On the Use of SOA-Based Tunable Dispersion Compensator in Ultrafast Incoherent Fiber-Optic CDMA Systems Under Temperature Variation

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ABSTRACT

The use of semiconductor-optical-amplifier-based tunable dispersion compensator (SOA-TDC) in ultrafast incoherent fiber-optic code-division multiple-access (FO-CDMA) systems with picosecond multiwavelength codes has recently been demonstrated. In this paper, results on the SOA-TOC's capability of compensating for fiber chromatic dispersion and distorted autocorrelation function caused by fiber temperature variation (FTV) in such a FO-CDMA system with a long fiber link are reported. The deleterious effects of FTV to the system performance are quantified in terms of "chip granularity" and studied by applying a recent multiple-QoS performance-analytical model.

Keywords: code division multiple access, dispersion compensation, optical fiber communications, quality of service, temperature variation.

1. INTRODUCTION

The deleterious effects of fiber temperature variation (FTV) to ultrafast incoherent fiber-optic code-division multiple-access (FO-CDMA) systems using picosecond multiwavelength codes have recently been studied [1]-[5]. Causing dispersion and time skew to these multiwavelength codes, FTV can distort the auto- and cross-correlation functions seen at receivers and thus create detection errors in transmitted data bits [6], [7]. In addition, chromatic dispersion (CD) accumulated in a long fiber link requires the application of dispersion compensating fiber (DCF). To fully compensate for CD, precise setup of the DCF is needed but rather difficult to achieve in a network. As a result, small amount of CD may still exit from the DCF. Besides completely eliminating the residual CD, Ahmed, *et al.* [3]-[5] proposed a semiconductor-optical-amplifier (SOA)-based tunable dispersion compensator (TDC) to compensate for the FTV distortion to the autocorrelation function, however, not to the cross-correlation function. To account for the effect of the FTV-distorted cross-correlation function (at the SOA-TDC output) to the performance of this kind of FO-CDMA systems, new analytical models were studied [6], [7].

In this paper, the use of the SOA-TDC in an ultrafast incoherent FO-CDMA system using picosecond multiwavelength codes in a long fiber link is reviewed in Section 2. The deleterious effects of FTV to this system are studied and quantified in terms of "chip granularity" [3]. In Section 3, a recent multiple-quality-of-service (QoS) analytical model [7] is applied to study the performance of this FO-CDMA system with different amounts of FTV (in terms of chip granularity) and QoS (in terms of code weight).

2. Overviews of SOA-TDC and Fiber Temperature Variation

In an ultrafast incoherent FO-CDMA system [8]-[10], if an arrival codeword of weight w (i.e., number of multiwavelength pulses) matches with the address (codeword) signature of a receiver, these w pulses will ride atop each other within one chip. This creates an autocorrelation peak of height w, and a data bit of 1 will be recovered correctly if there is no CD or FTV distortion. Besides residual CD exiting from the DCF, FTV distortion (in forms of dispersion and time skew) will be imposed to these mutliwavelength pulses if there exists temperature difference in the long fiber link between the transmitter and receiver. To achieve precise CD and FTV-distortion compensation in the SOA-TDC [3]-[5], the SOA's input-power sensitivity is tuned to the power level of the autocorrelation peak so that the gain-compression mechanism of the SOA is created accordingly and precisely. Fig. 1 shows the experimental setup of the SOA-TDC for such compensation. A picosecond supercontinuum laser is used to generate optical supercontinuum, which is sliced by a fiber-Bragg-gratings-based O-CDMA encoder [9], [10]. The encoder generates a 4-wavelength codeword of weight $w = 4$, based on wavelengths 1,550.12, 1,550.92, 1,551.72, and 1,552.52 nm of each 12 ps (FWHM) in pulse-width. The system's repetition rate is 2.5 GHz. These correspond to chip-width of 12 ps, code length of 33 chips, and data rate of 2.5 Gbit/s (i.e., period of 400 ps). The codewords then travel in a 20-km CD-compensated fiber link with 45 °C of temperature difference between the encoder and decoder. The distorted autocorrelation function at the decoder output is then properly compensated by the SOA-TDC. The compensation results are observed in a sampling oscilloscope. Fig. 2 shows the screen shots of the autocorrelation function before and after compensation by the SOA-TDC, respectively. Because of the sign of the FTV thermal coefficient [3]-[5], Fig. 2a shows the distorted autocorrelation peak being compressed to 8 ps (FWHM). While the SOA-TDC can fully compensate the autocorrelation peak back to 12 ps (FWHM), Fig. 2b illustrates the compensation can be adjusted to any value by showing a compensated peak of 14 ps (FWHM).

