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On the nonlinear tolerance of 42.8-Gb/s DPSK with co-propagating OFDM neighbors

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Abstract *The nonlinear tolerance of 42.8-Gb/s DPSK is investigated with co-propagating OFDM neighbors. It is found that the XPM that is generated by co-propagating OFDM neighbors is significantly stronger than DPSK and furthermore dependent on the spectral width of the OFDM signal.*

INTRODUCTION

State of the art long-haul data transmission systems operate up to 40-Gb/s with an appropriate usage of cost effective modulation formats such as non return-to-zero differential phase shift keying (NRZ-DPSK). Recent outburst in the development of digital end user equipment exhibited the requirement for high-speed data transmission. This increase in demand has initiated the next generation 100 Gigabit Ethernet (100GbE) protocol which has become of considerable interest [1]. Polarization division multiplexed orthogonal frequency division multiplexing (PDM-OFDM) is a promising modulation format that has been proposed for such 100GbE transmission systems [2]. PDM-OFDM offers a virtually unlimited tolerance against linear impairments and is easily scalable to higher level modulation formats [2, 3].

However, most of the PDM-OFDM transmission experiments reported have used an uncompensated dispersion map. It has been observed by Forozesh et al. that for a periodically compensated dispersion map, the influence of both self-phase modulation (SPM) and cross-phase modulation (XPM) is significantly larger than for a transmission link without inline dispersion compensation [4]. This reduction in nonlinear tolerance (NLT) is especially relevant for mixed data rate transmission scenarios where a high data rate OFDM channel is installed on an existing 10-Gb/s or 40-Gb/s network with periodic dispersion compensation. Du et al. have subsequently shown that through nonlinear pre- and post-compensation SPM impairments can be partly compensated for and thereby the reach of OFDM on periodically compensated dispersion maps can be increased [5, 6]. However, the XPM influence of the OFDM channel itself on its neighbors has not been analyzed so far.

In this paper, the XPM influence of coherently detected optical CO-OFDM on 42.8-Gb/s DPSK is investigated for a WDM-system. It is found that OFDM generates more XPM than DPSK, thereby impairing the DPSK signal in a similar fashion as the XPM influence of co-propagating 10-Gb/s OOK channels.

SIMULATION SETUP

Fig. 1 depicts the simulated system configuration. At the transmitter, a total of 7 WDM channels at 50-GHz channel spacing are simulated from which the center channel is modulated (and detected) with 42.8-Gb/s DPSK (2^{10} De Bruijn sequence length). The other WDM channels are modulated with several modulation formats in order to investigate the influence of XPM, namely: 42.8-Gb/s DPSK, 21.4-Gb/s CO-OFDM, 55.5-Gb/s CO-OFDM and 10.7-Gb/s OOK. Note that as only a single polarization is evaluated, the two OFDM signals correspond to a 42.8-Gb/s and 111-Gb/s PDM-OFDM signal (excluding OFDM overhead). At the receiver the center channel is selected with a 4th order 45-GHz Gaussian band-pass filter and the BER is evaluated.

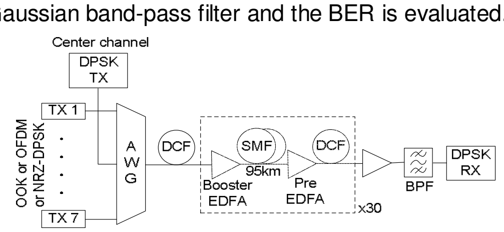

Fig. 1: System configuration, transmitter, transmission line and receiver for the center DPSK channel.

The transmission line comprises of 30 spans of 95-km single mode fiber (SMF). Dispersion compensating fiber (DCF) is used for pre, inline and post compensation. The loss of the SMF and DCF is 0.21-dB/km and 0.5-dB/km, respectively and a summary of the dispersion and nonlinear fiber parameters of the fibers can be found in Table 1. As illustrated in Fig. 1, an erbium-doped fiber amplifier (EDFA), with 6dB noise figure, is used for amplification after each span.

FIBER	D(ps/(nm.km))	S(ps/(nm^2.km))	γ(1/(W.km))
SMF	16.8	0.058	1.14
DCF	-170	-0.5869	5

Table 1: Optical Fiber Specifications.

The dispersion map used for the simulations is one that has been optimized for 42.8-Gb/s NRZ-DPSK transmission. The pre- and inline under-compensation are -800-ps/nm and 30-ps/nm, respectively.

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SIMULATION RESULTS

The NLT of the 42.8-Gb/s DPSK is investigated by simulating transmission over 2,850 km and evaluating the penalty in required OSNR for a BER of 10^{-4} as a function of the fiber launch power (Fig. 2a). The power launched into the SMF is varied from -15 dBm to 4 dBm while keeping the DCF launch power 7 dB lower in order to make sure that most of the nonlinear impairments occur in the SMF. In back-to-back configuration, the required OSNR for a BER of 10^{-4} is 13.4 dB and this is used as baseline for the plot shown in Fig. 2a.

