Suppression of collision-induced timing jitter in WDM RZ-pulse transmission by adjustment of decision timing

Masayuki Matsumoto

Department of Communications Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

matumoto@comm.eng.osaka-u.ac.jp

Abstract: Effectiveness of bitwise adjustment of decision timing at receiver in suppressing collision-induced timing jitter in dispersion-managed WDM RZ-pulse transmission is numerically analyzed. Influence of imperfect adjustment of decision timing is examined.

OCIS codes: (060.2330) Fiber optics communications; (060.5530) Pulse propagation and solitons

1. Introduction

Cross-phase modulation (XPM) between wavelength channels is one of the most serious factors liming distance, bitrate, and spectral efficiency of long-distance WDM fiber transmission systems. When return-to-zero (RZ) format is used for data modulation, the effect of XPM results mainly in the shift of temporal position of pulses occurring after collision of pulses in different channels. This is particularly true for optical solitons whose pulse shape is stabilized by the interplay between dispersion and nonlinearity. In soliton systems, furthermore, the particle nature of the pulse permits one to use simple control methods such as filtering to reduce the time shift. The effect of XPM, however, still induces large timing jitter even in filtered soliton systems when channel bitrate is high and channel spacing is small [1].

The collision-induced time shift in WDM RZ-pulse transmission is not random but determined by the bit pattern of neighboring wavelength channels. This means that when the bit-pattern information of surrounding channels is available, the time shift can be predicted and nulled in principle by using receivers capable of bitwise adjustment of decision timing [2]. In this paper we simulate the effectiveness of this method applied to filtered dispersion-managed soliton transmission. In the receiving end of the system, each channel is assumed to be equipped with two receivers: In the first receiver data are read with usual clock extraction. In the second receiver, with suitable delay from the first one, detection is made with corrected timing calculated with the data from the first receivers.

2. Collision-induced timing jitter

Here we consider a three-channel WDM transmission with equally spaced channels Ch.1, Ch.2, and Ch.3. The collision-induced time shift of pulses in Ch.2 is discussed below. The bit phase of all the channels is assumed to be the same at the entrance of the system $z = 0$. A pulse at a temporal position $t = t_k$ (at $z = 0$) in Ch.2 collides during propagation with pulses in Ch.1 positioned from $t = t_{k-m} = t_k - mT$ to $t = t_{k+n} = t_k + nT$ at $z = 0$, where T (ps) is the bit period. The integers m and n depend on the transmission distance, wavelength separation, and details of the dispersion map. For a two-stage dispersion map where an anomalous-dispersion fiber with GVD D_1 (ps/nm/km) and length L_1 (km) and a normal-dispersion fiber with D_2 (ps/nm/km) and length L_2 (km) constitute the amplifier span, the number of colliding pulses $n + m + 1$ is approximately given by

$$n + m + 1 = \mathrm{Int}\left[\left|D_{\mathrm{ave}}\right|\left(L_1 + L_2\right)N\Delta\lambda / T + \left(D_1 - D_{\mathrm{ave}}\right)L_1\Delta\lambda / T\right], \qquad (1)$$

where $D_{\mathrm{ave}} = \left(D_1L_1 + D_2L_2\right)/\left(L_1 + L_2\right)$ is the average dispersion and N and $\Delta\lambda$ (nm) are number of amplifier spans in the system and wavelength separation between channels, respectively. The time shift induced to the k-th pulse in Ch.2 due to the collision with pulses in Ch.1 is then given by

$$\Delta t_{2,k} = \sum_{l=k-m}^{k+n} s_{1,l}\, \delta t_{l-k} \,. \qquad (2)$$

In the above equation δt_{l-k} is the time shift induced by a collision of a pair of pulses in Ch.1 and Ch.2 separated by $(l-k)T$ at $z = 0$. $s_{1,l}$ is 1 or 0 when the pulse is present or absent at $t = t_l$ in Ch.1. (2) is modified to

$$\Delta t_{2,k} = \sum_{p=-m}^{n} \left(s_{1,k+p} - s_{3,k-p}\right)\delta t_p \qquad (3)$$

