Polarization Rotation Monitoring Using 2D-Pattern Recognition in Digital Coherent Receivers

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A novel polarization rotation monitoring method based on information extracted from the dynamic response of a digital coherent receiver is proposed for 100 Gb/s dual polarization DQPSK coherent systems. By tracking the time evolution of parameters involved in adaptive digital filtering processes on a two-dimensional (2D) feature-space, 2D-patterns can be recognized in the presence of polarization rotation around a convergence point. We report that such patterns can successfully be applied to identify polarization rotation of values above 10 Mrad/s that bring large number of bit errors that could not be corrected by forward error correction.

I. Introduction

Next generation optical networks comprise high levels of heterogeneity due to different types of services, modulation formats, bit rates and physical interfaces present in the optical transport layer. At the same time, flexibility and upgradeability in combination with self-configurable control require novel solutions within the field of network management. Optical performance monitoring (OPM) is a key building block to face up the network challenges and comply with Quality of Service (QoS) requirements to fulfill user demands. Digital coherent receivers in combination with digital signal processing is proving to be the proper technology approach to implement OPM [1], taking advantage of the already employed digital signal processing such as for example, using the coefficients of digital filter impulse response of adaptive equalizers. Monitoring of all deterministic linear optical channel parameters like chromatic dispersion (CD), polarization-mode-dispersion (PMD) and polarization-dependent loss (PDL) have been carried out using such approach [1]. However, even in the case of adopting optimized coefficient parameters, it has recently been pointed out [2] that angular rate of polarization rotation above 10 Mrad/s would cause a large number of errors. Significant polarization rotation have been observed within periods in the order of 100 μs [3], that in combination with possible hard hits in dispersion-compensating fiber reels, would lead to the mentioned high polarization rates [4]. Therefore, it is crucial to provide polarization rotation monitoring to network operators in order to alert of fiber stress and physical degradation problems along the optical path.

In this paper we present a two-dimensional (2D) pattern recognition method that allows detecting and alerting of high rates of polarization rotation in the transmission. 100% of accuracy is obtained over 1000 independent simulations, using polarization rotation rates from few tens rotations per second, to huge rotations around 100 Mrad/s. In the next sections we present the estimation algorithm used, that tracks the time evolution of converged FIR filters coefficients used for digital equalization and provide polarization rotation monitoring (PRM) using 2D pattern recognition.

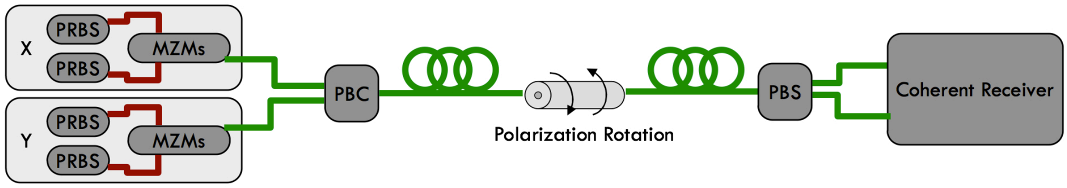

Fig. 1. General outline of the simulation setup for polarization rotation monitoring

II. System setup and digital coherent receiver

The simulation framework implemented is based on polarization-division-multiplexed (PDM) differential quadrature phase-shift keying (DQPSK) that can provide a solution for high-performance transmission [2]. The setup of our simulation is shown in Fig. 1. In-phase and quadrature branches of the Mach-Zehnder Modulators were differentially driven by two 28 Gb/s pseudorandom bit sequence (PRBS) of length $2^{15}-1$. Polarization multiplexing was achieved mixing the components from both polarizations with a polarization beam combiner (PBC). The signal is transmitted, and polarization rotation is loaded in the channel simulating an endless polarization rotation [2], [6], with the following Jones Matrix

$$J = \begin{pmatrix} \cos(wt) & \sin(wt) \\ -\sin(wt) & \cos(wt) \end{pmatrix}$$

where w is the angular rate of rotation. After fiber transmission, using a polarization beam splitter (PBS) both polarizations are divided and mixed with the local oscillator (LO) in the polarization-diversity 90ºHybrid (Fig. 2). After photodetection, using balanced detectors, the four signal components (I_x, Q_x, I_y, Q_y) are sampled and chromatic dispersion equalization in frequency domain is applied to both polarizations. Then adaptive equalization is implemented, using a butterfly filter structure with 7 taps T/2-spaced FIR filters (h_{xx}, h_{xy}, h_{yx}, h_{yy}) employing a constant-modulus algorithm (CMA) as adaptive method. Finally, the values of the coefficients of these filters are transferred to the monitoring algorithm for polarization rotation estimation.

