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Optical Performance Monitoring through signal processing in current and future optical communication systems

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Abstract: We review the current status of Optical Performance Monitoring(OPM) in deployed optical networks and discuss on emerging OPM trends and challenges brought about by the migration towards coherent communications with digital coherent receivers.

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1. Introduction

Optical Performance Monitoring (OPM) refers to the direct/indirect estimation of signal transmission quality across an optical network through the estimation of transmission impairments such as chromatic dispersion (CD), polarization-mode dispersion (PMD), optical signal-to-noise ratio (OSNR), fiber nonlinearity among others. Traditionally, OPM is needed to track the variation of the transmission impairments and detect and/or locate faults to ensure robust network operation. However, with coherent systems, advanced modulation formats, digital signal processing (DSP) and dynamic impairment-aware lightpath provisioning, OPM is empowered with new hardware capabilities such as digital coherent receivers but also face new technical as well as cost challenges.

In this paper, we will describe the current deployment status and industry needs for OPM and discuss emerging OPM trends and challenges brought about by digital coherent communications and dynamic optical networks.

2. Current OPM Market and Industry Needs as of 2012

Despite the rapid development and commercialization of polarization multiplexed coherent systems it is salient to note that today's long haul networks are still overwhelmingly dominated by 10-Gb/s OOK systems. Fault diagnosis on live traffic channels poses a challenging problem for network operators as current in-line optical monitors have limited functionality; often providing only power and wavelength measurements. Non-intrusive monitoring on live traffic is desirable as traffic diversion in order to measure impairments on dark fiber is costly and time consuming.

OSNR monitoring is required during channel setup. For both 10-Gb/s and 40-Gb/s channels that have passed through reconfigurable optical add drops (ROADM's) traditional out of band methods will be inaccurate. To the best of our knowledge there is no commercially available embedded OSNR solution. Techniques based on polarization nulling [1] for example, are not future proof against polarization multiplexed systems. Other challenges for OSNR techniques are the ability to distinguish multi-path interference noise and the accurate measurement of high OSNRs (25 dB) when tap powers are less than -20 dBm. ASE beat noise at these levels is approaches shot noise limits.

For fault diagnosis in the field it is convenient to have a single instrument that can measure CD, PMD and OSNR simultaneously. For this purpose, techniques based on waveform distortion as measured by histograms, eye diagrams or tap delay plots have been proposed [2,3] based on statistical signal processing or pattern recognition techniques. Results of a recent field trial using delay-tap sampling and pattern recognition [4] reveals the cause of high pre-FEC BER in 140 km 10-Gbs links was high chromatic dispersion (1200 ps/nm) due to the installation of an incorrect dispersion compensation module. Variations in rise time and extinction ratio due to finite transponder manufacturing tolerances severely limit the accuracy of techniques based upon waveform distortion. These variations are further magnified if high bandwidth receivers are used in an attempt to increase the sensitivity.

In addition to fault diagnosis, monitoring of fiber PMD is required to determine if fibers carrying 10-Gb/s channels can be upgraded to 40-Gb/s. Achieving required accuracy is challenging (< 3 ps) since 10G channels are relatively robust to PMD. For mean fibre PMD measurements, averaging over statistically independent samples is required. These samples can be taken from measurements over multiple wavelengths and time. The random alignment of the signal and Principal polarization states means that instantaneous measurements are of an effective differential group delay, DGD_{eff} which follows a Rayleigh distribution. Long measurement times are required as correlation times (time between independent samples) can be several hours [5].

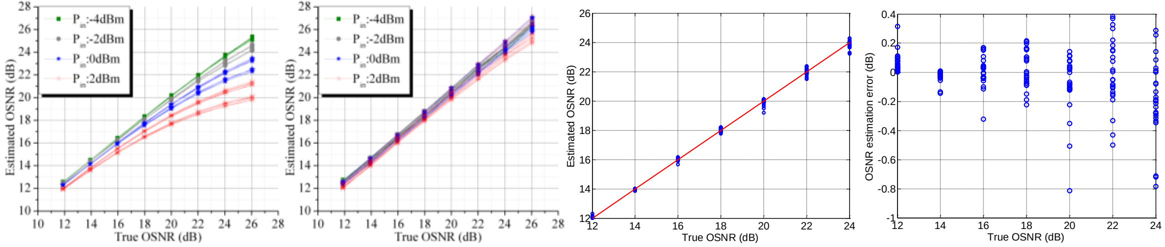
3. Emerging OPM capabilities and challenges for digital coherent systems

