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RESEARCH ARTICLE

In-band OSNR monitoring based on low-bandwidth coherent receiver and tunable laser

Yingqin PENG[1], Yuli CHEN[1], Qi SUI[1], Dawei WANG[2], Dongyu GENG[2], Freddy FU[2], Zhaohui LI (✉)[1]

1 Institute of Photonics Technology, Jinan University, Guangzhou 510632, China
2 Huawei Technologies Co. Ltd, Shenzhen 518129, China

Abstract An in-band optical signal-to-noise ratio (OSNR) monitoring technique with high resolution and large measurement range is demonstrated based on low-bandwidth coherent receiver and a tunable laser. The measurement range of OSNR is from 10 to 25 dB and the resolution can be controlled about ±1 dB.

Keywords optical performance monitoring (OPM), optical signal-to-noise ratio (OSNR), coherent communication, tunable laser

1 Introduction

With the rapid growth of network traffic demand in recent years, ultra-high speed and large-capacity optical transmission system is becoming more important than before. For example, 400-Gbps or even 1-Tbps per channel optical transmission technique is becoming one of the hottest research topics for next generation optical network [1]. In this case, the bandwidth of optical signal is becoming comparable to the channel spacing of conventional dense wavelength division multiplexing (DWDM) system. Along with the emerging modulation techniques, such as orthogonal frequency division multiplexing (OFDM) and quadrature amplitude modulation (QAM) and due to new multiplexing techniques, such as polarization division multiplexing (PDM) and space division multiplexing techniques, the optical transmission channel is becoming more sensitive and the penalty is becoming more difficult to compensate, although the coherent detection technique is applicable extensively. Optical performance monitoring (OPM) is a potential way to solve these issues because it can obtain the detailed status of the optical signal in real time and thus can improve the efficiency of optimization or compensation by assisting the post digital signal processing [1].

On the other hand, the reconfigurable optical network and flexible grid optical communication system are also attracting the interest and the potential solution to increase the efficiency of current optical network significantly. OPM is also the necessary technique to manage and realize the flexible and high efficient optical network [1].

Among the parameters of the optical signals that need to be monitored, optical signal-to-noise ratio (OSNR) is the most important to reflect the signal quality and influence the transmission bandwidth and distance. While the chromatic dispersion (CD) and polarization mode dispersion (PMD) monitoring or compensation become easier in the coherent optical communication system.

Conventional OSNR monitoring techniques, such as out-of-band noise estimation, polarization nulling technique, or other measurement scheme, are not applicable because the optical signals become comparable with the channel spacing or use PDM technique [2 – 4]. We have demonstrated a novel OSNR monitoring scheme based on low bandwidth coherent receiver [5]. The proposed technique is low-cost because it uses low-bandwidth devices, such as low-speed analog-to-digital converter (ADC) about the 2.5 GHz and low-complexity digital signal processor (DSP). However, the estimated resolution and measurement range cannot reach the practical requirement from optical network [5]. Recently, people demonstrated high resolution OSNR monitoring technique available for the PDM system using training symbol and low-cost coherent receiver. However, the insertion of special designed training symbol will change or occupy the bandwidth of the optical signal [6].

In this paper, we demonstrate an OSNR monitoring technique based on new digital signal processing technique

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E-mail: li_zhaohui@hotmail.com

together with low-cost coherent receiver and tunable laser. In addition, the proposed technique can also be extended to the measurement of other parameters of optical signal, such as fast optical power spectrum recovery [7], CD, PMD estimation and modulation format identification. We can use commercially available devices to perform the experiments, which illustrate the high measurement resolution and large range simultaneously.

2 Operation principle

In this scheme, we assume that the spectrum of amplified spontaneous emission (ASE) noise is uniform. When we use a tunable laser to beat with the modulated optical signal within the signal bandwidth at the optical coherent receiver, we can obtain the power spectrum information containing the optical signal and ASE noise. In addition, if we use a tunable laser to beat with the modulated optical signal, we can easily recover the whole optical power spectrum within the signal bandwidth, as shown in Fig. 1.