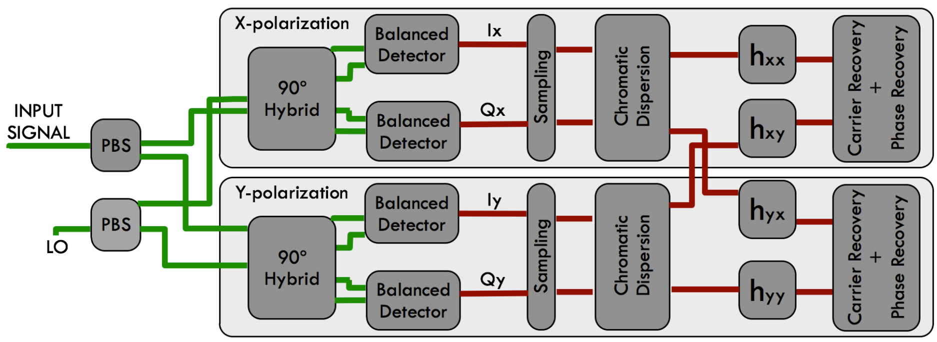

Fig. 2. Outline of the proposed blocks for the coherent receiver front-end

III. Method

In this section, an introduction to our proposed PRM approach is presented. Since polarization rotation is a dynamic channel impairment, convergence tracking over time of FIR filters in a butterfly realization (see Fig. 2) is used for PRM. The signal flowchart of the algorithm is depicted in Fig. 3 and the general setting can be described as follows: first of all, a complex plane comprised of the real and imaginary part of the FIR filter coefficients is defined as the feature-space (FS) for classification decision. On the defined FS, specific dynamic polarization rotation is mapped to specific two-dimensional (2D) convergence patterns of FIR coefficients. To classify among different 2D convergence patterns (characterization stage), the statistical variance on each axis is calculated after extraction of the stable-state of the 2D convergence pattern.

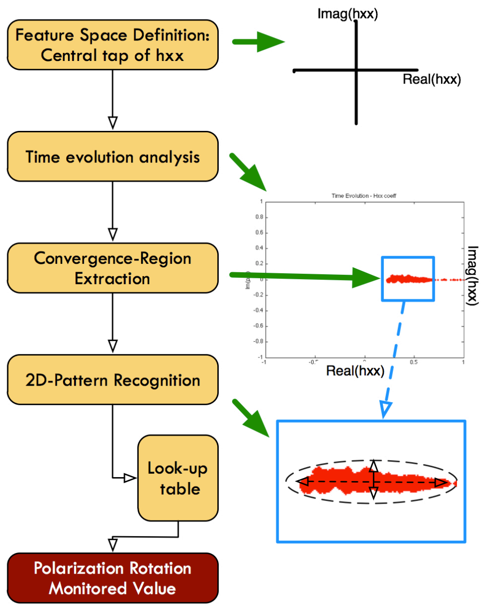

Fig. 3. 2-D pattern recognition PRM flowchart

We demonstrate that using the convergence pattern, the stable-stage region of the central tap of a single time-domain butterfly filter, is enough for robust PRM. Therefore, without loss of generality, h_{xx} for characterization stage is implemented. Convergence patterns can be mapped onto two classes (Fig. 4). One class for "slow" rotations until 100 krad/s where the statistical variance is low and remains almost constant in both axis of the FS, and other one for "fast" rotations above 500 krad/s where statistical variance of real axis takes over the dominant contribution of the pattern. Results and performance for this mapping are shown in the next section.

