Recent Progress in the Characterization of the G-SNR and the OSNR of Future SDM-based Subsea Open Cables

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Abstract: We characterized the G-SNR and the OSNR of an SDM-compatible submarine optical cable with different modulation formats and symbol rates up to 101 GBd, observing good agreement between all G-SNR measurements.

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1. Introduction

In recent years, submarine optical systems have evolved towards an open environment with disaggregated architectures between optical cables and the transceivers [1]. A new metric, referred as Generalized Signal-to-Noise Ratio (G-SNR), has been recently introduced to characterize a submarine open cable. On the other hand, new CMOS technologies have arisen permitting to increase the optical bandwidth of both transmitters and receivers. The transmission of larger symbol rates reaching 100 GBd is now available in the labs as presented in [2]. Indeed, increasing symbol rate of optical channels is the trend for next generation optical transponders since it can help to reduce the cost of the system by decreasing the number of the required optical transceivers. Taking advantage of this symbol rate growth, a technique to characterize automatically the OSNR and the G-SNR of a submarine optical cable was introduced in [3]. We tested this technique with two different modulation formats: dual polarization (DP)-QPSK/DP-8QAM and different symbol rates from 34 GBd to 95 GBd. The fact of increasing the symbol rate permitted to reduce significantly the required measurement time. In this work we have pushed the symbol rate up to 101 GBd with the aim of reducing again the measurement time and approaching our initial objective of completing a characterization of a fibre pair in less than 3 hours. Reaching this limit is necessary for fast characterization of future Spatial Division Multiplexing (SDM) systems with a large number of fibre pairs. This extended characterization serves to complete the previous study adding to the characterization signals with new different modulation formats such as DP-16QAM or DP-64QAM with three different straight-line test beds of 3,000, 6,000 and 9,500 km. Furthermore, it permits to experimentally assess the validity of G-SNR as the definitive metric to properly characterize a submarine open cable.

2. Experimental setup

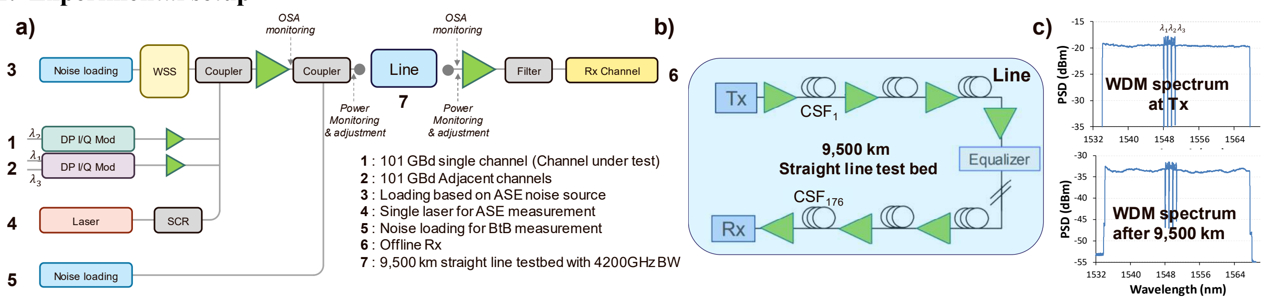

Fig. 1. Transmitter and receiver setup in a), straight-line configuration for transmission experiments in b and WDM spectra at the Tx and after 9,500 km and straight-line configuration for transmission experiments in c)