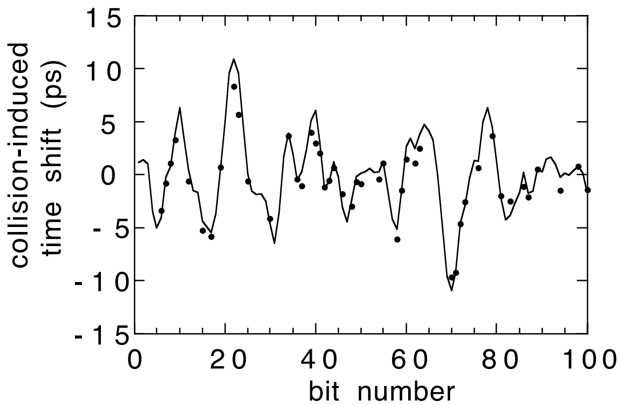

Fig.1. Collision-induced timing jitter of the central channel in three-channel WDM transmission. Dots are the results obtained by numerically transmitting pulse trains of 256 bits/channel. Solid curve is the time shift calculated with using the bit patterns of the surrounding channels and the time shift induced by the collision between two isolated pulses.

when we include the time shift due to collision with pulses in Ch.3. (3) indicates that the collision-induced time shift is determined by the bit patterns of the surrounding channels and time shifts due to individual collisions.

Fig. 1 shows an example of the time shift of dispersion-managed soliton transmission. A two-stage dispersion map with D_1=2.025ps/nm/km, D_2=-1.975ps/nm/km, $L_1 = L_2$=25km, number of spans N=120 (6000km), and fiber loss of 0.22dB/km are assumed. Fabry-Perot filters with equivalent 3dB bandwidth 250GHz are inserted at every in-line amplifier. Fiber nonlinearity, pulse energy at the output of the amplifier, bitrate, and channel separation are $n_2/A_{\rm eff}=0.55\times10^{-9}$ W^{-1}, 0.07pJ, 40Gbit/s/ch, and 1.6nm, respectively. Surrounding channels (Ch.1 and Ch.3) have the bit patterns that induce largest time shifts to some of pulses (22nd and 70th bits in Fig.1) in Ch.2. Solid curve is the time shift calculated by (3) where δt_p is obtained by a separate calculation using the Split-Step Fourier method. (We confirmed that an approximate variational approach [3] produces almost the same results.) Dots are the result obtained by numerically transmitting the three-channel signal with 256-bit length and calculating time shifts of the pulse peaks in Ch.2 at the receiver. The curve agrees with the dots indicating that (3) works well.

Fig.1 also shows that correlation distance of the time shift is not long because the number of collisions experienced by each pulse is small due to the small average dispersion ($D_{\rm ave}$=0.025ps/nm/km). In this case the method of jitter tracking proposed in [4] does not work well.

For WDM systems with more than three channels, contributions from collisions with all the other channels have to be included. (3), however, may be enough because the time shifts induced by the immediately neighboring channels dominate the total time shift.

3. Effect of adjustment of decision timing

Fig. 2 shows a schematic of the receiver. After demultiplexing, optical signal in each channel is tapped and received with usual clock extraction. Then (3) is used to predict collision-induced time shifts, where the data for time shifts of individual collisions δt_p may be obtained by numerical simulation, or more preferably, obtained by separate measurements. Detection is again made at the second receiver capable of bitwise adjustment of decision timing.

