Centralized light-source optical access network based on polarization multiplexing

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Abstract: This paper presents and demonstrates a centralized light source optical access network based on optical polarization multiplexing technique. By using two optical sources emitting light orthogonally polarized in the Central Node for downstream and upstream operations, the Remote Node is kept source-free. EVM values below telecommunication standard requirements have been measured experimentally when bidirectional digital signals have been transmitted over 10 km of SMF employing subcarrier multiplexing technique in the electrical domain.

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OCIS codes: (060.4510) Optical communications; (060.4230) Multiplexing; (060.4250) Networks.

References and links.

1. L. G. Kazovsky, W.-T. Shaw, D. Gutierrez, N. Cheng, and S.-W. Wong, "Next-Generation Optical Access Networks," J. Lightwave Technol. **25**(11), 3428–3442 (2007).
2. B. Ortega, J. Mora, G. Puerto, and J. Capmany, "Symmetric reconfigurable capacity assignment in a bidirectional DWDM access network," Opt. Express **15**(25), 16781–16786 (2007).
3. G. Talli, and P. D. Townsend, "Hybrid DWDM-TDM long-reach PON for next-generation optical access," J. Lightwave Technol. **24**(7), 2827–2834 (2006).
4. N. J. Frigo, P. P. Iannone, M. M. Downs, and B. N. Desai, "Mixed-format signal delivery and full-duplex operation in a WDM PON with a single shared source," in Optical Fiber Communications Conference, Vol. 8 of 1995 OSA Technical Digest Series (Optical Society of America, 1995), paper TuK5.
5. N. Deng, C. K. Chan, L. K. Chen, and F. Tong, "Data remodulation on downstream OFSK signal for upstream transmission in WDM passive optical network," Electron. Lett. **39**(24), 1741–1743 (2003).
6. W. Hung, C. K. Chan, L. K. Chen, and F. Tong, "An optical network unit for WDM access networks with downstream DPSK and upstream remodulated OOK data using injection-locked FP laser," IEEE Photon. Technol. Lett. **15**(10), 1476–1478 (2003).
7. L. Y. Chan, C. K. Chan, D. T. K. Tong, F. Tong, and L. K. Chen, "Upstream traffic transmitter using injection-locked Fabry-Perot laser diode as modultaor for WDM access networks," Electron. Lett. **38**(1), 43–45 (2002).
8. W. Hung, N. Deng, C. Chan, and L. Chen, "A Novel wavelength Shift Keying Transmitter Based on Optical Phase modulation," IEEE Photon. Technol. Lett. **16**(7), 1739–1741 (2004).
9. M. Attygalle, N. Nadarajah, and A. Nirmalathas, "Wavelength reused upstream transmission scheme for WDM passive optical networks," Electron. Lett. **41**(18), 1025–1027 (2005).
10. H. Takesue, N. Yoshimoto, Y. Shibata, T. Ito, Y. Tohmori, and T. Sugie, "Wavelength Channel Data Rewriter Using Semiconductor Optical Saturator/Modulator," J. Lightwave Technol. **24**(6), 2347–2354 (2006).
11. E. Rochat, S. D. Walker, and M. C. Parker, "Polarisation and wavelength division multiplexing at 1.55 mum for bandwidth enhancement of multimode fibre based access networks," Opt. Express **12**(10), 2280–2292 (2004).
12. D. van den Borne, S. L. Jansen, E. Gottwald, P. M. Krummrich, G. D. Khoe, and H. de Waardt, "1.6-b/s/Hz Spectrally Efficient Transmission Over 1700 km of SSMF Using 40 × 85.6-Gb/s POLMUX-RZ-DQPSK," J. Lightwave Technol. **25**(1), 222–232 (2007).
13. P. Boffi, M. Ferrario, L. Marazzi, P. Martelli, P. Parolari, A. Righetti, R. Siano, and M. Martinelli, "Measurement of PMD tolerance in 40-Gb/s polarization-multiplexed RZ-DQPSK," Opt. Express **16**(17), 13398–13404 (2008).
14. X. S. Yao, L.-S. Yan, B. Zhang, A. E. Willner, and J. Jiang, "All-optic scheme for automatic polarization division demultiplexing," Opt. Express **15**(12), 7407–7414 (2007).

