

# Reconfigurable Architecture for Point-to-Point Bidirectional Access Networks Allowing Multirate and Extended Reach

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**Abstract** An SOA and switch enable the bypass of a PtP OLT to obtain reconfigurable (via AMCC) multirate 25 Gbit/s NRZ or 50 Gbit/s PAM4 bidirectional real time transmission and extended reach up to 40 km (80 km total reach). ©2023 The Authors

## Introduction

Fiber optic transmission is currently the most deployed access solution with 797 million FTTH/B (Fiber To The Home/Building) subscribers worldwide by June 2022 [1]. This paper focuses on the Point-to-Point (PtP) network, where the Optical Line Terminal (OLT) is connected to the Optical Network Unit (ONU) by a single fiber. This infrastructure is mainly dedicated for FTTA (Antenna) or FTTE (Enterprise) transmissions. The international Telecommunication Union (ITU-T) is focusing on future standards for next generation of access networks, with the latest being High Speed PtP (HS-PtP), G.9806 [2]. Specifications for several data rates are provided, including 25 Gbit/s with Non-Return to Zero (NRZ) and 50 Gbit/s with 4-level Pulse Amplitude Modulation (PAM4). Different classes of Optical Budget (OB) are defined according to the fiber distance between the OLT and the ONU. In the case of a fiber from 0 to 20 km, the defined OB is 5-20 dB (Class A). For 20 to 40 km, the OB is 10-25 dB (Class B). The defined wavelengths are  $1289 \pm 8$  nm for the Upstream (US) and  $1314 \pm 8$  nm for the Downstream (DS). The choice of the O-band has the advantage of allowing close to the zero Chromatic Dispersion (CD) operation, thus preventing high penalties due to Intersymbol Interference (ISI) in the transmission.

Increasing bandwidth is necessary, but operators have taken great commitments to reduce their carbon footprint [3]. Solutions must

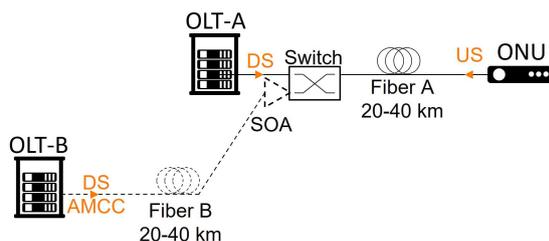
then be found to reduce the energy consumption of network equipment. The network also aims at becoming more flexible [4] with new control protocols [5]. As the maximum bandwidth is not constantly required in PtP mobile links, sleep modes of OLTs and multi-rate adaptation are proposed in this experimental study.

In this paper, we present a reconfigurable transmission infrastructure for multi-rate and extended reach, as depicted in Figure 1. To achieve this, an SOA-switch [6] is placed at the output of the OLT-A to allow an extended transmission (from 20 to 40 km) to another OLT-B. The link (SOA-switch and rate adaptation at ONU) can be remotely reconfigured by using an out-of-band Auxiliary Management and Control Channel (AMCC) [7].

