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Type of the Paper (Article, Review, Communication, etc.)

Programmable Adaptive S-BVTs for Future Optical Metro Networks Adopting SOA-Based Switching Nodes

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Abstract: Adaptive Sliceable-Bandwidth Variable Transceivers (S-BVTs) are key enabler for future optical networks. In particular, those based on Discrete MultiTone (DMT) modulation and Direct Detection (DD) can be considered a flexible solution suitable to address the cost efficiency requirement of optical metro networks. In this paper, we propose to use this cost-effective S-BVT option/implementation in optical metro networks adopting switching nodes based on Semiconductor Optical Amplifier (SOA) technology. Bit loading (BL) and power loading (PL) algorithms are applied to the Digital Signal Processing (DSP) modules, to maximize the performance and/or the capacity as well as enhance the flexibility and adaptability of the system. Our analysis considers switching nodes based on SOAs with and without filtering elements and fiber spans of 25 km. We present the results up to 100 km, with and without SOA-based nodes. Firstly, we analyze the adaptive BVT transmission using the Margin Adaptive (MA) BL/PL algorithm at a fixed bit rate of 28 Gb/s. The possibility of controlling the SOAs current is a key factor to face the transmission impairments due to the fiber and the filtering elements. We also analyze the system considering Rate Adaptive (RA) transmission at a fixed target BER of $3.8{\cdot}10^{-3}$, showing that a maximum capacity above 34 Gb/s can be achieved for a single span of 25 km. Although the cascading of filtering elements still constitutes a limiting factor, we show that an improvement of the net bit rate performance can be obtained thanks to the combined use of S-BVT and SOA technology at the switching nodes, resulting in a promising approach for designing future optical metro networks.

Keywords: Optical Metro Networks, Sliceable-Bandwidth Variable Transceivers (S-BVT), Orthogonal Frequency Division Multiplexing (OFDM), Semiconductor Optical Amplifier (SOA).

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1. Introduction

New challenges are envisioned for future optical networks in order to cope with the exponential and uncertain growth of internet traffic. Particularly, the metro segment is emerging as the most challenging, due to the stringent requirements of cost-efficiency and reduced power consumption, while offering very high capacity and dynamicity. To address these challenges, optical metro networks need to be equipped with flexible, adaptive and programmable transmission and switching systems able to efficiently manage the available resources as well as the high peak of traffic and adaptive bit rates with cost- and power-efficient solutions [1, 2].

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In particular, in order to overcome the increasing traffic demand, programmable adaptive transceivers have been proposed as a suitable transmission technology [3]. In dynamic future optical networks, adaptability, flexibility and programmability are of great importance, especially if deployed fiber infrastructure wants to be exploited. These requirements can be dealt with Sliceable-Bandwidth Variable Transceivers (S-BVT) [3]. They allow generating multiple flows while suitably and flexibly adapt the transmission in terms of bit rate, modulation formats, bandwidth and reach. Multiple parameters and S-BVT components can be suitably configured on-demand by means of an integration of the transceiver in a Software Defined Networking (SDN) control plane, following the SDN principles [4]. Particularly, an S-BVT based on Orthogonal Frequency Division Multiplexing (OFDM) offers the possibility to manage the capacity/spectrum at the subcarrier level [3, 5, 6]. The S-BVT architecture can be suitably tailored for the metro network segment [7]. For a cost-effective design Discrete MultiTone (DMT) modulation is preferred as the simplest OFDM implementation [5, 6].

Semiconductor Optical Amplifier (SOA) technology can be also advantageously used in elastic optical networks, particularly for the metro segment, where the cost and power consumption are critical issues. In fact, the main advantages of using SOAs are the low power consumption, low cost, small size and the possibility to be integrated with other optical components [8, 9]. On the other hand, SOAs have high noise value compared to EDFA (Erbium Doped Fiber Amplifier) and have residual polarization dependent operation < 1dB [10]. However some studies are focusing on the reduction of this impairments as in [11]. SOAs can be designed to optimally operate as an optical switch, either as a booster amplifier (post-amplifier), inline amplifier or preamplifier [9, 12]. Actually, by carefully adjusting the current injected into SOA, it can be used as an optical amplifier; while by turning on/off the electrical current, the SOA can act as a fast optical gate. Furthermore, SOAs can be used for wavelength selective applications by combining them with wavelength filtering technologies [8, 9]. In this work, we focus on the role of SOAs for optical switching. In particular, we consider SOA-based switching node with and without filtering elements. In the last case, the switching functionalities are performed by the SOAs and can find application also in filterless optical networks [13]. Filterless optical networks are simple network architecture based on passive splitters and combiners avoiding optical filters. Thus, they are more cost-effective than networks adopting filters; however, some functionalities are limited, such as wavelength reuse or capacity at high utilization rates [13, 14]. In [13], a comparison between the filterless option and active switching, in terms of cost and performance, is provided. In the case where SOAs are combined with wavelength filtering technologies, we consider SOA-based wavelength selectors as part of the Optical Add/Drop (OAD) nodes. These nodes have the capacity to insert or drop traffic to the optical network, by means of a SOA array with a splitter, a combiner and filtering elements based on Wavelength Division Multiplexing (WDM) technology [9].

