111-Gb/s POLMUX-RZ-DQPSK Transmission over 1140 km of SSMF with 10.7-Gb/s NRZ-OOK Neighbours

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Abstract *We demonstrate the transmission of 111-Gb/s POLMUX-RZ-DQPSK over an 1140 km EDFA-only link in the presence of 10x10.7-Gb/s OOK neighbours and show the impact of channel spacing on the cross-talk.*

Introduction

Driven by the demand for new bandwidth intensive applications, 100G serial transmission has recently witnessed a dramatic increase in the interest within the optical community. In [1, 2], it has been shown that reliable long-haul transmission for 111-Gb/s on 50GHz WDM grid can be achieved by combining polarization multiplexed- return to zero-differential quadrature phase shift keying (POLMUX-RZ-DQPSK) with coherent detection. Coherent detection proved to be an efficient technique to increase the tolerance of 111-Gb/s signals against chromatic dispersion [1], and polarization mode dispersion [3]. Moreover, the feasibility of applying coherent detection in real time has been demonstrated at a 43-Gb/s data rate in [4], which indicates that such solutions could also be applied to 111-Gb/s transmission.

In this paper we demonstrate the ability of transmitting 111 Gb/s POLMUX-RZ-DQPSK over an 1140 km EDFA-only link in the presence of 10 x 10.7 Gb/s OOK neighbours.

Experimental setup

Fig. 1 depicts the experimental setup for the transmitter, the re-circulating loop and the digital coherent receiver. At the transmitter, the output of an external cavity laser (ECL), emitting at a wavelength of 1550.116 nm, is pulse-carved using a Mach-Zehnder modulator (MZM) driven with a clock of 27.75 GHz. After pulse-carving, the signal is split into two parts using a polarization maintaining coupler and each tributary is DQPSK modulated using a nested-MZM. The two drive signals of the nested-MZM consist of a PRBS with length 2^{16}-1 at a data rate of 27.75-Gb/s. The drive signals are shifted over 8 symbols with respect to each other in order to generate a pseudo-random quaternary sequence (PRQS) with length 4^8. Both DQPSK modulated signals are then combined by means of a polarization beam splitter (PBS) to generate 111-Gb/s POLMUX-RZ-DQPSK modulation. To investigate the effect of XPM on the 111-Gb/s POLMUX-RZ-DQPSK signal, ten NRZ-OOK modulated signals, each with a data rate of 10.7-Gb/s, are combined with the 111-Gb/s signal using a 3-dB coupler. The OOK neighbouring channels are modulated using a MZM driven with a 10.7-Gb/s PRBS with length 2^{15}-1, and located on the 50GHz WDM grid. The re-circulation loop consisted of a pre-compensation DCF with a CD of -1360 ps/nm followed by 4 spans of SSMF with a length of 95 km and an average span loss of 18.5 dB. Double stage EDFA-only amplification is employed, and the input power into the DCF is kept 5 dB below the SSMF input power. The inline DCF has a CD of -1530 ps/nm/span, which results in inline under-compensation of 85 ps/nm. At the receiver side, an optical band pass filter (OBPF) with a bandwidth of 50 GHz is used to de-multiplex the 111-Gb/s signal.

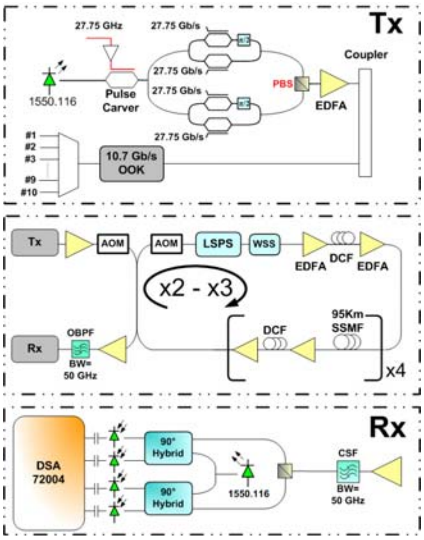

Fig. 1: System setup,
WSS: wavelength selective switch,
LSPS: loop synchronized polarization scrambler

A free running ECL laser with a linewidth of 100 kHz is used as a local-oscillator (LO) and the LO-to-signal ratio at the input of the QPSK-mixer is set to about 22 dB. The four outputs of the QPSK-mixer are detected using four single ended PIN/TIA photodiodes (PD). After the PDs, a DSA72004 digital storage scope samples the four tributaries at a sampling rate of 50 Gsamples/s and stores 2×10^6 samples from each tributary. For each measured

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point, 5 sets of data at different time instants are stored to obtain a total of $2x10^7$ bits. A desktop computer is used for off-line processing the stored data, which is first re-sampled into exactly 2 samples/bit and then equalized by using a FIR filter with a butterfly structure [1]. Following the equalization, a carrier recovery is implemented to remove the frequency offset between the LO and the transmitter laser. The carrier phase estimator (CPE) technique employs the Viterbi & Viterbi algorithm [5], and is implemented as described in [6].

