(O)FDMA PON over a legacy 30dB ODN

Benoît Charbonnier, Nicolas Brochier, Philippe Chanclou
France Télécom R&D, 2 avenue Pierre Marzin, 22307 LANNION Cédex, FRANCE
Author e-mail address: benoit.charbonnier@orange-ftgroup.com

Abstract: A reflective polarization independent carrier suppressed optical modulation system for FDMA/OFDMA PON over legacy infrastructures is proposed. A demonstrator is experimentally validated as an initial step towards full multi-user functionality.

OCIS codes: (060.0060) Fiber optics and optical communications, (060.1660) Coherent communications

1. Introduction

Next generation Access Networks are forecasted to increase their global capacity beyond 10 Gbps symmetrical and are expected to continue using Time Division Multiple Access (TDMA) for the uplink direction [1,2] in combination with Wavelength Division Multiplexing (WDM) with a view to offer data connections of the order of 1Gbps per user. However, on a per wavelength basis, alternative access mechanisms allowing a more flexible dynamic bandwidth allocation and relaxing the difficulties inherent with burst mode operation exist: Optical Code Division Multiple Access (OCDMA) [3], Frequency Division Multiple Access (FDMA) [4] and Orthogonal Frequency Division Multiple Access (OFDMA) [5]. Considering only the case when such shared access mechanisms are applied over a common wavelength in order to keep the WDM dimension available, then the last two approaches require a polarization independent reflective modulator capable of providing optical carrier suppression to avoid inter-ONU optical carrier beating noise. These approaches also necessitate coherent reception at the Central Office (CO) side. The use of coherent reception in Passive Optical Networks (PONs) as already been proposed and reported to successfully increase capacity as well as the RX sensitivity [5,6]. This paper proposes a sub-system allowing polarization independent reflective carrier suppressed optical modulation suitable for FDMA and OFDMA based PONs. It also makes such access mechanisms compatible with the current deployed infrastructures where the downlink and uplink signals are sent on the same optical fiber. Furthermore, this reflective modulator acts as a Faraday Mirror and allows the required coherent receiver in the CO to be simpler as the necessity for polarization diversity is removed [6].

2. Polarization independent reflective Mach-Zenhder modulator

To obtain optical carrier suppressed modulation, we employ a Mach-Zenhder Modulator (MZM) biased at its null point. To overcome the polarization sensitivity of this modulator and make it reflective, we place it inside a polarization diversity loop made of the two PM branches of a Polarization Beam Splitter/combiner (PBS) (Fig. 1 right). Each polarization component of the incoming optical signal travels through the loop in opposite directions and are modulated independently though the MZM. This is made possible thanks to the dual electrode configuration of the MZM where RF access to each electrode is provided on both ends. This allows the RF modulating signal to be sent in parallel on both sides of the modulator in the same direction as at least one of the two optical polarization components. Consequently, bidirectional modulation is obtained. Finally the two polarization components are recombined in the PBS. As the loop is symmetrical and the MZM is placed at the same optical distance from the two sides of the PBS, these two modulated counter propagating signals are recombined in phase. When the modulator is biased at its null transmission point, it can be shown, by using the equations of [7], that the two polarization components are recombined in a way that the output optical polarization is perpendicular to the input one. In that case, the Reflective MZM (denoted R-MZM) acts as a Faraday mirror and the same technique as the one described in [6] can be applied.

3. Experimental proof

To prove the concept, an experimental test bed is set-up (Fig. 1 left). An external cavity laser (ECL) with +12dBm power and a wavelength of 1544nm in the Central Office (CO) is sent via a PBS onto an Optical Distribution Network (ODN) simulating a PON i.e. containing up to 20 km of fiber and having between 13dB and 30dB of loss and then onto an Optical Network Unit (ONU) made of a single Semiconductor Optical Amplifier (SOA) with 24dB of gain and the R-MZM described above (V_π=4.1V at 1kHz, 4.6dB insertion loss, 9.6GHz modulation bandwidth). Note that the SOA acts as a bidirectional amplifier for the incoming and reflected optical signals. In the ONU, an optical coupler also provides a monitoring port of the ONU output for an Automatic Bias Control (ABC) circuit ensuring that the R-MZM is correctly biased (null). The reflected modulated signal is sent back to the CO with orthogonal polarization and recovered by the second branch of the PBS. This signal is re-amplified at the CO by a polarization maintaining Erbium Doped Fiber Amplifier (EDFA) and fed into a single polarization 90° hybrid along with part of the original ECL output that serves as Local Oscillator (LO). The simulated upstream data is generated using a Discrete Multi Tone (DMT) modulation thanks to a 10GS/s Arbitrary Waveform Generator (AWG) and recovered on the system's output by a Digital Sampling Oscilloscope (DSO) with 20GS/s for analysis.

