VIAVI Solutions

White Paper

Measurement of Optical Signal to Noise Ratio in Coherent Systems using Polarization Multiplexed Transmission

Measuring Optical Signal-to-Noise-Ratio (OSNR) in live Dense Wavelength Division Multiplexing (DWDM) systems using polarization multiplexed transmission (Pol-Mux) is an unsolved challenge. In this paper a novel method to calculate OSNR from the correlation between spectral components in the optical spectrum of a transmission signal is proposed.

Introduction

In today's high speed DWDM systems, coherent detection with digital signal processing and the use of Pol-Mux has become standard. The quality of modulated optical signals transmitted in long-distance fiber optic communication systems is frequently characterized by OSNR. Several methods to measure OSNR in DWDM systems are defined by standard bodies, but for systems using Pol-Mux transmission in a reconfigurable optical add-drop multiplexer (ROADM) network topology, no generally applicable method for in-service measurement of in-band OSNR is known so far. Transmission systems at 100 Gb/s (or higher) use all physical parameters such as wavelength, amplitude, phase, and state of polarization for signal encoding. So no independent physical parameter is available for noise separation and the calculation of OSNR. The measurement is further complicated by the fact that transmitted signals may be distorted by large amounts of chromatic dispersion (CD) and polarization mode dispersion (PMD). In this paper VIAVI is proposing a novel method based on spectral correlation measurements enabling in-service, in-band OSNR analysis in coherent systems.

Measurement of OSNR

OSNR is measured with an optical spectrum analyzer (OSA) and is defined as the ratio of optical power of the digital information signal (P_{Signal}) to optical noise (P_{Noise}) added to the signal by optical amplifiers (EDFA). For P_{Signal} the total signal power carried inside the channel-bandwidth ($B_{Channel}$), which is typically 50 GHz, has to be included. The noise power is normalized to B_{Noise} = 0.1 nm measurement bandwidth. The following formula describes the calculation of OSNR:

$$OSNR = \frac{P_{Signal}(B_{Channel})}{P_{Noise}(B_{Noise})}$$

Traditional OSNR method (IEC 61280–2–9)

The most commonly used method to analyze OSNR is the interpolation or out-of-band method standardized in IEC 61280-2- 9. With this method, noise power is measured outside the optical channel. This method is based on the assumption that the signal has a limited optical bandwidth whereas noise has a broadband distribution.

So an interpolation of out-of-band noise measurements in between optical channels (P_{NL} and P_{NR}) can be used to calculate noise power (P_N) inside an optical channel.

$$P_N = \frac{P_{NL} + P_{NR}}{2}$$

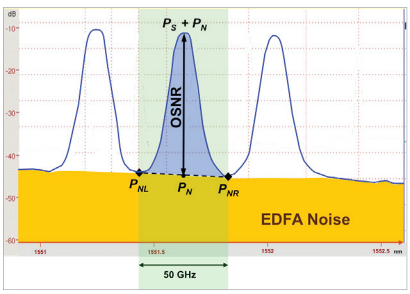

Figure 1: IEC 61280-2-9 OSNR method

In standard point-to-point systems with data rates up to 10 Gb/s, this method provides accurate results for OSNR.

OSNR methods for meshed optical networks

With the network topology moving from point-to-point towards dynamically reconfigurable, mesh-based architectures, the use of ROADMs has become a standard. ROADMs use de-multiplexers to separate the individual channels for add and drop functionality. The de-multiplexers are composed of optical filters that pass the optical signal but suppress optical power outside the channel band. So in a ROADM environment the broadband noise from EDFAs is no longer present. The noise characteristic changes to filtered noise, which means that noise outside an optical channel is no longer related to noise inside the optical channel.

$$P_N \neq \frac{P_{NL} + P_{NR}}{2}$$

The following graph shows the effect of filtered noise characteristic created by ROADMs

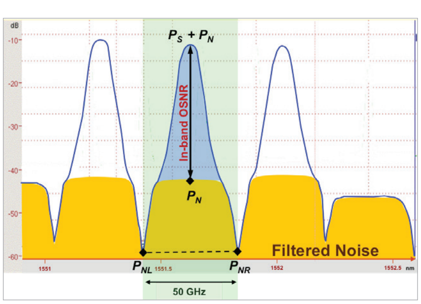

Figure 2: Effect of filtered noise in a ROADM system

In ROADM systems, the out-of-band measurement of noise power in between optical channels, used by the IEC method, no longer provides the correct OSNR result. In these systems, one needs to measure the optical noise floor within the spectral bandwidth of the signal to determine the signal's OSNR. Such measurements are referred to as in-band OSNR measurements. For conventional optical information signals using single polarization transmission such as amplitude or on-off-key modulation (OOK) at 2.5 Gb/s, 10 Gb/s and some 40 Gb/s systems a polarization nulling technique has been disclosed. Under the assumption that the transmitted signal is polarized and that the noise is unpolarized, a polarization filter can be used to suppress the polarized signal and measure unpolarized noise inside an optical channel to get the in-band OSNR.

