320 Gb/s RZ-DPSK Data Multicasting in Self Seeded Parametric Mixer

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Abstract: We report first experimental demonstration of 320Gb/s RZ-DPSK wavelength multicasting in self-seeded parametric mixer free of Brillouin backscatter. High efficiency multicaster operated without pump phase dithering for error free wavelength mapping of phase-coded channel.

OCIS codes: (060.2320) Fiber optics amplifier and oscillators; (190.4410) Nonlinear optics, parametric processes; (060.4255) Networks, multicast

1. Introduction

An ideal all-optical wavelength multicasting maps the input channel to arbitrary frequency grid and is invariant of input channel physical format. The technique provides for low latency and low dissipation signal replication and has received considerable interest in signal processing and broadcast applications. Increasing requirements for high spectral efficiency and channel granularity have increased the need for networks in which wavelength multicasting is core functionality, not only for dynamic routing and monitoring but also for parallel processing. Considering future optical networks where a wide range of modulation formats will be supported, it is important to consider processing units that are able to handle both amplitude and phase modulated signals. While many multicasting approaches have been proposed, most have been demonstrated for amplitude modulated signals and do not necessarily preserve phase information [1-2]. As phase and amplitude preserving process, four wave mixing (FWM) is uniquely suited for wavelength multicasting of phase and hybrid modulated signals [3-4]. Unfortunately, the combination of efficient and coherent, distortion-free multicasting is difficult as it requires both high power *and* phase-preserving parametric pumping. Indeed, stimulated Brillouin scattering (SBS) limits the pump powers that can be inserted into highly nonlinear fiber (HNLF) and thus the mixer efficiency. A conventional technique used to increase the SBS threshold can distort the output signal phase and can generally not be used in coherent multicasting devices.

In this paper, we report on wavelength multicasting of high-rate phase modulated signal in a two-pump parametric mixer. We achieve a 1-to-6 wavelength multicasting of a single channel single polarization 320 Gb/s RZ-DPSK using a self seeded CW FOPA [5] with longitudinal tensioning to overcome Brillouin threshold. The experimental results demonstrate excellent signal integrity of the multicast channel phase, with a minimum conversion efficiency of -4.3 dB over all 6 multicast channels. High efficiency and distortion-free phase retrieval was achieved by longitudinal tensioning of the HNLF to increase the stimulated Brillouin scattering (SBS). Error-free BER measurement of the newly generated copy confirmed the excellent performance of the new multicasting device.

2. Experimental Architecture

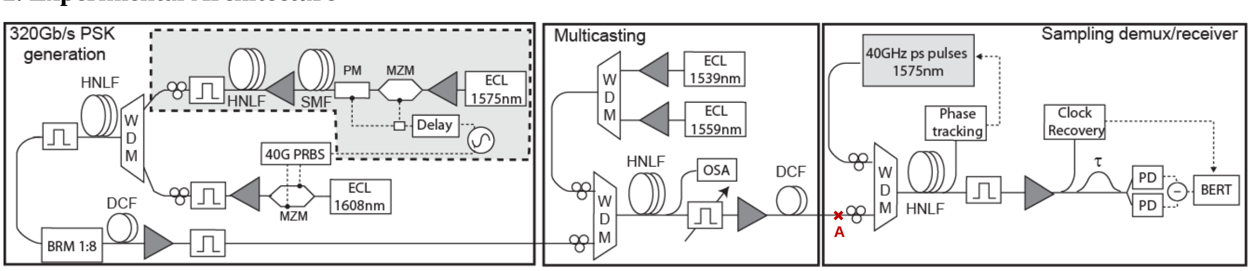

Fig. 1: Experimental setup. ECL: external cavity laser; MZM: Mach Zehnder modulator; PM: phase modulator; SMF: single mode fiber; HNLF: highly nonlinear fiber; DCF: dispersion compensating fiber; WDM: wavelength division multiplexer; BRM: bit rate multiplier; τ: delay.