The transmitter and receiver setup used is depicted in Fig 1-a). It consists of an optical coupler which combines the test channels with the continuous noise loading generated by an amplified stimulated emission (ASE) noise source and equalized by a wavelength selective switch (WSS) to obtain a flat 4.2-THz optical output. As discussed in [3], loading based on ASE noise is preferable to modulated channels since it reduces the complexity of the setup providing similar results and moreover, it is easily adaptable to any symbol rate. Two independent dual polarization offline transponders driven by a dedicated digital-to-analog convertor (DAC) are used to generate the test channels. The modulation formats chosen are 101 GBd DP-QPSK/DP-16QAM/DP-64QAM, shaped by a root-raised-cosine filter with 0.01 roll-off factor. Electrical pre-emphasis is used to compensate the distortion added by the electrical driver. No optical pre-emphasis was applied to reach 101 GBd. We measured the OSNR, always referred to the channel spacing, and the Q² factor of the first transponder (λ_2) in back-to-back conditions and after transmission to obtain the G-SNR estimation. The second transponder is simply used to generate adjacent channels (λ_1 and λ_3) and approaching the conditions of a real system, and particularly, the linear and nonlinear cross-talks induced by neighbour channels. To perform a characterization across the full C-band, these three test channels are swept along the band considering a 110-GHz grid, to keep similar bandwidth efficiency values than in [3], which corresponds to 38 frequency slots over the system bandwidth. The signal is amplified and coupled with a second flat noise source for back-to-back purposes. Three different straight-lines of 3,000, 6,000 and 9,500 km are considered. As depicted in Fig. 1-b), they consist of several spans of Coherent Submarine Fiber (CSF) with 55 km average length and 110 µm² effective area. Dedicated spans were equipped with shape equalizers to flatten the gain shape. We amplified the signal using 4.25 THz-wide C-band EDFAs with 16.8 dBm average output power to approach a real SDM operating point configuration. Fig 1-c) shows the WDM spectra at the transmitter and after the transmission of 9,500 km. At receiver, the channel under test is filtered by a 1.6 nm optical filter centred at λ_2 and launched to the offline receiver which estimates the mean Q² factor after 4 acquisitions (1 per second) using standard digital signal processing techniques.

3. OSNR characterization

To properly measure the OSNR, a novel technique was introduced in [3] consisting in the measurement of the noise contribution by replacing the test channel with a laser which is depolarized with a polarization scrambler (SCR), as shown in Fig 1-a). This method permitted us to access the noise floor without suffering from gain distortion associated to Spectral Hole Burning (SHB). Now to definitively validate this technique, a new measurement is done with a high-resolution optical spectrum analyzer (HR-OSA) at 140 MHz optical resolution. Fig 2-a) shows, the power spectral density (PSD) of the signal after 9,500 km at 1536.8 nm. At the top, the region of the interest is enlarged. In blue, the original signal with the test channel is shown. In the enlarged area we show how we can successfully access to the noise floor even with the test channel switched on. In orange, the same signal is shown but now with the test channel switched off. In the enlarged figure we observe the impact of SHB that overamplifies the noise floor. Indeed, we selected the measurement conditions that maximizes the impact of SHB. In contrast, when the depolarized laser is set to replace the test channel (green trace), SHB effect vanishes allowing to access at the actual noise floor. With this technique, the measurement of the noise floor is allowed even with regular OSA. Fig 2-b) shows the measured OSNR with this novel technique after the three straight-lines of 3,000 km, 6,000 km and 9,500 km, as a function of the wavelength measured with a regular OSA at 0.1 nm optical resolution.

