Advanced DSP for Monitoring and Mitigation in Optical Transport Networks

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Abstract: DSP-based transceivers with enhanced monitoring and mitigation capabilities enable highly efficient transport networking with minimized excess margin and open line systems with enhanced availability. Examples for such advanced DSP algorithms are introduced.

1. Introduction

The advent of flexible transceivers that can support various transmission throughputs in different spectral efficiencies has stimulated discussions on new approaches for designing and operating optical networks that would enable better utilization of fiber infrastructure [1-4]. Such approaches put their basis on monitoring the quality of transmission (QoT) of actual network by means of the transceivers in use to configure the optical paths, while conventional network design methods are based on off-line calculation assuming the worst-case scenario. The new approaches thus aim at extracting higher network capacity by minimizing the system margin to cover piece-to-piece and/or temporal variations of optical network elements. Optimum allocation of system margin should be more challenging when a network consists of multi-vendor equipment (e.g. open line system or optical disaggregation scenarios). In this paper, we discuss the importance of advanced monitoring and mitigation of various optical impairments in the above context and introduce some of our research progress on coherent DSP algorithms.

2. Implication of advanced physical layer monitoring and enhanced impairment tolerances

The core non-trivial issue in the optimal margin allocation is to identify how much is the real "excess" margin that can be eliminated while maintaining "essential" margin to maintain required availability and reliability of the network. Monitored QoT for each path in actual operation is free from piece-to-piece variation of relevant optical devices indeed and thus helps to eliminate some part of the "excess" margin. However, the main difficulty resides in potential temporal variation of QoT arising from various mechanisms that are not limited but at least polarization changes, reconfiguration of optical wavelength paths (i.e. channel addition, deletion, or switching), optical frequency drift of lasers in optical transmitters, polarization mode dispersion, polarization dependent loss (PDL), optical power deviation, and nonlinear distortions (Fig. 1). Under the impact of the above-mentioned effects, the QoT monitored at a certain point of time during its operation is neither the best, average, nor the worst for the wavelength path over its lifetime. As it is depicted in Fig. 2, temporal variation of QoT can exhibit at least four types of changes: (1) changes due to the ageing of components that are typically gradual in the order of months or years toward the end-of-life of the system, (2) changes arising from varying ambient temperature or manual operation on fibers that are typically in the order of seconds to minutes, (3) changes induced by planned or

