Narrow Filtered DPSK: an Attractive Solution for Hybrid Systems

Marco Bertolini, Paolo Serena, Nicola Rossi and Alberto Bononi
Università degli Studi di Parma, dept. Ingegneria dell'Informazione, v.le G.P. Usberti 181/A, 43100 Parma (Italy)
email: bertolini@tlc.unipr.it

Abstract *We propose an efficient Hybrid system based on 40G DQPSK and 10G narrow filter DPSK in place of OOK. This technique reduces XPM on DQPSK channels at low inline dispersion.*

Introduction

The increase in the capacity demand requires an upgrade of existing 10 Gb/s on-off keying (OOK) wavelegth division multiplexing (WDM) systems. To make this improvement as seamless as possible, the bitrate of some channels should be brought to 40 Gb/s or more, following the traffic growth. This configuration is often referred to as Hybrid system.

Differential quadrature phase shift keying (DQPSK) is considered one of the most suitable modulation format for the upgrade of selected channels. However many studies, both simulative and experimental, proved that DQPSK performance is strongly limited by the cross phase modulation (XPM) of neighboring OOK channels [1, 2]. A proposed solution is to turn off those OOK channels. This is suboptimal, since it reduces the maximum capacity and requires an accurate channel planning.

In this paper we propose to upgrade 10 Gb/s channels to differential phase shift keying (DPSK) while keeping most OOK hardware, and receive them using a narrow optical filter (narrow filter DPSK, NF-DPSK) [3]. This way the impact of XPM is reduced, since DPSK is a constant amplitude format. Numerical Monte Carlo (MC) simulations are carried out to support this claim, taking into account nonlinear phase noise in order to guarantee a fair comparison.

Setup and Simulation Parameters

Before focusing on the parameters used in the simulations, we will briefly describe the necessary modifications in the transmitter and receiver to upgrade OOK channels to DPSK. At the transmitter, a DPSK precoder must be added and the bias of the Mach-Zehnder modulator must be set to the null point: the drive voltage can be left unaltered (V_π, instead of $2 \cdot V_\pi$), since it gives only a small penalty on performance [4] which is easily compensated by the improved sensitivity of NF-DPSK [5]. At the receiver, the optical filter has a Gaussian shape and a bandwidth of ∼0.65×baudrate. This solution can be implemented using a circulator and a single device based on Bragg gratings that leaves DQPSK channels unaltered and filters NF-DPSK channels . This way preexistent OOK receiver can be left unaltered [6].

The numerical simulations were performed using an internally developed Matlab™ toolbox. The system under test was composed of 5 channels, 50 GHz spacing, launched over a link comprising pre/post compensating fibers before/after 25 identical spans, made of transmission and compensating fiber and an amplifier. All the results refer to the central channel. We verified that an increased number of channels does not significantly impact the performance.

The odd channels, and thus the central one, were always DQPSK modulated at 40 Gb/s (20 Gbaud) using a pseudo random quadrature sequence (PRQS) of length 4^5, while the even ones were in turn OOK or NF-DPSK modulated using a pseudo random binary sequence (PRBS) of length 2^9.

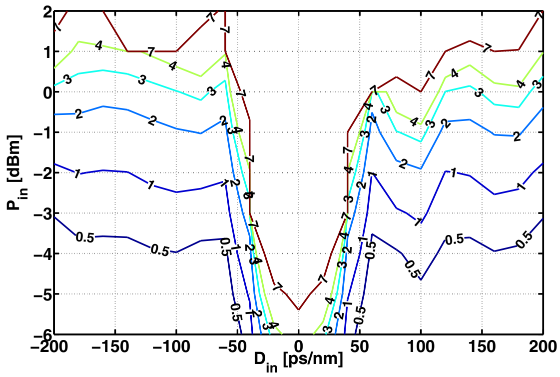

Fig. 1: *DQPSK sensitivity penalty vs. power and inline dispersion. Even channels OOK*

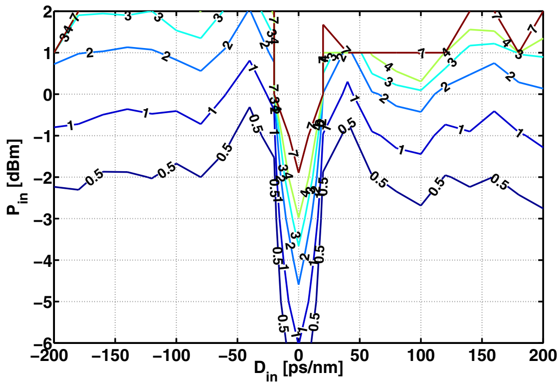

Fig. 2: *DQPSK sensitivity penalty vs. power and inline dispersion. Even channels NF-DPSK*

The propagation was modeled using a variable step-size split step Fourier method (SSFM), accounting for all linear and non linear impairments but polarization mode dispersion (PMD). The maximum nonlinear phase rotation per step was $3 \cdot 10^{-3}$ rad. The cumulated dispersion of both pre- and post-compensating fibers were optimized using Karhunen-Loève (KL) method [7], assuming white noise. The amplifiers

