Polarization-Insensitive Wavelength Multicasting of RZ-DPSK Signal Based on Four-Wave Mixing in a Photonic Crystal Fiber with Residual Birefringence

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Abstract: We demonstrate polarization-insensitive wavelength multicasting of RZ-DPSK signal. The input signal is copied to four different wavelengths using four-wave mixing with unequally spaced pumps in a dispersion-flattened, highly nonlinear photonic crystal fiber with residual birefringence.

OCIS codes: (060.4255) Networks, multicast, (060.5060) Phase modulation, (190.4380) Nonlinear optics, four-wave mixing, (060.5295) Photonic crystal fibers

1. Introduction

All-optical wavelength multicasting is desirable for high-speed wavelength division multiplexing (WDM) optical networks to provide applications like video conferencing and video distribution. The bandwidth can be effectively utilized when a single copy of the signal is transmitted in the network until a multicast device is used to distribute the data. Since the polarization of an optical signal changes randomly as it propagates in fiber-links, the multicast operation needs to be polarization-insensitive for practical use. Such kind of multicast device has been reported for on-off keying signal based on self-phase modulation (SPM) [1]. At the same time, differential phase shift keying (DPSK) modulation format is attractive for use in fiber communications owing to its large tolerance to nonlinear impairments in transmission and its 3-dB improvement in receiver sensitivity through balanced detection [2]. However, the SPM scheme cannot be used for DPSK signal as the phase information will be destroyed in the nonlinear process. Multicasting of DPSK signals based on format-transparent four-wave mixing (FWM) was previously demonstrated using equally-spaced pumps with careful polarization control [3], or unequally spaced pumps to avoid crosstalk from pump beatings [4] without addressing the problem of random input polarization. In this paper, we demonstrate for the first time to our knowledge, a polarization-insensitive wavelength multicast scheme for return-to-zero (RZ-) DPSK signal. Our scheme is based on FWM in a 64-m dispersion-flattened, highly nonlinear photonic crystal fiber (PCF) with residual birefringence. The input signal is copied to four different wavelengths using three unequally spaced pumps. Error-free operation is obtained for the multicast signals with a power penalty smaller than 4.2 dB.

2. Experiment

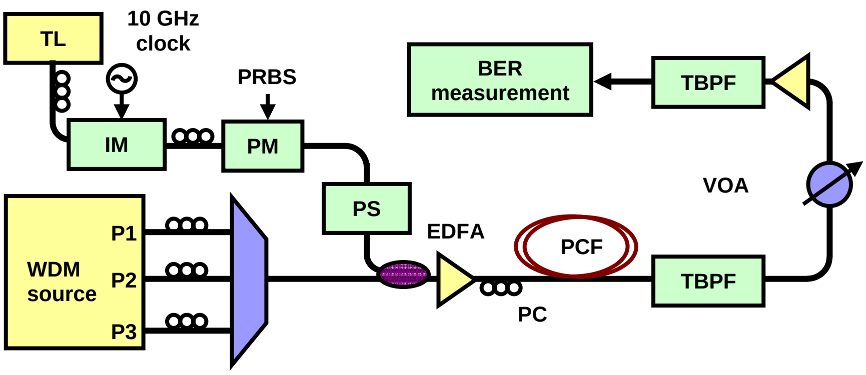

Fig. 1. Experimental setup for polarization-insensitive RZ-DPSK wavelength multicasting using a highly nonlinear PCF with residual birefringence. The pumps P1 to P3 are unequally spaced. TL: tunable laser; IM: intensity modulator; PM: phase modulator; PRBS: pseudo random binary sequence; PS: polarization scrambler; EDFA: erbium-doped fiber amplifier; PC: polarization controller; PCF: photonic crystal fiber; TBPF: tunable bandpass filter; VOA: variable optical attenuator.

