Advance Performance Monitoring Techniques for Future Photonic Network

Koushik Barman$^1$, Sankit R Kassa$^2$ and Deman Kosale$^3$

$^1$E&CE Department, NIT, Hamirpur
$^2$EE Department, NIT, Hamirpur
$^3$EE Department, NIT, Hamirpur

1ica.koushik@gmail.com, 2Kassasankit007@yahoo.co.in and 3Rajive.verma25@gmail.com

ABSTRACT
Performance monitoring is an important part of any optical network. Today’s photonic networks function in a fairly static fashion and are built to operate within well-defined specifications. But the forthcoming network will be dynamic, transparent and all optical type in nature. Due to the rapid growth of dense wavelength division multiplexing (DWDM) technology during the last decade, the capacity of fiber optic network has increased to well beyond 10 Tb/s. Because of such enormous amount of data traffic carried by each fiber, even a brief disruption of service could cause serious problems in every sector of society. Thus the goal of OPM is to prevent any network failures. In this paper we review different optical performance monitoring techniques developed to date. BER and Q factor monitoring using asynchronous Sampling, Chromatic dispersion monitoring using pilot tone and broadband light source have been reported. Simultaneous monitoring of chromatic dispersion (CD), polarization mode dispersion (PMD) and integration of different monitoring techniques has been proposed.

KEYWORDS
Amplitude modulation (AM), optical performance monitoring (OPM), chromatic dispersion (CD), broadband light source (BLS), polarization mode dispersion (PMD), pilot tone, reflected semiconductor optical amplifier (RSOA).

1. INTRODUCTION
Optical Networking sector is experiencing phenomenal growth and today’s optical systems are under pressure to offer higher data rates to enable rich content delivery to ever increasing number of subscribers. The capacity of optical network is increasing at a rate of 60% per year [11]. As the number of channel and bit rate per channel increases, fiber impairments like CD, PMD and nonlinearities threatens to close the window of operability. Further high spectral width, narrow channel spacing, high bit rate and transparent switching definitely create obstacles for next generation photonic network. Remarkable progress of Radio over Fiber in heterogeneous network platform causes increase of densely wavelength division multiplexing (DWDM) channels. This is a direct threat to keep maximum network availability and reduce down time for upcoming high capacity dynamic photonic network because variable Quality of service, different modulation format, subcarrier multiplexing, circuit plus packet switching etc. will definitely create difficulties for it. OPM has a crucial role to overcome these obstacles. OPM will be playing an increasingly important role in managing the heterogeneous networks. One of the major operational areas that carriers probably need to deal with is very quickly identifying a fault that has occurred, where it occurred, and what caused it. When considering impairments due to chromatic dispersion in dynamic networks, each channel will traverse a unique path through the network thus the channels arriving at the monitoring point will, in general, exhibit different amounts of residual dispersion. Therefore, in a dynamic network it is necessary to monitor all channels individually to quantify the degradation. Fig. 2 shows the advance features of future heterogeneous network.

As networks move to all-optical technologies, identifying these faults will become more difficult. This is because many of the faults are caused by optical impairments. OPM will be an essential tool to identify these soft faults and will play an important role in reducing the operation costs for the future optical networks. Fig. 3 illustrates a future self-managed network with OPMs integrated.

In all optical dynamic DWDM network, each channel can be exposed to a different amount of chromatic dispersion whenever the network is reconfigured[14]. Therefore, in a dynamic network it is necessary to monitor all channels individually to quantify the degradation, without the requirement of knowing the data path history. Also PMD

Fig. 1: Evolution of photonic network & capacity improvement.
effects are stochastic, temperature dependent, time varying, and worsen with higher bit-rates. Chromatic dispersion depends on seasonal temperature variations [3, 5]. Channel degradation due to chromatic dispersion is proportional to the square of the data rate; therefore 40 Gbit/s systems are 16 times less tolerant to the effects of chromatic dispersion than 10Gbit/s systems [5].