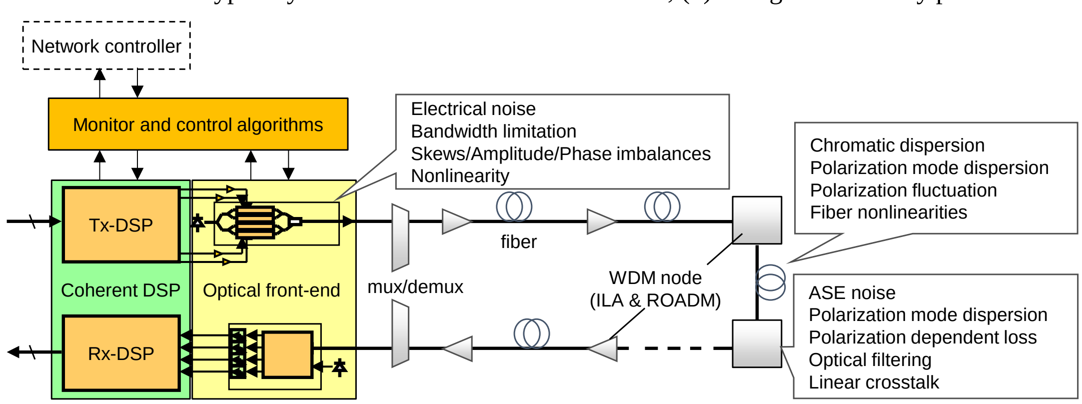

Fig. 1. Various sources of signal impairments of a wavelength path

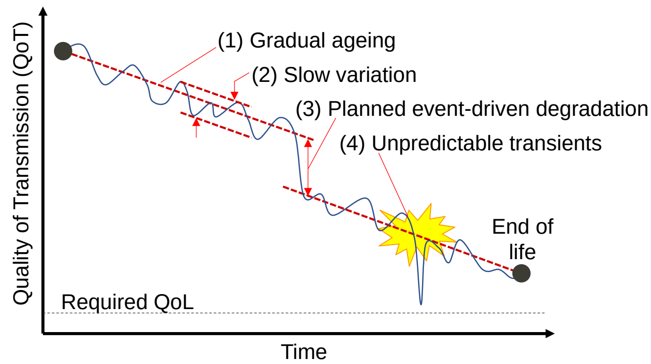

Fig. 2. Schematic image of temporally varying QoT of an optical path over its lifetime.

predictable events such as addition, deletion or switching of wavelength paths or manipulation on fiber plants, and (4) Unpredictable sudden changes such as the ones induced by lightning, mechanical vibration, cuts or mis-operation that can accompany with subsequent polarization and/or power transients in the order of less than a second. All the above need to be considered to guarantee the error-free signal reachability by assuming the worst case under the presence of the above (1) through (4). In this context, the importance of coherent DSP in the transceiver is evident in the monitoring and mitigation of impairments. It is because coherent DSP allows full access to the optical field information and thus has the maximum potential as physical layer monitoring and predicting the QoT of the wavelength path as well as counteracting it. With more advanced monitoring it should be possible to partially identify the sources of impairments and thus to eliminate some part of the system margin allocated for (1), (2) and/or (3) more aggressively. The system margin associated with (4), on the other hand, can be minimized when the transceivers have maximum tolerance to such transients. It should be noted that the importance of monitoring and mitigation should be crucial in operating open and/or disaggregated optical networks where multi-vendor equipment is contributing to the risk on QoT in an less-organized manner than it will be in a single-vendor situation.

3. DSP algorithms for combatting less-predictable impairments

In order to maintain a certain level of QoT with a sufficient availability ratio even under the impact of unpredictable impairments (associated with (4) in the above), transceivers should have a good tolerance to them. One of the most challenging phenomena to deal with is polarization dependent loss (PDL). PDL resides in optical components in transceivers and in ROADM nodes that are concatenated by the transmission fiber where the coupling of PDL axes are random and time varying, which can generate unpredictable time varying impairment. There are two strategies to

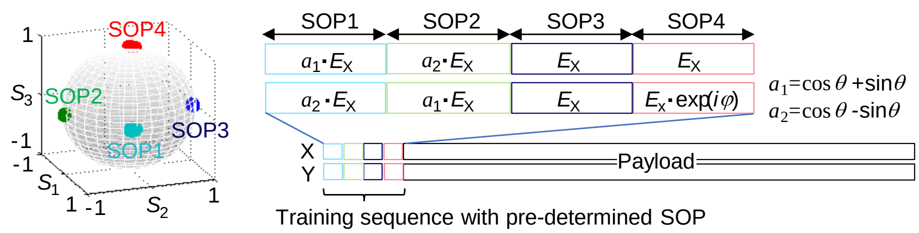

Fig. 3. Proposed structure of the training sequence for Müller matrix method of PDL estimation

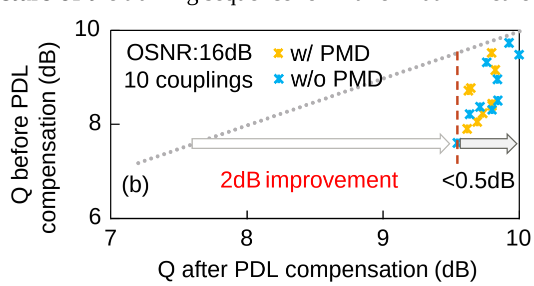

Fig. 4. Experimental verification results for PDL pre-compensation in an transmission through a PDL emulator consisting of 7 PDL emulators (each having a PDL of 1 dB) concatenated by random polarization couplings. Results with and without PMD (realized by 3.8 ps differential group delay element each inserted after each PDL emulator.)