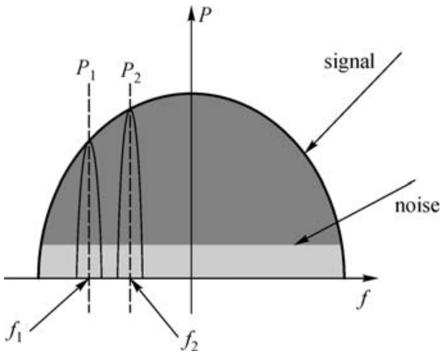

Fig. 1 Operation principle of the proposed OSNR monitoring technique

To measure the OSNR of the modulated optical signal, we only need to measure the power spectrum information P_1 and P_2 at any two frequency point f_1 and f_2, as shown in Eqs. (1) and (2).

$$aP_{\mathrm{s}} + cP_{\mathrm{n}} = P_1, \tag{1}$$

$$bP_{\mathrm{s}} + cP_{\mathrm{n}} = P_2. \tag{2}$$

P_1 and P_2 are the obtained power information at the optical coherent receiver at the measured frequency point f_1 and f_2. P_{s} is the power of optical signal, while P_{n} is power of noise within 0.1 nm bandwidth. *a* and *b* represent the proportion of signal power at the corresponding frequency point and the whole signal power as there is no noise. *c* means the proportion of filter bandwidth and 0.1 nm bandwidth. We can easily derive Eq. (3) from Eqs. (1) and (2). If we can know *a*, *b* and the bandwidth of filters, we can estimate the OSNR information from the received signal.

$$\frac{P_{\mathrm{s}}}{P_{\mathrm{n}}} = \frac{c(P_1/P_2 - 1)}{a - bP_1/P_2}. \tag{3}$$

We can also find that this OSNR measurement scheme is only dependent on the power spectrum profile of the modulated optical signal and transparent to the modulated formats and multiplexing schemes. We can optimize the measurement results by selecting the measuring frequency points, which are not influenced by the linear or nonlinear passive effects on the modulated optical signals.

3 Experimental results and discussion

To verify this technique, we carried out the experiment according to the schematic diagram shown in Fig. 2. We use 100 Gbps PDM-QPSK system as the modulated optical signal. An erbium doped fiber amplifier (EDFA) is utilized to generate ASE noise and a variable optical attenuator (VOA) is used to adjust the OSNR. An optical spectrum analyzer (OSA) is used to monitor the spectrum and obtain the real OSNR value. We use a tunable laser to adjust the local oscillator to beat with the modulated optical signal at different frequency points. A broadband

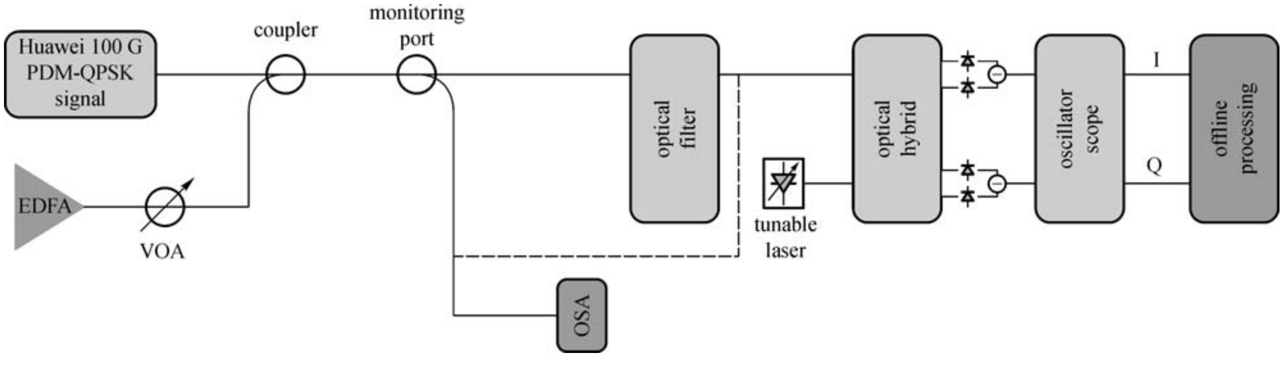

Fig. 2 Experimental setup. EDFA: erbium-doped fiber amplifier; VOA: variable optical attenuator; OSA: optical spectrum analyzer