The objective of Sampling Method is to reconstruct the eye diagram, explore the statistical information of an optical signal to derive the histogram [7, 8] and the BER of a transmission channel. It has been shown that high speed sampling allows obtaining open eye diagram, from where we can calculate Q factor and BER [2]. Synchronous sampling is used to measure fixed time Q factor (Qₜ), whereas asynchronous sampling is used to measure average Q factor (Qᵅavg) or Qₜ. It has been shown [2] that when the measured Qₜ value is 16.4 for a 10 Gbps signal, the BER of the signal is 10⁻¹⁰. The value of Qₜ become smaller at higher bit rate. In the literature Qₜ has been estimated from the eye diagram which is achieved by plotting all sampling points in time scale and satisfying the equation [2]

\[ T_{\text{step}} = \frac{1}{f_c} - \frac{1}{[(n/m) f_s]} = \frac{1}{kf_s} \]

Where \( f_s \) is signal bit rate, \( f_c \) is sampling clock rate, \( T_{\text{step}} \) is sampling time interval, \( n, m \) are natural numbers and \( k \) is the number of sampling points per time slot. Qₜ is given by,

\[ Q_T = \left| \mu_1 - \mu_0 \right| / (\sigma_1 + \sigma_2) \]

Where \( \mu \) and \( \sigma \) are mean and standard deviation. This method is Costly in WDM networks when implemented in every network element since they need demultiplexing and optoelectrical conversion of the signal. In addition, response time is usually in the order of milliseconds, making these techniques inadequate for dynamic networks operating on shorter timescales.

Fig. 2: Features of future heterogeneous networks.

Fig. 4: Simplified design of next generation all-optical networks.
4. OPTICAL SPECTRUM METHOD

The optical spectrum methods can provide carrier frequency and optical noise information. At present, commercially available optical performance monitors (OPMs) are known optical spectrum analyser made of either a tunable band pass filter or a diffraction grating. Thus, these OPMs can monitor the optical power and wavelength of each WDM channel, and estimate the optical signal-to-noise ratio (OSNR) by linearly interpolating the ASE level of the signal [12]. It has been demonstrated that polarization-diverse OSA-based method allows rapid and accurate in-band OSNR measurements for OSNR values up to 30 dB, even in the presence of strong emulated PMD [17]. However, it has been pointed out that the OSNR estimated by this method can be quite erroneous in the dynamically reconfigurable WDM network where each channel may traverse through different routes and different number of optical amplifiers [12].

5. RF SPECTRUM METHOD

Performance monitoring techniques based on RF spectrum analysis[13] are attractive compared to various other techniques. These techniques are applicable to the most widely used optical modulation formats such as non-return-to-zero (NRZ), return-to-zero (RZ) and carrier-suppressed return-to-zero (CS-RZ), and would be suitable for bit-rates beyond 40Gbit/s [4,5]. They are not intrusive and that they do not require transmitter modification. The monitor response time can be of a sub microseconds order, which may allow for real-time monitoring and compensation in dynamic networks with comparable switching timescales. The most popular RF spectrum method for today’s photonic network is pilot tone method or sometime called subcarrier multiplexing. A pilot tone is defined as a frequency component that has been added to the modulated signal at the transmitter. In a WDM system, a different tone frequency can be attributed to each channel. The pilot tone amplitude can be a measure of numerous parameters such as optical power, wavelength, OSNR, CD and PMD. When an optical signal with AM or PM pilot tone which has dual side band is transmitted over a fiber, CD creates a phase shift between LSB and USB, thereby causing RF power fading at the receiver. The normalized magnitudes of the received AM pilot tone is given by [1]

\[ P_{AM} \propto m \cos \left( \frac{\pi D L f^2}{c} \right) \]

Where \( c \) is the speed of light, \( \lambda \) is the wavelength, and \( m \) and \( f \) are the modulation index and tone frequency, \( D \) and \( L \) are the dispersion parameter and fiber length. The resolution [1] is given by \( \Delta P_{AM} / \Delta (DL) \) and measurement range [6] can be calculated as, \( GVD_{max} = \frac{c}{2 \lambda f^2} \).