In this paper, we propose a combined use of S-BVT and SOA technologies to design flexible and cost-effective solutions for future optical metro networks. Actually, bit loading (BL) and power loading (PL) algorithms can be implemented in the transceiver Digital Signal Processing (DSP) module, in order to enhance the capacity, adaptability and the resilience towards transmission impairments [5, 6]. We will present our results on the use of S-BVT in the context of elastic optical metro networks with switching nodes based on SOA technology, particularly analyzing the case of a cost-effective implementation of the S-BVT.

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The paper is organized as follows. In Section 2, the S-BVT and its cost-effective implementation are described. Then, in Section 3 further details on optical metro network adopting switching nodes based on SOA technology are provided. In Section 4, we present the proposed system for optical metro networks, adopting S-BVT and SOA technology. The experimental setup and system optimization are presented. In Section 5 the results obtained are discussed for the different analyzed scenarios and finally the conclusions are drawn in Section 6.

2. S-BVT architectures tailored for optical metro networks

The S-BVT is a key element in elastic optical networks since it supports programmable functions and multi-adaptive, software-defined optical transmission. In fact, a multi-rate, multi-format, multi-reach and multi-flow transmission is enabled on-demand with sub- and super-wavelength granularity thanks to the SDN programmability and S-BVT functionalities/capabilities [6]. The slice-ability concept confers more flexibility to the BVT since it implies the capability of aggregating and distributing different flows. Furthermore, the adoption of OFDM at the DSP offers the possibility to load the subcarriers individually, according to the channel profile [3, 5, 6]. Hence, the spectrum can be optimized according to the traffic demand. Figure 1 shows a modular S-BVT architecture composed by N BVT modules. The multiple flows are aggregated/distributed at the output of the array of the N BVTs by an additional element, which can be implemented for example by a bandwidth variable Wavelength Selective Switch (WSS) [6]. Different designs and implementations are possible [7]. For a cost-effective solution, the S-BVT is based on DMT, as the simplest version of the OFDM, and simple direct detection (DD). Despite the simplicity of DMT, the Chromatic Dispersion (CD) can limit the system performance due to the transmission over the fiber [5]. In DMT system, the Hermitian Simmetry (HS) is forced on the input of the Inverse Fast Fourier Transform (IFFT) obtaining a real signal [5]. Thus, the complexity of the DSP module is reduced. The main building blocks of a DMT-based BVT are illustrated in Figure 1. At the Transmitter (Tx), the input data is parallelized. After that, the signal is mapped adapting loading using Binary Phase-Shift Keying (BPSK) and M-ary Quadrature Amplitude Modulation (M-QAM) or with uniform loading, using 4-QAM. According to the signal-to-noise ratio (SNR) profile, estimated at the Receiver (Rx), with a uniform loaded probe signal, the DMT subcarriers are modulated at the transmitter side using BL and PL algorithms. The algorithms can be implemented under two criteria. The Margin Adaptive (MA) criterion considers fixed bit rate and energy minimization and the Rate Adaptive (RA) criterion considers a fixed energy for bit rate maximization [5, 15].

Training Symbols (TS) are added for zero-forcing equalization at the receiver side. Then, the IFFT is performed forcing the HS, the Cyclic Prefix (CP) is included, the signal is serialized (P/S) and finally it is symmetrically clipped (CLIP) [5]. After that, the digital signal is converted from digital to analog by means of a Digital to Analog Converter (DAC). The Tx optoelectronic front-end consists of an external modulator and a Tunable Laser Source (TLS), for arbitrary wavelength selection. At the Rx side, the signal is photo-detected by a DD optoelectronic front-end and converted from analog to digital by an Analog to Digital Converter (ADC). Finally, the signal is processed by the receiver DSP module. Thereby, the signal is firstly parallelized (S/P), then the CP is removed. After that, the FFT is performed considering that the signal has HS, it is equalized and the TS are removed. Finally, the signal is demodulated and serialized to obtain the original data.

