Network Innovations Brought by Digital Coherent Receivers

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Abstract: Operational efficiency improvements of optical networks enabled by digital coherent receivers are discussed in view of reliability, agility, performance and reduced operational complexity. Several specific technologies are briefly introduced to deliver some more insight.

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1. Introduction

Having full access to the optical field information of the received signal, digital coherent receivers provide extensive merit to photonic networks. It includes enhanced OSNR tolerance, better compatibility with advanced modulation formats, and enhanced electronic equalization of linear and nonlinear effects in the transmission link. All these aspects are not only beneficial for extending the transmission reach of high bit-rate signals but also attractive in the sense to realize additional functionality that delivers higher operational efficiency of optical networks.

2. Basic configuration of digital coherent receiver and its implication to the optical network operation

Fig. 1 shows an exemplified functional block diagram of a typical digital coherent receiver. The digital signal processing can include different functional blocks that address various types of signal distortion or imperfections. Most of those blocks adaptively realize digital filters that approximate the inverse of the corresponding distortion functions. As a result, it is not only possible for digital coherent receivers to undo the distortion but also to estimate the optical parameters relevant to such distortions based on the digital filter coefficients. Examples of such optical parameters are also summarized in Fig. 1.

Such parameter estimation capabilities would lead to several interesting enhancement to the optical network functions (Fig.2). The first function is obviously the monitoring: some of the optical parameters, e.g. chromatic dispersion [3,4], laser frequency offset [5,6], and bit error ratio, can be estimated with a sufficient accuracy and/or speed so that the network control can rely on it. Estimates of the other parameters such as PMD [3], nonlinear impacts [2,8], would be useful for the second function of path diagnosis: It would be possible to identify or predict possible sources of possible anomaly observed in link characteristics by comparing it with the link design.

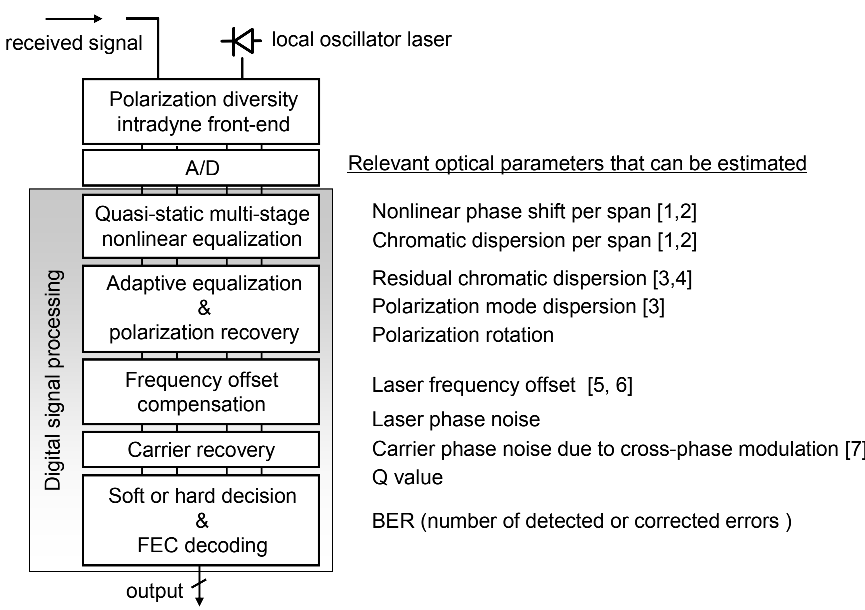

Fig. 1 Block diagram of an exemplified digital coherent receiver and relevant optical parameters that can be estimated by the digital signal processing. LO: local oscillator., FEC: forward error correction.