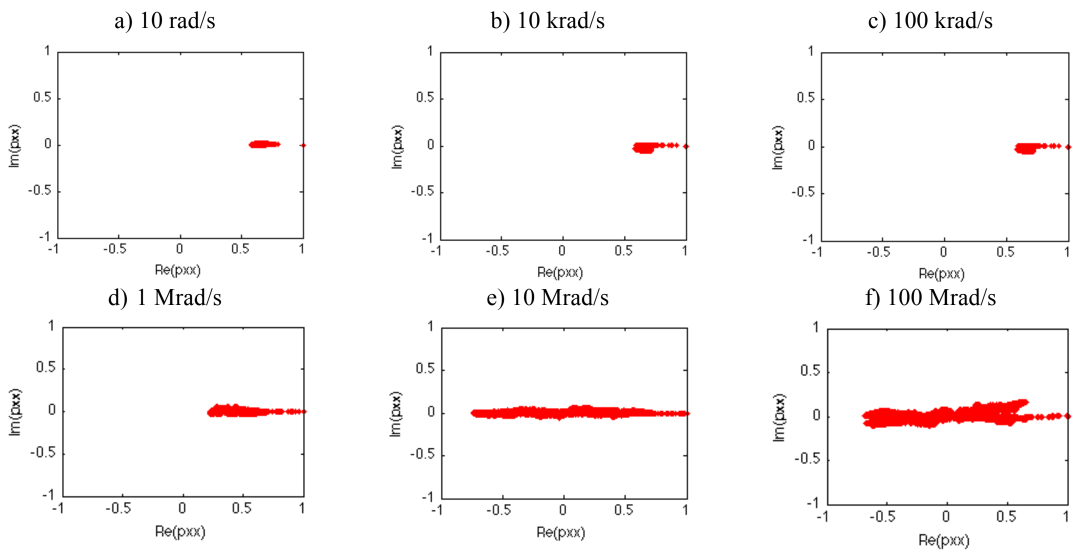

Fig. 4. FS time evolution convergence in the presence of polarization rotation from 10 rad/s (top left) to 100 Mrad/s (bottom right).

IV. Simulation Results

Polarization rotation monitoring is numerically investigated for 112 Gb/s (28 GBaud) PDM-DQPSK transmission at an OSNR of 14 dB within a 0.1-nm bandwidth. To test the proposed approach, 1000 independent simulations of the transmission were performed using 8 different rates for polarization rotations as is shown in Fig. 5. In this work, 2D convergence patterns are grouped in 2 classes as can be observed in Fig. 5:

- Slower than 200 krad/s: No alert is generated. Statistical variance in the FS takes values below 3×10^{-2}, typically providing bit error rate (BER) under 10^{-3}.
- Faster than 200 krad/s: Alert is generated. Statistical variance takes values over

$3x10^{-2}$. Angular rate of rotation becomes untrackable with accurately that will lead to large number of errors.

In Fig. 5, the behaviour of the variance in the stable-state of the FS is depicted for the 1000 independent simulations. Values of statistical variance corresponding to the same polarization rotation rate are represented by a unique colour. Separable classes on the diagram demonstrate the feasibility of our proposed approach. Using optimized ranges in the look-up table, accuracy of 100% was obtained in the classification of the polarization rotation.

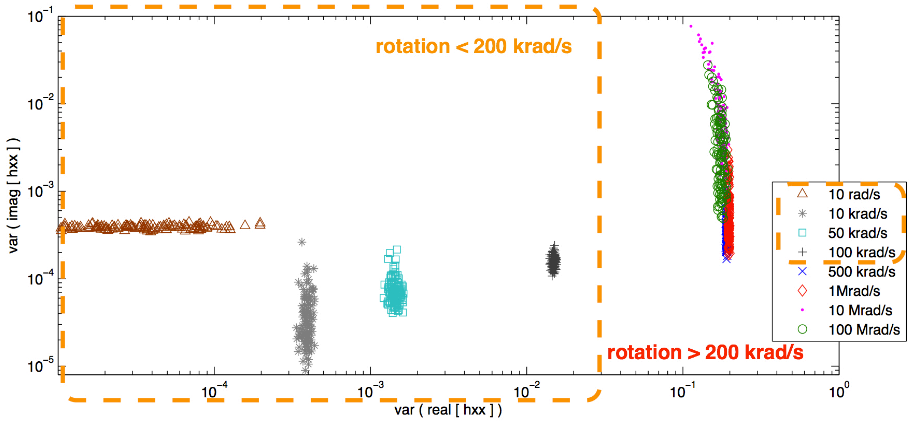

Fig. 5.Statistical variance in the FS for 1000 channel simulations using 8 different rates of polarization rotation.

V. Conclusion

A novel polarization rotation monitoring approach based on 2D pattern recognition is proposed. Two classes of polarization rotation are defined to characterize values slower than 200 krad/s and faster than 200 krad/s. Numerical investigations show successful classification between both classes in a simulated 100-G QPSK system by analysing the 2D statistical variance of the convergence pattern of FIR filter coefficients. The novel PRM approach opens the door to *n*-dimensional Pattern Recognition techniques for fiber impairments monitoring and shows a new perspective based on classes to relax optical network monitoring.

VI. Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7) under grant agreement n° 258644.

VII. References

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