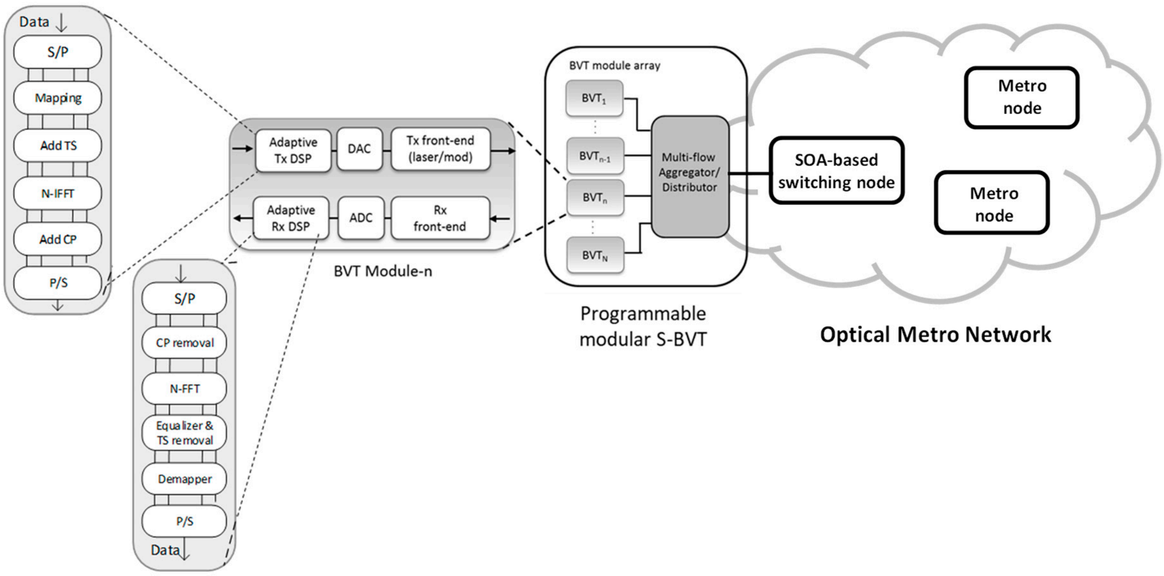

Figure 1. S-BVT architecture based on adaptive DSP using DMT for optical metro networks with SOA-based switching nodes. The S-BVT is programmable and composed by an array of BVT modules.

3. SOA Technology for Optical Metro Network Nodes

SOA technology can be adopted for implementing switching devices. There are other optical switching technologies based on Electro-Optic, Acousto-Optic, Thermo-Optic or Opto-Mechanical switching. The main advantage of SOAs with respect to these other switching technologies is the scalability. In addition, unlike them, when several switches are in cascade, SOAs can control the gain with the injected current and, depending on the node architecture, overcome the limitation due to the power decay. As losses due to the network elements can be compensated thanks to the presence of SOAs, this switching option can be envisioned also for applications in filterless optical networks. This would represent a cost-effective solution [13], as active optical elements are replaced by passive optical elements as combiners or/and splitters to interconnect the fiber links and to add or drop channel wavelengths at the nodes. Some advantages are expected for this networks as simplified maintenance or reconfigurability. However, in a filterless optical network we have to take into account the related drawbacks and limitations. In this scenario, the use of SOA-based switching nodes and S-BVT can be advantageous to compensate the attenuation and CD, due to the passive elements and the transmission over the fiber.

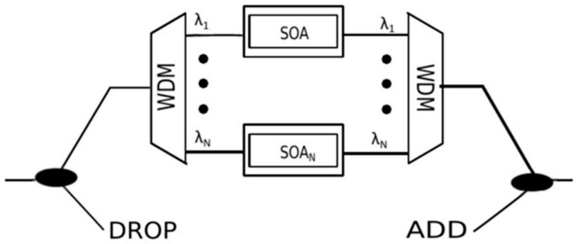

Figure 2. Architecture of a SOA-based OAD node.

On the other hand, a generic filtered optical mesh network is equipped with Optical Add/Drop (OAD) multiplexer, placed at the nodes, enabling to dynamically configure the dropping or adding of different wavelengths through the fiber, remotely. Typically, the reconfigurable OAD nodes adopt WSS technology. Particularly, in the context of elastic optical networks, flexible WSS are needed to deploy a more flexible and bandwidth efficient network [14]. The main disadvantage of this solution is the penalties in signal degradation due to the filter narrowing effect caused by the crossing through a cascade of WSS [14]. The use of S-BVT can flexibly adapt the transmission.

In this work, SOA-based wavelength selectors are considered as the key element in OAD nodes to drop and add traffic in the network [9, 16]. WDM optical cross-connect based on SOA has also been presented in [8] for interconnecting network elements, computing or storage resources in a metro network architecture. In our study, we analyze the performance when the OAD nodes with SOA-based wavelength selectors are included in an optical metro network. The OAD node consists of one splitter, one combiner, the SOA array for gating one or more wavelengths and two wavelength selectors. One acting as multiplexer and the other acting as demultiplexer. The architecture of the SOA-based OAD node can be seen in Figure 2. In this case, losses are generated by the transmission over the fiber links and the filtering elements as well. Adjusting the SOA bias current, the filtering effects mainly due to the wavelength selectors and the losses due to the fiber, can be compensated.

4. S-BVT for optical metro networks adopting SOA technology: experimental set-up and optimization

We propose to adopt the S-BVT described in Sec. 2 for optical metro networks adopting SOA-based switching nodes. In particular, the simplest S-BVT architecture using DMT and DD is considered attractive for a cost-effective implementation and, thus, it is envisioned to be used when SOA technology is adopted.

In order to analyze the performance of this approach, two scenarios are considered as shown in Fig. 3. Both scenarios take into account spans of 25km of fiber and different cascading nodes; scenario a) envisions the use of a simple SOA acting as switching node, while scenario b) introduces OAD nodes based on SOA technology, as specified in Fig. 2 and Sec. 3. As a reference, the case of multiple (up to 4) fiber spools of 25km, without any SOA is analyzed as well. The scenario without considering filtering elements (filterless) is analyzed to study the impact on the system performance at different transmission distances with and without SOAs. Then, we analyze the case of SOA-based OAD nodes after each span of fiber.