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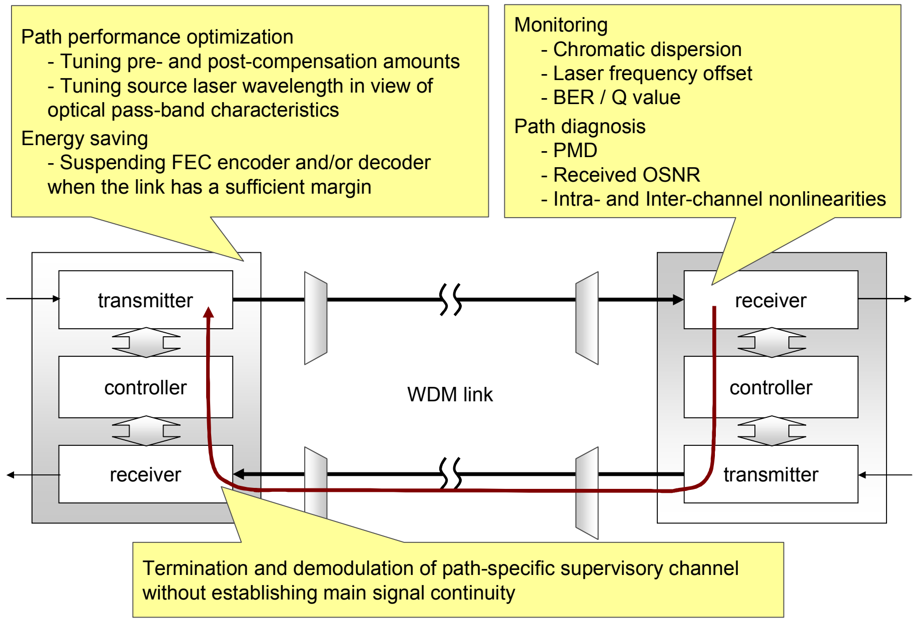

Fig. 2 Network functions that can be enabled or improved by digital coherent transceivers

The third function is to provide path-specific supervisory channels between the transceiver pair even without establishing the main signal continuity by employing a novel technique explained in the latter part of this paper. This technique can be used for optimizing joint start-up sequences between the transceivers in far ends as well as enabling the rest of the fourth and the fifth applications. The fourth is the path performance optimization by jointly tuning the parameters between the transceivers, e.g. the amount of pre- and post-compensations, and source laser wavelength in order to minimize the impact of optical pass-band characteristics of the WDM link. Last but not least, the fifth function is relevant to the energy saving. When the estimate of a path performance such as bit error ratio implies that there is sufficient amount of margin, it should be possible to suspend a part of or the entire FEC circuitry that are major contributors to the power consumption of transceivers.
All of the above five functions are considered to improve the efficiency of the network operation from viewpoints of reliability, agility, performance, and operational complexity and thus is important improvement to optical networks. In the following, three topics from the above are introduced with some more details.

3. Accurate monitoring of residual chromatic dispersion

Residual chromatic dispersion estimation from the filter coefficients of adaptive equalizer was proposed in [3]. An improved algorithm was proposed in [4] to enhance the robustness of estimation where a simple 2nd-order differentiation is used in place of phase unwrapping and quadratic fitting that are prone to complexity and error.
Fig. 3 shows the experimental results with the 112Gb/s DP-NRZ-QPSK signal where wide estimation range of ±400 ps/nm were achieved with excellent linearity even with optical noise (18 dB OSNR with 0.1 nm ASE bandwidth), polarization dependent loss (3dB), and differential group delay (18 ps). It is also important that the zero-crossing of

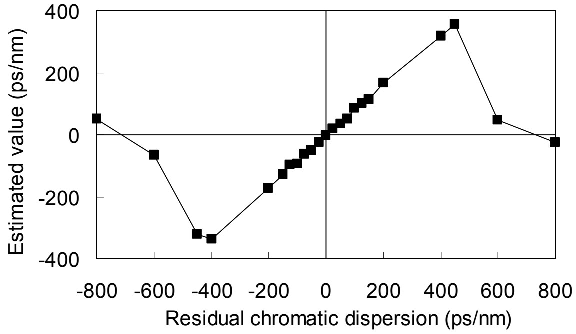

Fig. 3 Monitoring performance of residual chromatic dispersion equalized in a butterfly FIR adaptive filter under ASE noise (OSNR=18 dB), PDL (3dB) and PMD (18 ps, 1st order)

the estimation curve is very accurate, which is important in realizing a feed-back control loop of dispersion compensation value of preceding compensators.