The resolution could be improved by increasing the tone frequency, but it would reduce the measurement range. It has been shown that when the tone frequency is 8 GHz, the average resolution and measurement range are given by 0.006% ps/nm and 1000 ps/nm, respectively [1]. If we use low frequency pilot tone (2GHz), measurement range increases from 1000 to > 15000 ps/nm.

Although the pilot-tone-based monitoring technique has many advantages, it also has some limitations. The OPM techniques for CD monitoring using ARE or PM pilot tone is sensitive to PMD. The effect of PMD on the received RF power can be described as [4,14]

\[ P \propto 1 - 4\gamma (1 - \gamma) \sin^2(\pi f \Delta \tau) \]

Where \( \Delta \tau \) and \( \gamma \) are the differential group delay (DGD) and the power ratio between the fast and slow axes, respectively. The above equation shows that the magnitude of pilot tone decreases as the PMD increases. This effect can be overcome by using a Broadband Light Source. When the pilot tone is generated by using a BLS, the RF power variation of the received AM pilot tone, caused by CD, can be expressed as [4]

\[ P \propto \exp \left( -(\pi/2 DL \sigma_\lambda f)^2 \right) \]

Where \( \sigma_\lambda \) is the spectral width of the BLS, D is the dispersion parameter, L is the fiber length, and f is the tone frequency. The above relation shows that 2 GHz pilot tone is require to monitor CD upto 1000ps/nm (assuming that \( \sigma_\lambda =0.8 \) nm), hence the performance is less sensitive to PMD [4].
Chromatic dispersion (CD) monitoring based on RF power ratio measurement also has been demonstrated recently [15], the method is independent of received RF tone power and modulation format. Another method of Pre-scaled Clock-tone Detection [16] has been explained recently, which shows CD and PMD monitoring for high speed signal like 160-Gb/s RZ-BPSK or 40-Gb/s NRZ-OOK. The technique has advantage of simple contracture with very low electrical bandwidth [16]. Performance monitoring using chirped pilot tone [6] also has been proposed to monitor both the sign and amount of the chromatic dispersion. However, due to the chirp, this technique can also affect the performances of the modulated signals. The pilot tone can impose unwanted amplitude modulation on the data signal and degrade receiver sensitivity. The performance of the pilot-tone-based monitoring technique can be deteriorated by the “ghost tones” caused by the cross gain modulation (XGM) and stimulated Raman scattering (SRS).

**Fig. 6:** Measurement range vs. pilot tone frequency.

**6. Future Challenge**

In the future photonic networks, multiple data rate and modulation formats exist at the same time, OPM should be transparent to them. This is the first challenge for OPM. Secondly, these networks will utilize 100-Gb/s channels, which can endure virtually no dispersion and PMD. Moreover, for higher spectral efficiency, technology like polarization multiplexing & OFDM would be integrated in future DWDM network. Thirdly, in OPM, a certain technique only can be used to monitor a specific set of parameters, which makes OPM expensive if a lot of parameters are wanted. The challenge is how to monitor multiple channels and multiple parameters of each channel simultaneously [9, 10], using a single OPM technique. Fourthly, this is a direct threat to keep maximum network availability and reduce down time because it has been noticed in most of the papers that 40Gbit/s systems are 16 times less tolerant to the effects of chromatic dispersion than 10Gbit/s systems, due to the quadratic dependence of dispersion on signal bandwidth. Also PMD effects are stochastic, temperature dependent, time varying, and worsen with higher bit-rates. Finally, Standardization of OPM is also a significant issue.

**7. Conclusion**

Lot of methods have been proposed to monitor CD and PMD, like synchronous & asynchronous sampling, RF spectrum, Clock tone, pilot tone etc. but a standard method to monitor simultaneous CD and PMD for >40Gbps photonic all optical network is still a research topic. There is a need to develop a cost effective OPM technique which can monitor multiple impairments simultaneously. Multi impairment monitoring using pilot tone carried by broadband light source might be suggested for CD and PMD monitoring, whereas asynchronous sampling is preferable for Q factor and BER monitoring. There is a need to integrate multiple OPM techniques which will reduce the overall cost.

**REFERENCES**


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