Nonlinear Limitations in a Joint Transmission of 100Gb/s O-OFDM and 40Gb/s DPSK over a 50 GHz Channel Grid

Fred Buchali, Axel Klekamp, and Roman Dischler
Bell Labs, Alcatel-Lucent Deutschland AG, Lorenzstrasse 10, D-70435 Stuttgart, Germany
E-Mail: Fred.Buchali@alcatel-lucent.de

Abstract: We evaluate the nonlinearity impact of neighbouring DPSK DWDM channels on one 100 Gb/s PDM-OFDM channel. A new DSP-based SPM correction scheme enables complete compensation of the degradation of the nonlinear threshold of 1.8 dB.

OCIS codes: (060.1660) Coherent communications, (060.4510) Optical communication

1. Introduction

Optical-OFDM has been found to be an attractive candidate for next generation 100 Gb/s transmission systems multiplexing 2 orthogonal polarized 50 Gb/s signals. O-OFDM signals suffer from high peak to average power ratios requiring the investigation of nonlinear limitations in detail. Recently, the nonlinear tolerances of 100 Gb/s OFDM systems have been investigated and competitive nonlinear thresholds (NLT) for DCF free multi span transmission have been found [1]. However, in presence of dispersion compensation the nonlinear tolerances are reduced due to self phase modulation (SPM) [2, 3]. The deployment of 100 Gb/s may be performed by upgrade of bitrate of all channels of one fibre or by upgrade of few channels. Latter leads to a co-transmission of different bitrates and modulation formats on same fibre. Recently, coherent single and dual carrier PDM QPSK 100Gb/s systems were studied in the presence of 40 Gb/s and 10 Gb/s neighbouring channels [4] exhibiting 1 dB penalty in NLT for SMF transmission (2dB for NZDSF) for single and dual carrier QPSK induced by the surrounding 40 Gb/s channels.

In this paper we experimentally investigate the impact of 40 Gb/s DPSK channels to one 100 Gb/s PDM O-OFDM channel with QPSK subcarrier modulation in a 50 GHz spaced DWDM platform. First we characterize the linear interaction between 40 Gb/s and 100 Gb/s channels by back-to-back measurements. Next the nonlinear threshold of O-OFDM is investigated in a one span configuration. To improve the nonlinear tolerance of PDM O-OFDM we extend the SPM compensation scheme for WDM signals and investigate its effectiveness for nonlinear compensation of degradation in receiver only to WDM signals.

2. Experimental setup

The experimental setup of the O-OFDM transmitter is shown in Fig.1. We applied a 5 band OFDM superchannel generated by 5 line comb (Δf=6.8 GHz), which is co-modulated using an electrical OFDM signal stored in the memory of an AWG. The 50 Gb/s O-OFDM signal is polarisation multiplexed to generate a 100 Gb/s PDM O-OFDM channel, which is fed through linear operated 80 km SMF for complete decorrelation of the subbands.

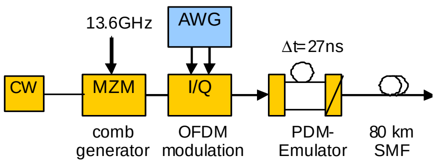

Fig. 1: *Experimental set-up of PDM-OFDM transmitter*

The OFDM signal consisted of 168 QPSK modulated subcarriers (256 point IFFT, analogous to [6]). The configuration allows a net data rate of 10.16 Gb/s (20.32 Gb/s in polarisation division multiplex) on each subband resulting in a capacity of 101.6 Gb/s for the PDM-OFDM channel within a total bandwidth of 34 GHz. As DPSK-NRZ source, a push-pull modulator is applied with bias at null point and $2xV_\pi$ data modulation with PRBS 2^{23}-1 [7].

The transmission testbed is depicted in Fig 2. We embedded the O-OFDM signal (λ_3) on a 50 GHz DWDM platform centred between 4 DPSK signals, which are modulated in 2 independent transmitters for even (λ_2 and λ_4) and odd (λ_1 and λ_5) channels. All channels are combined using 50 GHz interleavers. A single 80 km SMF span was applied for transmission and no DCF has been applied in the OFDM branch. The inset of Fig. 2 shows the optical spectrum after the SMF. In front of the OFDM receiver a tuneable attenuator was placed to allow additional noise loading by the following EDFA. A subsequent tuneable 30 GHz optical band pass filter (OBPF) rejects excessive out of band noise. For the OFDM Rx a state of the art dual polarization coherent receiver is applied in combination with a 50 GSa/s real time scope and offline data processing in a PC. The reception and the data processing were performed on subband level.