Fig. 3 is the numerically simulated Q factor of the central channel in the three-channel WDM transmission. Each channel contains 256 bits. ASE noise from in-line amplifiers (NF=6dB) is included in the simulation. Surrounding channels have the worst bit patterns that induce largest time shifts at z=6000km. Dashed curve in Fig.3 shows the Q factor with fixed decision timing. Collision-induced time shifts are as large as 11ps as shown in Fig.1 at z=6000km and the Q factor is degraded to as small as 3.8 (11.6dB) at this distance. Solid curve in Fig.3 is the Q factor when decision timing is adjusted according to (3) showing that large Q factor is recovered (Q=8.1 or 18.2dB) at z=6000km. For transmission distances different from 6000km, the Q factor is degraded because the adjustment of decision timing is optimized for z=6000km. If we vary the data δt_p in (3) as the distance varies, large Q factor is maintained for all the distances. The Q factor obtained with the adjustment of decision timing, however, is not as large as that of single-channel transmission. This is because the prediction of the time shift by

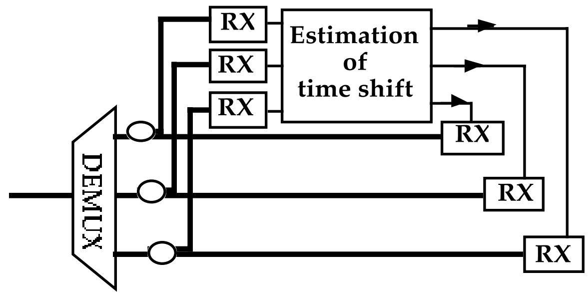

Fig.2. Schematic of the receiver with adjustment of decision timing.

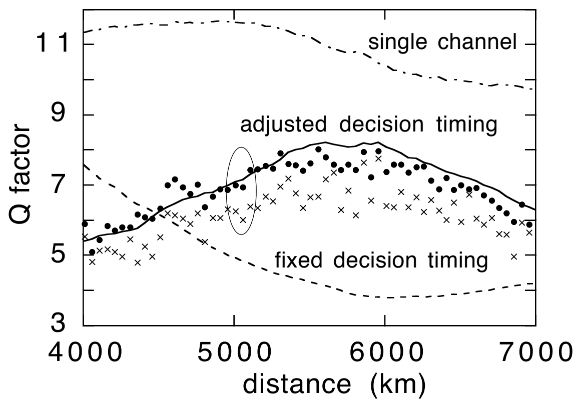

Fig.3. Q factor of the central channel in three-channel WDM transmission. Dashed curve is with fixed decision timing. Solid curve is with the decision timing adjusted according to (3). Dots and crosses are with imperfect adjustment of decision timing.

(3) has some error as shown in Fig.1, and the collision induces not only the time shifts but also shifts in amplitude, which are not compensated for by the present method.

In actual systems, the transmitted data in the surrounding channels can not be perfectly obtained at the receiver. We have to expect some errors in detection at first receivers in Fig. 2. A few percent of errors, however, is tolerated as shown by dots in Fig.3, which is obtained when the bit-information of 10 bits selected randomly from 256 bits in each surrounding channel is reversed. Crosses in Fig.3, furthermore, are the results when the time adjustment is not continuous but discrete with 5-ps steps. This assumes that decision is made at different phases with regular clock and one of the outputs is selected based on (3). Q factor larger than 6 is still obtained.

4. Conclusion

Effectiveness of bitwise adjustment of decision timing in suppressing collision-induced timing jitter in dispersion-managed WDM soliton transmission is numerically analyzed at 40Gbit/s/ch. The proposed method of jitter reduction can be applied to systems with lower channel bitrates, and can be used in non-soliton RZ transmission systems.

References

[1] M. Matsumoto, "Performance analysis of filtered WDM dispersion-managed soliton transmission", in *Conference on Lasers and Electro-Optics, OSA Technical Digest* (Optical Society of America, Washington DC, 2000), CMF3.

[2] T. Adali, B. Wang, A. N. Pilipetskii, and C. R. Menyuk, "A filtering approach for reducing timing jitter due to the acoustic effect", J. Lightwave Technol. **16**, 986-989 (1998).

[3] T. Hirooka and A. Hasegawa, "Chirped soliton interaction in strongly dispersion-managed wavelength-division-multiplexing systems", Opt. Lett. **23**, 768-770 (1998).

[4] L. F. Mollenauer, "Method for nulling nonrandom timing jitter in soliton transmission", Opt. Lett. **21**, 384-386 (1996).