With a coherent front-end combined with high-speed ADC, a digital representation of the optical field has become available and this opens up the way to employ channel acquisition techniques from classical communications. As the digital filter properties can be approximated by the inverse channel transfer function, efficient monitoring of multiple combined channel parameters can be performed over a wide range. Filter acquisition can be achieved by non-data aided (NDA) methods like decision-directed (DD) lest mean square (LMS) or the constant modulus algorithm (CMA) employing only the received data sequence itself. The resulting minimum mean square error (MMSE) filter solution jointly minimizes the impact of ISI and noise. Therefore, all kind of noisy distortions influence the estimated filter transfer function. In contrast, data-aided (DA) channel estimation using a known training sequence also enables maximum likelihood (ML) channel estimation. Inverting the channel transfer function, or zero-forcing (ZF) solution, might be inferior for equalization in bandwidth limited transmission due to noise enhancement of attenuated components but allows monitoring the channel more accurately [7].

Next to filter-based channel acquisition, where the degree of freedom is defined by the number of filter taps, filter banks can be applied, which perform an optimum-match search. Filter banks typically have a low degree of freedom but they provide robust estimation over a wide range, e.g. CD estimation in uncompensated links [8]. Finally, signal correlation properties can be evaluated for dedicated monitoring of single parameters as demonstrated in [9].

Various methods for single-carrier and multi-carrier transmission have been demonstrated systematically separating each parameter from the obtained filter transfer function and providing a true multi-impairment monitoring [6][10]. The feasibility of filter based-monitoring has been demonstrated in commercial products already [11]. In contrast to those NDA methods, DA channel estimation proved superior estimation of polarization-dependent loss (PDL) and OSNR [7] and provides immediate channel estimation with rapid channel acquisition suitable for frequently switched light-paths and burst-mode operation. As adaptive equalization is designed to track time-varying channel impairments, dynamic real-time monitoring can be achieved.

As linear equalization only allows robust and accurate estimation of linear impairments, reliable and practical approaches to estimate nonlinearities like SPM or XPM are a remaining challenge. Furthermore, it is an unsolved challenge to perform systematic separation of noise-like distortions resulting from nonlinearities, channel crosstalk, ASE noise and PDL and they are vital for fault identification and localization. To separate ASE noise from nonlinear distortions in digital coherent receivers, one can examine the nonlinearity-induced noise correlation among symbols to 'take out' the right amount of distortions and obtain nonlinearity-insensitive OSNR monitoring. Fig. 1 (a) and (b) illustrates the improvements of OSNR estimation when such noise correlation is taken into consideration. On another note, OSNR monitoring for coherent systems at intermediate nodes poses a new challenge as there will be huge uncompensated CD and cheap equipments are needed as monitoring units at intermediate nodes. Fig. 1 (c) and (d) denotes the OSNR monitoring results for a CD range of 0 to 27000 ps/nm using machine learning techniques with the signal RF spectrum as input to the algorithm.



(a) (b) (c) (d)

Fig. 1. Estimated OSNR vs true OSNR after 1200 km transmission for 112Gb/s PM-QPSK systems (a) without (b) with inclusion of nonlinearity-induced noise correlation effects for different signal power levels. (c) Estimated OSNR vs true OSNR and (d) corresponding estimation errors in presence of 0-27000 ps/nm of CD using signal RF spectrum as input to a machine learning-based OSNR monitoring technique.

4. Conclusions

Optical Performance Monitoring are important add-ons in current deployed networks and future optical networks with coherent detection and dynamic lightpath provisioning. Future research will further leverage coherent detection and/or various signal processing techniques to fully realize the benefits brought about by OPM to optical networks.

5. References

[1] J. H. Lee et al., IEEE Photon. Technol. Lett., 13, pp. 88-90, 2001.
[2] F. N. Khan et al, Paper 6B4_5, OECC 2011
[3] T. B. Anderson, et al., JLT, vol. 27, pp. 3729-3736, 2009.
[4] T. Morgan et. al, Paper NTu2E.4,OFC/NFOEC 2012.
[5] T. Xia et al, Paper NTu2E.5, OFC/NFOEC, 2012.
[6] F. N. Hauske, et al., JLT, vol. **27**,pp. 3623-3630, 2009.
[7] F. Pittalà, et al, paper OW4G.2, OFC 2012.
[8] R. A. Soriano, et al., JLT vol. 29, pp. 1627-1637, 2011.
[9] Q. Sui et al., Paper OW4G.3, OFC 2012
[10] X. Yi, et al., paper OThW3, OFC 2008
[11] S. L. Woodward, IEEE PTL. **22**, 706-708 (2010).