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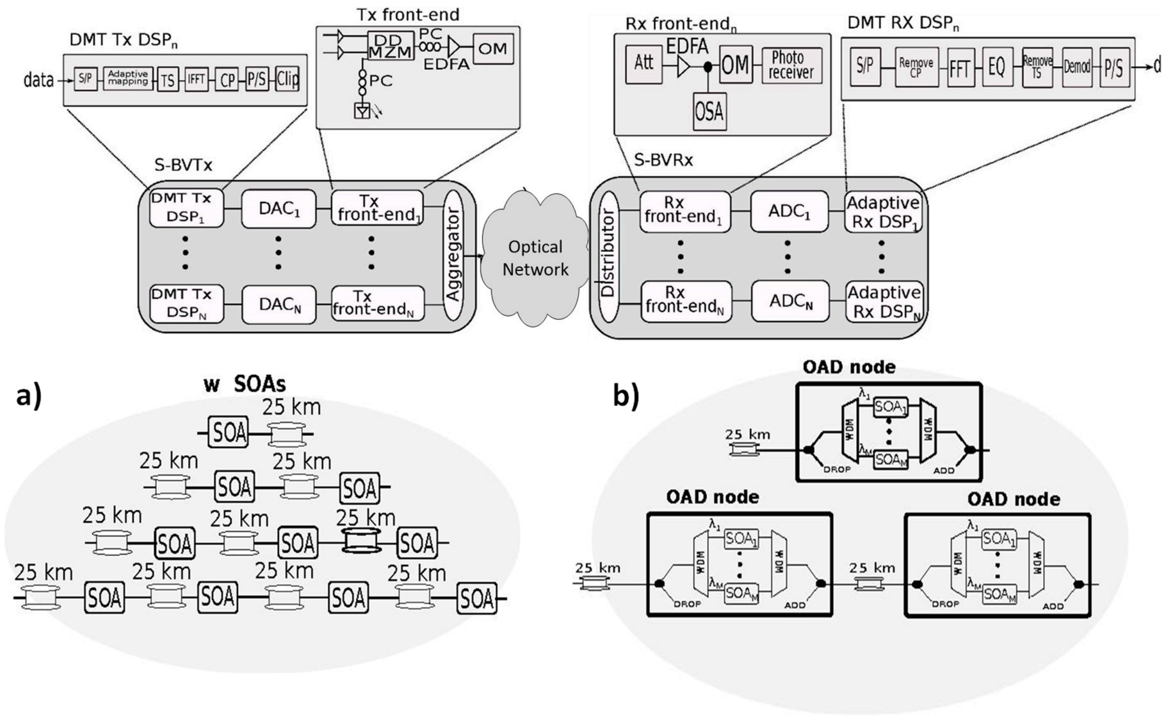

Figure 3. S-BVT architecture and experimental set-up. OM: optical power monitoring, Att: Attenuator, OSA: Optical Spectrum Analyzer, EQ: Equalizer. The different analyzed scenarios for the optical metro network are indicated: a) with SOAs and 25km SSMF spools, and b) with OAD nodes based on SOAs.

To experimentally analyze the proposed system, the setup of Figure 2 has been considered. A single BVT, based on DMT and DD, transmits over the cascading of fiber spools of 25km and SOA-based switching nodes according to scenario a) or scenario b).

Python software has been used at the DSP module. The IFFT with 512 subcarriers modulates the mapped sequence. Due to the HS, only half of the IFFT subcarriers supports data. The total number of frames is 125 being 5 of them TS. The CP is 1.9% and the Forward Error Correction (FEC) considered is 7%. As it is well-known, the clipping factor can cause distortions and the degradation of the system performance. For this reason, the best clipping level should be selected according to the adopted constellation format. To estimate the channel profile, uniform loading is adopted, in particular 4-QAM. The clipping level recommended for this modulation format is 7dB, which corresponds to a clipping factor of 2.24. When other modulation formats are used, 7dB can be not enough. The clipping level must be selected according to the highest modulation format, when bit loading is used. In our case, the highest modulation format used in this experiment is 16-QAM. Accordingly, we have determined that the best clipping level is 8.5dB giving a clipping factor of 2.6. The sample rate of the DAC is 28GS/s.

The obtained electrical signal is the input of a Dual Drive Mach-Zehnder Modulator (DD-MZM). The DD-MZM is working in the push-pull operation. The laser driving the DD-MZM is centered at 1550.12nm with 13dBm of output power. As the DD-MZM is polarization dependent, a Polarization Controller (PC) is needed in order to obtain the maximum power of the laser driving the DD-MZM. Another PC is at the output of the DD-MZM. With those PCs we can control the power at the input of the EDFA, obtaining a power value of 1.5dBm at the input and 13dBm at the output of the EDFA.

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Then, the power launched to the network is measured by an optical power monitor (OM). At the receiver, an attenuator followed by an EDFA is used to vary the OSNR. After that, another OM is placed for being able to ensure a constant power at the input of the photodetector. The sample rate of the ADC is 80GS/s. The OSNR is measured within 0.1nm and the target BER is set to $3.8 \cdot 10^{-3}$. The fiber spans are Single Standard Mode Fiber (SSMF) of 25 km each, with 0.2dB/km of attenuation.