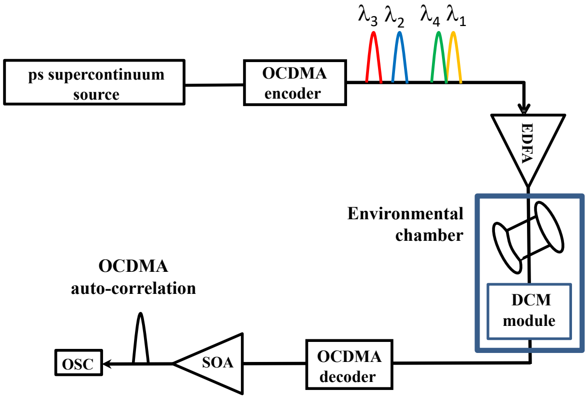

Figure 1. Experimental setup of a FO-CDMA link with the SOA-TDC. (OSC–oscilloscope, DCM–dispersion compensating module, and EDFA–Erbium-doped fiber amplifier.)

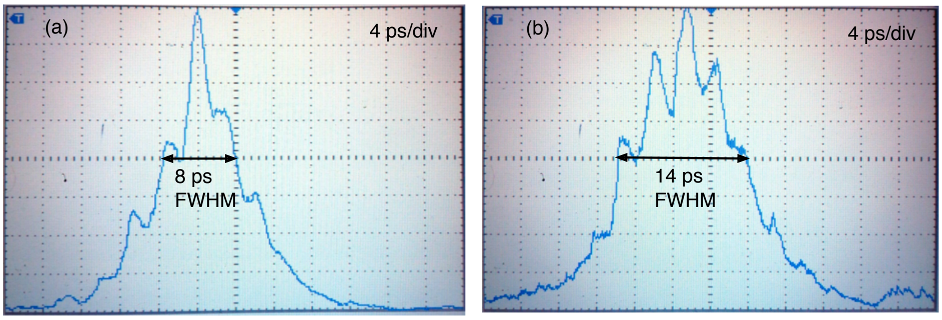

Figure 2. (a) A distorted autocorrelation peak of 8 ps (FWHM) after a 4-wavelength codeword of $w = 4$ with original chip-width of 12 ps (FWHM) being transmitted in a 20-km CD-compensated fiber link with 45 °C FTV. (b) A compensated autocorrelation peak of 14 ps (FWHM) after the SOA-TDC.

2.1 Quantifying Metric for the FTV Effects to Cross-Correlation Function

While the cross-correlation functions (from interfering codewords) are also distorted by the FTV time skew and dispersion [6], [7], they generally have much lower power and thus fail to trigger the gain-compression mechanism of the SOA-TDC. The deleterious effect of these distorted cross-correlation functions to the ultrafast incoherent FO-CDMA system performance need to be quantified and modelled accordingly.

As studied [6], [7], the envelope of the kth wavelength of the multiwavelength pulses from the picosecond supercontinuum laser under FTV can be modelled as

$$S_k(t) = \frac{\sigma}{\sigma-\Delta\sigma}\,\mathrm{sech}^2\left(\frac{t-k\Delta t}{\sigma-\Delta\sigma}\right) \qquad (1)$$

with time skew $\Delta t = D_{temp} \times \Delta T \times \Delta\Lambda \times d$ (ps) and dispersion $\Delta\sigma = D_{\mathrm{temp}} \times \Delta T \times \Delta\lambda \times d$ (ps) for $k \in [0, w-1]$, where D_{temp} (ps/nm/km/°C) is the FTV thermal coefficient and ΔT (°C) is the temperature difference in a fiber link of d (km). For these multiwavelength pulses, each wavelength has spectral linewidth $\Delta\lambda$ (nm), is equally spaced by $\Delta\Lambda$ (nm), and carries FWHM width (i.e., chip-width) $t_c \approx 1.76\sigma$, where σ is defined as the sech^2 pulse duration.

To illustrate the FTV effect to the cross-correlation function, carrier-hopping prime codes (CHPCs) of 31 chips and $w = 4$ with four wavelengths are used in this paper [9], [10]. Also assume that $t_c = 10$ ps (i.e., $\sigma = 5.68$), $\Delta\lambda = 1$ nm, $\Delta\Lambda = 1$ nm, $D_{\mathrm{temp}} = 0.0014$ ps/nm/km/°C, ΔT=45 °C, and $d = 20$ km. These parameters give $\Delta t = 1.26$ ps, $\Delta\sigma = 1.26$ ps, (dispersed) pulse width of $t_c = 1.76(\sigma - \Delta\sigma) = 7.78$ ps (FWHM), and time skew of the kth wavelength pulse $k\Delta t = 1.26k$ ps for $k \in [0,3]$. As a result, these multiwavelength pulses are regularly time-skewed as a function of Δt, and the time skew can be modelled in term of chip granularity $g = [\![t_c/\Delta t]\!]$ by subdividing each chip-width t_c into sub-chip-width Δt, where $[\![\cdot]\!]$ is a rounding function [6]. With $\Delta\lambda = \Delta t = 1.26$

ps and $t_c = 10$ ps, this example can be treated as a time-skew model of $g = 8$. The time skew will cause these multiwavelength pulses to partially fall into adjacent chips and thus create stronger multiaccess interference (MAI) in the cross-correlation function. As the cross-correlation function gets worsened (i.e., larger), the auto-to-cross-correlation ratio gets reduced and so is the system performance, even though the SOA-TDC is used to fully recover the autocorrelation peak. As shown in Section 3, the use of g to quantify the FTV effect to the cross-correlation function is an important parameter in determining the performance of such a FO-CDMA system.