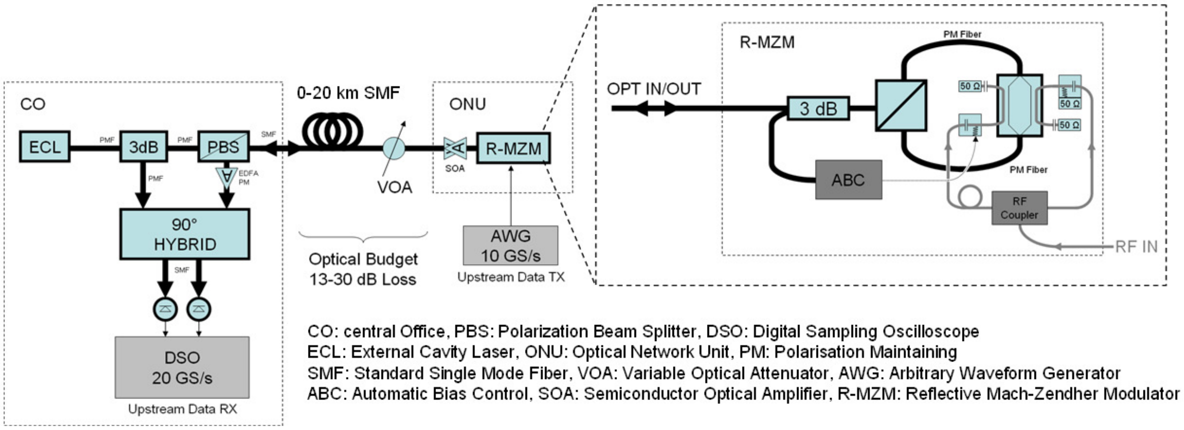

Fig. 1: Experimental set-up for the reflective Mach-Zendher modulator and the proof of concept OFDMA PON.

The captured signal is then post processed for performance evaluation with Matlab®. The DMT signal contains 127 sub carriers (SC) that can be arbitrarily modulated (with up to 64-QAM) or switched off. A cyclic prefix of 16 samples is introduced to prevent inter-symbol interferences. The underlying OFDMA mechanism (beyond the scope of this paper) will share the available SC between each ONU depending on the individual traffic needs and priorities, the individual transmission channel capability and global available capacity. In such a shared access technique, the different ONU are able to transmit data simultaneously using their individually attributed SC [5]. In our experimental tests, we simulate a number of SC attributed to the ONU (all the others are switched off) and compute the optimum capacity reached for a bit error rate of 10^{-4} by a two steps process: initially all attributed SC are modulated with QPSK and have equal power, then after transmission through the system and analysis of this probing signal and depending on the Error Vector Magnitude (EVM) found, a new bit/power optimized [8] signal is generated at the ONU which achieves a target BER (chosen to be 10^{-4}) with a given capacity. This capacity is then reported for different assignments of the SC and different power budgets with or without optical fiber.

4. Results and discussion

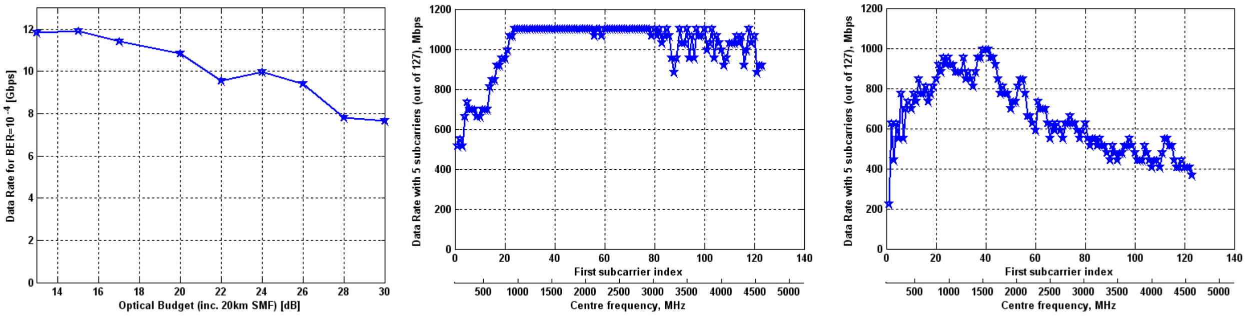

Fig. 2: Experimental results. Left: maximum single user data rate vs. optical budget (including 20km of fiber). Center and Right: Achievable data rate vs. first SC index when 5 consecutive SC are attributed to a single user in the minimum budget case (13dB, no fiber – Center) and maximum budget case (28dB, 20km fiber – Right).