A probe signal modulated with uniform loading (4-QAM) is sent to the channel in order to estimate the SNR profile at the receiver side. To calculate the SNR, a sliding window method is used. We name the number of samples taken after or before the subcarrier considered, as Window Size (WS). The total number of the subcarriers considered for calculating the mean is given by TW = WS 2+1 where TW is the total size of the window. Figure 4 shows the optimization for 75km (3 spans of 25km of SSMF). We can see that the minimum BER is achieved by a window size of 4 (meaning 4 subcarriers taken after and 4 subcarriers taken before the subcarrier considered) that corresponds to a TW size of 9.

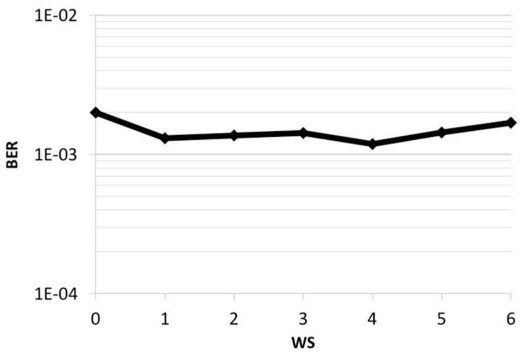

Figure 4. BER versus WS for 75km (3 spans of 25km of SSMF) and OSNR of 36dB without considering any SOA placed inline.

As an example, the SNR estimation for the different scenarios with and without SOAs and with SOA-based OAD is shown in Figure 5a considering two spans of 25km for a total of 50km of fiber. There it is possible to observe a degradation of the SNR around the 156th subcarrier, which is due to the CD. This attenuation depends on the fiber length and appears at certain frequencies that are given by the expression

$$f^n = \sqrt{\frac{\frac{c(2n-1)}{2\lambda^2}}{LD}}, \quad (1)$$

being c the speed of light, λ the center wavelength, L the fiber length, D the dispersion parameter and n the n-th attenuation peak (positive integer).

When the SOAs are included, this peak suffers a shift of around 10 subcarriers towards the lower frequencies. The maximum obtained SNR decreases 1dB, but the SNR profile is similar. This frequency shift, with respect to the theoretical frequency, is due to the variation of the injected current of the SOAs to find the best working point. In our case study, the best conditions are achieved for a SOA input power of -8dBm and an injected current within 60mA and 80mA.

When the SNR profile is estimated for the case using SOA-based OAD nodes, the maximum SNR decreases down to 14dB, and the fading frequency peak is shifted to higher frequencies, where

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the minimum SNR is about 6.5dB. In this case, the cascading of network elements, in particular the presence of filtering elements, causes the reduction of the obtained SNR for all the subcarriers and the shift of the fading peak. Indeed, for this case, the peak fading is not so pronounced as in the case without filtering elements and it covers a greater number of subcarriers (from the 120th to the 200th approximately).