We implemented a new SPM compensation scheme in the receiver following [8-10] for polarization multiplexed signals. Contrary to previous works we compensate SPM for each OFDM subband independently and limit the electrical bandwidth Δf of the AD converter to 8 GHz (corresponding to 16 GHz optical bandwidth) to suppress in frequency domain all contributions roughly 5 GHz away from the outest subcarriers of the subband under investigation. Numerical simulations proof the drastic decreased efficiency of nonlinear interaction of subcarriers, if their effective distance is beyond 10 GHz. These contributions are completely neglected in the implemented scheme.

Theoretically, the SPM compensation scheme has to be applied to the transmitted signal but in a reduced bandwidth window the fiber can be assumed to be dispersion free and the transmitted and the received time domain signals within this bandwidth can be assumed to be equal. This enables the SPM compensation within the receiver only, although [3, 8] show that it is more effective when integrated in both Tx and Rx for previous SPM compensation schemes. We applied a phase modulation $\Phi_{comp}^{x(y)}(\Delta f,t)$ to both polarizations dependent on the time dependent received power (P_x, P_y) in the two polarizations within Δf:

$$\Phi_{comp}^{x(y)}(\Delta f,t) = -\gamma[P_{x(y)}(\Delta f,t) + \frac{2}{3}P_{y(x)}(\Delta f,t)]NL_{eff} \qquad (1)$$

where γ is the fiber nonlinear coefficient, N is the number of fiber spans, and L_{eff} is the effective fiber length of each span [8]. The limitation in bandwidth enables the application of SPM compensation without insertion of DCF or without 100% compensation of CD.

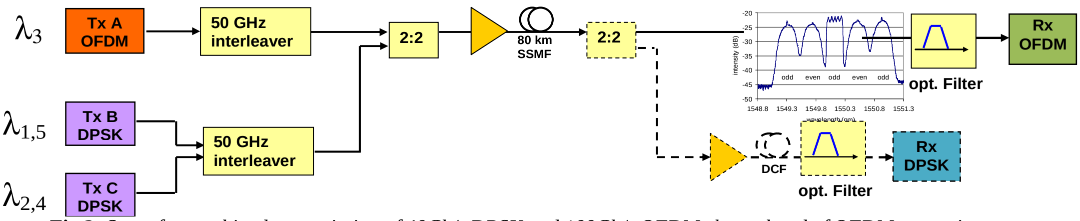

Fig 2: *Setup for combined transmission of 40Gb/s DPSK and 100Gb/s OFDM channel and of OFDM transmitter.*

For all BER measurements multiple sequences of typically 120 symbols were recorded and processed, until a total of more than 1.2 x 10^6 transmitted bits was reached. During BER measurements of a respective tributary, all neighbouring channels were adjusted to maximum power deviation below 1 dB. The values for BER and Q-factor presented in the following figures are mean values across both polarizations of the PDM-OFDM channel.

3. Results and discussion

Fig. 3 shows the back-to-back OSNR sensitivity for the 100 Gb/s OFDM channel without (Fig. 3a)) and with (Fig. 3 b)) neighbouring 40 Gb/s DPSK channels for all 5 subbands. In both cases a sensitivity of 15.8 dB @ BER 10^{-3} is achieved. Thus, no penalty due to linear crosstalk is introduced for the OFDM signal by the surrounding DPSK channels besides a tendency to flooring of the BER at lower BER (< 10^{-4}). A corresponding measurement was also performed for the 4 DPSK channels showing identical performance with and without the OFDM channel.

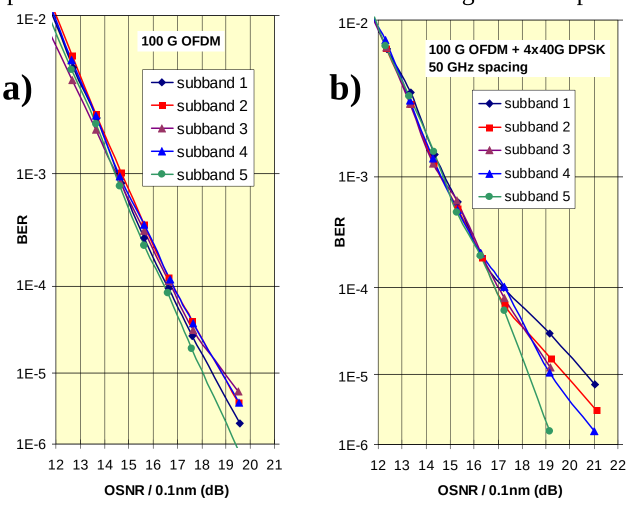

Fig. 3: Back-to-back OSNR sensitivity for 100 Gb/s OFDM single channel (left) and with neighbouring 40 Gb/s DPSK channels (right).

