TDM/DWDM PON Extender for 10 Gbit/s Downstream Transmission

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Abstract: This paper presents for the first time the network architecture and the multiple-wavelength operation of a novel SOA-based PON extender. In 10-Gbit/s four-wavelength 100-km configuration, the total optical budget for each wavelength is 58 dB.

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1. Introduction
Passive optical networks (PON) with broadband data connectivity are being deployed worldwide. In order to reduce the deployment and the operation costs, the use of optical amplifier to extend reach and splitting ratio in future PON systems are discussed [1]. Among the proposed solutions, semiconductor optical amplifiers (SOA) appear to be efficient and cost-effective for multiple-wavelength networks [2]. The use of a single SOA for budget extension of coexisting gigabit-capable PON (G-PON) and 10-gigabit-capable PON (XG-PON) was demonstrated [3].

Recently, a new optical amplifier configuration, the saturated collision amplifier (SCA), was developed and its advantages compared to single SOA amplification was demonstrated [4]. In this paper, a network configuration for downstream time- and dense-wavelength-division multiplexed (TDM/DWDM) PON using SCA is proposed. The device’s compatibility with the standardized XG-PON 1 is shown. The multiple-wavelength operation of the SCA is demonstrated for the first time, which enables the wavelength stacking of XG-PON 1 systems. The transmission performance and the obtained optical budget extension are assessed with bit error rate (BER) measurements.

2. Device description and network architecture
Fig. 1 shows the TDM/DWDM PON downstream system and the proposed extender using SCA. The OLT consists of DPSK transmitters which offer the wavelengths from 1 to N for downstream each to its own TDM PON tree. In the remote node, all DPSK signals are demodulated and amplified simultaneously by the PON extender. The DWDM signals are then demultiplexed by an AWG demux. After the remote node, each downstream wavelength is sent to the assigned TDM PON tree. The optional input of the PON extender can be used for protection.

In the PON extender, the delay interferometer (DLI) outputs a pair of complementary OOK signals that are coupled to and amplified by the SOA. As discussed in [4], this arrangement permits saturated SOA operation, which in turn results in maximized output power, low ASE noise, virtual absence of pattern effects, and minimized polarization dependence. Also, the ONUs need no DLI, because the modulation format conversion is performed in the remote node. The proposed PON extender is therefore already compatible with commercial XG-PON 1 network terminals. Only DPSK downstream transmitters at OLT are needed, which could be performed by cost-efficient direct phase, or frequency modulated lasers [5, 6].

Fig. 1. Downstream configuration of a TDM/WDM PON using SCA PON Extender.
The SCA scheme of the saturated SOA can also manage multiple-wavelength operation, particularly in a PON, as the OSNR is typically high. The multiple-wavelength operation allows additional flexibility and upgrade scenarios. For instance, if the output power of the extender outperforms the locally needed access budget for a closed customer group (e.g. 128 customers to be served by a given TDMA protocol), extra wavelengths can later be added without traffic interruption to serve further parallel PON trees while sharing the same feeder line infrastructure.

3. Measurement setup

The measurement setup is shown in Fig.2. The transmitter (Tx) generates a RZ-33% DPSK at 10 Gbit/s (PRBS of $2^{31}-1$) by using two Mach-Zehnder modulators, one for phase coding using push-pull setup and other for pulse carving. As only one DPSK transmitter is available, all considered wavelengths are modulated by the same transmitter and the signals are de-synchronized with a demux-mux combination that is connected with varying fiber lengths. The signals are boosted by an EDFA so that each wavelength has about 0 dBm power at the input of the feeder line. The used AWG mux/demux have a 100-GHz channel spacing and a 3-dB bandwidth of 55 GHz.

Fig. 2. Measurement setup: Tx - 10-Gbit/s RZ DPSK transmitter, PRBS of $2^{31}-1$; VOA - variable optical attenuator; SOA – semiconductor optical amplifier; AWG - arrayed waveguide grating; Rx - receiver.