Our multicasting of RZ-DPSK signal is based on non-degenerate (ND) FWM. The principle of polarization-insensitive NDFWM exploiting the birefringence in a PCF can be found in Ref. [5]. The key is to direct one optical pump to the PCF at 45 degree to the principal axes. The FWM conversion efficiency will be insensitive to the polarization of input signal since the relative polarization angle between the input signal and the pump varies periodically along the fiber [6]. Other pumps are then free to tune to produce the desired output wavelengths by NDFWM. Fig. 1 shows the experimental setup. A tunable laser set at 1545.28 nm is used to generate a 10 Gbit/s RZ-DPSK signal with an intensity modulator as the pulse carver and a phase modulator as the data encoder. No precoder for DPSK modulation is required since a PRBS pattern (with 2^{31}-1 bits) is used. A polarization scrambler (PS, Agilent Tech. 11896A) is added to change the polarization state of the RZ-DPSK signal. Three pumps of equal powers from a WDM source are combined through a multiplexer. To avoid crosstalk from pump beatings, the pumps are set at unequally spaced wavelengths at 1548.48, 1552.48 and 1557.28 nm. The spacing between the RZ-DPSK signal and the closest pump (pump 1) is 3.2 nm. The value is close to the lower limit of pump-signal detuning to achieve polarization-insensitive FWM in our PCF [5]. The pumps and the RZ-DPSK signal are launched into an EDFA, boosting the total power to 25 dBm. NDFWM takes place at a 64-m dispersion-flattened nonlinear PCF. The PCF has a nonlinear coefficient of 11.2 $W^{-1} km^{-1}$ and a dispersion coefficient of -2 $ps{\cdot}km^{-1}{\cdot}nm^{-1}$ at 1549.5 nm [7]. The dispersion slope is ~10^{-3} $ps{\cdot}km^{-1}{\cdot}nm^{-2}$ over the 1500 to 1600 nm wavelength range. The PCF birefringence is measured to be ~ $4.37{\times}10^{-5}$ at 1550 nm. No preventive measures for stimulated Brillouin scattering are needed at the power level of 25 dBm owing to the short length of fiber.

To achieve polarization-insensitive multicasting, the three pumps are first adjusted to have the same polarization. Many new frequency components are generated from optical beatings but most of them will not overlap with the multicast channels due to the use of unequally spaced pumps. Next, the input RZ-DSPK signal is added. The multicast signals generated by NDFWM between the input signal and pumps are then individually filtered out using a tunable bandpass filter (TBPF) with a 3-dB bandwidth of 0.3 nm. The output is demodulated by a 100-ps fiber-based delay interferometer and is then detected by a 32 GHz photodetector together with a 50 GHz oscilloscope. With an optimized setting of the polarization controller (PC) of pump 1, a clear eye is obtained even when the PS is turned on. The bit-error rate (BER) measurement is performed at different received powers using a variable optical attenuator (VOA) shown in the setup.

3. Results and Discussion

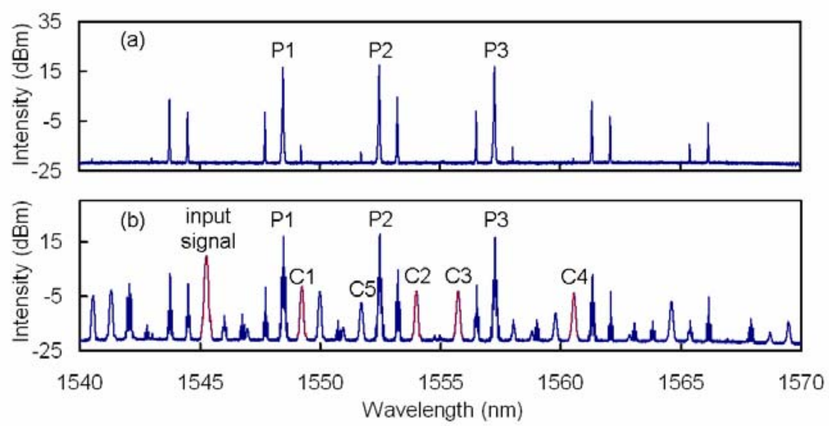

Fig. 2. Spectra of 10 Gbit/s RZ-DPSK wavelength multicasting based on NDFWM. (a) beatings occur among the pumps in the absence of the input signal; (b) multicast spectrum with the input and desired output components (C1-C4) shown in red color.

