Analyses and Simulation of a WDM PON based on Spectrum Slicing and Reflective SOA
C. Rodrigues\textsuperscript{1,2}, Paulo Mão-Cheia\textsuperscript{3}, A. L. J. Teixeira\textsuperscript{1,4}, R. Nogueira\textsuperscript{1}, M. J. N. Lima\textsuperscript{1,4}, J.L. Pinto\textsuperscript{1,2}, P. S. André\textsuperscript{1,2}

\textsuperscript{1}Instituto de Telecomunicações, Universidade de Aveiro, 3810-193 Aveiro, Portugal. \textsuperscript{2}Dep. de Física, Universidade de Aveiro, 3810-193 Aveiro, Portugal. \textsuperscript{3}PT Inovação, S.A., Rua Pinto Basto, 3810-119 Aveiro, Portugal. \textsuperscript{4}Dep. de. Electrónica e Telecomunicações, 3810-193 Aveiro, Portugal.
Phone: +351-234 377 900, Fax: +351-234 377901, e-mail: crodrigues@av.it.pt

Abstract — We propose a WDM - PON bidirectional architecture based on spectrum slicing and reflective semiconductor optical amplifier (R-SOA). The downstream signal is shared between 8 users, and part is modulated to generate the upstream signal. A R-SOA, with a polarisation insensitive at the ONU modulates the upstream signal with a bit rate of 1.25 Gbit/s, amplifies it and than reflects to the fibre. The proposed architecture was analyzed by simulation, recurring to VPItransmission Maker.

I. INTRODUCTION

The passive optical network (PON) is an optical fiber based network architecture, which can provide much higher bandwidth in the access network compared to the traditional copper-based networks. Wavelength-division multiplexing (WDM) is becoming the technology of choice to allow much higher bandwidth in a PON compared to the standard PON, where one wavelength is used for upstream transmission and a separate one is used for downstream transmission [1].

WDM PON is a promising approach for next generation optical access networks. They offer very high bandwidth possibilities, ranging from 100 Mbit/s to 1 Gbit/s per user. Its deployment has been hindered by the lack of an economical solution. One of the Key drivers for a low cost WDM PON is a colorless Optical Network Unit (ONU). Having a wavelength independent ONU will allow mass production and reduction of maintenance cost [2][3].

There have been several proposals for WDM PON scheme with colorless ONU. For example, using broadband optical spectrum light sources such as light emitting diode (LED) or reflective semiconductor optical amplifier (R-SOA) to cover several subscribers with spectrum sliced and allocated to each subscriber. In these schemes, erbium-doped amplifiers (EDFA) are used as amplifier or seed light source. In another category of WDM PON schemes with colorless ONU, a small extinction ratio modulated optical signal is transmitted to the subscriber’s ONU and remodulated by the R-SOA in the ONU[4].

The optical carrier technique can also be used in combination with a high output power broadband source at the Optical Line Terminal (OLT), which is spectrum sliced by an Array Waveguide Grating (AWG) and an Injection-Locked Fabry Perot (IL- FP) or a R-SOA at the ONU is then used to modulate the signal with upstream data. The drawbacks of these solutions are the high injection power that is required and the polarization dependency [2].

This paper relates the analyses by simulation of a polarization insensitive bidirectional WDM PON using spectral slicing of a SLED at the OLT and remote modulation at the colorless ONU with a Reflective SOA for upstream. The simulation was realized with the VPItransmission Maker.

We propose a scenario of providing 2.5 Gbit/s downstream and 1.25 Gbit/s upstream per user with one wavelength allocated to each of the 8 users.

II. WDM PON

A. Architecture

The tests were carried out with two different configurations of the WDM PON, one with 5 km optical feeder between the OLT and the remote node and 5 km optical fiber from the remote node (RN) to the ONU and another with 10 km + 10 km of optical fiber.

The architecture of the simulated WDM PON (Figure 1) consists of: At the OLT:
\begin{itemize}
  \item externally modulated laser transmitters for the downstream signals;
\end{itemize}

This work was support by the PT Inovação, S.A., the authors express they gratitude to the LOCO-PON (P-343) project.
• an 1xN AWG to multiplex the DWDM downstream signals;
• a SLED that emits a broadband signal;
• a 2x1 coupler to add all signals;
• a circulator to route the downstream signals and the broadband signal towards the ONU and the upstream signals towards the receivers;
• an 1xN AWG to demultiplex the DWDM upstream signals;
• a photodiode array.

At the RN:
• a 1xN AWG to demultiplex the downstream signals and multiplex the upstream signals.

At the ONU:
• a bandpass filter (BPF) to separate up-and-downstream signals;
• a photodiode to detect downstream signal;
• a R-SOA to modulate the optical broadband signal with the upstream data.

The used externally modulated laser transmitter is based on DFB laser, modulated with Mach-Zehnder modulator at 2.5 Gbit/s, with non return to zero (NRZ) 2^7 Pseudo Random Binary Sequence Generator (PRBS) bit sequences. The lasers emission frequencies were choose for each channel (from 193.1 THz to 193.8 THz, spaced by 100 GHz) with 5 mW average optical power and a bandwidth of the generated signal of 5.12 GHz.

The considered SLED emits a noise power density of 0.30x10^{-14} W/Hz.

The AWGs used in the simulation have a loss at the center frequency of 0.1 dB, a Free Spectral Range (FSR) of 2.5 THz with 100 GHz channel spacing, what gives expansibility up to 40 available wavelengths over the C band.

The BPF used has a transfer function Gaussian of first order with a bandwidth of 80 GHz and a active filter bandwidth of 10 GHz.

