PDM-OFDM for upgrade scenarios: An investigation of OFDM-induced XPM on 42.8-Gb/s DPSK over SSMF and LEAF

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Abstract: We investigate the nonlinear tolerance of 42.8-Gb/s DPSK with PDM-OFDM neighbors. It is found that the XPM penalty scales with the OFDM-bandwidth and that for data rates up to 40-Gb/s delta powers are required.

OCIS codes: (060.4510) Optical communications ; (060.4370) Nonlinear optics, fibers.

1. Introduction

The field of fiber optical communication has taken mammoth leaps since its first commercial development in 1975, scaling in bit-rate from 45 Mb/s to 40 Gb/s today. With the advents of further bandwidth-hungry applications, the next generation 100-Gb/s Ethernet protocol has been initialized. The solutions involving a combination of coherent receivers with digital signal processing are emerging as the best resolution for such 100G upgrades. One of the modulation formats employing them both is polarization division multiplexed orthogonal frequency division multiplexing (PDM-OFDM). The major advantage of PDM-OFDM is that it can tolerate extremely high amount of inter-symbol-interference (ISI) caused by the linear impairments of an optical fiber [1, 2]. However, for dispersion compensated maps, optical nonlinear effects, which limit the launch power per span, are generally discussed among the most challenging problems faced by PDM-OFDM as it exhibits high peak-to-average power ratio (PAPR).

The nonlinear performance of optical OFDM has been investigated for a variety of dispersion compensated maps [3-6]. In [3], Forozesh found that for an OFDM transmission system, an uncompensated dispersion map has better resilience towards nonlinear effects compared to a periodically compensated dispersion map. For green field deployment an uncompensated dispersion map can be used. However, when upgrading a legacy system with a high data rate OFDM channel, the performance will be reduced because of the periodic dispersion compensation. This problem can be mitigated with an electronic pre- and post-compensation scheme [4-5]. In [5], Lowery showed that for legacy systems with pre- and post compensation, self-phase modulation (SPM) can be significantly compensated for, resulting in a nonlinear tolerance of OFDM similar to single carrier modulation formats. However, with electronic pre- and post-compensation scheme, the effect of cross-phase modulation (XPM) generated by OFDM cannot be diminished. In [6], we performed the first evaluation of the amount of XPM generated by optical OFDM and have shown that it can have detrimental influence on the other neighboring channels.

In this paper, we provide a simulation overview of the XPM influence of coherently detected optical CO-PDM-OFDM neighbors on 42.8-Gb/s DPSK for both standard single mode fiber (SSMF) and large effective area fiber (LEAF). It is observed that 111-Gb/s PDM-OFDM neighbors produce much lower XPM influence than the 42.8-Gb/s PDM-OFDM neighbors. Furthermore, it has been shown that a delta power of 2 dB to 3 dB is required for the 42.8-Gb/s PDM-OFDM neighbors to alleviate these XPM penalties.

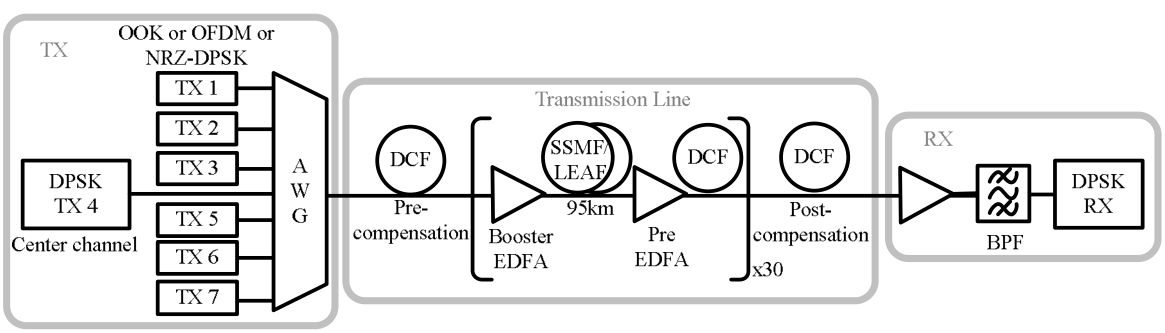

Fig. 1. Simulation architecture of the transmitter, transmission line and the receiver; TX: transmitter; AWG: arrayed waveguide grating; DCF: dispersion compensated fiber; EDFA: erbium-doped fiber amplifier; BPF: band pass filter; RX: receiver.