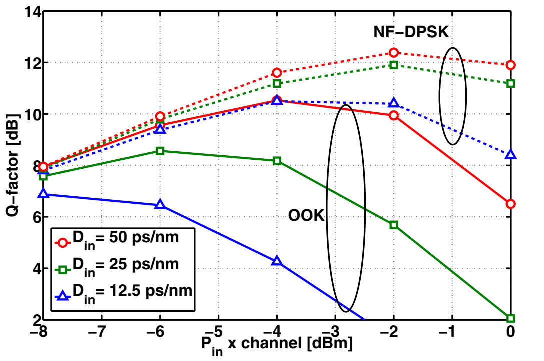

*Fig. 3: DQPSK Q-factor vs. P_{in} for three values of D_{in} on a **Leaf** fiber. Even channels OOK or NF-DPSK*

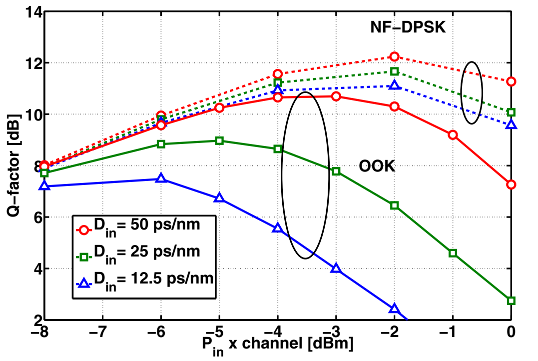

*Fig. 4: DQPSK Q-factor vs. P_{in} for three values of D_{in} on a **Teralight** fiber. Even channels OOK or NF-DPSK*

along the line were erbium doped fiber amplifiers (EDFA) with flat gain and a noise figure of 6 dB.

White Noise Analysis

Initially we tested both configurations simulating noiseless transmission over 20x 100 km span on Teralight^{TM} fiber and measuring the sensitivity penalty (SP) vs. back to back at bit error rate (BER) 10^{-5} as a function of both the average launched power P_{in} and the residual dispersion per span, D_{in}. The BER is computed using KL method. These simulations are very fast, enabling the exploration of a wide parameters range, but assume that the noise at the receiver is white, i.e. do not account for the effect of nonlinear phase noise.

Figs. 1-2 depict the contour plot of SP vs. P_{in} and D_{in} computed using KL. When even channels are OOK modulated, for values of D_{in} up to $\sim \pm$50 ps/nm, the performance is heavily degraded by XPM. When we use NF-DPSK, this range is reduced to $\sim \pm$ 20 ps/nm. Moreover, even for higher values of D_{in}, NF-DPSK still shows a gain $\sim$1 dB in SP. This confirms that XPM is reduced when using phase modulated 10 Gb/s channels. Separately we repeated the same simulations using a Leaf^{TM} fiber; though not reported here, the result show that the impact of XPM due to OOK channels is larger also for higher values of D_{in} and that the performance gain of NF-DQPSK is even more evident.

Nonlinear Phase Noise Impact

To account exactly for nonlinear phase noise, we then simulated a 25x100 Km system in both configurations, using noisy amplifiers. We measured the Q-factor of the central DQPSK channel vs. P_{in}, for three different values of D_{in}, 12.5, 25, 50 ps/nm and for two different type of transmission fiber, Leaf^{TM} (D =4 ps/nm/km @ 1550 nm) and Teralight^{TM} (D =8 ps/nm/km @ 1550 nm). The Q-factor was derived from the BER computed using the standard MC algorithm. The simulations ended when the relative error reached 20% with a Gaussian confidence of 95%. At least 100 errors were counted for every point.

Figs. 3-4 show the MC Q-factor as a function of P_{in} for different values of D_{in}.The performance of a DQPSK channel surrounded by NF-DPSK channels is better by at least $\sim$2 dB, when comparing curves at the same D_{in}. Also note that the dependence of the performance on the value of D_{in} is clearly stronger in the OOK case. We also compared these results to the ones obtained through KL method; it turns out that the impact of nonlinear phase noise due to OOK or NF-DPSK channels is similar.

Focusing on Fig. 3, which refers to the case of Leaf^{TM} fiber, we can say that, provided that the value of D_{in} is larger than 25 ps/nm, the system with NF-DPSK channels works close to its optimum. This constrain is further relaxed employing fibers with higher D, like Teralight^{TM} (Fig. 4).

Finally, it is worth to notice that NF-DPSK at D_{in} =12.5 ps/nm and OOK at D_{in} =50 ps/nm provide similar performance for a wide range of powers.

Conclusions

Upgrading 10 Gb/s OOK channels to DPSK with minimal hardware changes proves to be a viable alternative for the upgrade of deployed WDM systems.

The slightly more complex setup required at both receiver and transmitter is compensated for by a largely enhanced tolerance against XPM, which is the main impairment in such Hybrid systems. NF-DPSK is thus a good option for deployed system with very low D_{in}. For higher values of this key parameter OOK gives acceptable performance, making the upgrade unactractive. Cross channel nonlinear phase noise impact on DQPSK channels is comparable for OOK and NF-DPSK.

Acknowledgments

This work was supported by Alcatel-Lucent Bell Labs. The authors would like to thank G. Charlet for the fruitful discussions.

References

1. M. Lefrançois et al., OFC 2007, JThA44
2. S. Chandrasekhar et al., PTL **19** (2007), p. 1801
3. D. Penninckx et al., ECOC 2001, WeP40
4. A. H. Gnauck et al., JLT **23** (2005), pp. 115-130
5. Lyubomirsky et al., PTL **17** (2005), p. 492
6. D'Errico et al., El. Lett., **42** (2006), pp. 112-114
7. P. Serena et al., JLT **24** (2006), pp. 2026-2037

978-1-4244-2228-9/08/$25.00 (c) 2008 IEEE