Recently, optical code division multiple access (CDMA) systems have been actively studied as a candidate for optical local area networks. Up to now, various schemes for generating efficient code families have been suggested from one-dimensional (1-D) codes encoded in time or wavelength domain only to two-dimensional (2-D) codes with every pulse of a codeword encoded in time and wavelength or in time and space domain. Among them, the wavelength hopping and time spreading (WH-TS) 2-D coding schemes, in which active code chips are defined not only by time slots but also by wavelengths in the codeword, have attracted many research interests due to their good auto-/cross-correlation property and greatly increased cardinality of the code family [1].

The encoder/decoder for such a WH-TS 2-D optical CDMA system has been realized by the several structures such as a scheme using multiple fiber Bragg gratings (MFBGs) structure [3] or a scheme using arrayed waveguide gratings (AWGs) attached by fiber delay lines [4]. Both of the encoder/decoder schemes use broadband sources like superluminescent diodes (SLD) or amplified spontaneous emission from erbium doped fiber amplifiers (EDFA) to exclude the need of expensive and rapidly tunable lasers to provide hopped-wavelengths.

There have been many studies on the bit error rate (BER) performance characteristics for WH-TS 2-D Optical CDMA systems [1,2]. However, most of them have assumed the ideal case without considering practical impairments such as wavelength drift due to the environmental temperature variation or fabrication errors and time delay mismatches due to group velocity differences or inaccurate delay lines, which deteriorate the system performance. In this paper, we have studied the practical performance-degrading factors in WH-TS 2-D optical CDMA systems with MFBG structure and categorized them into two mismatch terms, such as wavelength-domain mismatches and time-domain mismatches to find out the influence of both of mismatch terms between an encoder and a decoder. The reduction of the autocorrelation peak intensity due to the mismatches within an encoder/decoder pair is analysed theoretically and verified empirically. Consequently, the tolerance of the mismatches is obtained through analysis of the system BER performance.

Analysis

Firstly, the wavelength-domain mismatch term mainly consists of the center wavelength mismatches of individual FBG pairs between an encoder and the desired decoder. We assumed that the reflected spectra of the pulses through fiber Bragg gratings can approximately be described by the Gaussian shape and the wavelength mismatches are randomly distributed along the MFBG structure with normal distribution. The autocorrlelation peak intensity at the desired decoder output can then be given as follows,

$$I = \sum_{i=1}^{P_h} \frac{S_l R_{ei} R_{di} B_G \sqrt{p}}{\sqrt{8 \ln 2}} \cdot e^{-\frac{2\ln 2}{B_G^2}(dl_i)} \tag{1}$$

where S_l is power spectral density of optical source and R_{ei}, R_{di} is ith FBG's peak reflectivity of the encoder and decoder respectively. The spectral widths of reflected spectra of all FBG's are assumed to be identical and are denoted as B_G. The Bragg wavelength mismatches of individual FBG pairs is denoted as d_{l_i}. P_h is the number of wavelengths used to perform WH/TS coding.

The degradation of the autocorrelation peak intensity deteriorates BER performance of the system, because the detector should decrease the threshold level to correctly identify the desired user's data. To evaluate the BER performance, we should derive the expression of BER considering the MAI and the reduced threshold level due to the autocorrelation peak degradation. We have analysed the system BER performance and the autocorrelation peak degradation by using Equations (1) and (2) for the 2-D encoder/decoder structure [5]. In order to calculate the BER, a specific code set, especially eqc-prime code [1] was chosen. We have assumed that the Bragg grating bandwidth B_G of the reflected pulses is 0.4 nm that is a reasonable value of the normal FBG, and there are 100 simultaneously transmitting users.

$$BER \le \frac{1}{2} \sum_{n=Th}^{(N-1)} \sum_{i=0}^{\lceil \frac{n}{2} \rceil} \frac{(N-1)!}{(n-2i)!\,i!\,(N-1-n+i)!} P_2^i P_1^{n-2i} P_0^{N-1-n+i} + \frac{1}{2} \sum_{n=N}^{2(N-1)} \sum_{i=(n-N+1)}^{\lceil \frac{n}{2} \rceil} \frac{(N-1)!}{(n-2i)!\,i!\,(N-1-n+i)} P_2^i P_1^{n-2i} P_0^{N-1-n+i}) \tag{2}$$

where

$$P_1 = \frac{K^2}{2Fp_h} - \frac{K^2(K-1)^2}{8F^2 p_h^2}, \quad P_2 = \frac{K^2(K-1)^2}{8F^2 p_h^2}, \quad P_0 = 1 - \frac{K^2}{2Fp_h}$$

The symbol $\lceil x \rceil$ means the largest integer value below x.