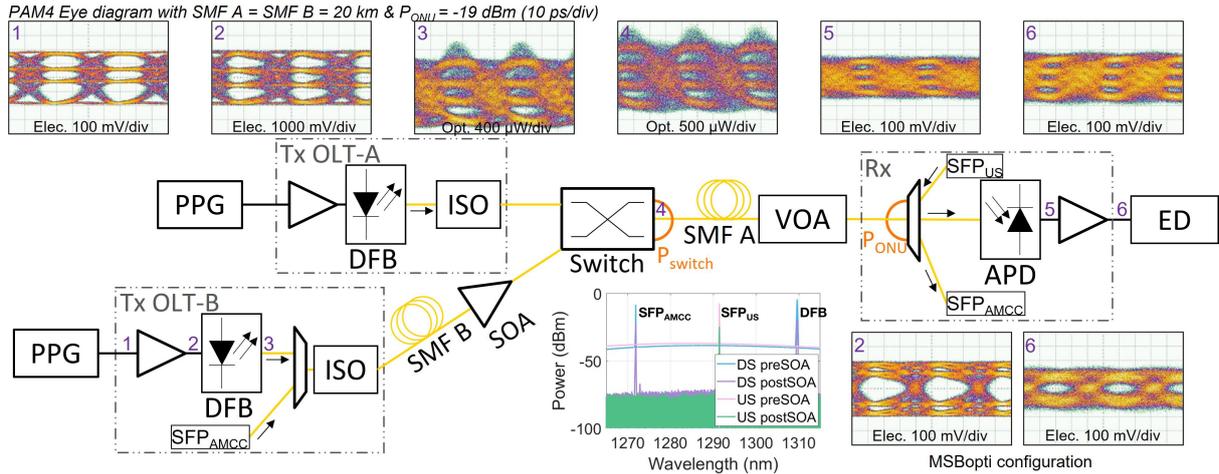
## Scenarios and experimental setup

Our experimental setup is shown in figure 2. The laser emission is provided by a commercial DFB with an 18 GHz-bandwidth, whose center wavelength is 1310 nm at 25°C. It is biased by a current of 65 mA and provides an output power of 8 dBm. The laser is modulated by a Pulse Pattern Generator (PPG) with a PRBS sequence of length  $2^{31}-1$ . Several modulation formats are used during the experiments. The PAM4 signal is generated with amplitude of 3.5 Vpp, more precisely with a lower to upper eye amplitude of 1.19, 1.06 and 1.26 Vpp. The lower one has larger amplitude to compensate for the non-linear response of the electrical amplifier placed at the output of the PPG. In reception, the decoding of the Most Significant Bit (MSB) alone allows to improve the sensitivity (as well as the OB) against a halved rate (25 Gbit/s). The modulation called "MSBopti" consists in increasing the amplitude of the middle eye only, keeping the same total amplitude, 0.64, 2.14 and 0.71 Vpp. Finally, the NRZ modulation has an amplitude of 5 Vpp.

The output of the DS Transmitter-assembly (Tx) (including the DFB and an optical isolator) is



**Fig. 1:** Our reconfigurable architecture in the HS-PtP bidirectional context

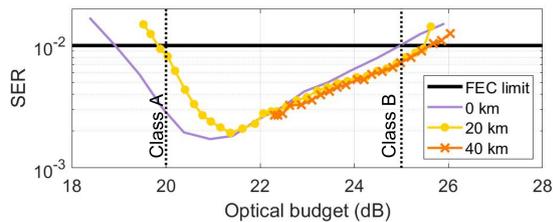


**Fig. 2:** Experimental setup, eyes diagrams at different parts of the transmission and optical spectrum at the inlet and outlet of the SOA in the US and DS directions

5.6 dBm. The DS optical receiver consists of an integrated Avalanche PhotoDiode–TransImpedance Amplifier (APD–TIA) [8] with an opto-electrical bandwidth specified at 25 GHz, with an avalanche voltage fixed at 23 V. The TIA output amplitude is limited to 150 mA, which requires an extra electrical amplifier before the Error Detector (ED). The DS PtP link is assessed with 20 or 40 km of SMF (SMF-A), followed by a Variable Optical Attenuator (VOA) to measure the Bit or Symbol Error Rate (BER or SER) according to the received power at the Receiver-assembly (Rx).

To provide a reconfigurable transmission to OLT-A or OLT-B according to the traffic demand, a dynamic commercial 2 to 1 optical spatial switch is inserted in this PtP link at the output of the Tx. In the case of low traffic demand, the OLT-A would be put to sleep mode to allow for power saving, and all traffic would be redirected to OLT-B that is placed 20 to 40km away via SMF-B. To provide this extended reach, an SOA is placed on one branch of the switch to amplify both DS and US PtP transmissions. The SOA provides 26 dB small signal gain at 200 mA at 25 °C, at 1310 nm. As PtP transmissions are symmetrical, we only assess here the DS but the US is present here in the transmission (in the SOA) with a 2.5 Gbit/s SFP emitting at 1291 nm, inserted at the ONU MUX (triplexer).

A second triplexer is placed at the output of the DS laser to extract the US channel and