#120488 - $15.00 USD Received 25 Nov 2009; revised 15 Jan 2010; accepted 16 Jan 2010; published 17 Feb 2010

1. Introduction

A mass-scale deployment of Passive Optical Networks (PONs) based on Wavelength Division Multiplexing (WDM) optical access nowadays require inexpensive configurations offering broadband connections to end users at a reasonable cost [1]. Since the Remote Node (RN) is the key element with a direct impact on the total cost of the access segment, the research is ongoing to centralize all the wavelength provisioning, monitoring and stabilization at the Central Nodes (CNs), the so-called Centralized Light Source (CLS) approach. In this way, because no light sources are incorporated in the Optical Network Unit ("Colorless" ONUs), the overall cost and management of the RNs are significantly reduced. In this context, a number of CLS-based WDM architectures have been reported with the fundamental purpose of locating all the WDM optical carriers at the CN. Generally they propose the multiplexing of a group of optical carriers generated at the CN for both downstream and upstream transmission and propagated from the CN to the RN. There, while the downlink carriers are photodetected and demodulated (for wired FTTH applications) or down-converted (for wireless radio over fiber applications), the uplink carriers are used for the upstream transmission and thus are modulated and looped back to the CN [2–10]. Some of these methods are based in either Time-Division Multiplexing (TDM) [3] or Sub Carrier Multiplexing (SCM) [4] and employ the same wavelengths for downstream and upstream data transport. The former locates the signal packets in different time slots assigned for downlink and uplink, an approach with a clear limitation in both downstream and upstream transmission bandwidths. The latter distributes downstream and upstream data signals onto different subcarriers but presents certain drawbacks to achieve full-duplex and large capacity transmission. Alternative techniques based on transmission and data remodulation have been proposed in order to achieve better wavelength efficiency and realize a low-cost upstream data transmission. They employ Optical Frequency Shift Keying (OFSK) for downstream and upstream signals [5], Fabry-Perot lasers injection-locked by a portion of the remaining power at the ONU [6,7], Wavelength Shift Keying (WSK) combined with optical Phase Modulation (PM) [8], Fiber Bragg Gratings (FBGs) filtering out the downstream optical carriers for upstream data modulation [9] and wavelength channel rewriters by using saturation gain of Semiconductor Optical Amplifiers (SOAs) to erase the downstream signal at the RN [10]. All these networks perform a wavelength reuse at the RN employing the same wavelength for downstream and upstream transmission and generally, the transmission runs over the same optical fiber. However, they present several disadvantages such as complex transceivers, high injection powers, additional light sources at the RN side and unwanted external reflections. In this paper, we propose a CLS optical access configuration based on the employment of optical Polarization Multiplexing (PolMUX) for bidirectional transmission. Traditionally, PolMUX techniques have been used to halve the symbol rate of an optical link by sending independent information in each of the two orthogonally polarized signals and thus achieving an increased spectral efficiency and tolerance to chromatic dispersion [11–14]. We experimentally demonstrate that the PolMUX approach can also be adapted for centralization purposes. Indeed it results to be an easy way to multiplex and distribute the downlink and uplink optical carriers from the CN to a RN allowing to perform high QoS bidirectional signals transmission.

2. Description of the POLMUX-based bidirectional access network

2.1 Principle of operation

Figure 1 depicts the scheme of the bidirectional access network based on the PolMUX principle. The CN is composed of different transceivers (TXs) which transmit different optical channels of the WDM access network. As shown in Fig. 1, each optical channel contains one linearly polarized optical carrier, represented by the optical wavelength λdown, which is amplitude modulated by the downstream signal in an external electro-optical

#120488 - $15.00 USD Received 25 Nov 2009; revised 15 Jan 2010; accepted 16 Jan 2010; published 17 Feb 2010
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modulator (EOM). In the same transceiver, an orthogonal polarized optical signal λup is multiplexed with signal at λdown by means of a polarization beam combiner (PBC). All optical channels are multiplexed and launched into a single mode fiber (SMF) link by means of MUX1. After transmission, both optical PolMUX carriers are demultiplexed to reach the RN through DEMUX2. There, a polarization controller (PC) is used to align the state of polarization (SoP) of both orthogonally polarized channels to the axes of a polarization beam splitter (PBS). The PBS function is to demultiplex both channels in order to separate λdown and λup separately. The optical downlink channel λdown is detected by a photodiode (PD) to recover signal information whereas the uplink carrier λup is modulated by the upstream signal and sent back to the CN through an optical circulator. Uplink signals are multiplexed in the MUX2, transmitted and demultiplexed just prior to reach the CN by means of DEMUX2. A circulator allows to recover the uplink signal after the detection.