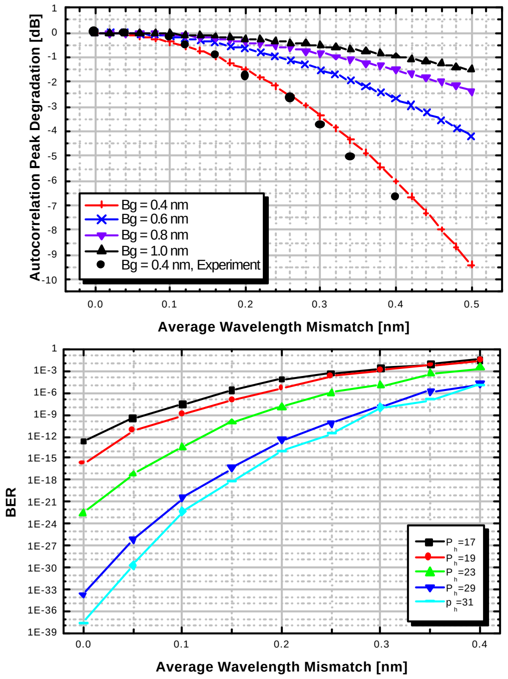

Figure 1. The autocorrelation peak degradation versus average wavelength mismatch and the corresponding BER performances (B_G = 0.4 nm)

As can be seen in the figure, the degradation of BER performance caused by the autocorrelation peak degradation is severe as the number of wavelengths used to generate code family increases. However, if we permit 10% (normalized to the Bragg grating bandwidth) wavelength mismatch, the autocorrelation peak degrades by about 0.8 dB and the corresponding system BER for P_h = 31 degrades from 10^{-38} order to 10^{-30} order which is still acceptable feature.

Secondly, the time-domain mismatch that mainly consists of inaccurate fiber delay lines and group velocity differences of individual wavelength pulses from an encoder can be similarly analysed. Fiber delay line mismatches are also randomly distributed along the MFBG structure with normal distribution, while group velocity differences are determined by the characteristics of the optical fiber, wavelength spacing, and transmission distance. The autocorrelation peak intensity at the decoder output considering time-domain mismatch is given as,

$$I=\sum_{i=1}^{P_h} I_{oi}(0)=\sum_{i=1}^{P_h} P_{oi}\exp\left[-4\ln 2\cdot d_{ti}^{\,2}/T_C^{\,2}\right] \qquad (3)$$

where $d_{ti}=d_{DM,i}+d_{GVD,i}=d_{DM,i}+\left(i-\frac{P_h+1}{2}\right)d\lambda\cdot L\cdot D$

and prime number P_h (= P_s for symmetric case) should be greater than 2. We assumed that the minimal dispersion wavelength could be centered among all the wavelengths used so that the group delay mismatch can be balanced to minimize the autocorrelation pulse distortion. Fig. 2 shows the autocorrelation peak degradation versus transmission distance of encoded pulses to reach the decoder output. A single mode fiber that has 18.2 ps/km of group velocity difference per nanometer is assumed and the chip duration is set to be 100 ps in FWHM.

From the figure, it is found that when 17 wavelengths are used to encode a code sequence (P_h = 17), even 1km transmission of encoded wavelength pulses degrades the autocorrelation at the decoder output by about –3.67 dB that corresponds the BER performance degradation from about 10^{-13} to about 10^{-3} order which is not acceptable at all. Therefore, the chromatic dispersion compensation scheme is required for wavelength hopping and time spreading 2-D optical CDMA systems as the number of wavelengths is increased as well as the chip duration is reduced to increase the cardinality of the code family and the supportable user data rate.

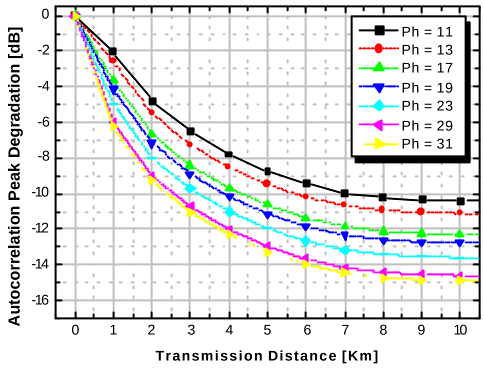

Figure 2. The autocorrelation peak degradation versus transmission distance between an encoder and the desired decoder. Wavelength spacing is assumed to be 0.8 nm

Conclusion

The autocorrelation peak reduction due to wavelength-domain and time-domain mismatches between an encoder and a decoder in wavelength hopping/time spreading (WH/TS) 2-D optical CDMA systems have been analyzed. From the analysis of the system BER performance, it is found that the time-domain mismatch terms, especially due to group velocity differences of individual wavelength pulses from the encoder severely degrades the system performance unless a dispersion compensation scheme, such as using chirped fiber grating before the decoder or incorporating pre-calculated delay mismatch to make up the group velocity differences, is adopted.

Acknowledgement

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