The ONU receiver consists of an avalanche photodiode and an electrical clock recovery. In back to back operation, the receiver has a sensitivity of -30 dBm for BER of $10^{-9}$ and -35 dBm for BER of $10^{-3}$. The feeder budget is defined as the optical budget between the OLT and the remote node, while the access budget corresponds to the optical budget between the PON extender and the ONU.

4. Results

A suburban scenario is first considered with 20 km feeder fiber and 25 km access fiber with two-wavelength operation (1552.5 nm and 1557.4 nm). The SOA current is optimized at 350 mA with an output power of 10 dBm. A complete bit error rate (BER) map was measured for 1557.4 nm signal (Fig. 3). The other wavelength had about the same performance. We can see that the feeder budgets of the 10G-PON E1 and E2 classes (access budget of 33 dB and 35 dB) [7] for an error free transmission (BER<10^{-9}) are extended by 15 dB and 11 dB, respectively. This corresponds to a maximum total budget of 48 dB for one wavelength at one extender output. If we consider the use of forward error correction code, the transmission BER can be degraded to $10^{-3}$. In that case, with feeder budget of 15 dB, the access budget can be extended to 40 dB. This access budget allows a transmission over an AWG demux (4-dB loss), 25 km of fiber (5-dB loss), 1:256 splitting ratio (24-dB loss), two filters/circulators (one at extender output, and other at ONU input) to separate up- and downstream signals (2x2 dB) and an extra budget of 3 dB. Consequently, with two wavelengths and two outputs of the SCA, the number of served clients can be up to 1024.
to the two-wavelength case. The BER performances of the two- and four-wavelength operations are compared to each other. Fig. 4 shows BER curves at feeder budget of 10 dB, the DLI input powers are about -7 dBm and -4 dBm for the two- and four-wavelength cases, respectively. As can be seen, the two curves overlap, which means there is no power penalty due to additional wavelengths. Fig. 5 depicts the BER contours of $10^{-3}$ for two- and four-wavelength configurations. The access budget decreases by 3 dB when the number of wavelengths is doubled. Consequently, the number of clients is not increased with the number of wavelengths, but with the same number of clients, the splitting ratio for each wavelength can be reduced and the data rate per client therefore increases.

A long reach rural scenario is also considered, in which the RN is placed at 75 km from the OLT and 25 km from the ONUs. A preamplifier and a dispersion compensating fiber (DCF) are put prior the delay interferometer (Fig. 6). As the feeder loss is considerably increased, the preamplifier is needed in order to keep the SOA of the SCA in the saturation regime. The preamplifier SOA is identical to the one use in the SCA. The preamplifier SOA injection current is 92 mA. The DCF, between preamplifier and DLI, compensates 65-km SMF transmission. Otherwise the setup was similar to previous one. Four-wavelength operation is measured.

Fig. 7 shows simultaneously the BER contours of $10^{-3}$ of four wavelengths in 100-km configuration. We obtained approximately the same performance for all wavelengths. In comparison to the previous scenario, the feeder budget is tremendously increased thanks to the use of the preamplifier. The access budget is however decreased due to amplified spontaneous emission noise and residual chromatic dispersion. The BER curves at a feeder budget of 28 dB are depicted in Fig. 8. At BER of $10^{-3}$, the worst case access budget is 30 dB. The total optical budget for one wavelength and one output is 58 dB in this long reach scenario.

5. Conclusion

We have demonstrated for the first time the multiple-wavelength operation of a novel two-output SOA-based PON extender for downstream transmission. In 45-km configuration, two- and four-wavelength operations are assessed and compared. In two-wavelength operation, an optical access budget of 40 dB for one wavelength at one output is obtained, which is sufficient to support 25-km transmission and 1:256 splitting ratio. A single device can therefore serve 1024 clients. When more wavelengths are added, no power penalty is observed, allowing flexible network upgrade without traffic interruption and infrastructure changes. A long reach scenario is also considered with 100-km transmission and four-wavelength operation. In this case, the total optical budget for one wavelength and one output is 58 dB. Full-duplex transmission can be performed by using an SOA for budget extension of the upstream.

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References