The length of the R-SOA was 500 µm and was simulated with a injection current of 0.27 A. The R-SOA was directly modulated with Mach-Zehnder modulator at 1.25 Gbit/s, with NRZ 2^7 PRBS bit sequences The R-SOA gain in this configuration is around 16 dB.

The receiver were based on ideal PIN photodiode with 0.8 A/W responsivity, a thermal noise density of 10^{-12} A/Hz^{1/2} followed by a 3rd order low pass Bessel filter (1.875 GHz bandwidth for the downstream signal and 0.9375 GHz for the upstream signal).

B. Separation of up and downstream signals

Two wavelengths bands are used to separate up and downstream signals. As the R-SOA operates in the spectral range from 195.6 THz to 196.3 THz, we have to use this range of frequencies for the upstream signals and the spectral range from 193.1 THz to 193.8 THz for the downstream signals. Wavelength spacing between up and downstream signals must correspond to a multiple of the FSR of the AWG in order to be correctly routed.

Thus the downstream signals are generated in range of 193.1 THz to 193.8 THz with one DWDM laser per user at the OLT. They are multiplexed on the transmission line and demultiplexed at the RN to be distributed to the corresponding ONU. A BPF separates upstream and downstream signals at the ONU.

The upstream signals are generated with a SLED emitting unpolarised light at the OLT that covers all range band. This light is injected in the transmission line using a ideal coupler and is than spectrum sliced through the AWG. Each user receives an incoherent spectrum slice, which is modulated with upstream data, amplified and reflected by the R-SOA. The signal passes back through the AWG and the transmission line. The upstream signals are finally directed towards the corresponding receivers via a circulator and demultiplexer at the OLT.

The optical band of the SLED cover the all emitting spectrum. Thus the R-SOA can operate with any wavelength of the band spectral range from 195.6 THz to 196.3 THz, what gives a colorless ONU if a tunable wavelength filter is used for selection of the signal.

Moreover the R-SOA has now Polarisation Dependent Loss (PDL) so that the entire architecture is polarisation insensitive.

III. RESULTS

A. Performance of Downstream

This architecture was tested for the downstream signal at the frequency of 193.4 THz, corresponding to the frequency used for downstream signals for ONU4.

The following figures correspond to the simulated configuration 10 km + 10 km optical fiber.

In Figure 2 is showed the eight signals of the lasers, well defined, and the signal of the SLED that is propagating in all band spectrum, the noise is overlapping the laser signal, imposing a noise floor of – 17 dBm.

Figure 2- Optical spectrum of the downstream signal after coupler, measured with a resolution of 12.5 GHz.
In Figure 3 we see the optical spectrum of the signal of the laser, well defined at 193.4 THz as well as the signal of the SLED at 195.9 THz that was spectrum sliced by the AWG transfer function.

At the ONU the laser and the SLED signals were splitter by the BPF, the laser signal was detected and the BER analyzed. Meanwhile the SLED signal will be injected in the R-SOA, to be modulated, amplified and re-injected in the transport optical fiber.

The noises induced by the feedback of the optical signals into R-SOA and the Rayleigh backscattering is negligible since the input power of the upstream transmission is high enough.

The BER versus receiver power for the ONU 4 signal (Figure 4) was obtained for back to back and two different architectures for downstream, one with 5 km + 5 km optical fiber and other with 10 km + 10 km optical fiber, for the 193.4 THz frequency.

The curves showed in Figure 4 present error free transmission (BER < $10^{-9}$) over 5 km + 5 km and 10 km + 10 km km. The penalty in relation to the back to back at 1.0x10^{-9} BER is 0.39 dB for 5 km + 5 km and 0.43 dB for 10 km + 10 km km of optical feeder and is a result of the degradation of the signal in the filters and the fiber. The increase of the power penalty is imposed mainly by the filter and splitter attenuation.

Downstream Signal

![Figure 3-Optical spectrum of the downstream signal after 10 km fiber at the remote node (RN) output, measured with a resolution of 100 MHz.](image)

**Figure 3-** Optical spectrum of the downstream signal after 10 km fiber at the remote node (RN) output, measured with a resolution of 100 MHz.

B. Performance of upstream

The performance of the simulated WDM-PON for the upstream signals was tested for the frequency used for the upstream signals to OLT4, 195.9 THz.

The 2.5 Gbit/s downstream signals were remodulated with a bit rate of 1.25 Gbit/s by the R-SOA at the ONU.

In the optical spectrum of the upstream signal at the exit of ONU4 modulated at 1.25 GHz, in the architecture 10 km + 10 km of optical fiber, (Figure 6) we observe a well defined incoherent and amplified signal at 195.9 THz, with a total optical power of + 7.95 dBm and a spectral width (FWHM) of 29 GHz corresponding to the spectral sliced signal, now modulated with the upstream information.

**Figure 5-** Eye diagram of the downstream signal after 10 km + 10 km of fiber, measured at the ONU.

**Figure 6-** Optical spectrum of the upstream signal at the exit of ONU4, measured with a resolution of 12.5 GHz.

IV. CONCLUSIONS

We have demonstrated the feasibility of a polarization insensitive WDM-PON architecture based on spectrum slicing of a SLED shared between several users and remote modulation at the ONU with a R-SOA. The 2.5 Gbit/s downstream signals were remodulated at 1.25 Gbit/s bit rate by the R-SOA at the ONU.

REFERENCES

technologies for broadband access: a review”, *Journal of Optical Networking*, vol. 4, No. 11, November 2005.