The experimental setup is shown in Fig. 1 and comprises 3 sections: 320Gb/s DPSK generation, wavelength multicasting, and optical demultiplexer/receiver. The 320Gb/s DPSK data was generated from a cavity-less 40GHz pulse source [6] shown in the grey box. The 40GHz, 1.4ps pulse train at 1575nm was coupled with a 1605nm NRZ-DPSK signal carrying a 2^{31}-1 PRBS and sent in 50m long highly nonlinear fiber (HNLF) for wavelength and format conversion. At the output of the HNLF a 1546nm idler with RZ-DPSK data was filtered out and sent through a 3-stage bit rate multiplier (BRM) resulting in a 320Gb/s RZ-DPSK data stream as shown in Fig. 2(a). Dispersion accumulated in the BRM and EDFAs was compensated with 9m of dispersion compensating fiber (DCF). Wavelength multicasting was achieved in a tensioned 2-pump self seeded parametric mixer. Two external cavity lasers (ECL) at 1539nm and 1559nm having 4kHz linewidth where amplified and coupled with the 320Gb/s RZ-DPSK signal in a 100m long segment of longitudinally tensioned HNLF characterized by a zero dispersion wavelength (ZDW) at 1550 nm, a slope of 0.03 ps/nm^2-km. Periodically increasing longitudinal tensioning was applied to the HNLF to shift the Brillouin frequency along the fiber thereby increasing the Brillouin threshold to circumvent the need for pump phase modulation without sacrificing efficiency. Indeed, Brillouin imposes a limitation on the available pump power, greatly reducing the efficiency of the mixer while phase dithering of the pumps can distort phase based data formats. The step-wise tensioning of the HNLF resulted in a 8dB increase of the SBS threshold. At the output of the multicasting stage, the generated copies were filtered by a tunable 5nm bandpass filter, demodulated by a delay interferometer (τ) and observed on a 500MHz optical sampling scope.

Additionally, the copy can be sent to the demultiplexer and receiver based on parametric sampling. A 40GHz pulse source similar to the one used for signal generation was coupled with the copy in a 50m segment HNLF with a 1572.8nm ZDW. The sampling gate was based on FWM between the strong 40 GHz pump pulses and the 320Gb/s copy, generating an idler pulse only when temporal overlap occurs. The sampled 40Gb/s RZ DPSK tributary was then sent through the delay interferometer and the bit error rate tester (BERT) after balance detection. Fully independent operation between the transmitter and receiver was achieved with full phase tracking [7] and clock recovery. The BER were measured as a function of optical signal to noise ratio (OSNR) by noise loading the copy with amplified spontaneous emission (ASE) at point A in Fig. 1.

3. Experimental Results

A high quality input 320Gb/s RZ-DPSK signal (Fig. 2a) was generated from the cavity-less pulse source. A wide open eye was observed and Q-factor of 20.3dB was measured. The ON/OFF wavelength multicast operation is illustrated in Fig. 2b. The signal power was controlled by an optical attenuator at the input of the device and set to 5dBm. The pumps powers were set to optimize the parametric response of the mixer without inducing stimulated Brillouin scattering. Values of 812mW and 1.02W were chosen for pump1 at 1539nm and pump2 at 1559nm, respectively. Four wave mixing between the signal and the two pumps resulted in first order copies and higher order copies around the self seeded pumps at 1579nm and 1519 nm, with a 1-to-9 multicasting operation spanning almost 100nm. High efficiency generation was achieved for 6 of the copies shown as C1 through C6 in Fig. 2b, with a minimum conversion of -4.3dB for C6 and maximum conversion of 1.3dB for C4 and C5. All 6 copies were individually filtered, demodulated and observed on a C and L band optical sampling scope. A wide open eye was retrieved on all 6 copies as shown in Fig. 3. The eye opening is expected to be further improved when both outputs of the delay interferometer are received by a differential receiver. The effect of the multicast device on the quality of the 320Gb/s data signal was first assessed by Q-factor values. Errorless Q-factors were measured and are summarized in Table1. Lower quality was measured on C4 with respect to the other multicast copies mainly due to its 1565nm wavelength location which is the upper boundary of the C-band EDFA in addition to operation at the edge of the detection device region. The quality of the remaining copies is very uniform with less than 1 dB Q-factor variation. The integrity of the higher order copies C5 and C6 shows that very little phase noise is accumulated in the self seeded process, as expected from the high quality original pumps. It is important to note that the signal Q-factor was reduced from 20.3 dB to 18.7 dB after the multicasting process due to FOPA-added noise and pump proximity.

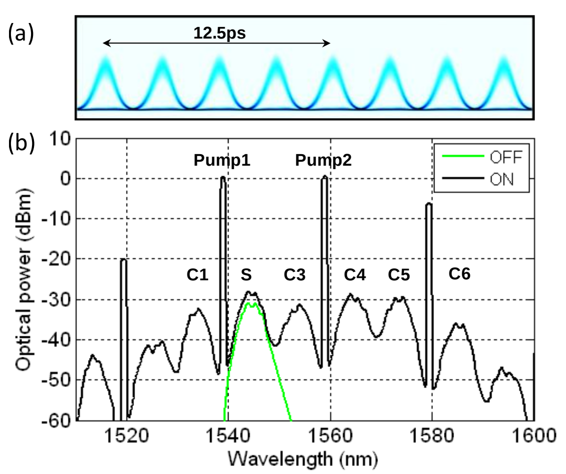

Fig. 2: (a) Demodulated waveform of the 320Gb/s PSK. (b) ON/OFF optical spectrum at the output of the mixer