Fig.2 (a) and (b) show the measured FWM spectrum. Higher order FWM components are observed even without the RZ-DPSK input signal, as shown in Fig.2 (a). When the input is added, the signal is copied to four wavelengths from C1 to C4 as indicated in Fig.2 (b). The dynamic index grating produced from the signal and pump 1 scatters pump 2 to generate C1 and C3, and scatters pump 3 to generate C2 and C4. Higher order FWM components of the pumps can be identified at the position of C1. Nevertheless, the power ratio of the multicast signal to pump FWM component is over 13 dB, and an open eye can be obtained. Another signal C5 is generated by degenerate FWM between the input signal and pump 1. However, C5 cannot be used as a multicast output since an error floor is observed. The optical signal-to-noise ratio (OSNR) degradation of this signal may be caused by two factors. First, pump 1 is optimized to achieve polarization-insensitive operation. The polarization of pump 1 has to be set at 45 degree to the principal axis of the PCF, while the polarizations of other pumps can be optimized to achieve higher conversion efficiencies. Another reason for the low performance is that the power ratio between the multicast signal and the pump FWM component is less than 10 dB at C5, leading to a lower OSNR.

Fig. 3 shows the eye diagrams of the outputs. Widely open eyes are obtained for C1-C4 while C5 suffers a relatively high noise level. A time jitter of ~ 9 ps is introduced by the varying polarization of the input signal and the birefringence in the PCF when the PS is turned on. The time jitter results in a narrower eye opening but the degradation can in principle be compensated by a polarization-maintaining fiber with a proper length.

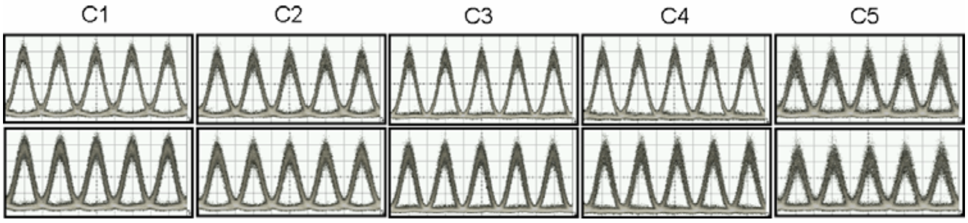

Fig. 3. Eye diagrams of the demodulated 10 Gbit/s RZ-DPSK multicast signals C1-C5. The P is turned off in the top row and turned on in the bottom row.

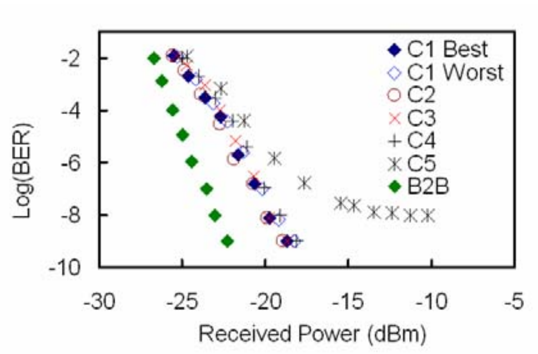

Fig. 4. BER measurements of 10 Gbit/s RZ-DPSK multicast signals.

Fig. 4 shows the BER of the multicast signals at different received power levels. The power penalty of C1-C4 ranges from 3.35 to 4.2 dB, indicating a relatively uniform multicast performance. An error floor at ~ 10^{-8} is observed for C5, making it unsuitable for error-free multicasting without using error correction coding. The BER for different polarization states of the RZ-DPSK input signal is measured to estimate the performance of multicasting for a practical, polarization-random signal. By adjusting the PC of the input signal, the best and the worst BER have been measured. The power penalty difference for C1 is found to be 0.45 dB. Similar results are obtained for other channels, showing good polarization-insensitivity performance of the multicasting approach.

4. Conclusions

We have demonstrated a polarization-insensitive multicast approach for RZ-DPSK signal based on NDFWM in a PCF with residual birefringence. Using three unequally spaced optical pumps, widely open eyes are obtained in four multicast output signals while the polarization of the input signal is scrambled. Error free operation is obtained for all the four outputs. The maximum power penalty is 4.2 dB and the difference in penalty caused by varying input polarization is 0.45 dB.

Acknowledgment

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