As a reference the NLT is evaluated for single channel, WDM with 42.8-Gb/s DPSK neighbors and WDM with 10.7-Gb/s OOK neighbors. The highest NLT observed in Fig. 2a is for single channel and WDM 42.8-Gb/s DPSK. Allowing a 1-dB penalty in required OSNR, the maximum tolerable launch power is 1.1 dBm and 0.5 dBm for single channel (marked with '□') and WDM DPSK (marked with '<'), respectively. Therefore, only a 0.6 dB difference between single channel and WDM DPSK is observed showing that 42.8-Gb/s DPSK generates only little XPM.

It is well known that 10-Gb/s OOK generates strong XPM, which severely impacts the performance of phase modulated modulation formats, such as DPSK and DQPSK. This can clearly be seen in Fig. 2a as well. For the case where the center 42.8-Gb/s DPSK channel is co-propagated with 10.7-Gb/s OOK neighbors (marked with '◊'), the allowable launch power for a 1-dB penalty is reduced to -2.2dBm. Compared to the WDM DPSK simulation there is a reduction in launch power of more than 2.5 dB.

The BER performance of the DPSK channel with 21.4-Gb/s and 55.5-Gb/s OFDM co-propagating channels are marked with '>' and 'O', respectively. Compared to the configuration with seven DPSK modulated signals, the nonlinear tolerance for both OFDM configurations is significantly lower. As a result, the maximum input power for a 1-dB OSNR penalty is -1.6 dBm and -0.6 dBm for 21.4-Gb/s and 55.5-Gb/s OFDM, respectively. From these results it can be concluded that OFDM induced XPM is significantly stronger than that of DPSK. Furthermore, it is observed that the XPM crosstalk is strongly dependent on the bandwidth of the OFDM signal. For a small bandwidth OFDM signal (21.4-Gb/s OFDM) an XPM penalty is observed close to that of OOK neighbors, whereas for 55.5-Gb/s OFDM the NLT is improved by about 1 dB. We conjecture that dependence of the OFDM bandwidth on the generated XPM is mainly caused by the fact that waveform variations of the OFDM signal as a function of the chromatic dispersion scale with the bandwidth of the OFDM signal [7]. Compared to a high bandwidth OFDM signal, the waveform shape of a small bandwidth OFDM signal varies less over the transmission link. As a result, the XPM phase kicks are more coherent, which increases the XPM penalty.

In order to evaluate the optimum input power for all investigated configurations the BER performance of the middle DPSK channel is evaluated after transmission taking the received OSNR into account (Fig. 2b). In this Figure a similar trend is observed as in Fig. 2a. The optimal input power is the highest (1 dBm) for a single 42.8-Gb/s DPSK channel and the lowest (-2 dBm) for 10-Gb/s OOK neighbors. Comparing co-propagating DPSK with co-propagating OFDM, a reduction in optimal launch power of 1.5 dB and 0.5 dB is observed for 21.4-Gb/s and 55.5-Gb/s OFDM, respectively.

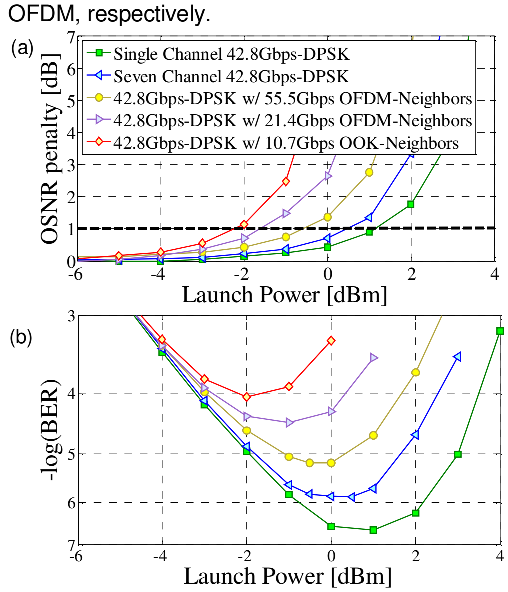

Fig. 2: (a) OSNR Penalties (BER of 10^{-4}) and (b) BER performance, after 2,850–km transmission.

CONCLUSIONS

In this paper, we have shown that the XPM generated by optical OFDM is significantly stronger then that of 42.8-Gb/s DPSK. Even though the XPM penalty of OFDM is not as bad as that of co-propagating OOK, care must be taken when using optical OFDM for upgrade scenarios.

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