Simple and effective solutions for low-cost coherent WDM-PON

E. Ciaramella F. Bottoni, R. Corsini, M. Presi,
Scuola Superiore Sant'Anna,
Istituto TeCIP, Via G. Moruzzi, 1,
Pisa, Italy
email: e.ciaramella@sssup.it

M. Artiglia,
CNIT
National Lab of Photonic Networks, Via G. Moruzzi, 1,
Pisa, Italy
email: massimo.artiglia@cnit.it

***Abstract*— This paper presents the most significant results achieved in the last two years by our group in coherent ultra-dense-WDM PON for λ-to-the-user access. Here we mostly focus on the architectures based on simple OOK-NRZ modulation format. We demonstrated the real-time implementation of our coherent receiver and we proved its compatibility with direct modulated laser (DML). Receiver sensitivities as low as -48 dBm at BER=1·10-3 for 1.25 Gb/s has been observed, showing the feasibility of a coherent ONU receiver based on devices commonly available and with limited cost. The system support quite high ODN losses and allows the λ-to-the-user approach.**

Keywords*— *coherent optical systems, WDM PON, optical access networks, mobile backhaul.

I. INTRODUCTION

Metro-only traffic is estimated to surpass long-haul traffic, and will account for 58 per cent of total IP traffic by 2017. In this scenario Passive Optical Networks (PONs) are architectures viewed as an attractive solution; they can offer simplicity and low operational cost with tens of Mbps offered to each user. Nevertheless, as bandwidth demands will further increase wavelength division multiplexed PONs (WDM-PONs) will be eventually deployed, eventually allowing for λ-to-the-user approach. However, in order to fulfil the mass deployment requirement, this technology needs to be based on low-cost components. Coherent receivers based on Digital Signal Processing (DSP) allow for advanced functionalities that could be advantageous in the access network environments, but their implementation cost is still an open issue.

Thus we aim at demonstrating the λ-to-the-user ultra-dense (UD) WDM approach through a different paradigm, i.e., low-cost, fully analogue optical coherent detection. In this paper, we will review our most recent results which clearly show that coherent detection in access networks can be effectively realized without expensive and power-consuming ADC's and DSP. The presented solution does also not rely on any expensive photonic device (e.g. external cavity tunable lasers).

II. LOW-COST COHERENT DETECTION FOR ONU/OLT

Since optical PLL is considered complex and difficult to implement we focused on phase diversity techniques. The receiver can be implemented in different ways: we focused here on the implementations able to respect the low-cost and simplicity criteria required by the operators and manufactures for the mass market of optical access networks. Namely our selected solution is based (Fig. 1) on a 3x3 power splitter, followed by 3 photodiodes and by an analogue processing stage, where the photocurrents are squared and summed together, thus yielding the demodulated signal.

The proposed system uses amplitude shift keying (ASK) as the modulation format since it can be detected more easily than other modulation formats and is insensitive to the phase/frequency difference between signal and LO. Of course, some tracking algorithm may be still required to keep the local-oscillator "in-band" with the signal, especially if a UDWDM grid is targeted. But such a control is expected to be operating at very low frequency and can be implemented by means of usual temperature/current controllers (the specifications of these commercial a . In particular, this advantage becomes significant when the bit-rate is increased to 10 Gb/s: in this case, detuning of few GHz are widely tolerated, allowing to use standard wavelength stabilization techniques. A first experimental demonstration showed the possibility to realize a 5x1.25 Gb/s system on a 6.25 GHz grid (fig. 2-b), where a single DFB was used to receive selectively each WDM channel by thermal tuning (see fig. 2-c) without any power penalty.

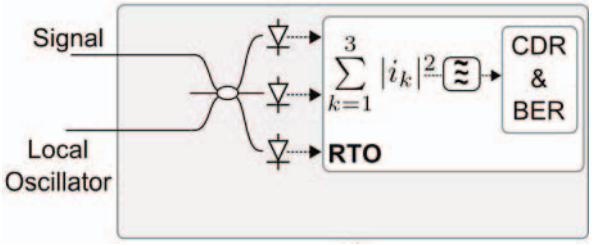

Fig. 1: Receiver schematics

III. KEY RESULTS

Using the above configuration, the following key achievements have been reached in the last two years:
a) demonstration of very low sensitivity at 1.25 Gb/s (around -50 dBm) [1]; this feature allows for higher power budget with