We measured the nonlinear threshold at constant OSNR of 16 dB corresponding to a Q-factor of 10.8 dB in the linear regime of transmission fibre. At 1 dB Q-penalty we have Q=9.8 dB, which is required to be error free after FEC (BER ≤ 10^{-3}). It should be noted that the Q-factors of the two orthogonal polarisations differ at maximum by 0.5 dB depending on the accidental polarization state of the surrounding DPSK co-polarized channels.

Fig. 4. presents the graphs of Q-factor versus P_{in}/ch for single channel and DWDM configuration, without and with SPM correction. In the single channel case a NLT of 8.8 dBm has been found. Applying the SPM compensation scheme a 2.5 dB improvement in NLT is achieved. In case of DWDM transmission the NLT is 7 dBm, which is 1.8 dB reduced due to XPM effects induced by sourrounding DPSK channels. Applying the nonlinear compensation scheme to the OFDM signals in DWDM case we found an improvement by 1.8 dB and the XPM degradation can be equalized by the SPM compensation scheme. Next we compared the NLT degradation in WDM case for all 5 subbands (cf. Fig. 5.) and found very comparable results for all of them. No remarkable degradation of the subbands at the edge compared to the center is observed.

In a further experiment we investigated the NLT of the OFDM subband for 100 GHz spacing to the sourrounding DPSK channels (cf. Fig. 6). Here we switched off the even DPSK channels and found a slight improvement of ~0.2 dB w/o. and w. SPM compensation in comparison to the case of 50 GHz spaced channels.

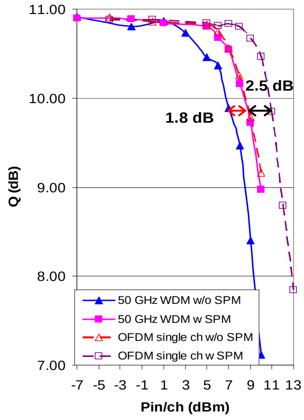

Fig. 4: Q-factor vs. fiber input power per channel for one OFDM subband for 50GHz DWDM (filled symbols) and single channel (open symbols) with and without SPM compensation

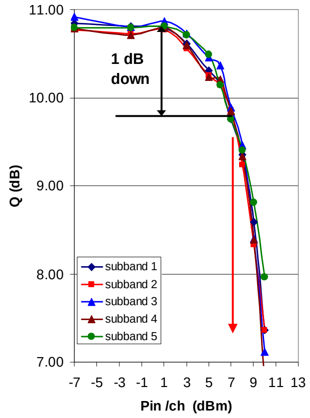

Fig. 5: Q-factor vs. fibre input power per channel for 100 Gb/s OFDM with neighbouring 40 Gb/s DPSK channels

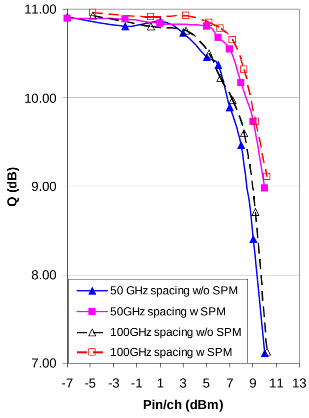

Fig. 6: Q-factor vs. fiber input power per channel for one OFDM subband for 50GHz DWDM (filled symbols) and 100GHz (open symbols) with and without SPM compensation

Comparing the degradation of NLT for OFDM and single carrier QPSK in presence of 40 Gb/s DPSK channels we found a degradation of same order for both (1.8 dB for OFDM, 1 dB for single carrier QPSK [4]). We could compensate this degradation for OFDM by implementing a new subband based SPM correction scheme. The efficiency of the SPM compensation scheme with a gain of 2.5 dB for single channel is of same order as has been published in [3, 8] although here only applicated in the receiver. For a lower bandwidth signal [9] higher compensation gains have been demonstrated, but, in case of higher bandwidth signals, both, single channel with >30 GHz bandwidth and WDM the efficiency of SPM compensation is limited due to dispersion effects.

Please notice that the used fiber input powers to measure the NLT values for the OFDM channel are well below the NLT for 40 Gb/s DPSK of 13 dBm [11]. Therefore, we assume that the DPSK channels are operated in the linear regime for all fiber input powers used.

4. Summary

We investigated the impact of neighbouring 40 Gb/s DPSK channels on 100 Gb/s PDM-OFDM. In back-to-back configuration no penalty due to linear crosstalk is observed for the OFDM as well as for the DPSK channels. The impact of the DPSK channels is limited to 1.8 dB of NLT degradation w.r.t. single channel case. This penalty can be completely compensated for by a new SPM correction applied to the OFDM signals. In single channel configuration the benefit of SPM correction increases to 2.5 dB which illustrates that some degradation due to XPM is still present even when enhancing the channel spacing from 50 to 100GHz.

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