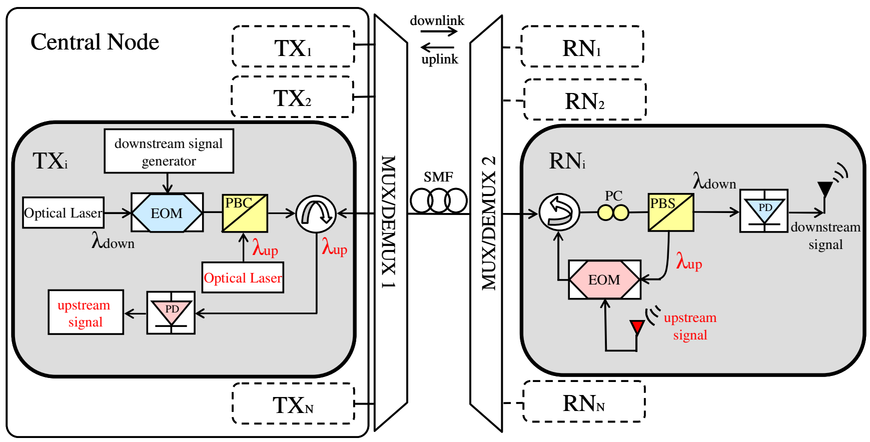

Fig. 1. Centralized light source access network based on PolMUX.

2.2. Experimental setup for bidirectional transmission system based on PolMUX

In a first experimental setup, we characterize the bidirectional transmission system using a single optical channel. We use two tunable optical lasers as downlink and uplink carriers in order to test previously the polarization extinction ratio (PER) that can be achieved at the RN using the PC. In this case, the PolMUX approach is equivalent to a 2-channels WDM system. In Fig. 2 we plot the optical spectra corresponding to the downlink and uplink channels when two lasers λdown = 1553.3 nm and λup = 1552.5 nm with a wavelength spacing Δλ = 0.8 nm are employed. Figure 2(a) plots the downlink signal spectrum measured at the RN and Fig. 2(b) represents the uplink optical carrier at the RN (solid line) previously to the round trip and also, at the CN (dashed line) after the way back. It can be observed that PER is over 50 dB can be achieved in the RN for both downlink and uplink channels. However, when the uplink channel is recovered at the CN, the PER is reduced due to unavoidable reflections up to 40 dB. Furthermore, due to environmental impairments, to keep a 40 dB polarization crosstalk level after the polarization demultiplexing process is not straightforward [13]. However, a crosstalk higher than 30 dB was measured at the receiving terminal in all cases, and also, the PER did not vary significantly when the wavelength separation Δλ was reduced. Measurements were performed with longer fiber links up to 30 km and PER kept over 30 dB.

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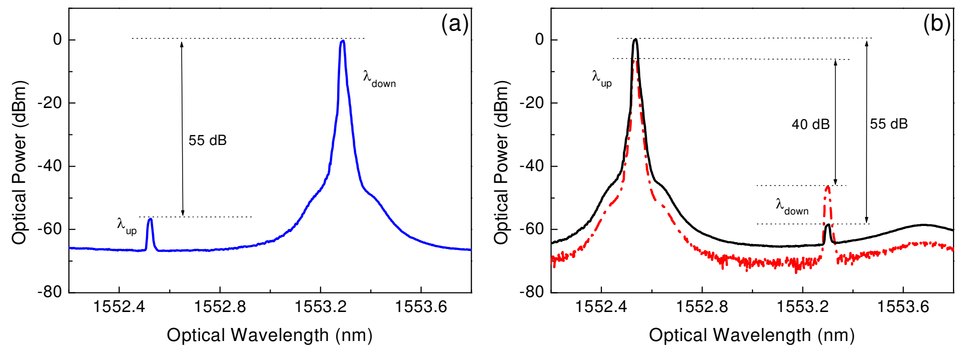

Fig. 2. Optical spectra for orthogonally polarized carriers with a wavelength separation $\Delta\lambda$ = 0.8 nm for (a) downlink channel and (b) uplink channel which is measured at CN (solid line) and at RN (dashed line)

3. Experimental measurements

In order to validate the PolMUX approach to centralize light sources in the CN, we have implemented experimentally the scheme proposed in Fig. 1. An electrical vector signal generator provides the downstream and upstream signals both based on a 5 Mb/s QPSK modulated signal at 10 GHz subcarrier frequency. Both data sequences are generated at the CN an RN respectively and propagated over 10 km of SMF.

