A Versatile Point-to-Point Network Architecture with Multi-Rate Adaptability from 100 Gbit/s to 10 Gbit/s

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Abstract: PtP networks are optimized with optical switch and extended reach (25-50 km) to another CO to allow flexible bandwidth and power consumption. Different transmission capacities and scenarios are experimented with a DFB, from 100 Gbit/s to 10 Gbit/s with/without FEC and SOA.

1. Introduction

Point-to-Point (PtP) networks is usually designated for Fiber-to-the-Antenna (FTTA) or Enterprise (FTTE) transmissions [1]. Like any other topology, PtP has throughput and latency requirements that tend to increase over time with the appearance of new services. Standardization bodies define technology specifications to meet those requirements, with ITU-T working lately on the development of G.9806 [2], the Higher Speed bidirectional PtP (HS-PtP) standard. The upper limit of Optical Budget (OB) to be achieved is 20 dB for class A (20 km) and 25 dB for class B (40 km). There are two additional classes (amd.3) for 20 km that are less restrictive in terms of dynamic range and optical budget: S_L (0-10 dB) and S_U (5-15 dB). Sensitivity specifications depend on the data rate, with -20 dBm, -15.9 dBm and -14.4 dBm respectively for 25 Gbit/s, 50 Gbit/s and 100 Gbit/s, considering Pulse Amplitude Modulation (PAM4) format for the last two and NRZ for 25 Gbit/s.

The rise of new challenges towards higher bitrate and low latency networks, along with the solid commitments made by telecoms operators to reduce their carbon footprint [3], put a fresh perspective regarding tomorrow's network. Up until now, a rigid network that allows for mass production and easier management to reduce CAPEX and OPEX has been preferred. However, bringing adaptability to networks appears to be the path forward, according to many industry players [4, 5, 6].

Flexibility can be enhanced by the ability to transfer data to a remote Optical Line Termination (OLT) in the remote Central Office (CO) as presented in Figure 1.a. This solution is especially pertinent during large gatherings such as sports events, concerts, and other mass meeting where huge numbers of people are attending. During these times, the antennas require significantly higher bitrate, whereas outside these events, the demand is much lower. The objective would be to have a nearby OLT that can supply high bitrate on demand and another OLT further up in the network with lower bandwidth and extended reach transmission but not with higher latency. Latency can be reduced through targeting a remote CO where the MEC is situated, avoiding successive active elements (for exemple $\sim$ 20 µs/OLT, $\sim$ 10 µs/aggregation switch, etc). Also bypassing the high-bitrate OLT would allow for the main CO to be shutdown , providing power solely to the remote CO in non-event periods or daily traffic fluctuations.In this paper, we assess this scenario utilising commercial pluggable transceivers for the 100 Gbit/s PAM4 transmission for the high-bitrate OLT, and Distributed Feedback (DFB) laser and Avalanche Photodiode (APD) for 25 and 50 Gbit/s Non Return to Zero (NRZ) for the remote OLT. Changing the modulation format from PAM4 to NRZ for the remote OLT will be studied for several distances. With 25 or 50 km between the remote CO and the high-bitrate CO, and 20 or 40 km between the high-bitrate CO and the Optical Network Unit (ONU). The transmission capacity is analysed with or without Forward Error Correction (FEC) and with or without Semiconductor Optical Amplifier (SOA).

