Deployment analysis of TDM/WDM Single Fiber PON with Colourless ONU Operating at 2.5 Gbps Subcarrier Multiplexed Downstream and 1.25 Gbps Upstream

Josep M. Fabrega[1], *member OSA*, Ahmad El Mardini[2], Victor Polo[1], José A. Lázaro[1], *member OSA*, Eduardo T. Lopez[1], Risto Soila[2], and Josep Prat[1], *member OSA*

(1) Universitat Politècnica de Catalunya (UPC), Dept. Signal Theory and Communications, Jordi Girona 1, D4-D5, 08034 Barcelona (Spain).
E-mail: jmfabrega@tsc.upc.edu
(2) Tellabs Inc., 18581 Dallas Parkway. Dallas, TX 75287 U.S.A
E-mail: ahmad.elmardini@tellabs.com

Abstract: A single-fiber full-duplex hybrid TDM/WDM-PON is demonstrated to operate at 2.5/1.25 Gbps rates, with RSOA ONU. It achieves high power budget (GPON compliant) at a distances higher than 20km, and serves up to 1280 users.

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1. Introduction

Access Passive Optical Networks (PONs) have emerged as effective platforms to deploy bandwidth demanding advanced services. Thus, next generation PONs have to solve several challenges, including high bitrate delivering and Wavelength Division Multiplexing (WDM). A mandatory specification is the use of a single fiber for both, upstream and downstream transmission, to reduce the size of the external plant and the complexity of the Optical Network Unit (ONU). Another interesting feature is the use of the same wavelength for upstream and downstream senses, unrestricting the wavelength's use, and leading to the use of reflective colourless ONUs.

In the past, some advanced designs which avoid the generation of light at the ONU by using different modulation schemes for downlink and uplink transmission have been demonstrated [1-2]. However, these methods may not be low-cost, due to the components needed for modulation and detection of the up/downstream signals. A more cost-effective solution can be the use of a subcarrier multiplex (SCM) technique [3-4]. Using this technique upstream and downstream spectrums are not overlapped, and the system becomes more tolerant in front of Rayleigh backscattering.

In this paper, for the first time, we demonstrate a 20 km full duplex PON operating at a rate of 2.5 Gbps downstream and 1.25 Gbps upstream using the SCM technique, giving service to a maximum of 1280 users. Aiming to reach the user with single fiber-scheme, the tolerance against Rayleigh backscattering ratios is also evaluated.

2. Experiments and discussion

The Optical Line Terminal (OLT) and ONU schemes to test are depicted in Fig. 1. For the 2.5 Gbps downstream signal we used a Mach-Zehnder Modulator (MZM) preceded by a laser (operating at 1550.12 nm), and followed by an EDFA. Please not that all the cost of the OLT is shared among all the users, thus giving to the operator the freedom to use several expensive techniques at the OLT side. A Pseudo-Random Bit Sequence (PRBS) with length of 2^{31}-1 was used as downstream signal. Once differentially precoded inside the downstream Pulse Pattern Generator (PPG1), it was mixed with a 5 GHz electrical oscillator (not synchronized with the PPG1 clock), and the resulting signal was driven to the MZM. At the electrical side of the ONU receiver, after the 70/30 optical coupler and the APD, a delay-and-multiply scheme was implemented using standard electrical mixers. This 70/30 optical coupling ratio was found optimum in order to equilibrate upstream and downstream power budgets, since the RSOA gain was found to be of 20 dB and the back-to-back sensitivity of the proposed SCM receiver was of -28.2 dBm (using no optical coupler). For the 1.25 Gbps upstream signal, we used another 2^{31}-1 PRBS from a second pulse pattern generator (PPG2), driving an RSOA in the ONU.

Based on those ONU/OLT designs, three different PON scenarios were tested, trying to keep a minimum system margin of 3 dB: first a pure TDM network with low coverage (8 users) used as a reference; secondly an standard medium hybrid TDM/WDM PON covering 160 users; and finally an optimized network capable to serve 1280 users.

The first scenario was assembled as a 25 km feeder spool, followed by a 1:8 power splitter and a 2.2 km drop spool; in a single-fiber configuration. This is shown in Fig. 2. It was intended as an access network for a large coverage area and low density of users, capable to serve up to 8 users. Thus, a pure TDM configuration was tested and saved as a reference.