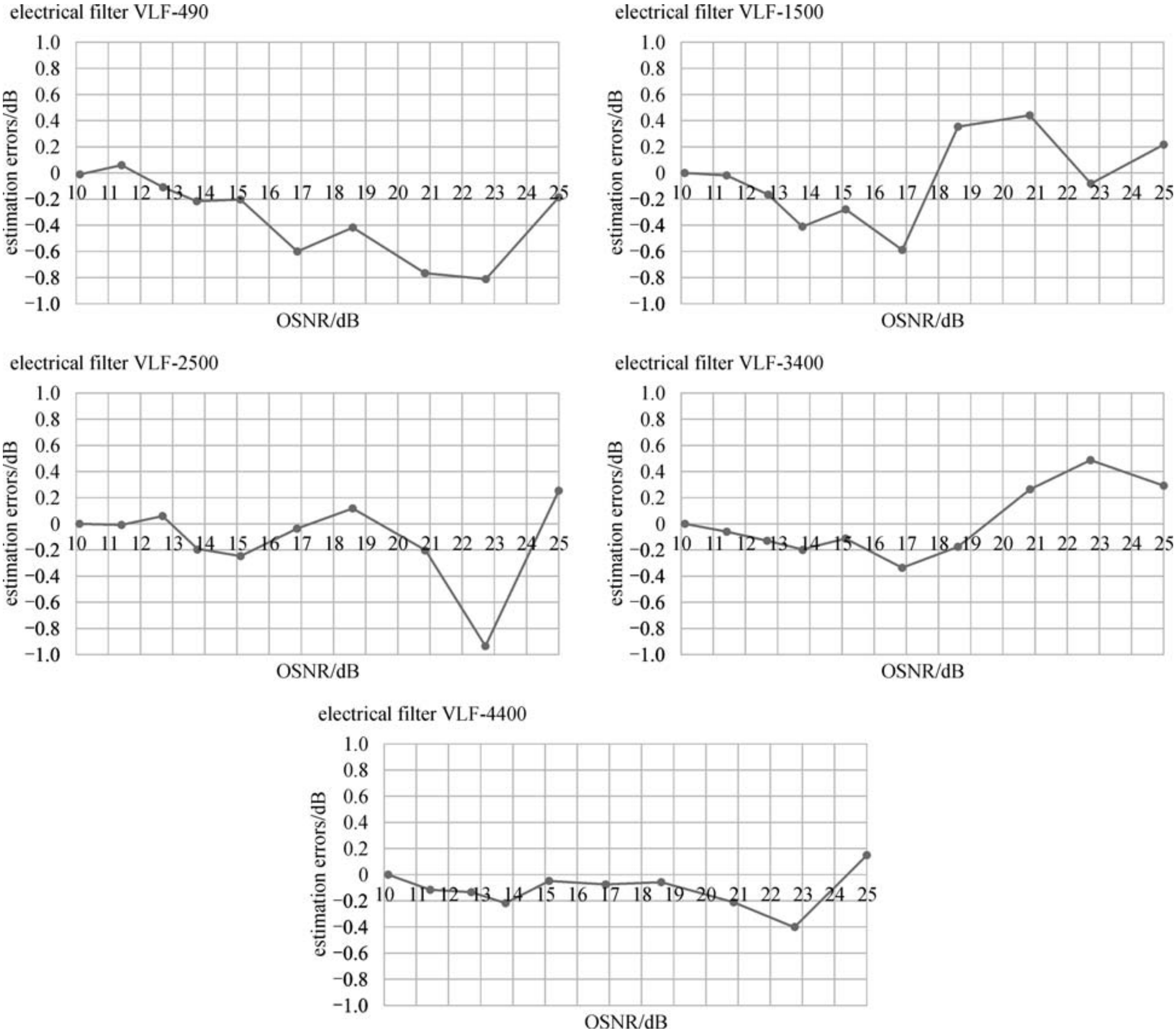

Fig. 3 Relationship of OSNR real values and estimation errors with different electrical filter bandwidth.VLF-490 means 1 dB bandwidth 490 MHz

optical coherent receiver and a group of Mini-Circuits electrical filters are used to study the influence of the bandwidth on the measurement. We use the Agilent Infiniium DSO93004L to sample the electric signal and MATLAB to do the post digital signal processing.

We set the center wavelength of the modulated optical signal at 1534.2500 nm. We select the measurement frequency points f_1 and f_2 as 1534.0140 and 1534.1340 nm respectively. We adjust the VOA to make the OSNR change from 10 to 25 dB. The optical filter is centered at 1534.2500 nm with 50 GHz bandwidth. We use different group of electrical filters to observe the relationship between estimation accuracy and signal bandwidth. The 1 dB-bandwidth of electrical filters are 490, 1500, 2500, 3400 and 4400 MHz respectively. These sampled time domain signals are transformed to frequency domain signal by using the fast Fourier transformation (FFT). The signal power is calculated at different electrical bandwidth and digital filter. The experimental results are shown as Fig. 3.It shows that the estimation errors drop with the growth of the bandwidth of electrical filters because we can get more accurate a and b as well as P_1 and P_2, which means we can improve accuracy by choosing the appropriate bandwidth coherent receiver. Every single image indicates that the larger the OSNR, the harder to estimate it accurately because the ASE noise is too weak to influence the value of P_1 and P_2.

We also study the potential influence of the channel filter effects, such as the reconfigurable optical add/drop multiplexer (ROADM) in practical communication system, on the measurement result.