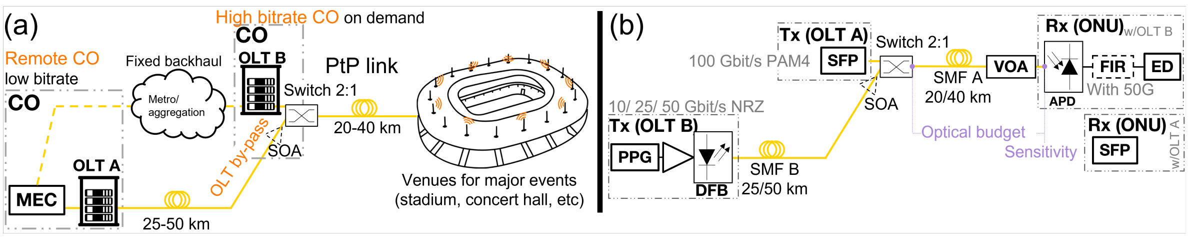

Fig. 1. (a) Scenario studied and (b) Experimental setup with bypass of OLT-A

2. Experimental setups

Our experimental setup is displayed in Figure 1.b and examined in various configurations. Initially, 100 Gbit/s transmission between the high-speed OLT (OLT-A) and the ONU is accomplished by utilizing commercially available PAM4 50 Gbd transceivers. These Quad Small Form Factor Pluggable (QSFP)28 utilize identical laser technology that we used later, namely a DFB. The bidirectional transceivers operate with an optical output powers of 0.4 dBm launched in each direction at 1308.8 nm Downstream (DS) and 1304.5 nm Upstream (US) in each direction in a single fiber. QSFP28's traffic is provided by an Ethernet tester capable of measuring Bit Error Rate (BER). For the 100G PAM4, the modulation has a baudrate of 53.25 Gbd, a payload of 99.8 Gbd with a Pseudo Random Binary sequence (PRBS)31. Ethernet traffic is made of jumbo frames of 10,000 bytes. A spatial optical switch located at the CO side, in the PtP link has a switching time about 10 µs and insertion losses of 2.7 dB. A Variable Optical Attenuator (VOA) is inserted in the link to measure its optical budget establishing BER curves.

Dedicated components are used for the bypass link between the remote OLT (OLT-B) and the ONU at lower bitrates. Modulation is generated via a Pulse Pattern Generator (PPG) with a PRBS31. We utilize a DFB laser, with a bandwidth of 18 GHz, emitting at 1310 nm for our experiments. Its output power is 9.25 dBm with a supply current of 60 mA. With this bandwidth, the PPG utilizes a pre-emphasis of three taps for 50 Gbit/s NRZ. The values are -4.5, -0.4 and -3.0 dB. The emitted signal passes through a standard Single-Mode Fiber (SMF), either 25 or 50 km long, referred here as SMF-B. Before reaching the switch, depending on the setup, the signal may go through an O-band SOA as used in [7]. The signal is then transmitted through another SMF either 20 or 40 km long, to reach either class A or B specifications, followed by a VOA, and lastly, the receiver. This device is a 25G-class APD associated to a Trans-Impedance Amplifier (TIA). For 50G NRZ transmission, the electrical signal undergoes post equalisation through a Finite Impulse Response (FIR) analog filter with six taps spaced by $\sim$ 7.5 ps. The number of errors is then quantified in real time using an Error Detector (ED).

3. Results and discussions

For the 100 Gbit/s PAM4 connection linking OLT A and the ONU, the commercial transceivers achieved an OB of 17.8 dB at a BER limit of $2.4.10^{-4}$. This OB was reached with 20 km of fiber, however, it is not meeting class-A specifications (20 dB). At this data rate, it confirms interest for lately standardized class S_U or S_L.

For the remote OLT (OLT-B) to ONU link, we will first investigate it without SOA to assess an architecture with lower cost and power consumption capabilities. For the two bitrates (50G NRZ and 25G NRZ), we will examine the four groups of distances referred to in the experimental setup section, which we label as 25/20, 50/20, 25/40 and 50/40 (with, for instance, 50 km of SMF-B and 40 km of SMF-A). Figure 2 presents the results of BER versus OB measurements for different configurations (line noSOA in table 1). For the highest speed (50G NRZ), the absence of SOA means that only the minimum distance of 25/20 can be reached (fig2.a), meeting sensitivity specifications (-18.2 dBm) but not the OB ones (15.4 dB). At 25 Gb/s with the same distance of 25/20, we can meet class A OB and sensitivity requirements with FEC (BER limit of 10^{-2}) and without FEC (BER limit of 10^{-9}). For class B configuration (specifically 25/40 (fig2.c)), FEC is mandatory as the OB objective (25 dB) is not met at 10^{-9} BER. Moreover, when SMF B has a length of 50 km, it is not possible to achieve 10^{-9} BER without FEC. Additionally, the omission of SOA is noteworthy as it reduces costs and power consumption, and is relevant in cases where there is a shorter additional fiber B distance (25 km). Both class A and B are validated with this distance, however, a FEC must be employed for class B (25/40). Measurements conducted under identical conditions to reduce the bitrate up to 10 Gbit/s have allowed achievement of similar optical budget classes, but results are not plotted here.

