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Long-Haul Optical Transmission using 111-Gb/s Polarization-Multiplexed DQPSK modulation

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Abstract *We study the tolerance of 111-Gb/s POLMUX-RZ-DQPSK to nonlinear impairments and show the advantage of using non-dispersion managed links and large effective area fibers in ultra long-haul transmission.*

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Introduction

In the past couple of years we have seen a rapid growth of the required bandwidth for a variation of internet applications. This has trigged a significant interest in the development of transponders with line rates of 111 Gb/s. Supported by its ability to translate the polarization, phase and amplitude of the optical signals into the electrical domain, coherent detection has enabled the full compensation of most linear transmission effects in the electrical domain. Among the many modulation formats considered together with coherent detection to achieve a data rate of 111 Gb/s is polarization multiplexed (POLMUX)-return to zero (RZ)-differential quadrature phase shift keying (DQPSK) [1-3]. POLMUX-RZ-DQPSK has established itself as the strongest candidate for the first generation transponders with data rate of 111 Gb/s. Due to its low optical signal to noise ration (OSNR) requirement and sound tolerance to nonlinear transmission impairments, this modulation format will allow for commercial deployment in long-haul transmission systems. In this paper, we will describe the impact of the dispersion map on the tolerance of the POLMUX-RZ-DQPSK signal to nonlinear transmission effects. Furthermore, we will demonstrate the benefit that can be achieved from using the newly developed family of super large effective area (SLA) fibers for long-haul 100-G transmission.

Experimental setup

Fig. 1 depicts the experimental setup for the transmitter and the re-circulating loop. At the transmitter (Fig. 1a), eleven lasers are grouped into odd and even channels using two array wave guides (AWG). The lasers are tuned to the 50-GHz ITU grid between 1548.5 nm and 1552.5 nm. After each of the two AWGs the signal is first pulse-carved using a Mach-Zehnder modulator (MZM) driven with a clock of 27.75 GHz. The signal is then DQPSK modulated using a nested-MZM that is driven by two binary PRBS16 sequences with a relative delay of 53 bits and a data rate of 27.75 Gb/s. Afterwards, the two RZ-DQPSK signals are interleaved using a 50/100-GHz interleaver, and polarization multiplexed

by splitting the signal into two parts and re-combining them on orthogonal polarizations after delaying one of the tributaries. The resulting 11 x 111-Gb/s POLMUX-RZ-DQPSK signals (100 G/s payload + 11 Gb/s overhead for Ethernet and FEC) are transmitted over a re-circulating loop.
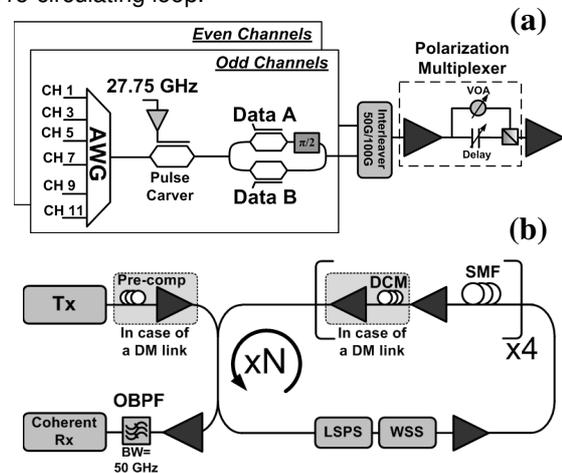

Fig. 1: System setup: (a) transmitter, (b) re-circulating loop

Two different fiber types are used in the re-circulating loop, namely SSMF and LongLine [3, 4]. Either four spans of 95 km SSMF or 100 km LongLine fiber are used to equip the re-circulating loop, as depicted in Fig. 1b. The signal is circulated for four times, which results in a transmission distance of 1520 km over SSMF or 1600 km over LongLine fiber. For the two fiber types either a dispersion-managed (DM) or non dispersion-managed (NDM) link is used. In the case of the DM link, a double periodic dispersion map with a period of 4 spans is employed [2]. For SSMF, a typical double periodic dispersion map similar to what is used in currently deployed networks has been used. The dispersion map has a pre-compensation of -510 ps/nm, and a per-span under-compensation for the first three spans of 85 ps/nm and for the fourth span of -85 ps/nm. For LongLine, the dispersion map has a pre-compensation of -1190ps/nm, and a per-span under-compensation for the first three spans of 160 ps/nm, and for the fourth span of -180 ps/nm. Such dispersion map is more suitable for data rates of 40 Gb/s and higher, due to its high per-span under-compensation, as going to be explained later.