2. Simulation setup

The nonlinear performance of the center 42.8-Gb/s DPSK signal is investigated by simulating transmission over 2,850 km of SSMF and LEAF. Fig. 1 depicts the system configuration for the transmitter, the transmission line with double periodic dispersion map and the receiver. At the transmitter, a total of 7 WDM channels at 50 GHz channel spacing are simulated from which the center channel is modulated with 42.8-Gb/s DPSK (2^{10} De Bruijn sequence length). The other neighboring WDM channels are modulated with several modulation formats in order to investigate the influence of XPM, namely: 42.8-Gb/s DPSK, 111-Gb/s CO-PDM-OFDM, 42.8-Gb/s CO-PDM-OFDM, 10.7-Gb/s CO-OFDM and 10.7-Gb/s OOK. The bit rate of the OFMD signal here is the nominal data rate that includes 7% overhead for forward error correction (FEC) and about 4% for the Ethernet protocol. The FFT size of 256 and 7.81% of cyclic prefix overhead is used with 4-QAM constellation on each sample. Each polarization OFDM signal is half the bit rate of PDM-OFDM signal. At the receiver, the center 42.8-Gb/s DPSK channel is selected with a 4th order 45 GHz Gaussian band-pass filter and the performance (required OSNR for a target BER of 10^{-4}) is evaluated.

Table 1: Fiber Specifications

FIBER	D(ps/(nm·km))	S(ps/(nm^2·km))	γ(1/(W·km)	α(dB/km)
SSMF	16.8	0.058	1.14	0.21
LEAF	4.2	0.086	1.3	0.21
DCF	-170	matched	5	0.5

The transmission link comprises of 30 spans of 95 km optical fiber. The nonlinear tolerance is investigated for two fiber types, namely SSMF and LEAF. Dispersion compensating fiber (DCF) is used for pre, inline and post compensation. A summary of the dispersion, nonlinear fiber parameters and attenuation of the fibers can be found in Table 1. The slope parameter for DCF has two distinct values that have been matched to the respective fiber types. The slope of DCF is matched to -0.5869 ps/(nm^2·km) and -3.481 ps/(nm^2·km) for SSMF and LEAF transmission lines respectively. A double periodic dispersion map with a periodicity of 5 spans is used to improve the robustness to inter-channel effects in WDM systems [7]. A pre-compensation, per-span inline-under-compensation and per-subdivision post-compensation of -900 ps/nm, 66 ps/nm and -1710 ps/nm, respectively, are used in the SSMF configuration and -300 ps/nm, 59 ps/nm and -585 ps/nm, respectively, in the LEAF configuration. The accumulated dispersion at the receiver is zero. In back-to-back configuration, the required OSNR for a target BER of 10^{-4} is evaluated to be 13.48 dB.

3. Simulation results

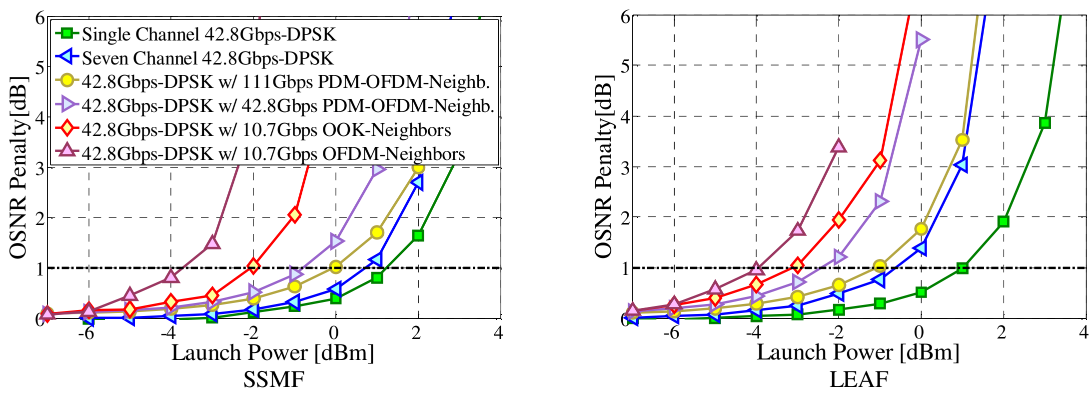

Fig. 2. OSNR Penalty for a target BER of 10^{-4} for different transmission signals after 2,850 km transmission for SSMF and LEAF links.

Fig. 2 shows the nonlinear performance of the center 42.8-Gb/s DPSK channel. Allowing a 1-dB penalty in required OSNR, the nonlinear tolerance (NLT) is the highest for single channel 42.8-Gb/s DPSK with maximum launch power of 1.3 dBm for SSMF and 1 dBm for LEAF, respectively. With WDM DPSK, the maximum launch power is reduced to 0.7 dBm and -0.8 dBm for SSMF and LEAF, respectively. This 0.6 dB (SSMF) and 1.8 dB (LEAF) penalty with respect to single channel is observed due to the XPM induced penalties. As expected, a larger XPM penalty is observed for LEAF due to its lower dispersion coefficient.