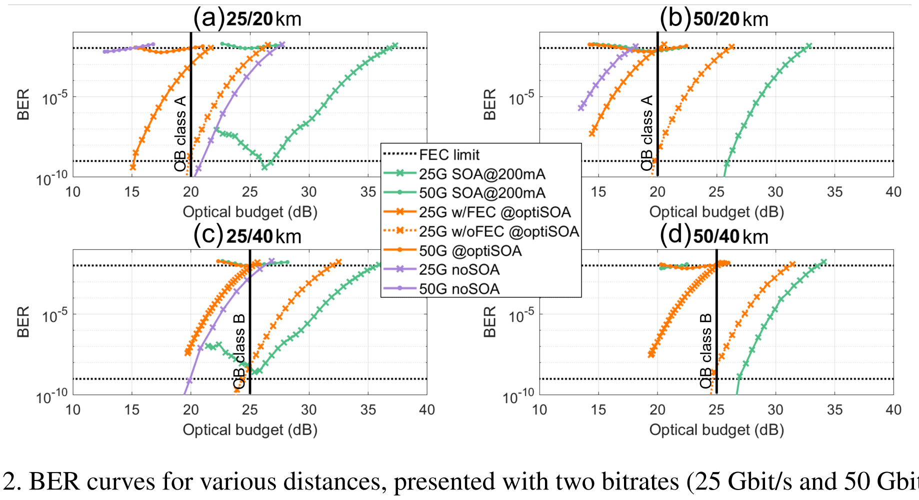

Fig. 2. BER curves for various distances, presented with two bitrates (25 Gbit/s and 50 Gbit/s NRZ) and with three different configurations: SOA at 200 mA, optimised SOA current and no SOA

To achieve the longest distances, the use of a SOA is required. Thus, the transmission is analysed by inserting the SOA that could be controlled remotely with an Auxiliary Management and Control Channel (AMCC) together with the optical switch as we demonstrated in [8]. The SOA operates at bias currents of 100, 200, 300 or 400 mA and is also optimized to currents as low as possible ”opti SOA” to reduce its power consumption according to different links. The experiment considers the same sets of distances and two linerates, 50 and 25 Gbit/s both in NRZ. Table 1 displays the results achieved with various currents, providing insight into potential energy consumption optimisation based on current. Firstly for fixed currents, the performance at 50G is profoundly variable depending on the set of parameters. Except for the longest total distance (50/40), sensitivity and OB can be achieved with at least one bias current. However, the limitation of the TIA excursion leads to a poor dynamic range. For 25G, all distances have at least one operating point reaching the standard. The limit here applies more for short SMF-B distances, where the SOA will be in saturation mode. Lastly, SOA proves to be a valuable solution for achieving an extended reach. Depending on the individual circumstance, the SOA current can be modified to attain the desired outcome whilst keeping power consummation in mind.

