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O, S, C and L-band SOA-based OADM nodes in Metro Networks

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Abstract *SOA-based O, S, C and L-band OADMs are experimentally verified for providing optical transparency between metro aggregation nodes and far-edge OLTs. Results with 28 GBd PAM-4 transmission show operation below the FEC-threshold for up to 3 nodes and 24 km of SMF in the C-band. ©2022 The Author(s)*

Introduction

Boosted by the heterogeneous traffic generated by Edge Computing, 5G, IoT, massive machine-to-machine communications and industry 4.0[1], metro and access networks requirements in terms of capacity, flexibility and latency are becoming more demanding. Therefore, metro networks will need to adapt and provide dynamic and programmable optical transmission and switching systems to serve multiple network functions virtualization (NFV) applications such as virtual base band units (vBBUs), content delivery networks (CDNs), among others.

A promising approach to adapt do these requirements is by providing an optical continuum between metro and the access far edge and computing nodes, exploiting the transparency and programmability offered by the optical add-drop multiplexers (OADMs), as shown in Fig. 1. By providing this optical transparency between different layers of the optical network, several services that require a low and deterministic latency can be allocated further away in remote virtualized DCs, as optical wavelength switching is capable of providing a deterministic latency between optical nodes. Also, the costs and power consumption associated with the deployment of these network nodes can be reduced by eliminating expensive electronic aggregation switches. However, as the network grows with more antennas and very high bandwidth demands (in the next 6G generation, predictions indicate needs ranging from 100 Gb/s to 1 Tb/s per cell), there could be the situation where the limited optical channels in the C-band are not sufficient to support the capacity demand as well as enabling the desired optical continuum. A possible solution is the use of the Multi-band (MB) optical low-loss spectra of single-mode fiber (SMF) fibers, from 1260 nm to 1625 nm[2],[3], to increase the capacity of the networks and also provide optical transparency between the metro access networks while minimizing the occurrence of wavelength contention given the large number of optical channels available in the MB spectra.

The implementation of such transparent MB networks, requires advanced MB-OADMs that are able to transparently bypass, drop or add the MB channels. Several MB devices suitable for the OADM composition were proposed and demonstrated in[4]–[7], but suffered low extinction ratio (ER), high insertion losses (ILs) and polarization-dependent loss (PDL), making extra amplification stages necessary in the network.

In this work, we present a lossless semiconductor optical amplifier (SOA) based MB-OADM, operating in the O, S, C and L-bands suitable for the transparent and programmable metro-access networks nodes and prone to Photonic Integration as shown in previously C-band only works[8]. The operation of the MB-OADM is investigated in the context of the network depicted in Fig. 1, for optical paths corresponding to communications between regional DCs and Metro-DCs, communications between Remote radio-units (RUs) and Metro-DCs, and communications between remote dedicated business link and Metro-DC, all without additional in-line erbium-doped fiber amplifiers (EDFAs), and supporting all the remote virtualized network functions and other services already presented.

Our experimental validation was conducted for a total of 16 channels (4 in each band), each modulated by pulse-amplitude modulation (PAM)-4 at 28 GBd and the number of errors was kept below the forward error correction (FEC) threshold of 3.84×10^{-3} for up to three traversed OADMs and 24 km of SMF.

Multi-band OADM Operation

The schematic of the MB-OADM used in the metro network experimentn is depicted in Fig. 2. Tunable lasers sources in the O, S, C and L-bands are configured for channels 1295.56 nm, 1300.05 nm, 1304.58 nm

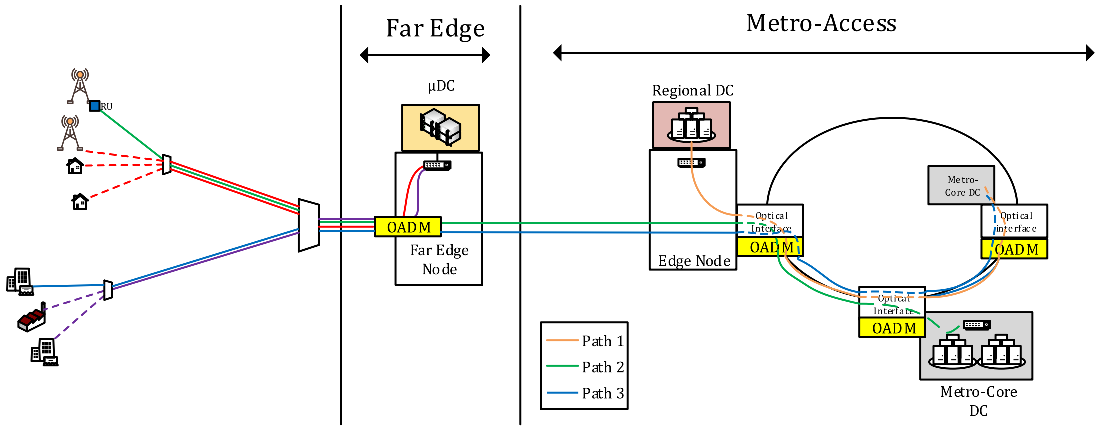

Fig. 1: Metro access networks (MAN) reference architecture with dynamic optical continuum paths between metro core elements and other layers of the network.