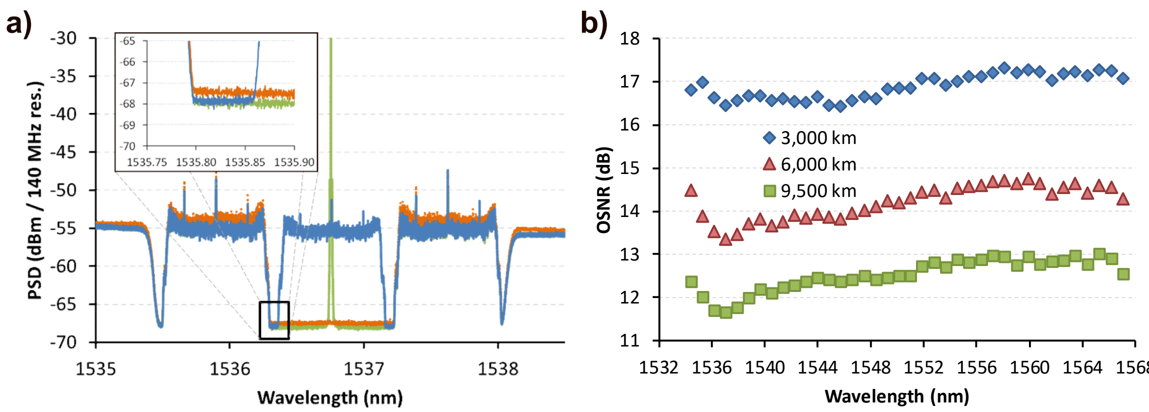

Fig. 2. PSD measured after 9,500 km with a HR-OSA at 1536.8 nm in a) and OSNR measured for full C-band at 3,000 km, 6,000 km and 9,500 km in b)

4. G-SNR characterization

For G-SNR characterization, back-to-back measurement is required to isolate the impact of optical transceivers. A complete WDM back-to-back characterization for the full C-band usually takes more than 24 hours. It is then the main limitation that avoid us to reach the target time of 3 hours. If fast G-SNR characterization is required, WDM back-to-back can be easily simplified. Fig 3 shows the back-to-back characterization for 69 GBd DP-QPSK used in experiments in [3]. In a), we plot the measured Q² factor when the OSNR is fixed to 11.2 dB as a function of wavelength: diamonds represent the result for all the 56 channels, dotted line represents the linear fit and dashed line, the value of Q² factor at the central channel (1550.9 nm). We observe that if linear fit is taken, the error committed is not higher than 0.04 dB, while if it is considered the central channel, the max. error is 0.06 dB. Fig 3.b) serves to generalize this measurement as a function of OSNR. In red, the max. difference between channels is shown for any given OSNR target. This difference of ~0.2 dB is attributed to the first channel whose performance increases because it is only affected by a single adjacent channel. If we do not take it into account, the difference is reduced to ~0.1 dB which is represented in green. Finally, in blue is represented the max. error committed if only the central channel is considered. We observe that the penalty is limited: ~0.05 dB at 9,500 km and 6,000 km and ~0.1 dB at 3,000 km. Thus, for the measurements done in this paper back-to-back is performed in the central channel only, which permits to drastically reduce the measurement time with no excessive penalty. An intermediate solution should be taken a linear fit, for instance by measuring one channel at the beginning and at the end of the band, with an error not higher than 0.04 dB.

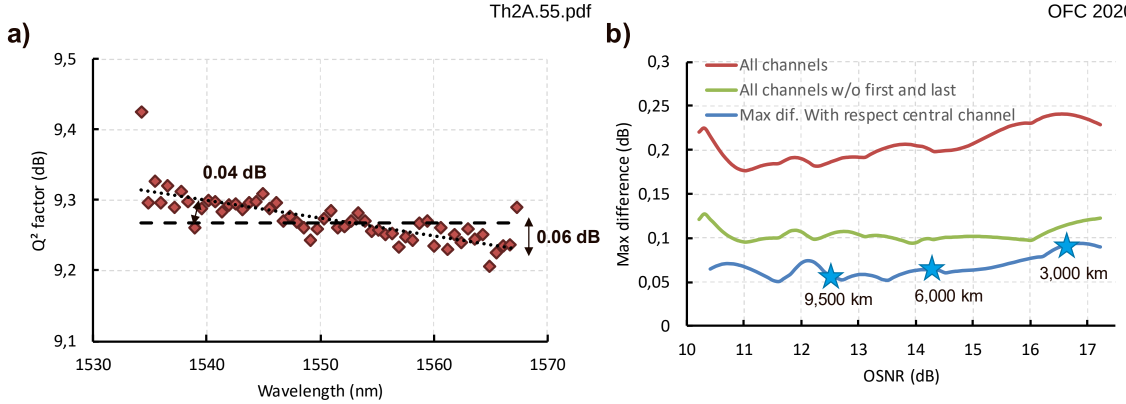

Fig. 3. Full C-band back-to-back characterization for 69 GBd DP-QPSK: in a) Q² factor for OSNR = 11.2 dB and in b) max. difference between all the curves at any given OSNR with and w/o first and last channels