combat with PDL by means of transceiver DSP: employing a specifically designed dual-polarization coding scheme such as space-time code [5, 6], and compensation of PDL based on the monitoring of PDL monitoring at the receiver [7]. In the following, an inverse matrix method based on Müller matrix monitor is introduced as an example for the latter approach. By sending a training sequence that exhibits pre-determined four distinct sates of polarizations (SOPs) (Fig. 3), the end-to-end PDL vector of the link can be estimated by the Müller matrix method. Once identified it is possible to cancel-out the PDL within the transmitter DSP. Such approach has been experimentally demonstrated for 32 Gbaud DP-QPSK transmission verified successful suppression of PDL-induced impairment even under the co-existence of polarization mode dispersion (PMD) as shown in Fig. 4.

4. Advanced DSP algorithms for visualizing the optical path characteristics

Although conventional monitoring techniques based on coherent DSP are already powerful to some extent, they can only estimate end-to-end cumulative quantities over the path. In order to better help the network operator even in multi-vendor situation by identifying which kind of physical layer anomalies are generated where, we have proposed a receiver DSP algorithm to estimate the longitudinal profile of such physical parameters in a distance-resolved manner with the help of Kerr nonlinearity inherent to the optical fiber propagation [7] (Fig. 4). Initial experiment for a 506 Gbit/s DP-16QAM signal transmission over a 5-span showed a positive sign by successful visualization of the number, locations, and fiber launch powers of in-line amplifiers and the location of an excess lump loss (Fig. 5).

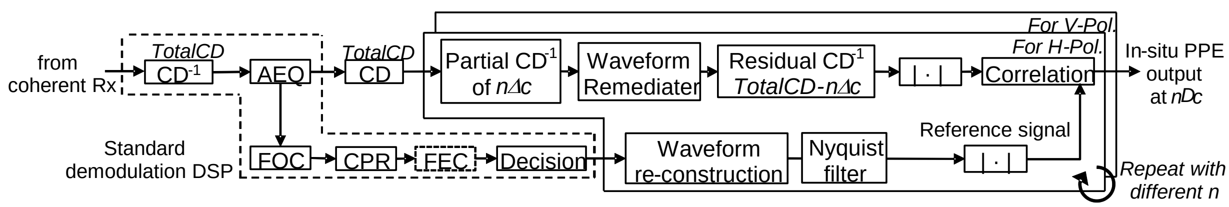

Fig. 4. Functional block diagram of receiver DSP for in-situ power profile visualization

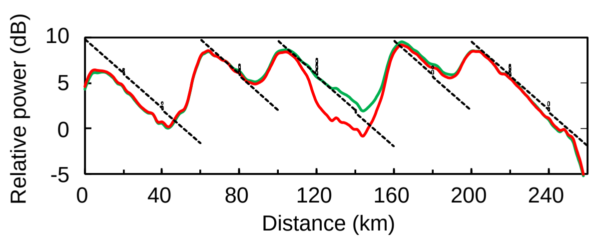

Fig. 5. Experimental verification of the proposed in-situ power profile monitoring (red and green curves). Locations of 4 repeaters (at 60, 100, 160, and 200 km) and lumped loss (at 120km, red curve only) are identified. Fiber attenuation coefficient also showed reasonable agreement with separate measurement by OTDR (dotted line).

4. Summary

Allowing the full access to the optical field data of the optical signal, the coherent transceiver has a good potential for monitoring and mitigating physical layer impairments for optical wavelength path. Examples of such research efforts have been introduced, showing a good sign of their feasibility in reducing CAPEX and OPEX of the optical networks, in particular the open or disaggregated ones, by innovative DSP algorithms.

Acknowledgement

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