FABULOUS NEWSLETTER

FDMA Access By Using Low-cost Optical Network Units in Silicon photonics

Number 2

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Table of contents:

Laser Tunability in TWDM-PON vs. reflective solutions

FSAN and now **ITU-T** are today working on defining the new standard for NG-PON2, which will be based on **TWDM-PON** under the set of Recommendations **ITU-T G.989** titled "40-Gigabit-capable passive optical networks 2 (NG-PON2)". The general requirements have been made public in 2013 by releasing the Recommendation G.989.1, while the Physical Media Dependent (PMD) layer specification is today under final discussion. One of the PMD aspects that is currently getting significant attention in FSAN is the control of the upstream wavelengths for TWDM-PON, since it is perceived as a critical point, due to the fact that the upstream wavelengths will use a 100 GHz grid so that, for the first time in PON, the ONU laser will need to be:

- Accurate enough to match a 100 GHz grid
- Tunable on at least four wavelengths.

These technical requirements would be easily matched by tunable lasers available today for long-haul core networks, but their cost is absolutely prohibitive for PON, and in particular for ONU. New solutions should thus be found, and the general consensus today is that the only viable solution cost-wise is thermally tunable DFB or DBR lasers with a tuning algorithm remotely controlled by the central office through some proper signaling. Anyway, during an ONU "bootstrap" phase, the emitted upstream wavelength is random and it may "blank" some of the other active ONUs. A very complex "upstream wavelength bootstrap" procedure will thus need to be defined.

… now let's have a look on the **reflective solutions proposed in FABULOUS**: all wavelengths for both upstream and downstream are generated at the central office, while the FABULOUS ONUs do not require tunable lasers at all, but only tunable optical filters that can be locked locally (i.e. inside the ONU) on one of the already existing wavelength. Is this something that may be of interest **for a future NG-PON3?**

Roberto Gaudino
Politecnico di Torino
Scientific coordinator

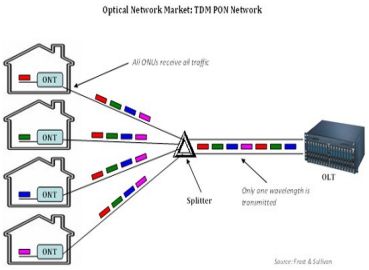
18 FABULOUS months!

FABULOUS has already reached half of its life, and is undergoing its second review shortly.
In these 18 months, a lot of results have been achieved already, in particular for what concerns the assesment of the maximum performances the architecture will be able to reach: we have demonstrated the flexibility of the FDMA approach, we have shown that reflective PON can compete with standard PON, we have understood that the FABULOUS architecture is more resilient to Rayleigh backscattering with respect to conventional reflective PON. Unfortunately, FSAN has decided for a different, and less ambitious, architecture to be standardized for NG-PON2.
Given all these reasons, **this issue of the newsletter is mostly focused on system aspects**, that have achieved a consistent level of maturity.
First version of the components have recently been taped out: we have SOAs, the modulator, the filter, the driver, and they are in progress of being improbe. So wait for the next issue, that will be focused on components aspects, and keep visiting the project website for being up-to-date

FABULOUS at a glance:

Start date: 1st October 2012
Duration: 36months
Total project cost: 4,2M€
EU financing: 2,9M€

Is TDMA really the way forwawd?



TDMA PON. Every ONU receives all the traffic

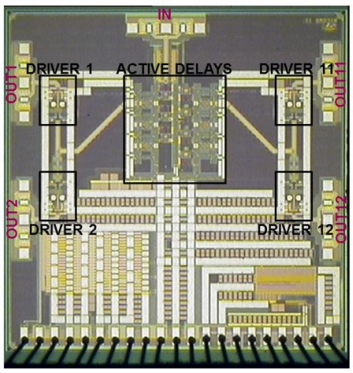
In current PON systems (G-PON and E-PON) but also in future PON systems such as NG-PON1 (XG-PON1 and 2), 10G-EPON and NG-PON2, the users share the available bandwidth in the time domain (a.k.a. TDM/TDMA). That is, the active users receive a constant flow of data at 1Gbps (E-PON), 2.5Gbps (G-PON) or 10Gbps (NG-PON) which they have to demodulate and analyze even if they are only making a phone call (several tens of kbps of useful capacity). The same applies for the transmit side which has to operate at a high line rate (1Gbps for E-PON, 1.25Gbps for G-PON, 2.5Gbps or even 10Gbps for the others). Is this not a waste of electrical power?
A common belief is that FTTH customers are all bandwidth hungry people, eagerly looking for more data rate and capacity, in which case the TDM model above fits nicely with the customer's requirements. But, if this 'early adopters' view was certainly true at the start of the optical deployments when FTTH connections were scarce and expensive, this is not true anymore. Indeed, as PON infrastructures are being deployed and FTTH service cost is decreasing, it is becoming apparent that FTTH users have very diverse requirements. This is also completely understandable when we think of a future optical local loop completely replacing the copper one, a time when all users have FTTH access. How will it be possible to accommodate over the same network different classes of services? How much beneficial would be a solution that would allow all customers to have their capacity dynamically adapted to their instantaneous needs?
At the same time, even if the FTTH local loop deployed today is based on the same topology as the copper local loop with closely spaced customers (less than 4km around central offices), it can be shown that the optical loss between each individual ONU (customer premises equipment) and the OLT (central office) varies randomly. We have measured the statistics of this loss value per PON tree for a 64 split architecture and found that the average customer loss is at 21.4dB with a standard deviation of 1.4dB. However, with current PON technology, based on TDMA media access control, all users operate with the same module, designed for the highest loss customer (specified at 28 dB optical loss) even if there is only 1 in a million chance of having a customer with such a high loss! Wouldn't it be nice to take party of this lower than expected loss value to reduce the electrical power consumed by the network (of course, without compromising the ability to provide gigabit access for the highest loss customers…)?