The objective of the following measurements was to reach the standard specifications with the minimum SOA current possible for every distance (line opti SOA in table 1). For 50G transmission, a rather high SOA current is still necessary. Even though a high current of 400 mA is utilized for the 50/40 scenario (fig2.d), the OB is not reached. For distances of 50/20 and 25/40 (fig2.b/c), standard performance is achieved with currents of 180 and 200 mA respectively, which remains relatively high. SOA current optimisation is interesting in the 25/20 scenario (fig2.a), whereby the standard can be obtained using only 56 mA. For 25G, the SOA current was minimized to achieve performances with and without FEC. At this bitrate, the current requirements are relatively low, with a maximum current requirement of 140 mA for the 50/40 case without FEC. The interest of these results lies in the contrast between the performance obtained with and without FEC. For the four cases 25/20, 50/20, 25/40 and 50/40, the difference in current is 10, 40, 30 and 70 mA respectively. This study highlights the possibility to find trade-offs between increasing the SOA current and avoid the power consumption of a FEC or reduce considerably (divide by 2) the SOA current when using FEC.

Table 1. Results for the various configurations, with a target sensitivity of -20 dBm @25G and -15.9 dBm @50G, and an optical budget of 20 dB for class A and 25 dB for class B

	Class A (reach 0-20 km & OB = 5-20 dB)												Class B (reach 20-40 km & OB = 10-25 dB)											
distance	25/20						50/20						25/40						50/40					
bitrate	25G w/o FEC		25G w/ FEC		50G w/ FEC		25G w/o FEC		25G w/ FEC		50G w/ FEC		25G w/o FEC		25G w/ FEC		50G w/ FEC		25G w/o FEC		25G w/ FEC		50G w/ FEC	
measure	sensi	OB	sensi	OB	sensi	OB	sensi	OB	sensi	OB	sensi	OB	sensi	OB	sensi	OB	sensi	OB	sensi	OB	sensi	OB	sensi	OB
noSOA	-23.4	20.6	-29.5	26.7	-18.2	15.4			-29.8	17.7			-22.7	19.9	-28.6	25.8					-28.5	16.4		
100 mA	-21.8	27.0	-29.0	34.2	-17.7	23.4	-22.2	22.5	-28.2	28.5	-17.7	17.6	-20.4	25.7	-27.7	32.9	-18.0	23.7	-23.1	23.4	-29.1	29.4		
200 mA	-19.0	24.5	-28.0	36.8	-16.2	25.2	-22.1	26.4	-28.2	32.5	-17.5	21.8	-17.5	26.3	-26.9	35.7	-16.3	25.3	-23.0	27.5	-29.1	33.6	-17.6	22.1
300 mA	-18.5	26.6	-27.7	37.8			-22.2	28.0	-28.3	34.0	-17.2	23.2			-26.6	36.8			-22.7	28.6	-28.9	34.8	-17.6	23.7
400 mA	-18.3	29.1	-27.5	38.3			-22.3	28.6	-28.4	34.6	-17.1	23.7			-26.4	37.3			-22.7	29.1	-28.8	35.2	-17.5	24.2
opti SOA	-23.5	20.2	-29.4	21.6	-19.2	20.1	-22.3	20.2	-28.1	20.1	-17.1	21.3	-21.4	25.0	-28.6	25.2	-16.3	25.3	-22.1	25.0	-28.1	25.1	-17.5	24.2
(courant)	40 mA		30 mA		56 mA		75 mA		46 mA		180 mA		80 mA		40 mA		200 mA		140 mA		70 mA		400 mA	

sensi: sensitivity in dBm at a BER threshold of 10^{-2} w/FEC and 10^{-9} w/o FEC OB: Optical budget in dB

: BER threshold not reached : Standard limit not reached : both sensitivity & optical budgetstandard reached

4. Conclusion

We demonstrate in this paper the possibility to adapt the PtP links reach and bitrate from 100 Gbit/s to 50 Gbit/s, 25 Gbit/s or even 10 Gbit/s with the help of an optical switch and an SOA. The latter would optimises the networks performance in terms of latency and energy savings. An OLT bypass is proposed with extended reach (up to 40+50 km) PtP links with DFB and APD. These solutions facilitate flexibilty in the network to deliver high bitrate on demand during large public events and reduced energy with OLT (& CO) shutdown during low-volume traffic demand periods. The energy consumption can be further optimised to find trade-offs between SOA being present/absent, at optimised current and with FEC activated or not.

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