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Polarization-based Monitoring in WDM Systems
(Invited paper)

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Abstract *Optical performance monitoring in WDM networks and polarization-based methods are discussed. In particular, the feasibility of a polarization modulation based monitoring scheme is addressed and demonstrated in an 820 km installed transmission link.*

Introduction to optical monitoring

The functionality of optical wavelength division multiplexing (WDM) networks is governed by routers and switches, combining optical point-to-points links to obtain different communication paths. So far, these connections are established by high-speed electronic switches/routers in combination with optical-to-electrical-to-optical conversions. This means that all optical paths are well defined and can be designed with a fail-safe margin. Consequently, the possible dynamic events or system break-downs are limited to a few events, *e.g.* add/drop of wavelength channel, fiber cut, transmitter or optical amplifier break-down. This is also reflected by the optical monitoring topology found in today's optical networks, which basically is restricted to ensure correct channel wavelengths and power levels in transmitters and receivers. The channel power measurements require tunable optical filters followed by a single photo detector or arrayed-waveguide gratings (AWG) in combination with several photo detectors.

The situation will change dramatically as the optical networks develop towards optically reconfigurable networks to increase capacity. The networks will then comprise dynamic optical cross-connects, optical add-drop multiplexers, wavelength converters, optical regenerators, compensators etc. In these systems any optical path can be set-up at any time, with the consequence of dynamically changed optical properties of the network paths. As a result, it is no longer sufficient to measure wavelength and power to ensure network functionality and quality. Here, more advanced optical monitoring is required, such as monitoring of optical signal-to-noise ratio (OSNR), dispersion, polarization-mode dispersion (PMD), polarization dependent loss (PDL), and Q-factor [1]. Among these, OSNR and PMD are of particular interest; OSNR because it is closely related to bit-error rate, and PMD due to its time-varying nature. To achieve complete control of the network performance and of every component of an optical network, monitoring should ideally be conducted at every available point of the network, *i.e.* at each transmitter, amplifier, router, etc., see Fig. 1. In practice, the number of monitors becomes limited by the complexity (price) of the monitors (usually related to the monitoring capability.) The monitors are then placed at strategic positions in the network, *i.e.* around routers and at the end of transmission paths. However, this limits the ability to localize the cause of any system malfunction.

Polarization-based monitoring

Many different techniques to conduct performance monitoring have been proposed over the last years including utilization of the polarization properties of the light. Since the polarization properties are bound to each WDM channel, the polarization properties provides channel-individual information independently of how the channels are routed or added/dropped through the network. Most polarization-based monitoring methods are similar to regular power monitoring in a sense that it requires tunable filters or AWGs. However, the polarization information can offer additional information, *e.g.* the ability to determine the channel OSNR through polarization-nulling [2, 3] or from the degree of polarization [4]. The polarization-based OSNR measurements rely on the property that the amplified spontaneous emission (ASE) noise of optical amplifiers is unpolarized, in opposite to the coherent optical signal. Hence, the in-band ASE noise can be determined by blocking the signal by means of a polarizer. The polarizer is then realigned to the orthogonal state of polarization to pass the optical signal to through the polarizer. The two power measures provide the in-band OSNR of the WDM channel. The technique relaxes the requirements on the optical filters compared to conventional OSNR measurement methods. The method can be implemented with one AWG in combination with N sets of polarization-based OSNR measurement devices (N equal to the number of WDM channels), or by one tunable optical filter and a single OSNR measurement device.

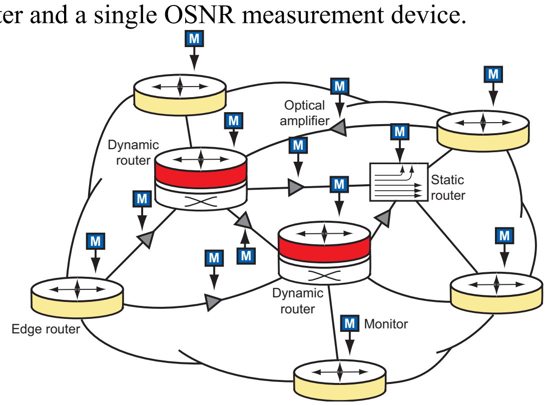

Fig. 1. A schematic optical network illustrating the large number of relevant monitor points.

