Homodyne crosstalk tolerance enhancement by self-phase modulation based all-optical regeneration

Yuen-Ching Ku, Chun-Kit Chan, Lian-Kuan Chen, *Frank Tong
Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong SAR.
Tel: +852-2609-8479; Fax: +852-2603-5032; Email: ycku2@ie.cuhk.edu.hk
*Now with Acasia Technologies (HK) Limited.

Abstract: We propose and experimentally investigate the use of SPM broadened spectrum filtering technique to suppress homodyne crosstalk of high-speed optical signals. Crosstalk tolerance is found to be enhanced by about 4-dB for 10-Gbps RZ data.

1. Introduction
Wavelength division multiplexing (WDM) is a promising technology to dramatically enhance the transmission capacity of optical fibers. However, performance imperfections of optical components in network nodes such as optical cross-connects (OXC) produce optical crosstalk, which is one of the major impairments in WDM systems [1]. The degradation to high-speed optical signals is even worse when the crosstalk sources are of the same wavelength, which cannot be eliminated by mere optical filtering. Several techniques have been proposed to mitigate such homodyne crosstalk, including bit-pattern misalignment [2], Manchester-coding [3], and phase scrambling [4]. These techniques suffered from various limitations such as fixed bit-rate, increased bandwidth requirement and introduction of other noises.

All-optical regeneration is an attractive technology for high-speed optical communication systems, as it can effectively combat various system impairments such as dispersion and nonlinearity. Among the all-optical regeneration schemes [5] proposed recently, optical filtering of the self-phase modulation (SPM) broadened signal spectrum [6] is one of the simplest techniques as it is bit-rate transparent and polarization insensitive. This technique has been previously demonstrated to improve the extinction ratio of RZ-data [6]; and restore pulse waveform distorted by polarization dispersion [7] and chromatic dispersion [8].

By making use of such pulse waveform restoration property of the SPM-based all-optical regeneration, it is expected that the rapid power fluctuation induced by the beating between the data signal and the homodyne crosstalk can be effectively clamped. In this paper, we, for the first time, propose and experimentally investigate the use of SPM-based all-optical regeneration to alleviate the signal degradation due to homodyne crosstalk. Crosstalk tolerance enhancement of about 4 dB (at 1-dB power penalty) for 10-Gb/s optical signals were experimentally achieved, thus proved the effectiveness of the proposed scheme.

2. Experimental setup

Fig. 1. Schematic of experiment setup for crosstalk mitigation using SPM spectrum filtering

Fig. 1 shows the experimental setup. A 10-GHz optical pulse train of 2.5-ps pulse width at 1547 nm from a mode-locked fiber laser was externally-modulated by a 10-Gbps 2^31-1 PRBS data. The modulated signal was amplified by an Erbium-doped fiber amplifier (EDFA) and was then split into two fiber paths via a 3-dB fiber...
coupler. The crosstalk path (lower arm) consisted of an optical attenuator, a piece of 1.1-km dispersion shifted fiber (DSF) and a polarization controller (PC). The 1.1-km DSF was well beyond the 5-meter laser coherence length, thus the signal in both the data signal path and the crosstalk path were de-correlated. This setup simulated the homodyne crosstalk scenario in optical networks. The crosstalk level was controlled by the optical attenuator, and both the delay time and the polarization state of the crosstalk signal were aligned to that of the data signal so as to simulate the worst homodyne crosstalk scenario. In our experiment, the worst-case homodyne crosstalk level was varied from -38 dB to -20 dB. The data signal, having combined with the crosstalk, was then fed into an all-optical 2R regenerator, which comprised an EDFA, 4.4-km dispersion shifted fiber (DSF) and an optical band-pass filter (BPF), to achieve homodyne crosstalk suppression via optical filtering of the SPM broadened signal spectrum.