Figure 4 shows the relationship of OSNR real values and

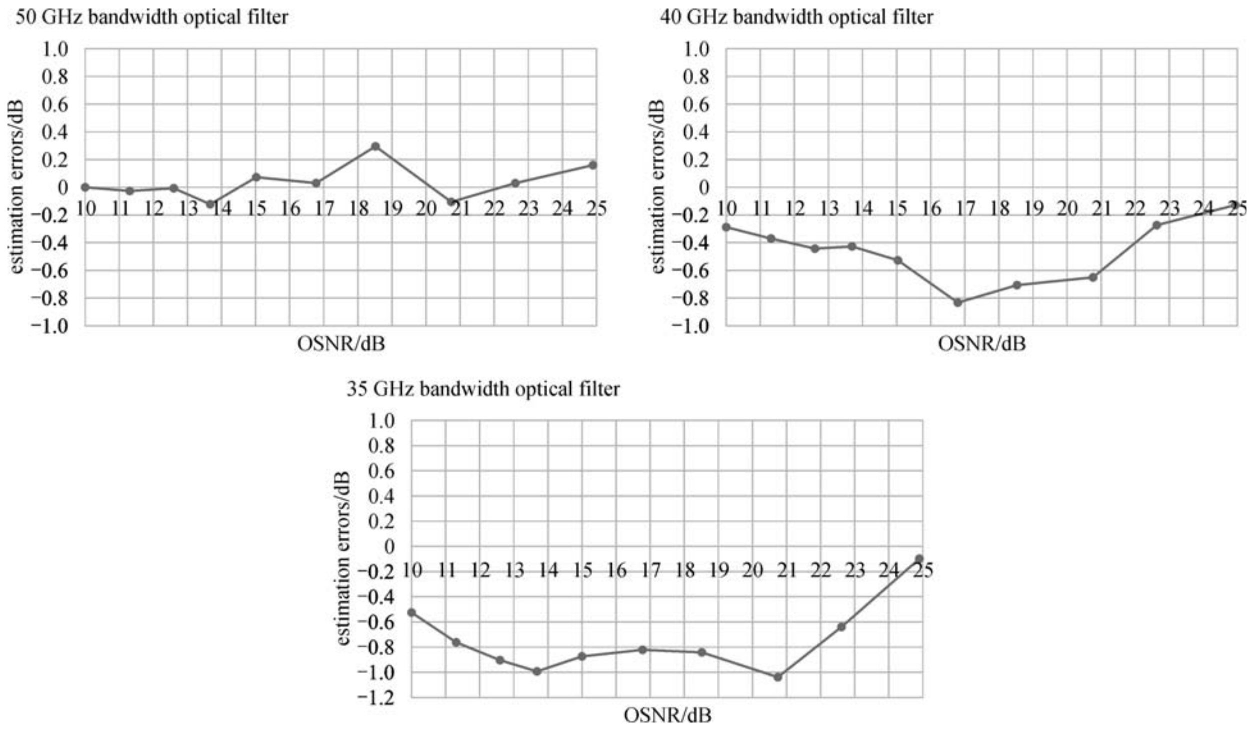

Fig. 4 Relationship of OSNR real values and estimation errors with different optical filter bandwidth

estimation errors with different optical filter bandwidth. We select VLF-2500 as the electrical filter. Figure 4 shows that the estimation errors will increase with the decrease of the bandwidth of optical filter because it can affect the shape of optical spectrum. But the estimation errors are less than 1.1 dB even if the optical bandwidth is only 35 GHz. Optical filter has not that much influence on this scheme if the bandwidth is broad enough.

4 Conclusions

A high resolution and large range OSNR estimation technique is proposed and demonstrated based on the low-bandwidth coherent receiver and tunable laser. In addition, this monitoring technique is transparent to different modulation formats and multiplexing techniques.

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Yingqin Peng obtained his B.Eng. degree in Huazhong University of Science and Technology, Wuhan, China in 2013. Currently he is working toward a master's degree in optical communication, Institute of Photonics Technology, Jinan University, Guangzhou, China. His major work is about optical performance monitoring.

Qi Sui obtained his B.Eng. degree in electronic engineering from Shanghai Jiao Tong University, China in 2007, and Ph.D. degree from The Hong Kong Polytechnic in 2015. Then he joined the Institute of Photonics Technology, Jinan University. His current research interest is coherent fiber-optic communication systems and optical performance monitoring.

Zhaohui Li obtained his B.S. degree in the Department of Physics and M.Sc. degree in the Institute of Modern Optics from Nankai University, China, in 1999 and 2002, respectively, and Ph.D. degree from the Nanyang Technological University in 2007. He joined the Institute of Photonics Technology, Jinan University, China, as professor in 2009. His research interests are optical communication systems and optical signal processing technology and ultra-fine measurement systems. He has over 100 publications in internationally refereed conferences and journals.