The challenge for high speed transmission using polarization mulitplexing

Coherent systems running at 100 Gb/s and higher are using Pol-Mux transmission. With this technique two data streams are transmitted simultaneously at the same wavelength with orthogonal polarization states. In a measurement instrument such as an optical spectrum analyzer those signals appear as unpolarized. Therefore the polarization nulling technique using a polarization filter to separate signal from noise cannot be used to measure in-band OSNR.

While several methods have been disclosed to measure in-band OSNR in Pol-Mux signals, they generally only work with optical signals of a predetermined bit-rate, modulation format, and/or signal waveform. Consequently, these methods may be suitable for monitoring of in-band OSNR at certain points in a communication system, but are difficult to use as a general test and measurement procedure. Furthermore, some of these methods are not suitable for determining in-band OSNR in signals substantially distorted by CD or PMD.

A method for in-band OSNR measurements using conventional spectral analysis of the optical signal power has been disclosed by using spectral shape comparison. But spectral filtering effects of ROADMs, transmission ripples, as well as OSA's repeatability remain major sources of error in those measurements. Methods in the time domain need high speed optical receivers covering the full transmission bandwidth of 100 Gb/s or higher. This technique cannot be used as system monitor points do not provide enough power to feed such high speed receivers. The only known method in the industry for measuring in-band OSNR is the channel turn-off, or On/Off, method. This is an out-of-service method as noise inside a channel is measured when signal is turned off. This method cannot be used in a live system.

Up to now, there has been no commercially available method to measure in-service, in-band OSNR in coherent systems with Pol-Mux.

Correlation measurements – a novel measurement parameter

In high speed coherent systems running in a ROADM environment, there is no physical parameter like frequency, power, or state of polarization that can be used to separate a modulated signal from amplifier noise to measure in-band OSNR. An alternative parameter is needed that differentiates between signal and noise.

Using the correlation property of measurement samples inside an optical channel turns out to be a viable solution for this purpose. Correlation is a technique for investigating the statistical relationship between two quantitative variables like, for example, amplitude samples of an optical signal. Analyzing the correlation function can be used to calculate OSNR based on the fact that measurement samples from digitally modulated signals are correlated whereas measurement samples from white noise are not correlated.

Correlation properties of digitally modulated signals

The correlation coefficient *Corr* is a statistical measure that provides indication on how closely two variables co-vary. It can vary from 0 (no correlation) to 1 (perfect correlation = two identical samples).

The following graph shows an example of a binary modulated signal overlaid by white noise.

For illustration the correlation between measurement samples from pure signal (grey) and pure noise (orange) shall be compared. The measurement samples shall be taken in a distance that is significantly smaller than the bit length T_B.

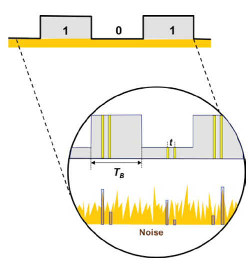

Figure 3: Correlation measurements

Signal correlation:
The measurement samples from signal (yellow samples) show high coincidence whether measured at a '1' or at a '0' state. The correlation coefficient will therefore be *Corr* = 1.

Noise correlation:
Taking similar samples from white noise (blue samples) shows that the probability to capture two identical amplitude values is very low, resulting in a correlation coefficient of *Corr* = 0. A mixture of signal and noise will therefore give a correlation coefficient between 0 and 1 indicating the relationship between signal and noise which can also be expressed as signal-to-noise ratio.

This is an example in the time domain. As mentioned above, methods in the time domain need high speed optical receivers which will not work at a system's monitor points. Using the Fourier transformation enables performing the correlation analysis in the frequency domain.

VIAVI Spectral Correlation Method (*SCorM*)

VIAVI has disclosed a novel spectral correlation method (*SCorM*, US patent US20160164599 A1) that works in the frequency domain and avoids the need for high speed optical receivers and clock and data recovery (CDR).

The technique is based on correlation measurements inside the optical spectrum of a transmission channel using the fact that spectral components from modulated signals are correlated whereas spectral components from noise are not correlated. OSNR can then be calculated from measuring correlations between predetermined pairs of spaced apart, time-varying wavelength components in the optical amplitude spectrum of the signal. The challenge is to analyze and compare two very thin frequency slices within an optical channel containing both correlated signal and uncorrelated noise components. The measurement bandwidth needs to be far smaller than the optical bandwidth of a transmission signal which is typically less than 50 GHz in a standard DWDM system. For measuring the correlation properties of spectral components, two independently tunable optical receivers are required with ultra-high resolution in the range of <50 MHz. This is more than 100 times better than what high resolution OSAs based on free space optics can deliver. This high measurement resolution can only be achieved using a coherent detector design, similar to high speed coherent optical receivers.

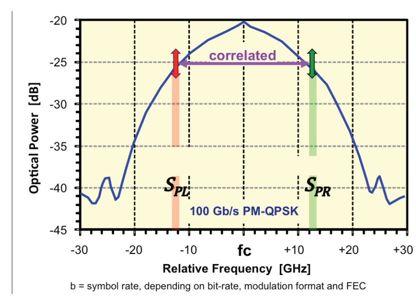

Figure 4: Spectral correlation measurement

Figure 4 shows the spectrum of a 100 Gb/s Pol-Mux quadrature phase shift keying signal (PM-QPSK). Spectral density S_{PL} and S_{PR} represent the measured spectral components inside the optical channel that include both, signal and noise.