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and without using optical amplifiers, which can support higher number of users (higher splitting ratio) and/or longer reach;
b) ultra dense WDM detection (6.25 GHz spacing) enabled by the above receiver structure [2]; this feature can allow for higher number of channels, i.e. higher network throughput;
c) theoretical demonstration [3] and, later, experimental proof of a novel polarization-independent receiver solution for ASK signals (see Fig. 2), obtained by simply exploiting the 3rd input of the 3x3 coupler [4]; this allows for polarization independence without resorting to complex solutions (polarization diversity, automatic polarization alignment etc.)
d) demonstration of operation with directly-modulated laser sources (DML) up to 10 Gbit/s [5]; this feature is quickly summarized in Fig. 3, and it allows using cheaper and simpler transmitter at ONU.
e) demonstration of extension of the RX scheme reported in Fig.1 to detect DPSK [6], which can be used if DPSK format is preferred by some other considerations;
f) experimental demonstration of bidirectional transmission with simplified polarization-independent receiver [7]: this feature allows for more effective implementations, although it involves a more complex design;
g) extension to 10 Gbit/s for long reach PON [8]; this last feature can be seen as direct extension of ongoing standard NG-PON2.

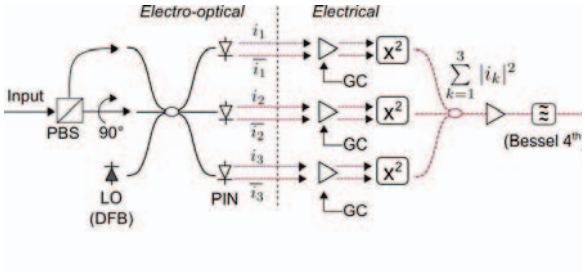

Fig. 2: Schematics of novel polarization-independent receiver

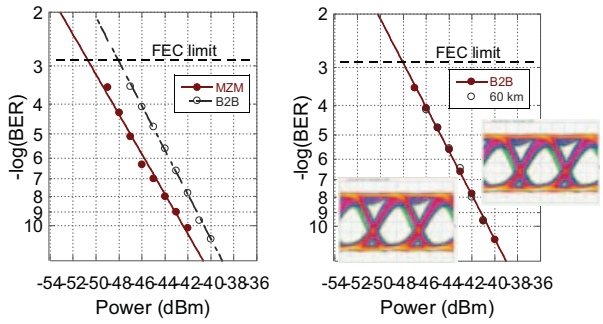

Fig. 3: Characterization of RX with signals produced by external (MZM) or direct modulation (DML).

In all above experiments, the receiver performance was also tested in a transmission experiment over 60 km of G.652 fiber (SMF). The proof of concept demonstrations were first obtained by using a real-time oscilloscope with offline processing. However, finally, the most recent efforts led to the demonstration of real-time signal processing by exploiting a simple electrical signal processing, based on simple (and cheap) analog processing blocks [9]. Few results are reported in Fig. 4.

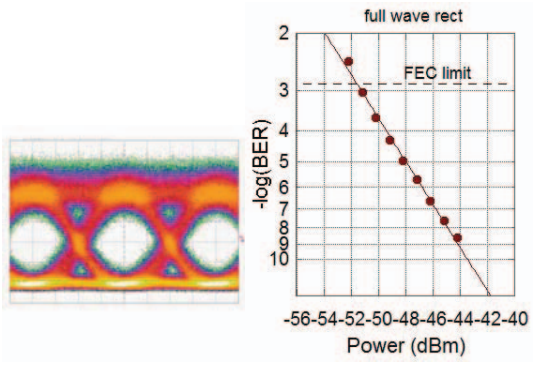

Fig. 4 Real-time RX: (a): eye diagram (b) : BER curves in back-to-back.

IV. Conclusions

We presented a series of experimental demonstrations enabling new concepts for ultra-dense WDM PON based on fully analogue processing. Receiver sensitivities as low as -52 dBm (-49 dBm for DML) at BER=$1\cdot10^{-3}$ for 1.25 Gb/s have been observed, in various configurations. They prove the feasibility of an optical access system with a loss budget of 50 dB and ultra-dense WDM spacing (6.25 GHz), compatible with installed distribution networks, which are splitter-based.

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