Advanced Optical Performance Monitoring for Next Generation Access Networks

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Abstract

Optical performance monitoring is crucial to monitor the network status and signal quality. In this paper, we discuss the requirements and various techniques of network and signal monitoring in next generation optical access networks.

I. Introduction

In next generation optical access networks, the traffics are data centric and thus require high quality of system and service provisioning. This implies high network availability, high data capacity, long system reach, and flexible network reconfiguration. To assure the quality of the access networks, optical performance monitoring (OPM) [1] is an indispensable element in network management. In addition of nominal control of network elements and link setup, OPM supports fault forecasting, detection, diagnosis, localization, as well as resilience mechanism activation. The monitoring information can also be used to enable optimal compensation of various optical impairments, thus assures good signal quality in data delivery. OPM may include monitoring of different analog or digital parameters of the transmission system, including signal wavelength, power level, optical signal-to-noise ratio (OSNR), bit-error-rate (BER), Q-factor, chromatic dispersion (CD), polarization mode dispersion (PMD), and the status of in-line components and fiber links. In this paper, the respective state-of-the-art OPM techniques for different key aspects of network and signal monitoring in an optical access network will be discussed.

II. OPM techniques for access networks

In next generation optical access networks, in addition to simple monitoring of optical signal power level and signal wavelength value, it is also important to monitor the status of the fiber links and locate the faulty fiber link for signal re-routing, via protection switching. Moreover, various signal quality parameters, including OSNR, and accumulated CD or PMD are highly desirable to be extracted for performance analysis and enables optimum compensation of the respective optical impairments.

A. Fiber Link Monitoring

In order to assure network availability, physical layer monitoring techniques, especially detection and localization of equipment failure and fiber faults, are indispensable [2]. Traditionally, Optical Time Domain Reflectometry (OTDR) is used to remotely monitor the status of the point-to-point fiber links. However, identification of the faulty fiber branch in a point-to-multipoint access network is a great challenge, as the backscattered lights from different branches add together at the central office. One simple solution was to integrate the OTDR function at the optical network unit (ONU), where the embedded OTDR measured the back-reflected and backscattered echoes caused by the upstream light [3]. However, such distributed control and status reporting incurred high complexity in network management. In [4], a multi-wavelength OTDR was used to characterize the individual fiber branches separately, but the wavelength-tunable OTDR and the other wavelength-specific components at the ONUs induced high system costs. In [5], an alternative was to introduce a reference reflection at the end of each fiber branch so as to detect the presence and the height variation of the reference reflection peaks. However, it required distinct fiber length on each branch. In [6], a switchable reflective element (SRE) was placed at each ONU. However, it required dynamic control of all the SREs at the ONU side and extra components have to be installed at each ONU. Recently, a scheme based on OTDR trace correlation analysis was reported [7]. The correlations of the measured OTDR trace and a set of hypothesized OTDR traces, which are synthesized by the pre-measured reference traces, were computed. Hence, the faulty fiber branch was easily identified by selecting the hypothesized OTDR trace with the highest correlation value with the measured OTDR trace at the central office.

B. Optical Signal-to-Noise Ratio (OSNR) Monitoring

The traditional out-of-band OSNR monitoring technique involves measuring and interpolating the noise power from adjacent channels using optical spectrum analyzer (OSA), arrayed waveguide grating (AWG) or tunable filters [8]. However, it may under-estimate the amount of noise falling into the signal spectra. Therefore, a number of in-band OSNR monitoring techniques have been reported. In [9], each wavelength signal was associated with a sub-carrier. The electrical carrier-to-noise ratio (CNR) of the sub-carrier was determined and the OSNR was then derived. However, the addition of the subcarrier might degrade the original signal. In [10], polarization nulling technique was reported to measure either total power or noise power. However, it suffered from large errors in networks under influence of strong PMD and polarization dependent loss. To solve this problem, off-center narrow-band optical filtering [11] and transmitter-side polarization scrambling [12] were proposed to enhance the PMD robustness. In [13], a phase modulator embedded fiber loop mirror (PM-FLM) was proposed to periodically separate the data signal and the noise to facilitate OSNR monitoring. This approach achieved over 40-dB dynamic range and was robust to PMD and partially polarized noise.

C. Chromatic Dispersion (CD) Monitoring

In order to adaptively compensate chromatic dispersion so that the induced signal degradation can be minimized, chromatic dispersion monitoring is required to provide feedback control. In [9], RF tones were added to the data to modulate light at the transmitter side. CD can be monitored by measuring the power variation of different sub-carriers, due to fading under dispersion, at the receiver. In [14], CD was monitored by measuring the regenerated clock component in non-return-to-zero (NRZ) systems and the faded clock component in return-to-zero (RZ) systems under dispersion. The main advantage was that no modification was needed at the transmitter side. In [15], CD monitoring was realized by comparing the arrival times between the upper and the lower sidebands of the optical signal. It offered high sensitivity, but optical sideband filtering and high-speed electronics were needed. In [16], a birefringent fiber loop was adopted to derive the CD value based on the measured RF power at a specific chosen frequency. This technique required no modification at the transmitter, and provided large monitoring range.

III. SUMMARY

Various optical performance monitoring schemes for network and signal monitoring in optical access networks have been reviewed. With the evolution of the high-speed optical fiber transmission technology, different advanced optical modulation formats, including multi-level modulation and optical orthogonal frequency division multiplexing (OFDM) format, may also be adopted to support high-speed optical signal transmission in the next generation optical access networks. More specific techniques would be required to extract the signal quality parameters. Recent advent of high-speed optical coherent receivers has also created a feasible option for OPM and even the signal impairment compensation by means of electronic digital signal processing techniques [17-20]. However, the high cost of the high-speed optical coherent receivers is still a critical issue for them to be employed in optical access networks, which are usually cost-sensitive. In general, the major considerations of practical OPM schemes include low-cost, low complexity, high accuracy, wide dynamic range, and good robustness under the presence of other optical impairments.

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