4 × 10 Gb/s Time and Wavelength Multicasting with NRZ to RZ Format Conversion Using Four-Wave Mixing in a Highly Nonlinear Photonic Crystal Fiber

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Abstract: We demonstrate simultaneous time and wavelength multicasting with NRZ to RZ format conversion by four-wave mixing of the input signal with a time- and wavelength-interleaved laser source. Error-free operations are obtained in all the outputs.

OCIS Codes: (060.2330) Fiber optics communications; (060.4255) Networks, multicast;

1. Introduction

Multicasting is an important process in communications for transmitting the same information to different locations at the same time. It is particularly useful for bandwidth-insensitive applications such as IPTV distribution and teleconferencing in WDM and OTDM networks. Different approaches have been proposed to achieve wavelength multicasting. Examples include cross-absorption modulation in an electro-absorption modulator [1], four-wave mixing in a highly-nonlinear fiber [2], and optical parametric amplification aided by self seeding [3]. Here, we first demonstrate an approach for simultaneous time and wavelength multicasting that can be adopted for use in different networks. Our principle is based on four-wave mixing (FWM) of the input signal with a time- and wavelength-interleaved laser source in a highly nonlinear photonic crystal fiber (PCF). We have previously reported the generation of time- and wavelength-interleaved laser sources using different approaches and their applications in photonic analog-to-digital conversion, all-optical sampling, and OTDM to WDM conversion [4-7]. In this work, we experimentally demonstrate time and wavelength multicasting of a 10 Gb/s NRZ-OOK signal to 4 ×10 Gb/s RZ-OOK outputs using an interleaved laser source. Error-free operations have been obtained for all the multicast outputs with a maximum power penalty of 4 dB.

2. Principle and Experimental Setup

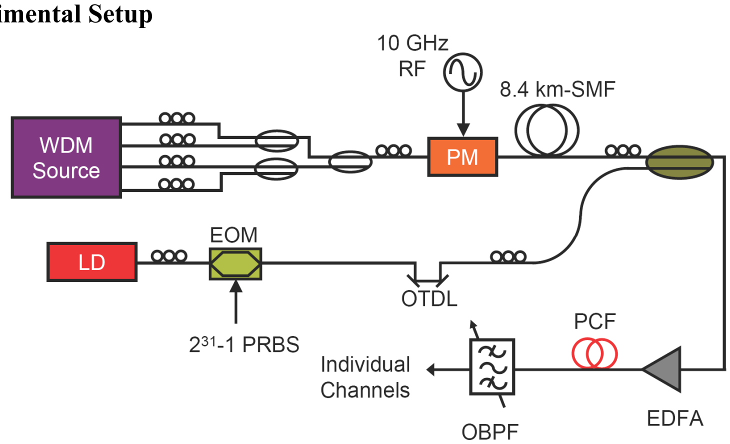

Fig. 1. Setup for simultaneous time and wavelength multicasting. LD: laser diode; EOM: electro-optic modulator; PRBS: pseudorandom binary sequence; PM: phase modulator; OTDL: optical tunable delay line; EDFA: erbium-doped fiber amplifier; PCF: photonic crystal fiber; OBPF: optical band pass filter.

The experimental setup is shown in Fig. 1. Four CW lasers with adjacent wavelength spacing of 1.25 nm are obtained from a WDM source. The laser outputs are combined with optical couplers connected to the input port of an optical phase modulator. The modulator is driven with a 10 GHz RF signal to induce chirp on the CW lights. The outputs are then connected to a reel of 8.4-km single-mode fiber (SMF). As the frequency of light in each of the four lasers is now time-dependent, group velocity dispersion (GVD) in the SMF will compress the CW lights to generate short pulses [8]. The time spacing between adjacent channels is ~25 ps, governed by the wavelength spacing and the GVD of the SMF. As a result, a 40 GHz time- and wavelength-interleaved laser source is achieved at the output of the SMF. To generate a 10 Gb/s data stream, a tunable laser is modulated by an electro-optic modulator driven by a 2^{31}-1 pseudorandom binary sequence. The pulsed source and the data stream are then combined with a 50/50 optical coupler. An optical tunable delay line is used in the setup to adjust their relative delay. The coupled lights are subsequently amplified by an erbium-doped fiber amplifier (EDFA) to 26 dBm and directed to a 64-m PCF with a nonlinear coefficient of 11.2 $(\text{W}\bullet\text{km})^{-1}$ around 1550 nm.

