Performance Evaluation of O-band OADM-based Optical Distribution Networks at 50Gb/s and 100Gb/s PAM-4

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Abstract *We assess the performance of transparent and data-rate adaptive aggregation network with cascaded O-band OADM nodes. Experimental results show transmission of single-wavelength pluggable 100Gb/s Ethernet traffic and 50Gb/s PAM-4 SER with power penalty < 3dB and 2.5dB across 2 and 3 nodes (30km and 40km),respectively.* ©2023 The Author(s)

Introduction

The rapid growth of applications with high bandwidth and stringent latency requirements has prompted the need for a redesign of optical networks to ensure optimal performance and costs. These applications often demand real-time response, given low latency a critical factor, as well as variable bandwidth capacity. This will change the way optical network infrastructures will transport high and variable capacity data from the access points and aggregation nodes to close by (a few tens of km) edge computing nodes and the distribution of data back to the access points.

Typical optical distribution network is based on horseshoe architecture with passive or active OADM (optical add-drop multiplexer) network elements and protection mechanism (see Fig. 1a). Although the distance is limited to a few tens of kilometres, the amount of access points can introduce substantial losses to be compensated by optical amplifier, also considering the lower received sensitivity at high data rate. Indeed, current data rate is 25 Gb/s and WDM is used for scaling the capacity. This is expected to scale to multiple 50 Gb/s and 100 Gb/s in the near future. One possible option is to use PAM modulation format as trade off cost for short reach with respect to coherent technology. However, as the data rate is moving to 50 and 100 Gb/s, even for short distance, dispersion is clearly a limiting factor in C-band transmission. Besides, O-band features a very low chromatic dispersion, therefore can be a good candidate for high data rate and short link communication (as for the short link the fibre losses are not the limiting factor). This has also pushed industry to standardize and commercialize O-band transceivers at 100G PAM 4 for 20 km duplex and 400GBASE-LR8 (8x50G based on 25Gbaud PAM-4).

Therefore, the implementation of horseshoe based optical distribution network architecture using O-band transmission is an interesting alternative to be investigated. However, to implement such architecture, O-band OADM network elements and optical amplifiers are required. O-band semiconductor optical amplifiers (SOAs) are possible solution to address the optical amplification as well as used as switching element for implementing an O-band OADM with similar architecture as the one demonstrated for the C-band [1].

In this architecture, SOAs can compensate for optical losses [2] and have the potential to be integrated in PICs (photonic integrated chips) [2] for low cost and volume. A network architecture with SOA-based OADMs allows for the transparent connection of multiple endpoints to the horseshoe as depicted in Fig. 1a. This flexibility in connecting nodes as well as the a drop and continue capability of the OADM node enables more efficient use of network resources (wavelength channels) and facilitates the rapid deployment of new services in a cost effective manner. Additionally, it helps improve the overall scalability of the network architecture. However, the usage of SOA-based optical switches also introduces challenges such as noise and non-

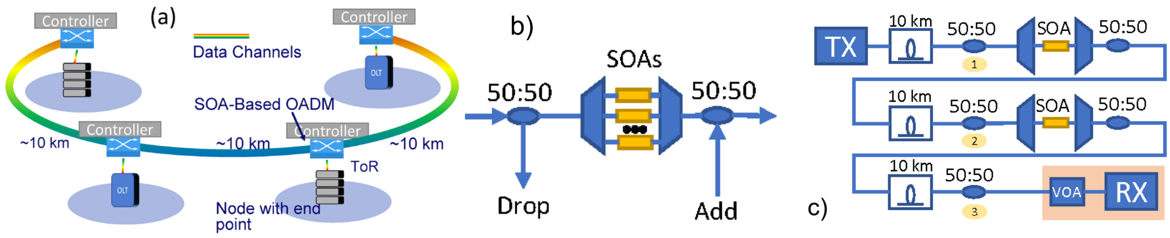

Fig. 1: (a) Network in horseshoe topology, (b) OADM detail and (c) experimental setup.

linearities, which must be carefully managed to maintain overall network performance. Therefore the scalability of this architecture is critical aspect to be assessed with PAM signals crosses multiple nodes and data rates increase above 50 Gb/s.