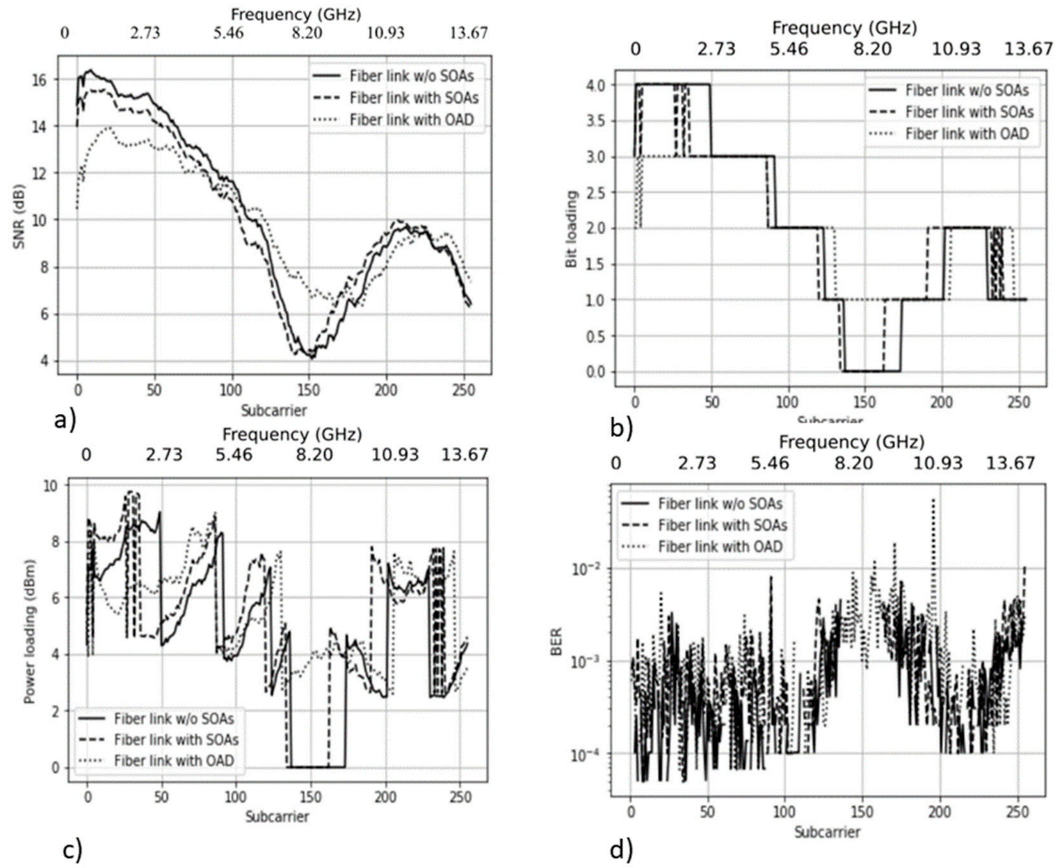

Figure 5. a) SNR profile, b) BL assignment, c) PL assignment and d) BER per DMT subcarrier considering MA transmission at 28Gb/s over two SSMF spans of 25km, with and without SOAs and for SOA-based OAD, at 34dB of OSNR.

According to the SNR profile, the subcarriers for each scenario are modulated at the transmitter side using BL/PL algorithms. Figure 5b shows the bit distribution according to the SNR estimation in Figure 5a and considering the MA criterion with a fixed gross bit rate of 28Gb/s at 34dB of OSNR. It can be seen that the modulation format order decreases with the reduction of the SNR values and increases with the increase of the SNR values. For the OAD scenario, since the SNR profile is more affected by the fiber impairments and the filtering elements, lower bits per symbol are loaded onto the subcarriers. In Figure 5c, the power loading distribution according to the SNR profile is presented. It can be seen that the subcarriers corresponding to the lower SNR values for the case with SOAs do not have power assigned. For the OAD scenario, all the subcarriers have power assigned and the power variation corresponds to the change from one modulation format to another. In Figure 5d, the BER per subcarrier for the different analyzed cases is reported. We can observe that for the OAD scenario, the subcarriers affected by CD present high number of errors.

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5. Results and Discussion

As shown in Figure 3 and detailed in Sec. 4, the experimental analysis considers two scenarios: the first using simple SOAs acting as switching nodes and the second adopting OAD nodes based on SOA technology. Fiber spans of 25km until a maximum of 4, for a total path of 100km, are considered. In particular, in order to observe the impact of adopting the SOAs in the system, we place an SOA after each span of fiber and compare the results with the transmission over the fiber link without them. To analyze the second scenario, we consider SOA-based switching nodes based on the OAD node architecture of Figure 2. For both scenarios, the current injected into the SOA is properly varied to compensate the losses due to the fiber impairments or/and the different elements (splitters, combiners, filtering elements) of the OAD node.

First of all, we analyze the case at fixed bit rate (28Gb/s) using the MA BL/PL algorithm for maximizing the performance. The BER performance at the varying of the OSNR is presented in Figure 6. It is interesting to observe that a similar behavior is obtained for 75km (3 spans) of fiber without SOAs, 50km (2 spans) of fiber with an SOA after each span and one fiber span of 25km with an OAD node, being the difference between these cases lower than 1dB at the target BER of $3.8 \cdot 10^{-3}$. Similar results are obtained when we compare the BER curves for 100km (4 spans) of fiber, 75km (3 spans) of fiber with an SOA per each span and 50 km (2 spans) of fiber including 2 OAD nodes (one after each span), being as well the penalty less than 1dB, at the target BER. Up to 100km reach (4 fiber spans) can be achieved cascading 4 SOAs with an OSNR value of 33dB. While, it was not possible to retrieve results after 75km (3 spans) with the OAD nodes because of the losses accumulation, mainly due to the filtering elements, and the noise introduced by additional SOAs.