3.1 Two different wavelengths per orthogonally polarized channel

In the first set of measurements we evaluate the impact of the PER on the signal transmission degradation. For this purpose we consider two different optical wavelengths for downlink and uplink as those depicted in Fig. 2 which are λdown = 1553.3 and λup = 1552.5 nm. Figure 3 plots the Error Vector Magnitude (EVM) as a function of the PER when both optical signals are demultiplexed at the RN. We observe that the EVM values reached by the downstream channel (●) are independent on the polarization crosstalk and are kept below 2.3%. In fact, since λup is a CW, the demodulated RF subcarrier corresponding to λdown is not affected by the DC component received at the PD. In contrast, the upstream signal quality (●) worsens drastically for polarization crosstalk levels lower than 20 dB as confirmed by the huge increasing of the EVM. Indeed the downstream signal, which is orthogonally polarized to the upstream one, spectrally overlaps with the upstream signal at the RN due to the polarization crosstalk.

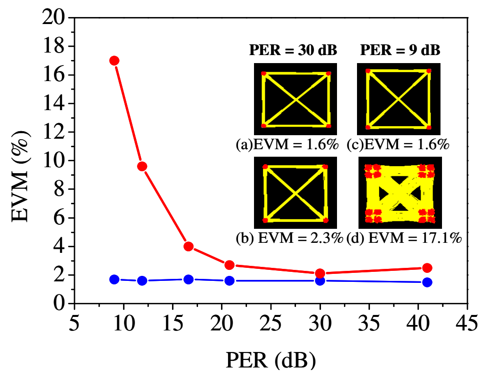

Fig. 3. EVM as a function of the PER for downstream (●) and upstream (●) channels. Insets represent constellation diagrams for (a) downstream and (b) upstream signals when PER = 30 dB. (c) Downstream and (d) upstream signals for a PER = 9 dB.

Insets of Fig. 3 display the constellation diagrams captured for a PER of 30 dB and 10 dB. The constellation diagrams indicates that the downlink signals have almost the same degradation with EVM values around 1.6% when the PER is either 30 dB or 10 dB as plotted in Fig. 3(a) and Fig. 3(c), respectively. On the other hand, the uplink signal quality gets worse since the measured EVM changes from 2.3% to 17.1% when the polarization crosstalk value decreases from 30 dB to 10 dB as shown in Fig. 3(b) and Fig. 3(d), respectively. Indeed, the constellation diagram of Fig. 3(d) shows that two QPSK signals corresponding to the downstream and upstream transmission are simultaneously demodulated and overlap each other. Therefore, we can conclude that the proposed PolMUX technique is suitable for a bidirectional CLS optical link once a 30 dB polarization crosstalk is guaranteed at the RN.

3.2 Channels degradation as a function of the wavelength separation Δλ

In this section we analyze the use of a single wavelength instead of two different wavelengths for both orthogonally polarized downstream and upstream channels in order to increase the cost-effectiveness and the wavelength efficiency of the optical access network. With this aim, we measure the transmission degradations in terms of EVM as a function of the wavelength spacing between the two PolMUX optical carriers λdown and λup. Experimental results of this test are shown in Fig. 4(a) for a PER of 30 dB at the RN and a launch optical power of 13 dBm. Figure 4(a) shows the EVM of the downstream channel (●) around 1.6% and is almost independent of the channel spacing Δλ. With regard to the upstream channel (●) the EVM presents an increase from 2% to 5% when the wavelength separation is reduced up to a null value. This degradation is due to the coherence time of the optical lasers. To overcome this limitation the quality of transmission of both downlink and uplink channels must be equalized. Since the EVMs measured for the downstream signal are lower compared with the ones obtained over the uplink path for an equal launching optical power, a solution we propose is to unbalance the launching optical power between the two orthogonally polarized channels and produce an increase of the relative PER. Figure 4(b) depicts the EVM achieved by the upstream (●) and downstream channel (●) when the launch optical power of the first one is kept unchanged at 13 dBm and the optical power of the second one is reduced (unbalanced) from 13 dBm to 3 dBm at the CN.