FWM takes place in the PCF. The input data stream acts as a pump and interacts with four probes represented by different wavelength components in the interleaved laser source. Consequently, new wavelength components will be generated and they will carry the same data spaced by ~25 ps. By filtering out the four generated components, we obtain the multicast outputs. It is worth mentioning that since the probes are pulsed sources, the duty cycle of the multicast outputs is determined by the chosen width of the pulses, leading to format conversion from NRZ-OOK to RZ-OOK with an adjustable duty cycle.

3. Results and Discussion

The waveform and the optical spectrum of the time- and wavelength-interleaved pulsed source are shown in Fig. 2 (a) and (b), respectively. The repetition rate is 40 GHz. The wavelengths are selected at 1548.20, 1549.55, 1550.80, and 1552.05 nm to produce a time separation of ~25 ps between the generated pulses. The width of the individual pulses at each center wavelength is ~ 14 ps, as confirmed by measurement with a 500-GHz optical sampling oscilloscope. Fig. 3 shows the 10 Gb/s NRZ-OOK data. The PRBS data are generated at 1545 nm with a pattern length of 2^{31}-1 bits. Since the rise time of the data is relatively long, we deliberately introduce an offset in one channel of the pulsed source to minimize distortions caused by the eye crossing region in the input data.

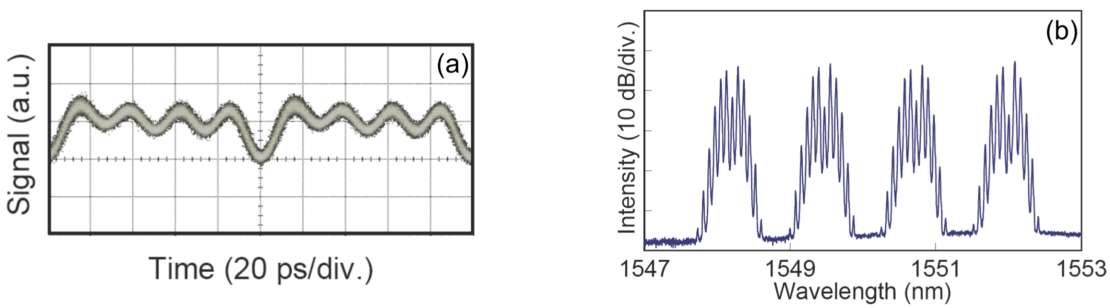

Fig. 2. Time- and wavelength-interleaved laser source. (a) Temporal profile. Adjacent pulses appear to be overlapped due to finite response of the measurement system. The actual pulse widths are determined to be ~14 ps with an optical sampling oscilloscope. (b) Optical spectrum.

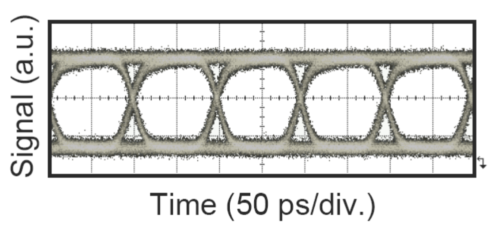

Fig. 3. Eye diagram of the 10 Gb/s NRZ-OOK input signal.