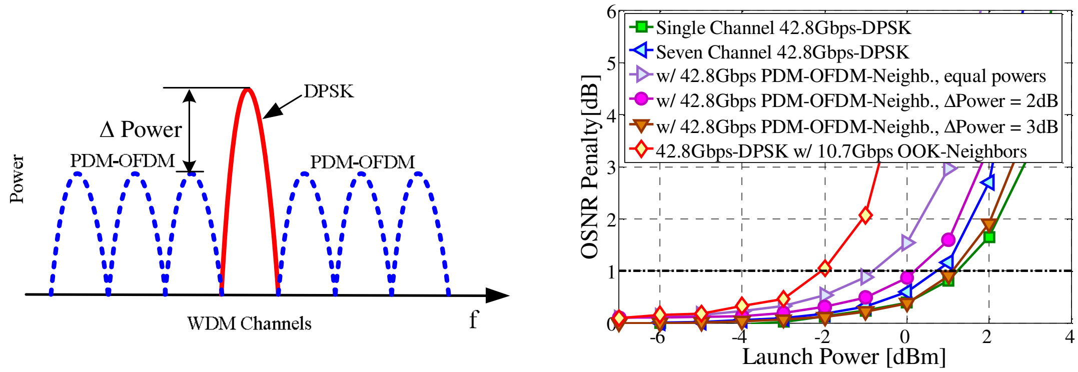

Fig. 3. Delta powers and OSNR penalty for DPSK center channel with 42.8 Gb/s PDM-OFDM employing different delta powers for SSMF.

The maximum launch power for 42.8-Gb/s DPSK with 10.7-Gb/s OFDM co-propagating channels is -3.6 dBm (SSMF) and -4.0 dBm (SSMF). For a reference case we investigate 42.8-Gb/s DPSK with 10-Gb/s OOK neighboring channels and found the maximum launch power to be -2.1 dBm (SSMF) and -3.1 dBm (LEAF), respectively. From literature, we know 10-Gb/s OOK generates strong XPM, which severely impacts the performance of phase modulated modulation formats [8], clearly seen in Fig. 2. From these results it can be inferred that 10.7-Gb/s OFDM induced XPM is even stronger than that of 10.7-Gb/s OOK for such a double periodic dispersion map.

The DPSK channel with co-propagating 42.8-Gb/s and 111-Gb/s PDM-OFDM channels is investigated next. The XPM-induced launch power penalty caused by 42.8-Gb/s and 111-Gb/s PDM-OFDM transmission is 2.1 dB and 1.3 dB for SSMF and 3.4 dB and 2.1 dB for LEAF, respectively. Similar to [6, 9], we find that the XPM crosstalk is strongly dependent on the bandwidth of the OFDM signal. For both the fiber types the XPM tolerance of DPSK with 111-Gb/s PDM-OFDM neighbors is much better than with 42.8-Gb/s PDM-OFDM neighbors. Clearly, the XPM penalties produced by 111-Gb/s PDM-OFDM neighbors is almost identical to the impairment caused by DPSK neighbors, rendering the usage of 111-Gb/s PDM-OFDM suitable for a 100G upgrade scenario. However, for 40-Gb/s or lower bit-rate PDM-OFDM neighbors, a moderate to large penalty is observed.

In order to reduce the XPM generated by 42.8-Gb/s PDM-OFDM neighbors, further simulations were undertaken with the application of delta powers. Delta power is the difference in the optical powers between the center DPSK channel and the neighboring PDM-OFDM channels as illustrated in Fig. 3 (left). The XPM penalties caused by the 42.8-Gb/s PDM-OFDM for SSMF with a delta power of 2 dB and 3 dB were considered and compared to the case when equal powers are employed. As seen in Fig. 3 (right), a substantial improvement in NLT is observed for the case when delta powers are applied. The maximum launch power for 42.8-Gb/s DPSK with 42.8-Gb/s PDM-OFDM neighbors is the largest for the case with delta power of 3dB and is nearly the same as the single channel case. This implies that the XPM generated by the PDM-OFDM neighbors is insignificant and results in a performance similar to single carrier modulation formats. Thus, for future upgrade scenarios, delta power is an efficient means to reduce the XPM penalty caused by 40-Gb/s PDM-OFDM neighbors. It is noted that the use of delta powers does reduce the received OSNR of 40-Gb/s PDM-OFDM and with that the optimal performance.

4. Conclusion

In this paper, we compared the nonlinear tolerance of 42.8-Gb/s DPSK with co-propagating PDM-OFDM for SSMF and LEAF, and found that the XPM penalties arising from LEAF are larger than SSMF. We showed that the XPM penalty depends on the bandwidth of the OFDM signal. We observed a relatively small XPM penalty from 111-Gb/s PDM-OFDM neighbors making it suitable for 100G upgrades. In the case of co-propagating 42.8-Gb/s PDM-OFDM a 2 dB to 3 dB delta power with respect to DPSK was required for the mitigation of XPM.

5. References

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