However, in presence of PMD [5], PDL [6] or by nonlinear effects [7], the accuracy of the OSNR measure may be deteriorated. Consequently, various methods have been developed to mitigate or compensate their influence, usually by additional optical filtering [8-12]. This can at the same time provide an estimate of the system PMD. To obtain the complete polarization properties of the system the Stokes parameters must be measured spectrally with high resolution [4, 10, 13].

Polarization modulation monitoring

A monitoring system that obtains the Stokes components over the C-band with high resolution is possible, but would be rather costly (complete spectrally resolved polarimeter at each monitor.) By introducing a polarization modulation of the channel state of polarization (SOP) at each channel transmitter before transmission, the polarization modulation can be used throughout the system at an arbitrary number of monitoring nodes (see Fig. 2) to achieve monitoring of channel power (modulus of Stokes vector) as well as polarization properties of the system [14]. The spectral resolution becomes limited to the channel spacing of the system, but on the other hand no optical filter is required and each monitor only requires a polarizing detector. Thus, the monitors are inherently low-cost and can be placed in a large number throughout the network. The polarization modulation causes not any restriction; in fact in presence of PMD a well-designed polarization modulation can improve the performance of forward error correction algorithms [15].

The monitoring system is characterized by a calibration node directly after multiplexing of the WDM channels, shown in Fig. 2. The calibration can run continuously and adapt the system to changes in the polarization modulation. This way the polarization modulation can be implemented without the use of polarization-maintaining equipment. The calibration defines the initial channel Stokes vectors, the virtual SOP, to be constant and aligned directly after the multiplexer. This property can be used to detect PMD in the system, since PMD influences the transfer functions differently for different wavelength channels. Thus the monitored virtual SOPs are misaligned in proportion of the amount of PMD and

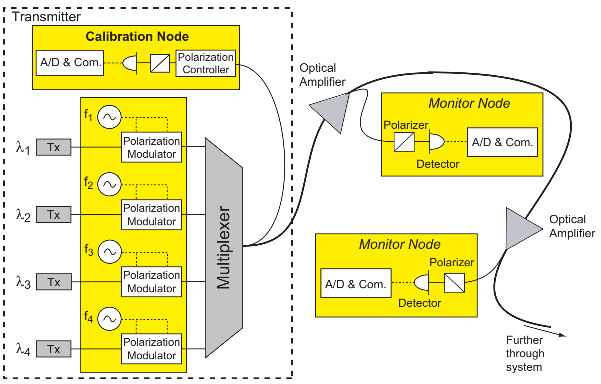

Fig. 2. Illustration of the polarization modulation based monitoring system.

the channel wavelength separation. Consequently, if the channel wavelengths are known, the birefringence can be determined (or vice versa). Further, channel power monitoring before and after optical amplifiers provides information about the individual channel gain of the amplifiers.

A feasibility study of the monitoring system was realized in an 820 km field transmission link consisted of 12 dispersion compensated amplifier spans. Five WDM channels on a 100 GHz ITU grid were monitored, one 40 Gbit/s carrier-suppressed return-to-zero (CS-RZ) modulated channel and four 2.5 Gbit/s non-return to zero (NRZ) channels. The link was monitored at nine different distances via a built-in monitoring tap of the optical amplifier modules. The Stokes vectors of each wavelength channel were obtained at all nodes and subsequently power, virtual SOP (shown in Fig. 3), and first-order PMD were computed. In addition, channel wavelengths were monitored at the transmitter and OSNR was estimated based on the channel powers and assumed amplifier noise figure [16].

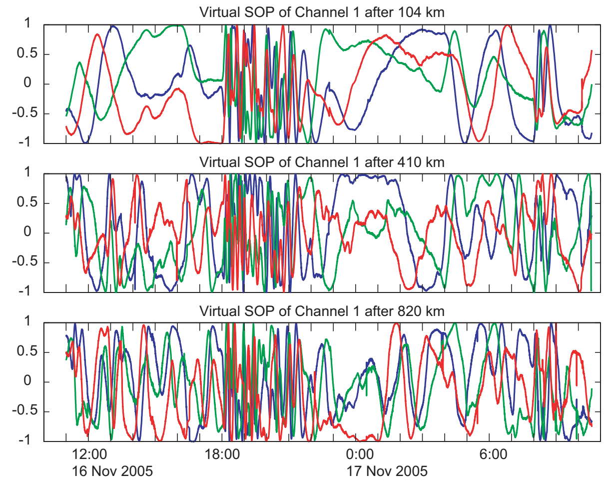

Fig. 3. The Stokes parameters of one channel measured at three different transmission distances during 24 hours.

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