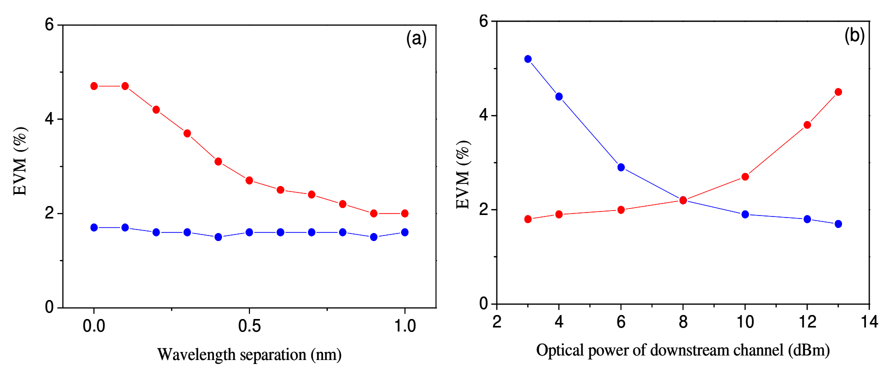

Fig. 4. (a) EVM versus wavelength spacing Δλ between the downstream (●) and upstream (●) channels.(b) EVM versus downstream optical power for fixed upstream optical power of 13 dBm: (●) Downstream (●) Upstream channels.

As expected, the downstream signal quality deteriorates from EVM values around 1.6% to 5.2% as the optical power of the downlink channel decreases. In the uplink transmission, the signal quality is better and lower EVM values are reached. Under this condition, a compromise in terms of launching optical power between the downlink and uplink channels can be found in order to achieve similar EVM values for the downstream and upstream

#120488 - $15.00 USD   Received 25 Nov 2009; revised 15 Jan 2010; accepted 16 Jan 2010; published 17 Feb 2010
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signals. Indeed, as shown in Fig. 4(b), acceptable EVM values of 2.2% have been measured for both downlink and uplink channels for unbalanced optical powers of 8 dBm and 13 dBm, respectively.

Finally, we have tested the optical access network for different optical wavelengths in order to evaluate the degradation of the POLMUX based transmission system. The optical carriers are separated 0.8 nm. When the condition of unbalanced power is considered, we have obtained that the EVM remains lower than 3% for uplink and downlink in all C-band.

4. Conclusions

In this paper we have proposed and implemented experimentally the feasibility of a bidirectional optical access network whose light sources are all centralized in the CN by means of optical polarization multiplexing technique. At the CN two orthogonally polarized carriers are multiplexed in a polarization beam combiner. One of them is modulated by the downstream data whereas the other one is let as a continuous waveform in order to be used for upstream transmission at the RN. The upstream signal is launched back into the fiber link by an optical circulator from the RN to a second circulator at the CN where is detected. A polarization controller is required in the RN, but commercial products can be found which have been designed for this purpose. In the experimental setup we first considered two independent and orthogonally polarized laser sources in order to evaluate the impact of the polarization extinction ratio on the fiber transmission in both directions, concluding that a polarization crosstalk of 30 dB between the two orthogonally polarized channels is needed to guarantee high quality transmission performance. We also evaluated the effect of the wavelength separation on the EVM by using 5 Mb/s QPSK data modulating 10 GHz electrical subcarriers as a conventional subcarrier multiplexing technique. We observed a good agreement between the achieved EVMs and standard EVM values when both downlink and uplink signals are propagated from the CN to the RN with the same optical power and a wavelength separation of 0.8 nm. Finally we studied the case of using a single wavelength for both orthogonally polarized channels in order to improve the wavelength efficiency and implementation costs of the optical access network. Since we found larger degradation of the upstream signal quality than the downstream one, in order to overcome this limitation, we propose to unbalance the optical power of both downlink and uplink channels, and therefore, equalize their degradation levels With 5 dB difference between both channels, EVMs around 2.2% have been achieved in both directions confirming that the proposed PolMUX approach successfully enables the centralization of lightwave sources in both downlink and uplink directions. Finally, different optical carriers are considered in the optical access network when the unbalanced power procedure is realized. We have found that degradation through EVMs values remains lower than 3% over C-band.

Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7) under project 212352 ALPHA "Architectures for fLexible Photonic Home and Access networks". Also the authors wish to acknowledge the Vicerrectorado de Innovación y Desarrollo de la UPV support trough project PAID-06-07 (Ref. 3297) and PROMETEO 2008/092 MICROWAVE PHOTONICS a research programme of Excellency supported by the Generalitat Valenciana.

#120488 - $15.00 USD Received 25 Nov 2009; revised 15 Jan 2010; accepted 16 Jan 2010; published 17 Feb 2010
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