We filter out the four individual channels for analysis from the PCF output using a 0.3-nm optical band pass filter. The respective center wavelengths are 1541.50, 1540.25, 1539.00 and 1538.80 nm. The eye diagrams of the multicast outputs are shown in Fig. 4 (a) – (d). The outputs are in RZ-OOK format with a duty cycle of 25%. It is observed that some ripples appear at the ground level of channel 1. The reason is that the eye crossing region has a partial overlap with channel 1 in the pulsed source, resulting in a poorer extinction ratio in the multicast output. The unequal amplitudes of the output eyes are mainly caused by unflattened optical gain in the EDFA. To analyze the multicasting performance, we also perform BER measurement. The results are shown in Fig. 5. Error free operations (10^{-9} BER) have been achieved in all channels. The power penalties range from 1 to 4 dB. The degraded receiver sensitivity of channel 1 is caused by the appearance of ripples as mentioned above. The power penalties of other channels are attributed to ASE noise from the EDFA and to the reduced optical signal-to-noise ratio after FWM.

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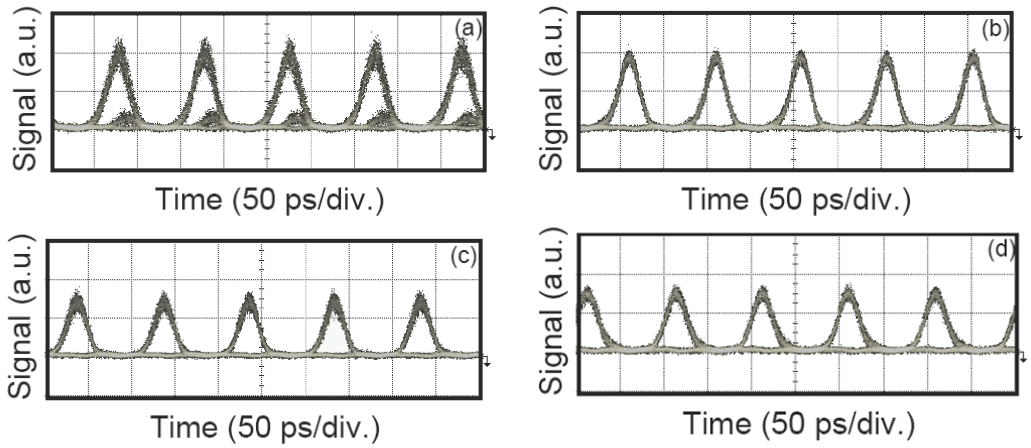

Fig. 4 (a) – (d). Eye diagrams of the four time- and wavelength-multicast channels.

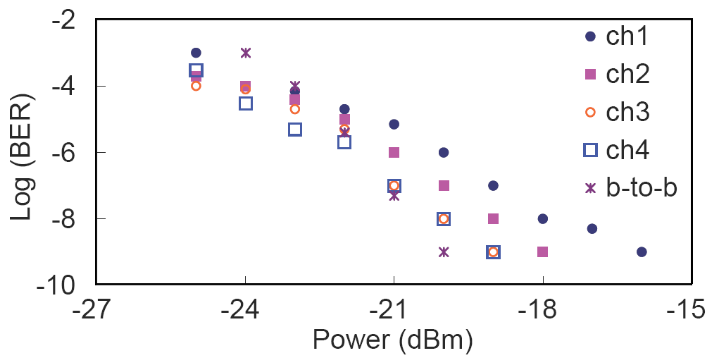

Fig. 5. BER performance of the 10 Gb/s back-to-back and the 4 multicast outputs.

4. Conclusion

We demonstrate 4 ×10 Gb/s simultaneous time and wavelength multicasting together with NRZ to RZ format conversion using FWM between the input signal and a time- and wavelength-interleaved laser source in a 64-m highly nonlinear PCF. Error-free operations have been achieved for all multicast outputs with a maximum power penalty of 4 dB. The scheme is potentially scalable to produce additional multicast channels when more components are generated in the time- and wavelength-interleaved laser source.

5. Acknowledgment

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6. References

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