PDL-aware In-band OSNR Monitoring based on the Spectral Properties of Concatenated CAZAC Sequences

Fabio Pittalà[1,2,3], Fabian N. Hauske[1], Yabin Ye[1], Neil G. Gonzalez[1], Idelfonso T. Monroy[2], Josef A. Nossek[3]
1: European Research Center, Huawei Technologies Duesseldorf GmbH, Riesstrasse 25, D-80992 Munich, Germany,
2: DTU Fotonik, Technical University of Denmark, Ørsteds Plads 343, DK-2800 Kgs. Lyngby, Denmark.
3: Institute for Circuit Theory and Signal Processing, Technische Universität München, Arcisstr. 21, D-80290 Munich, Germany
E-mail: fabio.pittala@huawei.com

Abstract: A novel method for accurate in-band OSNR monitoring based on analysis of the power spectral density of concatenated received CAZAC training sequences is demonstrated over a wide range of combined linear distortions.
OCIS codes: (060.1660) Coherent Communications; (060.4261) Network, protection and restoration.

1. Introduction

The optical-signal-to-noise ratio (OSNR) is a direct indicator of the channel quality in reconfigurable optical networks with higher-order modulation, flexible switching and wavelength routing. Therefore, efficient operation and maintenance of such dynamic optical networks require the monitoring of the OSNR for each wavelength-division multiplexed (WDM) channel. An accurate in-band OSNR monitoring is primarily required for link setup and optimization, for efficient traffic growth-oriented transportation platform of any type of data traffic, for early fault analysis, for the activation of resilience mechanisms and for the verification of the service-level-agreement [1].

During the past decade, the research community has attempted to develop techniques capable of monitoring the given OSNR of a communication system. Those techniques are mainly based on polarization nulling, optical spectral analysis, asynchronous histograms, neural networks [1, 2] and recently also on signal equalization [3]. However, these methods are not applicable to polarization-division multiplexing (PDM) systems with amplitude and phase modulation or have not been evaluated in systems with polarization dependent loss (PDL) and combined deterministic and statistic channel impairments proving reliable estimation under realistic conditions.

In this paper, we extend the method for joint OSNR and PDL estimation in coherent receivers with digital signal processing (DSP) based on data-aided (DA) 2×2 multi-input multi-output (MIMO) frequency domain equalizer (FDE) [4, 5]. By concatenating consecutive constant-amplitude zero-autocorrelation (CAZAC) training sequences the properties of the resulting power spectral density (PSD) allow superior estimation performance at high OSNR regime (>20 dB). Still this technique is insensitive to dispersive impairments and polarization effects as in [5].

2. Operating Principle

Following the scheme presented in [5], after equalization the known CAZAC sequences are extracted. In each frame, two concatenated training sequences per polarization are sent (a larger number of consecutive CAZAC sequences would increase the system overhead but at the same time it would rapidly average out the impact of noise on the PSD). Once the two CAZAC sequences are extracted, a fast Fourier transform (FFT) covering both CAZAC lengths is performed to obtain the PSD, Fig.1-left. The odd frequency points of the resulting PSD contain the signal power plus half of the noise, whereas the remaining noise is distributed in the even frequency points, Fig. 1-center. Then, for each polarization tributary, the ratio between the sum of the odd frequency points and the sum of the even frequency components is calculated (O/E). By means of the PDL monitoring, in each polarization a predefined 4D lookup table is reduced by one dimension and the best fit between the estimated O/E values and the two resulting 3D lookup tables leads to the extraction of the OSNR value, Fig. 1-right.

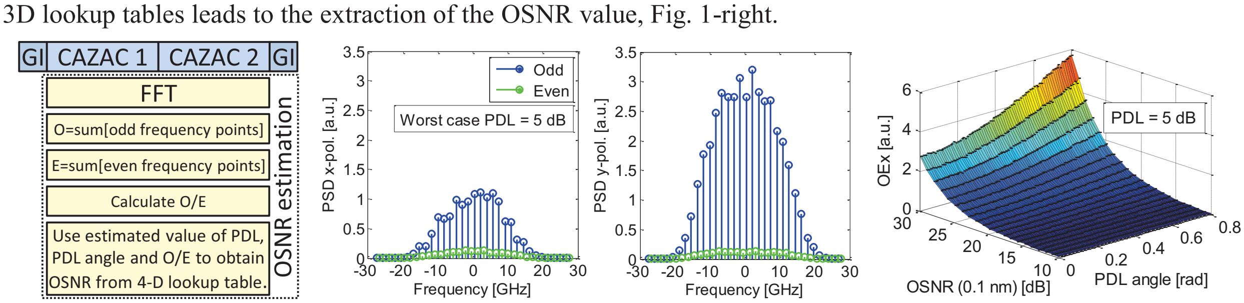

Fig. 1. OSNR estimation procedure (left), power spectral density (PSD) of the equalized CAZAC training sequences with worst-case PDL equal to 5 dB in x- and y-pol. respectively (center), ratio of total power of the odd and even frequency points of the PSD in one polarization as function of OSNR and the PDL orientation angle for a given PDL value equal to 5 dB (right).