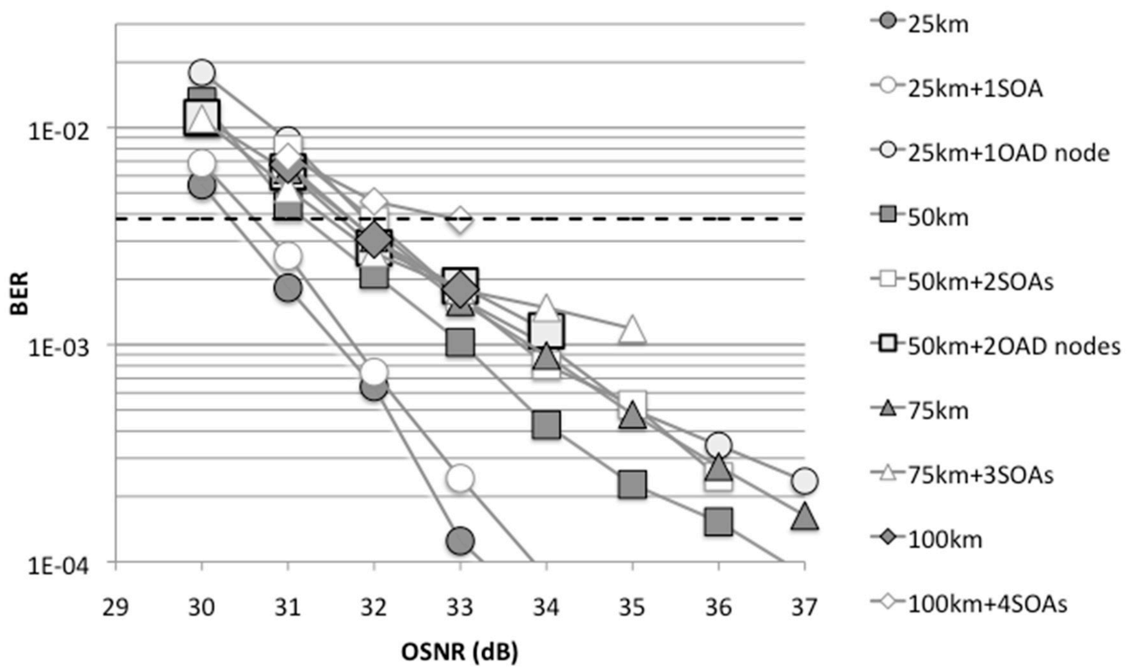

Figure 6. BER versus OSNR (with and without SOAs and including SOA-based OAD nodes) using BL and PL under the MA criteria for a fixed gross bit rate of 28Gb/s.

Then, we have studied the maximum achievable net bit rate, adopting the RA BL/PL algorithm, for different transmission distances and scenarios. In Figure 7, the results at 33dB of OSNR, are presented. We can see that, as the fiber length increases, the maximum net bit rate decreases, being

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this decreasing more pronounced for the case of fiber transmission without SOAs. In fact, for the 50km (2 spans) of fiber, the maximum net bit rate is obtained when 2 SOAs or 2 SOA-based OAD nodes are included in the optical path, obtaining 26.5Gb/s. The value of the net bit rate when only 2 spans of fiber are placed inline, is lower, being its value 26.1Gb/s. So, the introduction of the SOAs, as switching nodes themselves or either as part of the OAD node, improves the net bit rate performance at least for fiber links higher than 50km. This is due to the possibility of better optimizing the transmission by controlling the SOAs in combination to the transceiver adaptability by means of the BL/PL algorithm. According to the obtained results, a 25Gb/s connection can be supported up to 50km considering 2 cascading SOA-based OAD nodes and up to 75km considering 3 cascading SOAs without filtering elements.

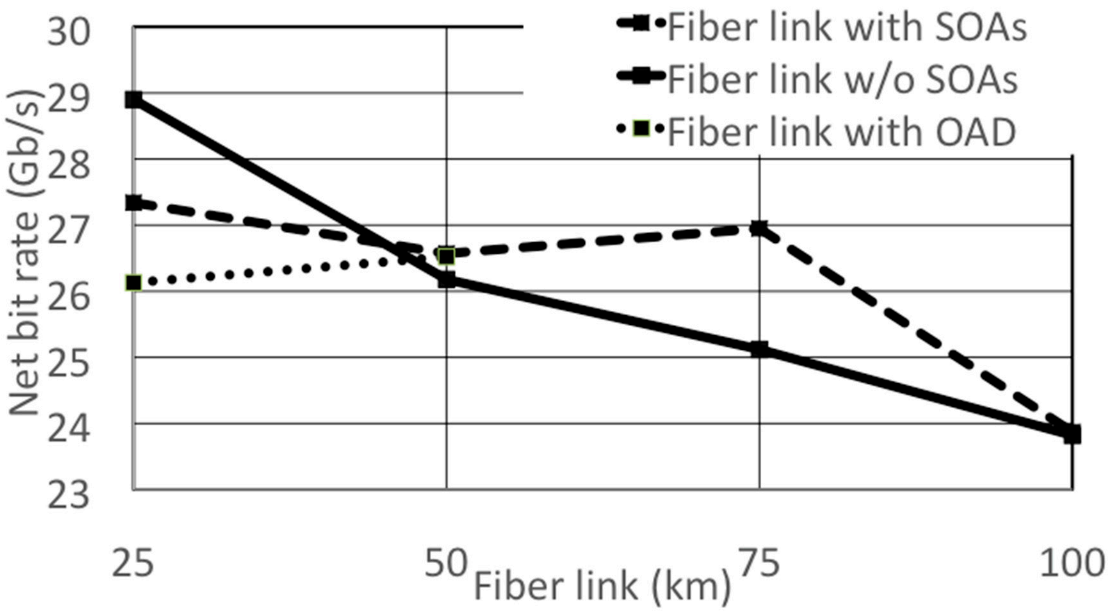

Figure 7. Net bit rate versus fiber link (with and without SOAs and including SOA-based OAD nodes), using RA BL/PL algorithm, for an OSNR of 33dB at a target BER of 3.8 10^{-3}.

Table 1 shows the maximum achievable net data rate at different transmission distances for the considered scenarios adopting RA BL/PL. Note that the maximum net bit rate of 37.32Gb/s is achieved for 25km of fiber when the SOAs are not included. On the other hand, the net bit rate penalty between the cases of 25km of fiber and 100km of fiber is greater (12.25Gb/s of difference) when the SOAs are not included than when the SOAs are added (10.7Gb/s of difference). So, there is a reduction of the penalties, when SOAs are included.