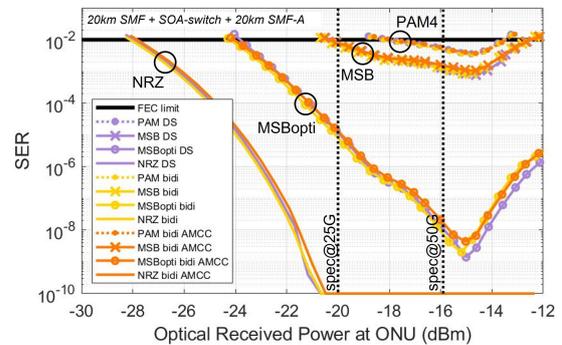


**Fig. 3:** SER @50 Gbit/s (PAM4) vs optical budget for OLT-A to ONU transmission

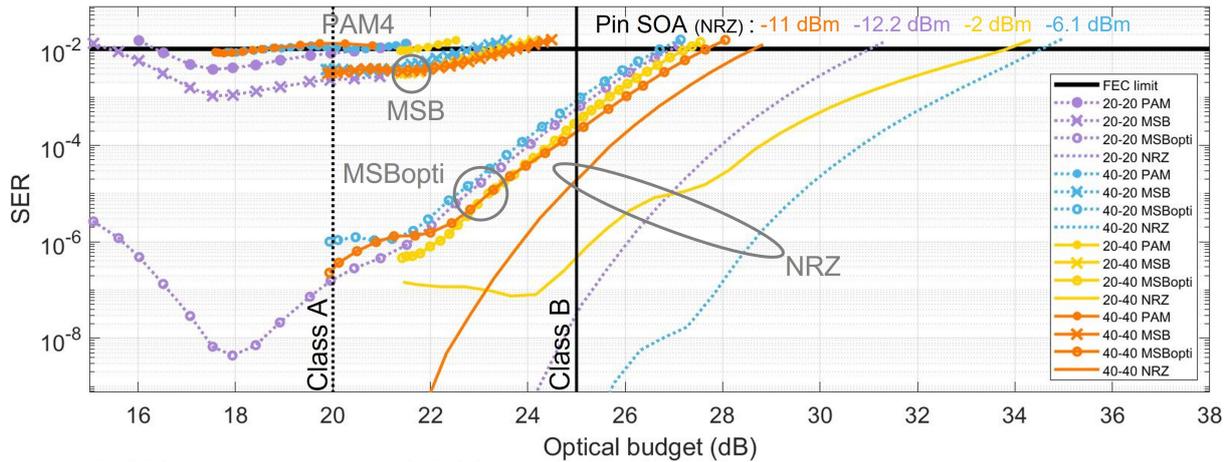
transmit the out-of-band AMCC in addition to the DS. This channel is transmitted from a 10 Gbit/s capable FPGA platform by an SFP emitting at 1271 nm with an output power of 2 dBm and modulated with NRZ at 2.5 Gbit/s. An optical budget of 35.7 dB (at  $10^{-9}$  BER) was measured to the AMCC receiver at the ONU. The AMCC receiver can also be placed either at the switch or SOA to control their transmission parameters dynamically. Finally, the optical budget of the PtP link is defined as the difference between the switch output power and the input power at the Rx.

## Results and discussions

Figure 3 displays the measurements obtained for OLT-A to ONU transmissions (i.e. without SOA). The transmission is performed in real time with PAM4 modulation at 50 Gbit/s without equalization using 0, 20 or 40 km of SMF fiber. To carry out the transmission under conditions close to reality, it is made with the US and AMCC signals always on in the link. Considering a SER target of  $10^{-2}$  (pre-FEC), an optical budget of 25 dB is reached for the three distances, allowing an OB of class B. However, the dynamic range is not satisfying with only 6 dB for 0 km and 5.5 for



**Fig. 4:** SER vs received power at ONU, for OLT-B--ONU transmission with only DS, DS-US (bidi) and DS-US-AMCC (bidi AMCC)



**Fig. 5:** SER vs optical budget in the OLT-B-ONU transmission for the four modulation formats, and for different distances involved (in the form X-Y with X distances of the fiber B and Y the fiber A)

20 km, which are limited by the current Rx TIA that is not designed with automatic dynamic gain.

For OLT-B to ONU, the PtP transmission goes through the SOA placed at the input of the switch (DS direction). Figure 4 shows the SER curves for the different modulation cases: PAM4, MSB decoding only with the same PAM4 signal generated, MSBopti and NRZ. The transmission was performed for 20 km of extended reach (SMF-B) and 20 km in the access (SMF-A). In this configuration, the DS wavelength at 1310 nm, the AMCC at 1271 nm and the US wavelength are transmitted through the SOA. The corresponding optical spectra are shown as the inset (b) in figure 2. Comparing results in the case of DS only, bidirectional (“bidi”) US and DS, and with additional AMCC, no penalty was noticed due to the simultaneous transmission of these 3 wavelengths through the SOA. Figure 4 also highlights the performance obtained with the different modulation formats. The PAM4 demodulation is not the relevant case here since we target to downgrade the transmission bitrate and extend the reach when a low traffic demand occurs. When the Tx is modulated with PAM4, decoding the MSB alone at 25 Gbit/s increases the sensitivity by 1.6 dB. The optimization of the Tx PAM4 modulation as “MSBopti” provides 3.5 dB more on the sensitivity (i.e. 5.1 dB more than for PAM4 decoding). Adapting the Tx with NRZ modulation format gives the best power sensitivity with 10.8 dB enhancement compared to PAM4. In that case, sensitivities below PtP specifications at 25 Gbit/s are obtained even at a  $10^{-9}$  BER which allows us to avoid or adapt the use of FEC for lower energy footprint and enhanced useful bandwidth [9].