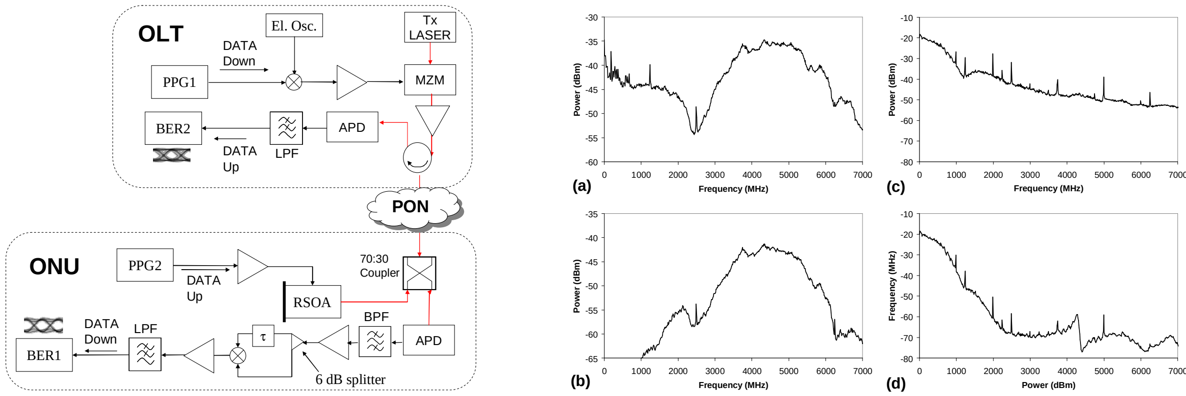

Fig. 1. Left: ONU and OLT schematic. Right: Electrical power spectrums at the receiver side: (a) before filtering at the ONU, (b) after filtering at the ONU; (c) before filtering at the OLT, and (d) after filtering at the OLT.

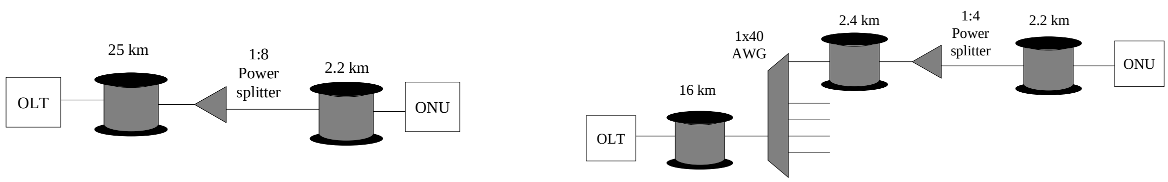

Fig. 2. Schematics for scenario 1 (left) and scenario 2 (right).

In this first case, total network losses were measured to be 16 dB. The ONU input power was of -16 dBm, and its output power was measured to be of +1 dBm, meaning that the ONU net gain was of 17 dB and the RSOA gain was of 20.5 dB. 0 dBm were injected from the OLT to the feeder fiber, generating a measured Rayleigh Backscattering (RB) of -33.5 dBm (having a 17.5 dB of upstream optical Signal to Rayleigh-backscattering Ratio, oSRR). Under these conditions, upstream and downstream transmission curves were measured. Results are shown in Fig. 3. For the downstream we found a sensitivity of -20.1 dBm, while for the upstream the sensitivity found was of -18.4 dBm, both for a BER of 10^{-10}. This means that we achieved a downstream power budget of 20.1 dB (system margin of 4.1 dB) and an upstream power budget of 19.4 dB (system margin of 3.4 dB).

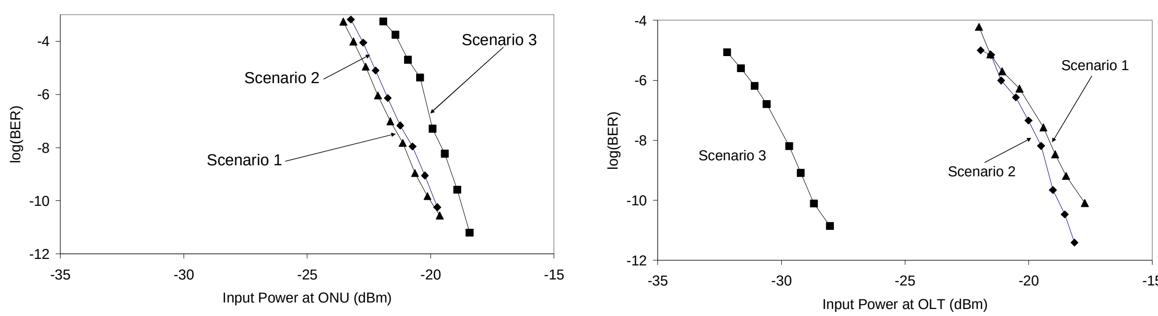

Fig. 3. Downstream sensitivity curves for the three different scenarios (left), Upstream sensitivity curves for the three scenarios (right)