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Table 1. Achievable net bit rate and maximum OSNR for different transmission distances using RA BL/PL algorithm, for different fiber link with and without SOAs and considering SOA-based OAD.

	Fiber link w/o SOAs	Fiber link with SOAs	Fiber link with OAD
Reach (km)	Net bit rate (Gb/s)	Net bit rate (Gb/s)	Net bit rate (Gb/s)[1]
25	37.32	34.57	34.77
50	33	31.78	27.97
75	31.4	27.68	-
100	25.07	23.87	-

In case of considering SOA-based OAD nodes, the net bit rate decrease is greater than the case of using only SOAs. However, the maximum net bit rate achievable after 25km of fiber is similar: 34.57Gb/s and 34.77Gb/s, with a simple additional SOA or including an OAD node, respectively

In Figure 8 (a) and (b) the net bit rate versus the OSNR for 25km and 50km of fiber are presented. It can be observed that the overlapping between the results of the different scenarios is higher when 2 spans (50km) of fiber are considered. This is due to the increase of the number of elements in the optical network, either SOAs acting as switching nodes or AOD nodes. In fact, this enables the possibility to suitably manage (and carefully adjust) the SOAs bias current. As a consequence, the system performance can be better optimized. Actually, for 50km of transmission distance, there is an improvement of the performance when 2 OAD nodes are included (it is maximum at 31dB of OSNR) with respect to the case of fiber spans without using SOAs. Unfortunately, in this experiment, it has not been possible to further increase the cascading of more OAD nodes due to the cumulative losses and noise introduced in the system.

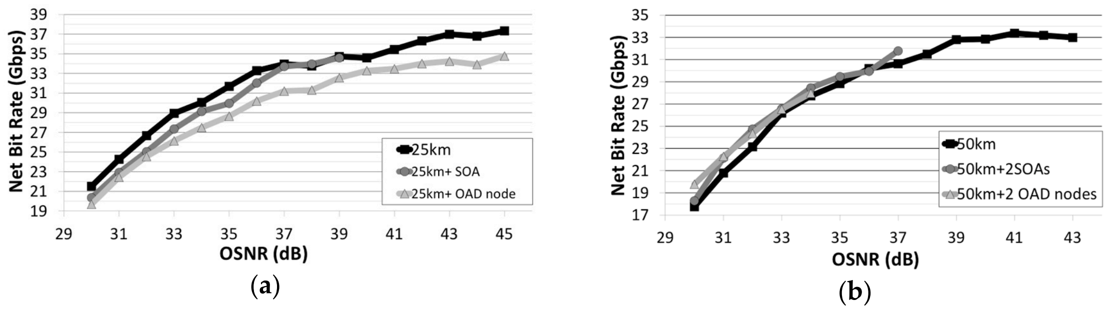

Figure 8. Net bit rate versus OSNR for (a) 25km and (b) 50km for the different scenarios at the target BER.

6. Conclusions

In this paper, the use of S-BVTs, based on DMT modulation and DD, with adaptive loading capabilities has been proposed as a flexible and adaptive cost-effective solution for optical metro networks adopting SOA-based switching nodes. This system has been experimentally assessed considering two scenarios: with or without filtering elements. Using loading algorithms for both scenarios the limitations due to transmission impairments (caused by the CD, DAC bandwidth or the network elements) can be mitigated enabling higher transmission rates and reach.

When BL and PL algorithms are implemented using the MA criterion, the results show that the BER performance obtained for a 25km of fiber link with an SOA-based OAD node has similar BER performance than the case of 50km (2 spans of 25km) of fiber with 2 SOAs acting as switching nodes, or the case of 75km (3 spans) of fiber. Thus, the introduction of the SOAs or the OAD node, in terms

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of BER performance, results as if an additional span of 25km of fiber is included.

On the other hand, using the RA criterion, the net bit rate performance improves including SOA elements in the transmission system, compared to the case of simply adding fiber spans. This is due to the possibility of controlling the SOA current to face the transmission impairments. Thus, as the number of SOA-based switching nodes increases, more SOA elements can be controlled, to ensure a better optimization of the system and an improvement of the performance. However, adding SOAs or/and filtering elements limits the maximum achievable OSNR and thus the number of cascading nodes that can be traversed by the adaptive signal generated by the S-BVT. In particular, 25Gb/s connections can be supported up to 75km including 3 SOAs acting as switching nodes without any filtering element, while 50km is the maximum achievable reach including 2 OAD nodes.

The experimental assessment demonstrates that thanks to the possibility of controlling the injected current to the SOAs and the application of loading schemes at the adaptive transceivers, high flexibility, scalability and adaptability can be obtained. Monitoring techniques and the SDN paradigm play a key role to enable these features. The combination of the proposed cost-effective implementation of programmable (SDN-enabled) S-BVT and SOA-based switching nodes seems to be promising to be further investigated in order to address the challenges of future optical metro networks.

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