EDFA-only amplification is used in all of the measurements reported in this paper. The launch power into the DCM is kept at -5 dBm, while the launch power into the fiber is varied between -4 dBm/ch and +5 dBm/ch.

At the receiver side, an optical band pass filter (OBPF) is used to extract the center channel at 1550.5 nm. Afterwards, a polarization diversity coherent receiver is deployed to detect the received signal. The structure of the receiver and the DSP algorithms employed are discussed in details in [2].
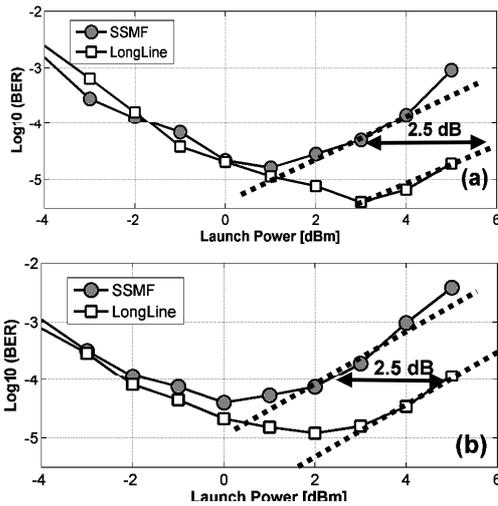
Fig. 2: Transmission over a NDM link: (a) single channel and (b) multichannel transmission

Experimental Results

Fig. 2 compares the transmission results achieved for the two fiber types using a NDM link structure. The results for both single-channel and multi-channel transmission are compared in Fig. 2a and Fig. 2b respectively. For launch powers higher than 1 dBm, where the transmission is mainly limited by nonlinear transmission effects, both the single and multichannel configurations show an advantage of 2.5 dB for LongLine over SSMF. We conjecture that this advantage is due to the lower nonlinear coefficient (γ) and high dispersion (D) coefficient for the LongLine [3, 4]. The nonlinear coefficient (γ) for LongLine is as low as 0.8/W.km which is a result of its large effective area (A_{eff}=120 μm^2). The dispersion coefficient for LongLine is about 20.3 ps/nm/km which represents a ~20% increase compared to SSMF, and results in a faster walk-off between adjacent channels as well as between consecutive symbols in the same channel. Consequently, this results in a reduction of both inter- and intra- channel nonlinear effects.

Fig. 3 compares the performance of the two fiber types when using a DM link. For single channel (Fig. 3a), SSMF maintains approximately the same performance difference with LongLine in comparison to the NDM link case. The performance difference between the two fiber types is on the other hand

increased up to 4 dB in case of multichannel transmission (Fig. 3b). We conjecture that the reduced performance of SSMF is a result of using a dispersion map with moderate per-span under-compensation [5, 6]. Low per-span under-compensation implies that there is only a small walk-off between adjacent channels, and therefore the signal at the input of consecutive spans is highly correlated. This results in - so called - correlated phase kicks, which result in a higher XPM penalty and therefore worsen the overall nonlinear tolerance. The dispersion map used in combination with transmission over LongLine uses a higher per-span under-compensation compared to SSMF, and as such the difference between DM and NDM transmission is smaller in this case.
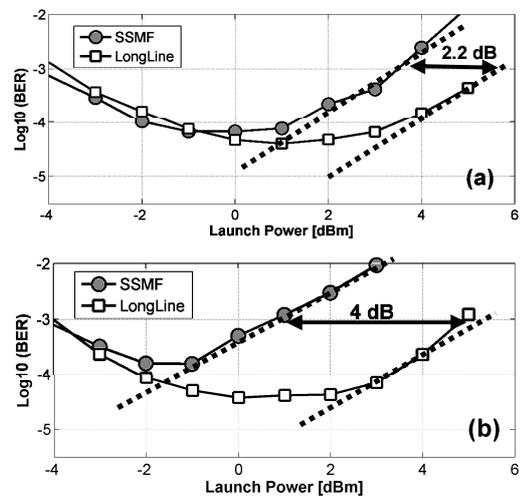
Fig. 3: Transmission over a DM link: (a) single channel and (b) multichannel transmission

Conclusions

We have experimentally studied long-haul transmission of 111-Gb/s POLMUX-RZ-DQPSK over both LongLine and SSMF in DM and NDM link. We have shown that in a NDM link, LongLine can provide an advantage of up to 2.5 dB over SSMF in terms of the tolerance to nonlinear transmission effects. Furthermore, we demonstrate that increasing the residual dispersion per span in DM links can effectively decrease the nonlinear transmission effects and diminish the performance difference between NDM and DM links.

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