In a first step, all SC are attributed to the ONU and we investigate the data rate achieved for this condition as the total optical loss between the CO and ONU is varied from 13dB to 30dB (including 20km of fiber). The RF power sent onto the R-MZM is optimized to maximize the signal to noise ratio (SNR) while avoiding distortions and is set to +8dBm. Results are reported in Fig. 2 left. For a target BER of 10^{-4}, the data rate achieved varies from 12Gbps and 7.5Gbps. This represents the maximum capacity that a user could reach in this configuration if he was alone to transmit over the PON. In a second step, we set the optical budget to 13dB without optical fiber (the minimum budget case) and attribute only 5 consecutive SC out of the 127 to the user. If the first SC index is denoted N_0, the attributed SC are N_0 to N_0+4. Depending on the first SC index and the quality of the transport channel at the concerned frequencies, the data rate achieved varies. The same modulating RF power of +8dBm is used. This should lead to a much higher SNR per SC than in the case when all SC are attributed to this user. Results are plotted in Fig. 2 center. The data rate available to an ONU with minimal optical budget is comprised between 500Mbps and 1.1Gbps depending which group of 5 SC it has been attributed. Note that, as we have set the maximum allowed number of bits per sub-carrier to 6 (64-QAM), the maximum achievable data rate when using only 5 SC is 1.1029Gbps (= 6 bit/sc × 5 sc × 10^{10} S/s / 272 S where 272 is the number of samples per symbol computed from the number of data SC, null SC and cyclic prefix). Finally we repeat the 5 SC per user case but this time with an optical budget of 28dB including 20km of fiber (worst case). Results are shown on Fig. 2 right. The available data rate can be as low as 200Mbps but in the middle of the available RF band (around SC number 40 at around 1.5GHz) there exist a region where it is still possible to provide this user with 1Gbps capacity. The OFDMA mechanism will hence attribute those SC in priority to this user when it requires transmitting data (at 1Gbps). We also note that the performance obtained for the SC closest to the zero frequency is worse. We attribute this to the fact that the modulation efficiency of the R-MZM is worse at low frequencies because the counter propagating optical signal and RF modulating signal in the MZM electrodes interact more hence reducing the benefits of the dual drive opposite direction modulation.

5. Conclusion

We have demonstrated a set-up providing reflective, polarization independent, suppressed carrier, optical modulation for application in FDMA and OFDMA PON. Furthermore, the sub-system acts as a Faraday mirror which can be used to simplify the coherent optical receiver at the CO side by removing the need for polarization diversity. Also, thanks to this sub-system, a conventional single fiber infrastructure can be used to deploy (O)FDMA PON. Initial experimental results show that from 7.5Gbps and 12Gbps can be transported when the whole RF spectrum (5GHz wide) is attributed to a single user (with DMT modulation). On the other hand, if a user is attributed only a small fraction of this spectrum (5/127th), then he still has access to a capacity of 1Gbps.

4. Ackowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) within the project ICT ALPHA under grant agreement n° 212 352.

4. References

[1] Davey R. *et al*, "Options for Future Optical Access Networks" in IEEE Comms Mag 44 (10), October 2006, pp 50-66

[2] Nakagawa J. *et al,* "First Demonstration of 10G-EPON and GE-PON Co-existing System Employing Dual-rate Burst-mode 3R Transceiver", Optical Fiber Conference, 2010, Post deadline Paper PDP10.

[3] Lui J. *et al,* '"Demonstration of Low-Cost Uplink Transmission in a Coherent OCDMA PON Using Gain-Switched Fabry–Pérot Lasers With External Injection", in IEEE Photonics Technology Letters,22 (8), 2010, pp 583 – 585

[4] Zhang C. *et al*, "Bidirectional 60-GHz radio-over-fibre systems with downstream OFDMA and wavelength reuse upstream SC-FDMA" in Otics Express, 18(18), 2010, pp. 19429-19437

[5] Cvijetic N. et al: "Orthogonal Frequency Division Multiple Access PON (OFDMA-PON) for Colorless Upstream Transmission Beyond 10 Gb/s", in IEEE Journal on Selected Areas in Communications, 28 (6), 2010 , pp 781 – 790

[6] Cho K. Y. *et al*, "Self-Polarization-Stabilization Technique for Long-Reach Coherent WDM PON", Optical Fiber Conference, 2010, Post deadline Paper PDPD7.

[7] Cartledge, J.C., "Optimizing the bias and modulation voltages of MQW Mach-Zehnder modulators for 10 Gb/s transmission on nondispersion shifted fiber", in Journal of Lightwave Technology, 17 (7), 1999 , pp 1142 – 1151

[8] J. Campello, "Optimal discrete bit-loading for multicarrier modulation systems", ISIT'98, page 193, IEEE International Symposium on Information Theory 16-21 Aug. 1998 Page(s):193