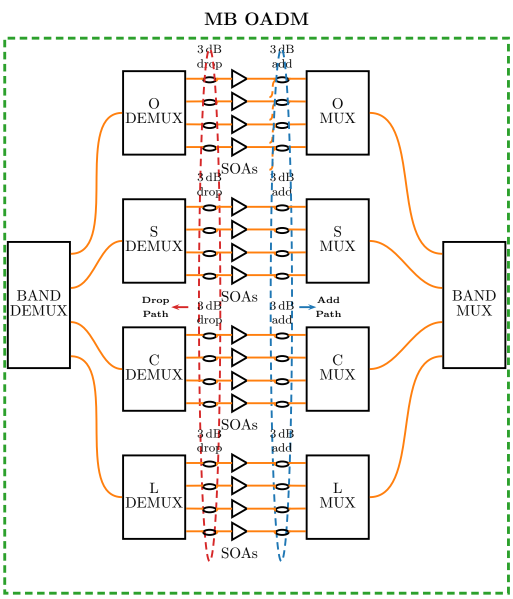

Fig. 2: Experimental setup for the MB-OADM.

and 1309.14 nm in the O-band, 1510.04 nm, 1511.63 nm, 1513.22 nm and 1514.78 nm in the S-band, 1555.75 nm, 1556.56 nm, 1557.36 nm and 1558.17 nm in the C-band and 1590.32 nm, 1592.00 nm, 1593.68 nm and 1595.28 nm in the L-band. The channels for the S and L-bands were chosen based on the operation region of the wideband SOA as shown in Fig. 3 and for matching the channels of the available arrayed-waveguide gratings (AWGs) used as multiplexers and demultiplexers. The O and C-band channels were chosen based on the Local-Area-Network Wavelength Division Multiplexing (LWDM) and dense wavelength-division multiplexing (DWDM) grids respectively. After the lasers, Mach-Zehnder modulators (MZMs) modulates the continuous wave signal with 28 GBd 4 level PAM data streams with a pseudorandom bit sequence (PRBS) length of $2^{15}-1$.

The first OADM block is located after a SMF span of 16 km. It consists of a band demultiplexer and multiplexer used to separate and combine the input MB signals, the used band demultiplexer/multiplexer are comprised of fused fiber WDM splitters[9]. After band separation SOA-based O, S, C and L-bands OADMs are used to control each channel in each band. The SOA-based OADM consists of a demultiplexer to separate the single band signals into individual channels, an array of SOAs that selectively and dynamically blocks or passes each channel, and a multiplexer for combining the channels. The SOAs partially compensate the muxes/demuxes losses as well as the losses in the optical links. The drop stages are realized by a 3 dB splitter before each SOA and the add stages are realized in the same manner after the SOA and before the multiplexing stages.

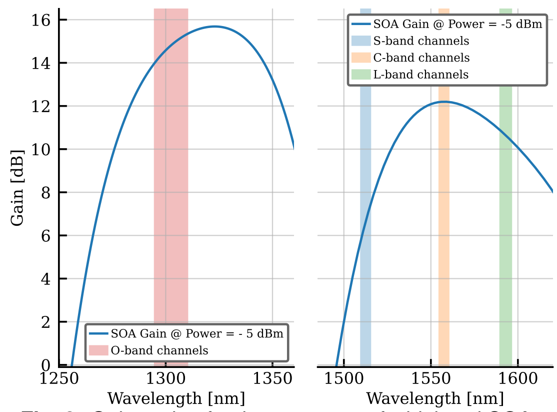

Fig. 3: Gain region for the two types of wideband SOAs employed in this work.

Experimental Results

Three scenarios were considered for evaluating the performance of the proposed solution. The first one, Path 1, corresponds to communications between Regional-DC and metro-DC, with one traversed MB-OADM and 16 km of SMF. The second one, Path 2, corresponds to remote-RUC to