Considering different fiber reach in SMF-A and SMF-B, Figure 5 represents the SER with respect to the access optical budget, calculated as the SOA-switch output power minus the Rx

input power. PAM4 modulation allows to reach class A optical budget (20 dB) but not class B (25 dB), even with MSB decoding. This limitation is related to excessive SNR degradation after the SOA (Eye Diagram #4 in Figure 2). On the other hand, in the cases of Tx configured in MSBopti or NRZ, the results become interesting as all pairs of distances allow to exceed the limit of the class B. Different optical budget target are reached in the case of NRZ modulation since the SOA input powers (and thus its output power and SNR) vary according to the inserted SMF-B fiber spools loss. In any case, optical budgets above the specification limits at 25 Gbit/s are reached with NRZ, and FEC can be adapted and even removed for 20 km of SMF-A links.

## Conclusions

In the PtP context, we assess a reconfigurable bidirectional transmission with an SOA-switch and transmission of an AMCC for remote configuration of the SOA, spatial switch and ONU. To adjust the energy footprint to the traffic demand, we propose to downgrade the transmitted bitrate from 50 Gbit/s PAM4 to 25 Gbit/s MSB or NRZ and use an SOA to extend the transmission reach up to 80 km. Optical budget reaching class B of the PtP standard are demonstrated. Those multi-rate and multi-reach network configurations allow to bring flexibility where the OLT can be put to sleep-mode and the Tx and FEC parameters can be dynamically reconfigured according to the traffic demand.

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## References

- [1] "World FTTx Markets, Markets as for June 2022 & Forecasts up to 2026", Idate report, December 2022.
- [2] Standard ITU-T G.9806 recommendation on "Higher speed bidirectional, single fiber, point-to-point optical access system (HS-PtP)"
- [3] "Environmental commitment: net zero carbon emissions by 2040", available online : <https://www.orange.com/en/commitments/oranges-commitment-to-the-environment>
- [4] In-line protocol-independent control and management method in end-to-end optical connections via Photonic Gateway," ECOC2021, Th2F.6, 2021.
- [5] M. Yoshino, S. Kaneko, N. Shibata, R. Igarashi, J. Kani, and T. Yoshida, "New Photonic Gateway to Handle Digital-Coherent and IM-DD User Terminals and Enable Turn-back Connections in Metro/Access-Integrated All-Photonics Network," in *Optical Fiber Communication Conference (OFC) 2023*, Technical Digest Series (Optica Publishing Group, 2023), paper W3F.5.
- [6] M. P. G. Rombouts and N. Calabretta, "Scalability Assessment of O-band SOA-based Broadcast and Select Switch with 100 Gb/s LWDM Commercial Transceivers," in *Optical Fiber Communication Conference (OFC) 2023*, Technical Digest Series (Optica Publishing Group, 2023), paper Th3D.3.
- [7] S. Pachnicke *et al.*, "Tunable WDM-PON System With Centralized Wavelength Control," in *Journal of Lightwave Technology*, vol. 34, no. 2, pp. 812-818, 15 Jan.15, 2016, doi: 10.1109/JLT.2015.2502319.
- [8] J. Potet *et al.*, "Uncooled High Speed Ge/Si Avalanche Photodiode for 50 Gbit/s-PON with 60 km Reach," 2023 Optical Fiber Communications Conference and Exhibition (OFC), San Diego, CA, USA, 2023
- [9] R. Borkowski *et al.*, "FLCS-PON – A 100 Gbit/s Flexible Passive Optical Network: Concepts and Field Trial," in *Journal of Lightwave Technology*, vol. 39, no. 16, pp. 5314-5324, 15 Aug.15, 2021, doi: 10.1109/JLT.2021.3102383.