4. Estimation of link conditions by multi-stage nonlinear compensator and XPM phase monitor

Multi-stage nonlinear compensator is attractive for improving the reach by counteracting the intra-channel nonlinear effects in an alternating row of linear and nonlinear equalizers [1]. The feasibility of semi-blind adaptation using limited prior knowledge on the link is demonstrated in [2]. Fig. 4 shows an interesting simulation result of the blind equalization of a 10-span link consisting of 8 SSMF and 2 NZ-DSF spans having equal fiber input powers, by a 20-stage nonlinear compensator. It should be noted that the equalization parameter for nonlinear phase shift showed clear peaks at the 6th and 16th stages. This perfect accordance with the link configuration was achieved without any initial input on the fiber types, and thus indicating a sign that this can be useful in diagnosis of link condition.
Another interesting tool for the link diagnostic can be the cross-phase modulation (XPM) monitor proposed in [7]. Since XPM is one of the most serious impairment sources and is dependent on various link conditions, it is believed to be worth checking when the path performance shows large discrepancy from its design.

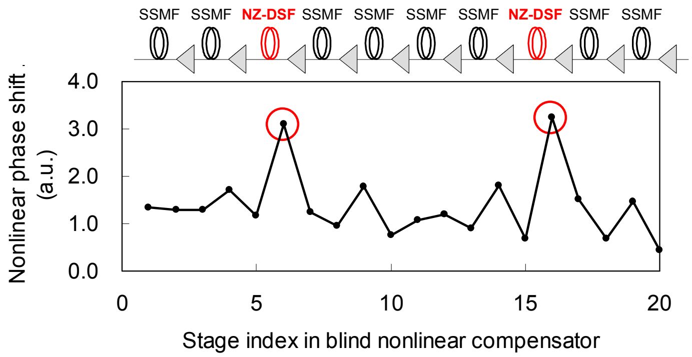

Fig. 3. Correlation between link condition and blind nonlinear compensation parameters.
Top: Link configuration having 10 spans, Bottom: corresponding nonlinear phase shift estimated by the NLC.

5. Termination and demodulation of non-AM pilot tone in frequency offset compensator

As a means to realize path-specific supervisory channel that can be established before signal continuity, we propose to use a non-AM pilot tone superimposed to the main signal. Being different from the AM pilot tone that is prone to cross-talk due to EDFA response and stimulated Raman scattering [8], much less crosstalk and smaller impact to the main signal can be expected. As an example, schematic diagram of FM pilot tone termination and demodulation by a frequency offset compensator is shown in Fig. 5. Assuming a response speed of the compensator to be in the order of 100 kHz or beyond, the supervisory channel can have a bandwidth around 10kHz that seems to be acceptable for many applications depicted in Fig. 2.

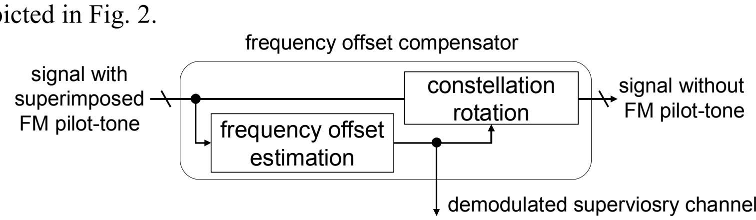

Fig. 5 (a) Termination and demodulation of frequency modulated (FM) overhead by frequency offset compensation circuit

5. Summary

Optical parameter estimation enabled by digital coherent receiver can improve the efficiency of the network operation from viewpoints of reliability, agility, performance, and operational complexity and thus is important improvement to optical networks. Three topics are introduced and discussed to some details as examples.

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