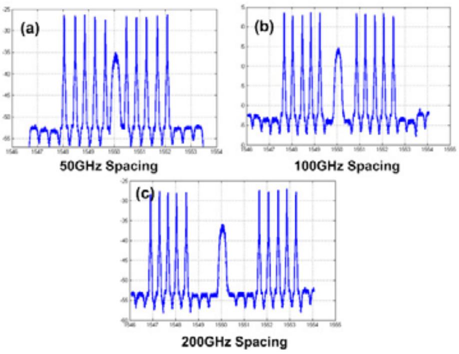

Fig. 2: Optical spectra of the 111-Gb/s signal with 10.7-Gb/s OOK signals at different channel spacing.

Experimental Results

The 10 x 10.7-Gb/s neighbouring channels are first placed 50 GHz away from the 111-Gb/s signal, as demonstrated in Fig. 2 a. The transmission results of this configuration after 760 km (2 loops) and 1140 km (3 loops) are depicted in Fig. 3. The figure shows the BER results of the 111-Gbit/s signal at different launch powers for the transmitted signals. All transmitted signals are kept at equal launch powers with respect to each other. As expected, the figure shows an optimum launch power that represents a trade-off between the OSNR value and nonlinear impairments from neighbouring channels, and the optimum launch power is found to be -3 dBm after both 760 km and 1140 km transmission. At this optimum launch power, it is evident that for both distances the BER is still below the FEC limit (assumed to be $2x10^{-3}$).

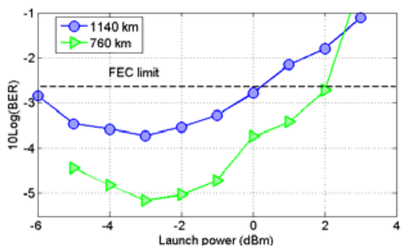

Fig. 3: BER vs. launch power after 1140 and 760 km

The CPE applied in this case for the 111-Gb/s signal uses an estimation interval of 9 symbols. A variation in the CPE length is depicted in Fig. 4, which shows several curves obtained using different CPE lengths after 1140 km transmission. This shows that for low launch powers a better performance can be obtained by choosing a longer CPE averaging interval. However, using an averaging interval longer than 9 symbols makes the performances worse in the non-linearties limited regime, as the fast phase changes induced by non-linear phase noise cannot be averaged out.

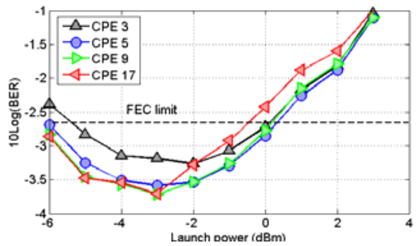

Fig. 4: Transmission results for 1140 km, with different CPE averaging intervals

One possible solution to reduce the impact of the co-propagating 10-7-Gb/s NRZ-OOK channels is to place these channels further away from the 111-Gb/s signal. Fig. 2 shows the three configurations, with respectively a wavelength spacing of 50 Ghz (Fig. 2a), 100 GHz (Fig. 2b) and 200 GHz (Fig. 2c). Fig. 5 shows the measured transmission performance with different wavelength spacings, this indicates that removing the nearest 10.7-Gb/s NRZ-OOK neighbors is sufficient to strongly decrease the penalty from the co-propagating NRZ-OOK channels.

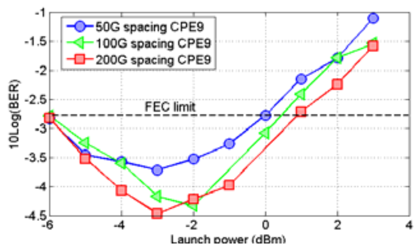

Fig. 5: Results of different channel spacings

Conclusions

We experimentally demonstrated 111-Gb/s POLMUX-RZ-DQPSK transmission over 1160 km with co-propagating 10x10.7Gb/s OOK neighbors and analyzed the impact of wavelength spacing and CPE length.

References

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