3. Experimental results and discussion

Fig. 2 shows the optical spectrum of the cross-talk corrupted signal (at 1547 nm) before passing through the 4.4-km DSF, which had the zero dispersion wavelength at 1550 nm. At the output of the DSF, the signal spectrum was broadened to about four times, via SPM, as shown in Fig. 2(b). An optical BPF with 0.2-nm bandwidth centered at 1545.98 nm was then used as the power limiter; and the filtered optical spectrum was shown in Fig. 2(c).

Fig. 2. Optical spectra (a) before entering the 4.4km DSF, (b) after the 4.4km DSF, and (c) after the output BPF

In order to investigate the regeneration property by optical filtering of the SPM broadened signal spectrum, the transfer characteristic was measured, as shown in Fig. 3, by injecting the signal with different power levels. The flat regions were used to clamp the amplitude fluctuation due to homodyne crosstalk, thus greatly suppressed the homodyne crosstalk induced degradation.

Fig. 4 shows the measured eye diagrams at a homodyne crosstalk level of -12.55 dB with and without the SPM-based all-optical regeneration. As shown in Fig. 4(a), the signal marks were severely corrupted by large bursts of crosstalk-induced beat interference. However, as shown in Fig. 4(b), such burst noises were greatly suppressed by inserting the all-optical 2R regenerator, thus definitely improved the system performance.

Fig. 3. Transfer characteristics of the SPM-based all-optical regenerator
We have measured the bit-error-rate (BER) performance using 9.953-Gbps 2^{31}-1 PRBS data with and without the all-optical regeneration at various homodyne crosstalk levels. The power penalty measurements (at BER=10^{-9}) were depicted in Fig. 5. When no optical regeneration was employed, less than 0.5-dB power penalty (at BER=10^{-9}) was observed for homodyne crosstalk level less than -30 dB. However, the power penalty increased drastically as the homodyne crosstalk level was further raised. On the other hand, when SPM-based optical regeneration was used, the homodyne crosstalk level could be tolerated up to -24 dB such that the induced power penalty (at BER=10^{-9}) could still be kept within 1 dB. At 1-dB power penalty, the tolerable homodyne crosstalk level was greatly enhanced from -28 dB to -24 dB, which corresponded to a reduction of crosstalk requirement of about 4 dB.

At all homodyne crosstalk levels, it was shown in Fig. 5 that the induced power penalty was largely alleviated when all-optical regeneration was employed. The enhanced homodyne crosstalk tolerance was attributed to the regenerator’s nonlinear transfer characteristics, as shown in Fig. 3, which suppressed the crosstalk induced amplitude fluctuations.

The choice of the injected signal wavelength and the filtered wavelength were quite critical in this scheme. The injected signal wavelength should be chosen in the normal dispersion regime with a small dispersion value not only to achieve sufficient spectrum broadening but also to avoid the relatively larger noise present in the anomalous
dispersion regime due to modulation instability (MI). On the other hand, the optical filtering wavelength should also be centered at the normal dispersion regime to avoid the amplified noise due to MI. However, when the filtering wavelength was set very close to the injected signal wavelength, the filtered or regenerated signal will suffer more from the initial ASE noise present in the injected wavelength. Nevertheless, if the filtering wavelength is too far away from the injected signal wavelength, the transfer characteristics of the SPM-based optical regenerator will become linear and thus it is no longer suitable for all-optical regeneration. Thus, design optimization of these parameters is desirable.

4. Summary
We have proposed and experimentally investigate the SPM-based all-optical optical regeneration technique to enhance the system tolerance of the homodyne crosstalk. Experimental results proved the effectiveness of the scheme and a homodyne crosstalk level up to about -24 dB could be tolerated within a power penalty (BER=10⁻⁹) of 1-dB. This corresponded to a reduction of crosstalk requirements of about 4 dB at the data rate of 10-Gbps. This work was partially supported by a research grant from the Research Grants Council of Hong Kong SAR (CUHK4228/00E).

References