In this work we experimentally assess the performance of cascaded O-band OADM nodes based on SOA amplifiers/switches with variable 50G and 100G PAM-4 data to implement a network architecture suitable for transparent and low-latency connections. Experimental results show transmission of single-wavelength pluggable 100 Gb/s Ethernet traffic and 50 Gb/s PAM-4 SER with power penalty < 3 dB and 2.5 dB across 1 and 2 nodes (20km and 30km), respectively. In case of 25 Gb/s NRZ, a power penalty < 2.5 dB at 10^{-9} was achieved after 3 nodes (40 km).

Network Architecture

The horseshoe network architecture that connect end points such as edge computing nodes to access points as depicted in Fig. 1a (protection is not included in this work). The interconnect network comprises nodes with network interfaces responsible for aggregating data flows from access points, for example optical line terminals (OLTs) and top-of-rack (ToR) switches. Data flows can traverse the network transparently between nodes, depending on the configuration of the SOA-based OADMs.

The node architecture is as follows: at each node's entrance, a splitter divides the traffic into two categories: traffic to be dropped and traffic that will traverse the node. The SOA-based OADM is composed by the combination of two arrayed waveguide gratings (AWGs) in a demux-mux configuration, along with SOAs situated between them, form a wavelength blocker (WBL) element. The first AWG in the WBL separates wavelengths, directing them to multiple SOAs functioning as gating elements. Consequently, each SOA receives only one wavelength, enabling the architecture to operate on a per-wavelength basis. This per-wavelength approach enables wavelength reutilisation in the network. Besides blocking the wavelengths, the SOAs also provide gain to compensate for the losses in the fibre spans and in other elements of the node.

A fast optical switch controller governs the SOAs, which can be turned on and off to allow for wavelength reuse in the network once a channel is dropped at a node, and also to set different modulation formats for the transmission [4].

Following the 1x2 splitter at the node entrance, the flows are dropped to the receivers within the node, constituting the drop section of the architecture. A 1x2 combiner merges the optical flows that bypassed the node with those originating at the node. It is assumed that the node controller can prevent potential contentions when adding optical flows to the network.

When transmission takes place between adjacent nodes, the total losses are the losses of the combiners in the add section of the source node, the splitters of the drop section of the destination node, and the fibre span. Note that the SOAs in the OADM provide gain to compensate all losses. The gain of the SOA as function of the optical input power and applied current is shown in Fig. 2 (25 °C, 1302 nm). The linear gain is about 20 dB which compensate the OADM passive components losses (around 12 dB) and also the fibre span.

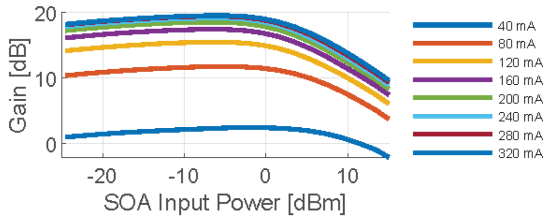

Fig. 2: Gain vs input power characteristics of the SOA

Experimental Evaluation

The experimental setup is shown in Fig. 1c. We conducted a series of experiments using a signal quality analyser and an Ethernet traffic analyser. Our experiments focused on analysing the network's performance under two different conditions: PAM-4 modulation at 50 Gb/s and PAM-4 modulation at 100 Gb/s, both operating at a wavelength of 1310 nm. Between the nodes there are 10 km of fibre.

First, we utilized a signal quality analyser to assess the transparent network's performance with PAM-4 modulation at a data rate of 50 Gb/s. We measured key parameters such the symbol error rate (SER), and eye diagrams, which provided valuable information about the network's capability to maintain high-quality data transmission under these conditions. This was done for the scenarios of transmissions up to 3 OADM nodes crossed (40 km of fibre).

Next, we employed an Ethernet traffic analyser to evaluate the network's performance using 1310 nm commercial bidirectional transceivers at a data rate of 100 Gb/s also employing PAM-4 modulation. Note that these 100 Gb/s PAM-4 transceivers are certified to operate properly up to 20 km which means 2x10 km fibre spans and one OADM node. This experiment aimed to assess the network's ability to handle real-world Ethernet traffic at a higher data rate while maintaining reliable and efficient

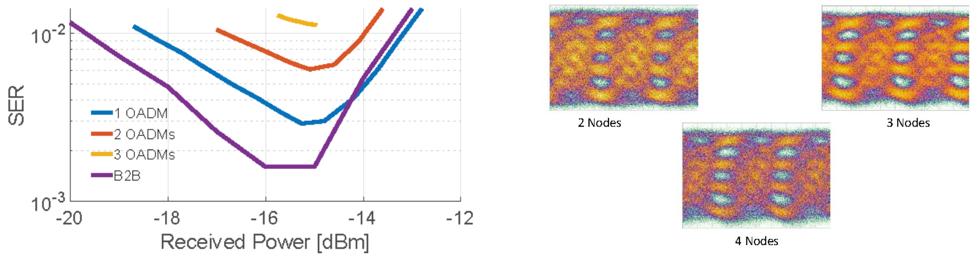

Fig. 3: (a) BER performance at 50 Gb/s PAM-4 and (b) eye diagrams.

data transmission. We monitored the packet error rate to determine the network's overall performance and stability under these conditions.