3. Simulation Results

The robustness of the OSNR estimation presented in this paper has been investigated on a simulated 112 Gbit/s coherent transmission system (28 GBaud PDM quadrature phase-shift keying (QPSK) modulation). The linear optical channel includes chromatic dispersion (CD), higher-order polarization-mode dispersion (PMD), PDL using the lumped model as described in [6], PDL orientation angle θ, polarization rotation angle α and polarization phase φ defining the state of polarization (SOP). At the receiver additive white Gaussian noise (AWGN) is loaded onto the signal. After an optical Gaussian band-pass filter (2^{nd}-order, double-sided 35 GHz), a polarization-diverse 90°-hybrid and an electrical Bessel filter (5^{th}-order, 19 GHz), an analog-to-digital converter (ADC) stage digitalizes the received signal at 2 samples per symbol. For each OSNR value, 100 random channels have been generated leading to a total number of 2400 trials with parameters randomly chosen from the distributions specified in Table 1. The optical channel was estimated with the aid of two concatenated CAZAC sequences with a total length of 40 symbols, including 4-symbols of guard interval at the beginning and end of the sequence. Each 16-symbols CAZAC sequence is represented by a QPSK constellation. The received signal is equalized by a minimum-mean-square-error (MMSE) filter converged after 20 channel estimation averages [4], whereas the PDL value is extracted from the estimated zero-forcing (ZF) filter matrix (CD and PMD could be simultaneously monitored) [2].

In Fig. 2-center the accuracy of the OSNR estimation for given OSNR values ranging from 12 to 28 dB is shown. For OSNR values lower than 12 dB the OSNR estimation is progressively degraded due to the increasing impact of noise on the PSD of the equalized training sequences, Fig. 2-left. However, even in highly noisy channels the estimation does not exhibit any failure. The OSNR estimation proves a zero mean error and, considering given OSNR values in the range from 12 to 28 dB, the maximum estimation error equals 0.7 dB, Fig. 2-right.

TABLE 1
Parameter Range and Distribution
for Channel Simulations

Impairment	Distribution	Value range
PMD	Maxwellian	Mean 25 ps
CD	Linear	[-500: 500] ps/nm
α	Linear	[0: 2π] rad
φ	Linear	[0: 2π] rad
PDL	Linear	[0:10] dB
θ	Linear	[0: π/4] rad
OSNR (0.1 nm bandwidth)	Constant	[5:28] dB

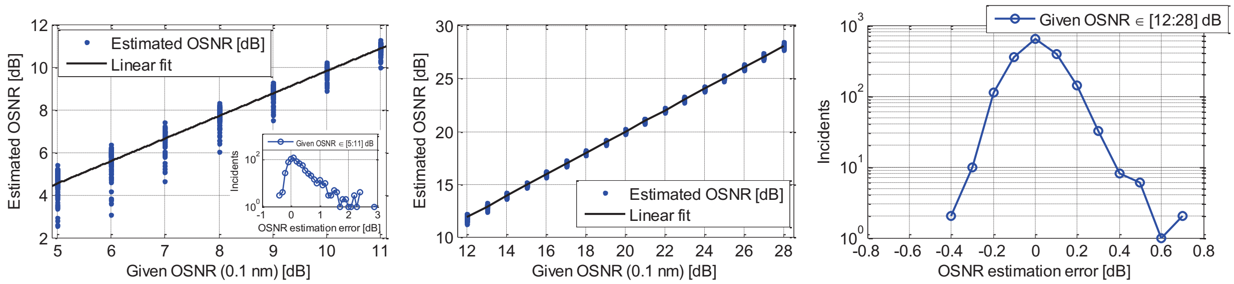

Fig. 2. OSNR monitoring performance: Given OSNR versus estimated OSNR when the given OSNR is ranging from 5 to 11 dB (left) and from 12 to 28 dB (center), histogram of the OSNR estimation error for given OSNR ranging between 12 and 28 dB (right).

4. Conclusions

In-band OSNR monitoring supported by data-aided FD channel estimation employing concatenation of very short training sequences has been demonstrated in presence of combined linear channel impairments. OSNR estimation proves a zero mean error and accuracy within ±0.7 dB, for given OSNR ranging between 12 and 28 dB.

5. Acknowledgement

The research leading to these results has received funding from the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement n° 258644, CHRON project.

6. References

[1] Chan, Calvin C. K., *Optical Performance Monitoring - Advanced Techniques for Next-Generation Photonic Networks*, Elsevier, 2010.
[2] D. Dahan, U. Mahlab, A. Teixeira, I. Zacharopoulos, I. Tomkos, "Optical performance monitoring for translucent/transparent optical networks", IET Optoelectronics **5**, 1-18 (2011).
[3] D.J. Ives, B.C. Thomsen, R. Maher, S. Savory, "Estimating OSNR of Equalised QPSK Signals", in ECOC 2011, Tu.6.A.6.
[4] F. Pittalà, F. N. Hauske, Y. Ye, N. G. Gonzalez, I. T. Monroy, "Data-Aided Frequency-Domain 2×2 MIMO Equalizer for 112 Gbit/s PDM-QPSK Coherent Transmission Systems", in OFC/NFOEC 2012, OM2H.4.
[5] F. Pittalà, F. N. Hauske, Y. Ye, N. G. Gonzalez, I. T. Monroy, "Joint PDL and In-band OSNR Monitoring Supported by Data-Aided Channel Estimation", in OFC/NFOEC 2012, OW4G.2.
[6] Chongjin Xie, "Polarization-dependent loss induced penalties in PDM-QPSK coherent optical communication systems", in OFC/NFOEC 2010, OWE6.
[7] T. Duthel, C.R.S. Fludger, J. Geyer, C. Schulien, "Impact of Polarisation Dependent Loss on Coherent POLMUX-NRZ-DQPSK", in OFC 2008, OThU5.