The correlation coefficient *Corr* can then be expressed as a function of S_{PL} and S_{PR} with a value between 0 and 1, and

$$Corr = f\ (S_{PL}, S_{PR})$$

The in-band OSNR (*OSNRC*) can be calculated from *Corr*:

$$OSNR_C = f\ \ (Corr)$$

Low *Corr* values indicate low OSNR and high *Corr* values indicate high OSNR.

VIAVI Pol-Mux OSCA-710 based on *SCorM*

The VIAVI Pol-Mux OSCA-710 is the first instrument to use *SCorM* for performing in-service, in-band OSNR measurements. VIAVI *SCorM* works with standard single polarized amplitude or on-off keying (OOK) signals, as well as with coherent phase modulation (xPSK) signals and quadrature amplitude modulation (xQAM) signals using Pol-Mux in a ROADM topology. It is insensitive to large CD- or PMD-induced signal distortions, and does not require prior calibration with a similar noiseless optical signal.

The OSCA is based on two independently tunable coherent receivers with advanced digital signal processing. This enables a complete signal characterization in amplitude, frequency, phase, and polarization to be independent of modulation formats. This setup further allows to analyze signal's symbol- or baud-rate and to measure per channel chromatic dispersion in live systems. The instrument provides standard spectral measurements with an ultra-high resolution bandwidth of 20 MHz in the C-band.

The block diagram shows the main components of the VIAVI Pol-Mux OSCA-710.

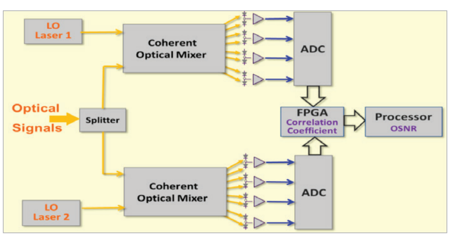

Figure 5: OSCA-710 block diagram

T-BERD/MTS-8000 with OSCA-710

Measurement results

The measurement of in-service, in-band OSNR with 100 Gb/s and 200 Gb/s coherent signals has been performed with the VIAVI Pol-Mux OSCA-710. As a reference measurement for OSNR, the out-of-service, On/Off OSNR method was used.

Figure 6 shows the relationship of measured in-band OSNR based on VIAVI *SCorM* ($OSNR_C$) to the reference OSNR measured with the On/Off method ($OSNR_{On/Off}$) for a 100 Gb/s PM-QPSK signal at a symbol rate of 28 Gbaud in a 400 km link.

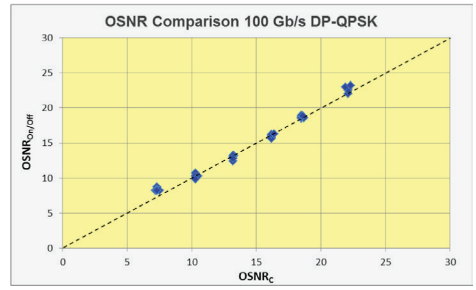

Figure 6:OSNR comparison 100Gb/s

Accordance of < ±1 dB was achieved in a measurement range between 10 and 22 dB OSNR.

Also for Nyquist shaped signals, VIAVI *SCorM* is applicable.

Figure 7 shows 200 Gb/s Nyquist shaped signal at 16 QAM modulation.

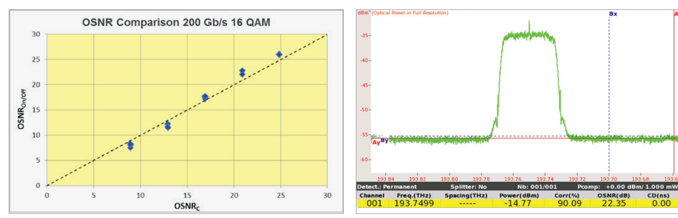

Figure 7:Nyquist signals and OSNR results

Conclusion

OSNR is still the key parameter to characterize the quality of modulated optical transmission signals. In this paper we have shown that commonly available methods for measuring OSNR are not applicable for high speed coherent systems in a ROADM network topology. The VIAVI Pol-Mux OSCA-710 is the first instrument to use a novel spectral correlation technique to enable the measurement of in-band OSNR, and per channel chromatic dispersion of 40 Gb/s, 100 Gb/s, 200 Gb/s and 400 Gb/s coherent transmission signals utilizing Pol-Mux in a live system. The method is independent of modulation format and data rate and is tolerant of large amounts of CD and PMD as well as spectral filtering in ROADMs.

The VIAVI *SCorM* method enables the first ever measurements of in-band OSNR in live, coherent systems with Pol-Mux. The OSCA-710 will significantly simplify optical testing during installation, commissioning and maintenance, and minimize overall system downtime and man-hours.

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