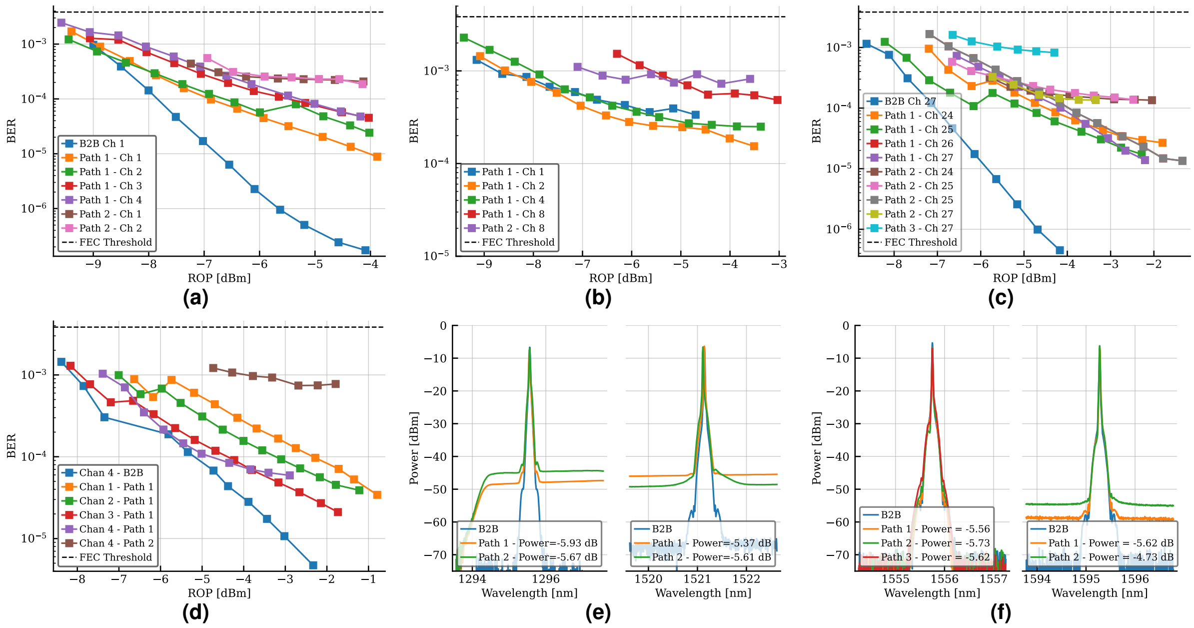

Fig. 4: Fig. 4a O-band BER results. Fig. 4b S-band BER results. Fig. 4c C-band BER results. Fig. 4d L-band BER results. Fig. 4e The received signal spectra for the O and S bands. Fig. 4f The received signal spectra for the C and L-bands.

metro-DC communications, with 2 traversed MB-OADMs and two spans of SMF of 16 km and 6 km. The last scenario, Path 3, corresponds to communications between a dedicated business link and another metro-DC, with 3 traversed MB-OADM nodes and SMF spans of 16 km, 6 km and 1.6 km. These optical paths are highlighted in Fig. 1.

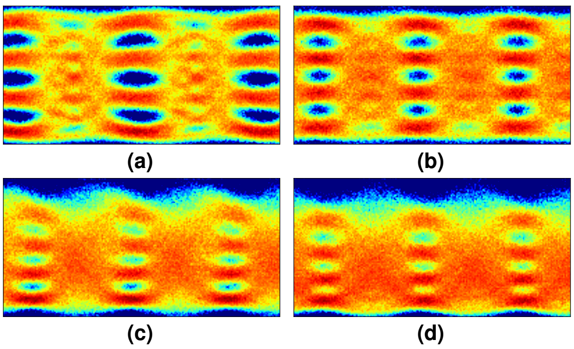

Fig. 5: Fig. 5a Back-to-back Eye Diagram in the C-band. Fig. 5b Eye diagram after 1 MB-OADM. Fig. 5c Eye diagram after 2-MB-OADMs. Fig. 5d Eye diagram after 3 MB-OADMs.

In Fig. 4 the experimental results for the described optical paths for all bands are shown. In Figs. 4a, 4b and 4d the results for the O, S- and L-bands, respectively, are shown. In the three cases successful transmission for up to two nodes was demonstrated for several channels, all below the FEC threshold of 3.84×10^{-3}[10]. In the C-band case, Fig. 4c, successful transmission for up to three nodes, which corresponds to Path 3, was successfully accomplished with a power penalty of around 3 dB when comparing this case to the back-to-back case. The reason of the increased penalty can be easily verified from the eye diagrams of Fig. 5 where the noise increases as we cascade more SOA-based MB-OADMs. In the same Figs. 4e and 4f we highlight the loss compensation mechanism of the proposed MB-OADM. In these figures it is shown that the losses introduced by the passive components in the MB-OADM structure, as well as the losses introduced by the fiber spans are compensated by the SOAs after each path, making the proposed architecture essentially lossless. By correctly mapping the operation condition of the SOAs, mode advanced features, such as power equalization, can also be implemented in the current design.

Conclusions

In this paper we demonstrated a SOA-based MB-OADM to implement a lossless and fast optical switching solution for future MB metro-access networks. Experimental data transmission showed the scalability of the proposed MB-OADM, supporting 28 GBd PAM-4 transmission for up to 3 nodes in the C-band, paving the way for future metro networks without the expensive in-line amplification.

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