Each OSNR and G-SNR characterization (back-to-back included) took no more than 6 hours. To have some numbers in mind, first characterizations performed, with 37.5-GHz spaced signals and 112 channels, required more than 2 days. We have then significantly reduced the measurement time approaching to the target thanks to both: the reduction of the number of channels and the simplification of the back-to-back measurement. This time reduction will permit characterize a future SDM submarine cable with many fiber pairs in a reasonable period. Fig 4-a) shows the G-SNR measured at 101 GBd for the three straight-lines: while DP-QPSK is represented in blue, DP-16QAM, in red. We also plot in green the DP-64QAM results for 3,000 and 6,000 km. We observe that all curves show a good agreement with similar mean values (difference not higher than 0.15 dB). Finally, to conclude our study, in Fig 4-b) we join the novel results with the ones shown in [3] at 6,000 km. Figure represents the estimated G-SNR using different symbol rates (from 34 to 101 GBd), modulation formats (DP-QPSK/DP-8QAM/DP-16QAM) and even different transceivers (offline and real-time). It allows us to assess the robustness of this new metric, the G-SNR, that can properly characterize an open cable with a mean value discrepancy not higher than 0.39 dB.

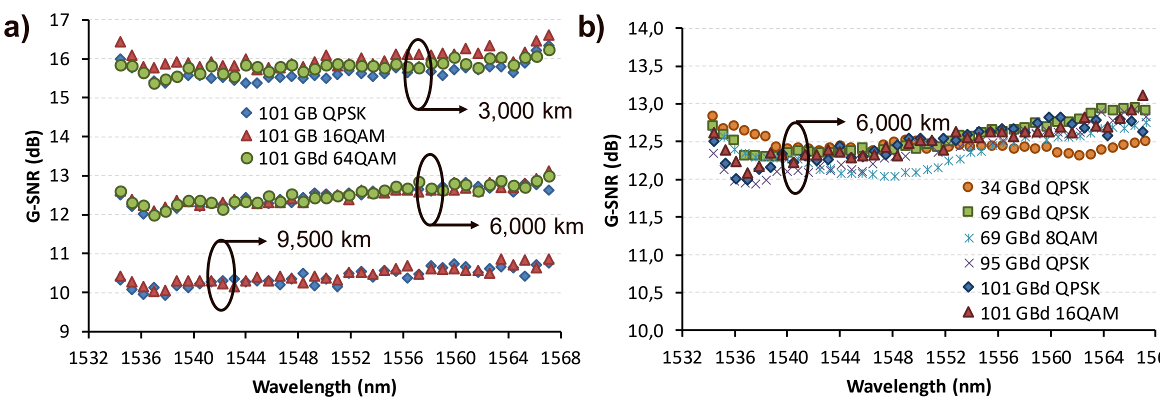

Fig. 4. G-SNR in a) measured after 3,000, 6,000 and 9,500 km for 101 GBd DP-QPSK/DP-8QAM/DP-64QAM and in b) for 34 GBd DP-QPSK, 69 GBd DP-QPSK/DP-8QAM, 95 GBd DP-QPSK and 101 GBd DP-QPSK/DP-16QAM

5. Conclusion

We have measured the OSNR and the G-SNR of three different straight-line testbeds of 3,000, 6,000 and 9,500 km with signals modulated at 101 GBd DP-QPSK/DP-16QAM/DP-64QAM. We observed a very good agreement since the difference in mean values is not higher than 0.15 dB. Finally, we have combined them with previous results showing that the G-SNR of open cable can be estimated with a large range of equipment test configurations: different transponders, symbol rates and modulation formats, with a difference in mean values not higher than 0.39 dB. As far as we are aware, this is the first widescale experimental assessment done to validate the G-SNR for the characterization of open submarine cables. Recent increase of transceivers optical bandwidth has made possible to reduce the number of test channels from 112 to 38. It has permitted to significantly reduce the measurement time, which will be required for fast characterization of G-SNR and OSNR of future SDM-based systems.

6. References

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