Table 1: Measured wavelength, conversion and Q-factors

Copy	C1	S (C2)	C3	C4	C5	C6
λ (nm)	1534	1545	1554	1565	1574	1585
Conversion (dB)	-1	2.6	0	1.3	1.3	-4.3
Q-factor (dB)	16	18.7	16.7	14	16.3	16.3

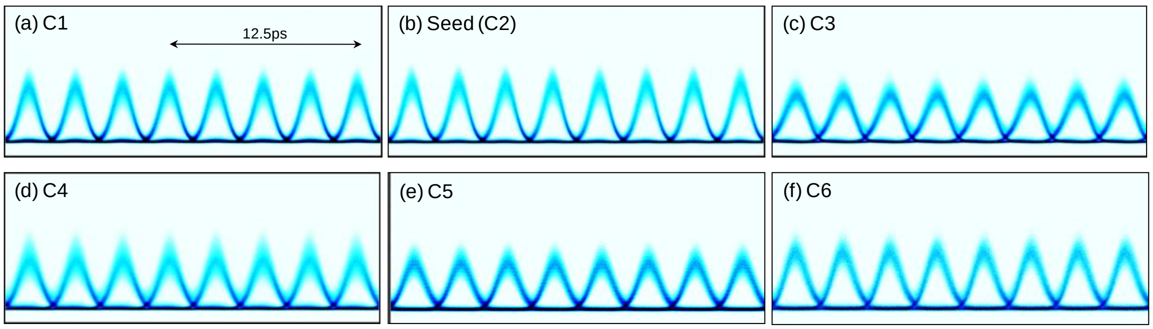

Fig. 3: Waveforms of the 320Gb/s DPSK copies collected on an ultrafast sampling scope at one output of the delay interferometer. (a) C1 at 1534nm, (b) Seed (C2) at 1545 nm, (c) C3 at 1554nm, (d) C4 at 1565nm, (e) 2nd order C5 at 1574nm and (f) 2nd order C6 at 1585nm.

The sampling gate operation is shown in Fig. 4. The 40GHz strong pulsed pump at 1575nm and the selected 320Gb/s RZ-DPSK copy 3 C3 at 1554nm were sent through the parametric sampling gate. Sampling was achieved by temporal overlapping between the input signal and the 40GHz pump. The sampled 40Gb/s RZ-DPSK idler was generated at 1594nm. With the phase tracking ON, stable operation was achieved without temporal drifts and one of the 40Gb/s tributaries was captured by sampling gate (see Fig. 4). The average idler power was measured to be 16dB lower than the input signal, which translates to -7dB conversion efficiency by taking into account the 9dB pulsing ratio between 320Gb/s and 40Gb/s. The BER measurements obtained on C3 after balance detection are shown in Fig. 5. The results are compared to sampling of the original signal without going through the multicasting stage and are plotted in Fig. 5. The BER curve confirms the error free performance of the device with a BER of 10^{-9} reached for 35.7dB OSNR. A penalty of 4.1dB at 10^{-9} BER was measured with respect to the sampling gate back-to-back and is attributed to the FOPA-added noise and loss of OSNR in the multicast stage due to crosstalk.

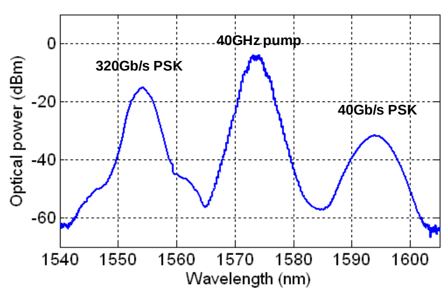

Fig. 4: Optical spectrum at the output of the sampling HNLF

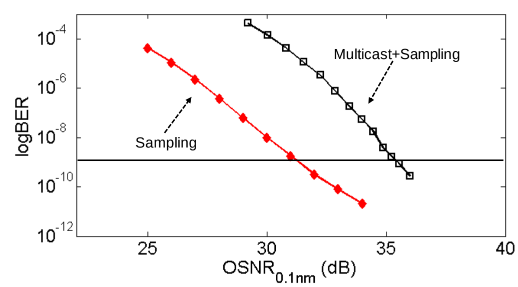

Fig. 5: (a) BER vs. OSNR for C3 compared to sampling gate only.

4. Conclusions

We presented the first demonstration of 320Gb/s RZ-DPSK wavelength multicasting in Brillouin-free, self-seeded parametric mixer. The input signal was successfully copied to 6 wavelengths for 1-to-6 multicasting with conversion efficiency between -4.3dB and 1dB. High efficiency and channel copy phase integrity were simultaneously achieved by selectively tensioning the HNLF. BER measurements confirmed the excellent performance of the multicasting unit and its viability as a format transparent processing unit for high bit rate data.

Acknowledgement: the authors want to thank Sumitomo Electric Industries for supplying HNLF

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