3. Adjustable-QoS System Performance Analysis

To account for the actual effect of FTV under the SOA-TDC, the adjustable-QoS, hard-limiting error probability (i.e., performance-analytical model) of the CHPCs in an incoherent FO-CDMA system with on-off-keying modulation has been formulated as [7]

$$\mathrm{Pe} = \frac{1}{2}\sum_{i=0}^{w}(-1)^{w-i}\binom{w}{i}\left[q_0 + \frac{i}{w}q_1 + \frac{i(i-1)}{w(w-1)}q_2\right]^{K-1} \tag{2}$$

with the probabilities of getting zero, one, and two hits in the FTV-distorted cross-correlation function given by $q_0 = 1 - q_1 - q_2$,

$$q_1 = \frac{[2w(N-w+1)-N-1]g}{2N(N-1)(2g-1)} \tag{3}$$

$$q_2 = \frac{(w-1)^2(2g-1)}{8N(N-1)(g-1)} \tag{4}$$

respectively, where K-1 represents the number of interfering users, N is the number of chips, $w < N$, and $g \geq w$.

Fig. 3 compares the hard-limiting error probability P_{e}, from (2)-(4), of the CHPCs in the adjustable-QoS performance-analytical model with $N = 13$ chips, weight $w = \{7,8,9\}$, and chip granularity $g = \{2,3,4,5,8,20\}$. The dashed curves show the P_{e} of the baseline case of no FTV distortion (i.e., $\Delta t = 0$). Because $g = \llbracket t_c/\Delta t \rrbracket$, this ideal case is equivalent to $g = \infty$ and gives the performance lower bound. The P_{e} generally gets worsened as the number of simultaneous users K increases because more interferers will create stronger MAI and thus worsen the cross-correlation function. On the other hand, the P_{e} improves with w because heavier code weight increases the autocorrelation-peak's height for better MAI discrimination. By varying w, the QoS of the system can be adjusted. With the same w, the P_{e} improves with g and will approach to that of the ideal $g = \infty$ case as g gets larger. Because the FTV time skew is a function of Δt, chip granularity $g = \llbracket t_c/\Delta t \rrbracket$ gets smaller when the FTV effect is worsened (i.e., Δt gets larger). A larger Δt (i.e., smaller g) means that more portions of MAI will fall into adjacent chips in the cross-correlation function, resulting in larger hit probabilities and, in turn, worsening system performance. In other words, as the FTV effect gets lessened, a larger g value indicates smaller amount of MAI and thus better system performance.

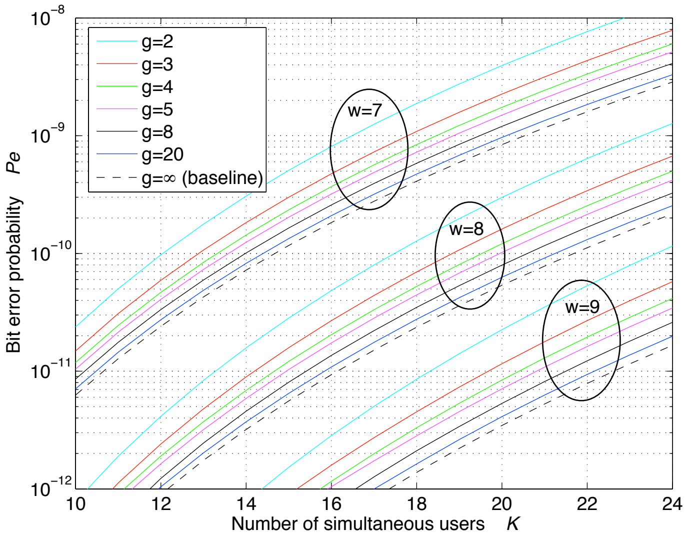

Figure 3. Harding-limiting bit error probability P_{e} of the CHPCs in the adjustable-QoS performance model versus the number of simultaneous users K with $N = 13$ chips, $w = \{7,8,9\}$, and $g = \{2,3,4,5,8,20\}$.

4. CONCLUSIONS

The use of the SOA-TDC in an ultrafast incoherent FO-CDMA system with picosecond multiwavelength codes in a long fiber link under the influence of FTV was reviewed. The FTV effects to such a FO-CDMA system were overviewed and modelled in term of chip granularity. An adjustable-QoS performance-analytical model was applied to quantify the system performance with different amounts of FTV (in terms of chip granularity) and QoS (in terms of code weight). With the use of the SOA-TDC to recover the original autocorrelation function, the study showed that the FTV effect to the cross-correlation function could not be ignored and, in fact, should be related to chip granularity. A lessened FTV effect was reflected by larger chip granularity, which, in turn, gave better system performance.

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