Results

Fig. 3a shows the SER performance at 50 Gbit/s PAM-4 for crossing up to 3 OADM nodes and thus 4x10 km fibre spans. We see that for the cases were 1 or 2 OADMs (20 and 30 km) were crossed, the SER remains under 10^{-2} in a power range of 5.5 dB and 3 dB, respectively. However, for 3 OADMs (40km), the BER remains just above the 10^{-2} threshold. It has been measured a 1.2-dB penalty at the SER of 10^{-2} for 1 OADM node crossed with respect to the B2B curve. There's an additional 1.3-dB penalty at 10^{-2} SER when the data flow crosses another OADM node and 10 km more of fibre. For the transmission crossing 3 OADM nodes (4x10km), it was not possible to obtain SERs below 10^{-2}. For comparison we have also reported in Fig. 4 the transmission in the same scenario but with 25Gb/s NZR to cross 3 OADMs (40 km). Results show that error-free transmission with power penalty < 2.5 dB.

Fig. 5 shows the packet error rate obtained by using the 100 Gbit/s commercial transceivers and an Ethernet traffic analyser. For the cases of 10 km only (no OADM) and 1 OADM node crossed (20km), we managed to achieve zero packet loss ratio. For the case of 2 OADMs crossed (30 km), it was not possible to achieve a packet error ratio below 10^{-5}. A packet error rate limit of $1.2\text{x}10^{-5}$ corresponds to BER limit of $1\text{x}10^{-9}$ with ethernet packets with a frame length of 1450 bytes. Note that in this case we were bridging a distance beyond the 20 km for which the transceivers were designed.

The results demonstrate that the transparency

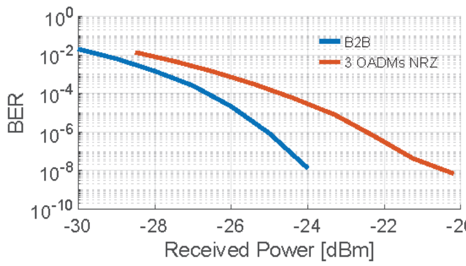

Fig. 4: BER for 3 OADM crossings with 25G NZR

of network up to 2 OADM (30km) crossings for 50G b/s or 100G b/s PAM-4 modulation with a penalty of 2.5 dB employing the commercial transceiver with certified operation up to 20km. Beyond 2 nodes (>30 km), a different transceiver with extended reach or a modulation format like 25G b/s NZR should be used. This extended reach can be achieved through reconfiguration via a supervisory channel. In this experiment, CWDM filters were used in O-band but considering higher possible number of channels, with DWDM filters results could be improved by improved filtering of ASE noise.

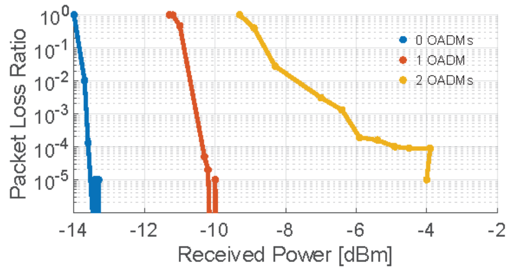

Fig. 5: Packet Error Rate for 0, 1 and 2 OADMs crossed

Conclusions

We experimentally evaluated the performance of cascaded O-band OADM nodes based on SOA amplifiers/switches with variable 50 Gbit/s and 100 Gbit/s PAM-4 data.

The results demonstrate that the transparency of network up to 2 node (30km) crossings for 50 Gbit/s or 100 Gbit/s PAM-4 modulation with power penalty < 3 dB and 2.5 dB across 2 and 3 nodes (30km and 40km), respectively. . Beyond 2 OADMs crossed (>30 km), a different transceiver with extended reach or a modulation format more robust to noise such as 25 Gbit/s NZR should be used.

Acknowledgements

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