The second test-bed was composed of a 16 km feeder spool, followed by a 1:40 AWG demultiplexer. Next to it, a 2.4 km distribution spool was preceding a 1:4 power splitter and a 2.2 km drop spool. This is shown in Fig. 2 (right). This scenario was for an area with medium density of users, capable to serve up to 160 users.

Total network losses were measured to be 16.4 dB. The ONU input power was -16.4 dBm, and its output power was measured to be of +0.8 dBm, meaning that the RSOA gain was of 20.7 dB. Also, 0 dBm were injected from the OLT to the feeder fiber, generating a RB of -33.5 dBm; and having a 17.5 dB of upstream oSRR, too. Again, upstream and downstream transmission curves were measured. Results are shown in Fig. 3. For the downstream we found a sensitivity of -20.6 dBm, while for the upstream the sensitivity found was of -19 dBm, both for a BER of 10^{-10}. This means that we achieved a downstream power budget of 20.6 dB (system margin of 4.2 dB) and an upstream power budget of 19.8 dB (system margin of 3.4 dB).

Finally, an upgraded third test-bed was assembled. In this case, a double fiber feeder is proposed, so the RB amount generated was very low; only due to de distribution and drop stages. Now a couple of 16 km feeder spools were implementing a double fiber path from the OLT to the AWG. Next to it, a 2.4 km distribution spool was preceding the 1:32 power splitter and a 2.2 km drop spool. This is shown in Fig. 6. Also, an optical preamp was used for upstream detection, since there was no RB limitation, and OLT costs are shared among all users. This scenario was intended as an improved access network, covering as many users as possible (up to 1280).

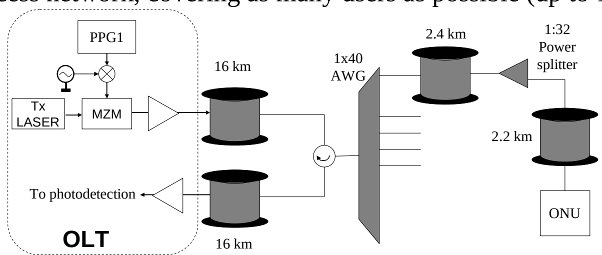

Fig. 6. Scheme for scenario 3

Now, total network losses were measured to be 26.6 dB. The ONU input power was of -16.6 dBm, and its output power was measured to be of +0.8 dBm, as in the second scenario. Please note that the Rayleigh backscattered signal was negligible, and the OLT output power could be increased to +10 dBm. Under these optimized conditions, upstream and downstream transmission curves were measured. Results are shown in Fig. 3. For the downstream we found a sensitivity of -19.6 dBm, while for the upstream the sensitivity found was of -28.8 dBm, both for a BER of 10^{-10}. This means that we achieved a symmetrical power budget of 29.6 dB (system margin of 4 dB). Table 1 shows a summary comparison between the three scenarios.

Tab. 1. Summary for the 3 scenarios

	Power Budget		**System margin**
	Upstream	**Downstream**	
Scenario 1	20.1 dB	19.4 dB	3.4 dB
Scenario 2	19.8 dB	20.6 dB	3.4 dB
Scenario 3	29.6 dB	29.6 dB	4 dB

Conclusions

An advanced hybrid TDM/WDM access solution has been studied and experimentally demonstrated. It is based on the transmission of 2.5 Gbps SCM downstream and 1.25 Gbps upstream using colourless reflective ONU.

Three scenarios were evaluated: Large coverage area and low density of users; area with medium density of users; and improved access network, covering as much users as possible. In the first and second test-beds, transmission experiments have shown a network power budget of 20 dB, for a single fiber configuration, combined with the capacity to serve up to 160 users. For the third one, the power budget could be increased up to 29 dB, matching clearly the typical values of GPON deployments, and serving up to 1280 users. In all the cases a minimum system margin of 3 dB was achieved.

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