So, is TDMA really the way forward?

Benoit Charbonnier
France Telecom

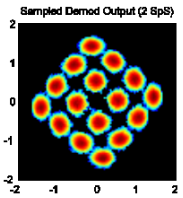
> "as PON infrastructures are being deployed and FTTH cost is decreasing, it is becoming apparent that FTTH users have very diverse requirements"

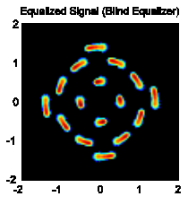
Electrical driver for the FABULOUS modulator

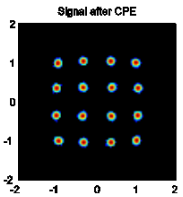


Photomicrograph of the driver testchip

The integrated Reflective Mach Zehnder Modulator (R-MZM) constituting the core of the FABULOUS ONU upstream transmitter section has been designed to be electrically driven by an integrated driver realized in standard 65nm CMOS technology. A distributed driving architecture has been chosen, to ensure a proper handling of the R-MZM phase modulator capacitance and the desired driving voltages with the proper delays all along the R-MZM length. The full Electrical IC, to be interfaced to the Optical IC, has been designed to be compatible with copper pillar 3D assembly, and thus intrinsically does not allow stand-alone electrical testing of the driver. Consequently, in order to verify the stand-alone driver performance in the presence of a QAM modulation signal, a dedicated testchip has been integrated. The chip photomicrograph is reported in the left figure. The testchip has been jointly characterized by WP-COMP and WP-SYST FABULOUS partners. 16QAM modulated input data has been provided by means of an Arbitrary Wave Generator operating at 12GS/s, whilst output data has been sampled with a real time oscilloscope and processed by DSP to calculate EVM and BER. In the central figure it is shown an example of constellation measured at 3GHz at the first driver stage output before and after DSP: the sampled demodulated output is first equalized by means of a blind equalizer, and then of a CPE. The resulting constellation features an EVM always lower than 3%, proving the correct behavior of the stage. The above results are promising in view of the overall performance of the 3D integrated modulator and driver.







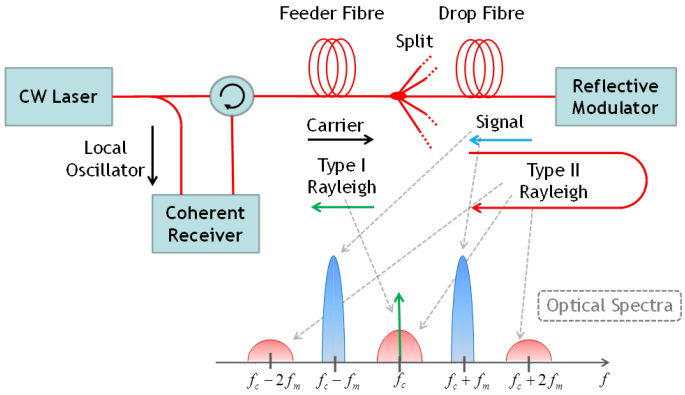
Resulting 16QAM constellation at 3GHz at first driver stage output

Enrico Temporiti
STMicroelectronics

FABULOUS doesn't care Rayleigh Backscattering!

PON architectures that make use of reflective modulators and distribute the optical carrier from a centralized location, like the FABULOUS architecture, allows to employ FDMA and DWDM, to share the upstream band between the users, without the issues associated with deploying tightly wavelength specified lasers at the customer site. One of the major drawbacks of these reflective architectures is their susceptibility to the noise induced by Rayleigh backscattering and localized reflections. The impact of Rayleigh backscattering noise in carrier distributed PON is well characterized in the literature. Two contributions to the noise are present: Type I being generated by the optical carrier when it is distributed down the PON and Type II, which is generated by the modulated upstream signal and is then remodulated in the reflective modulator.

The introduction of the balanced self-coherent detection and FDMA modulation of the upstream implemented by FABULOUS has a positive impact on the tolerance to Rayleigh backscattering noise, which is greatly increased compared to other architectures. An analytical study has shown that the impact of Type I Rayleigh backscattering is negligible thanks to the balanced detection used at the coherent receiver and to the subcarrier upstream signal. This result is also applicable to Type I reflections in the PON distribution network and to the residual carrier and spurious DC component from the modulator at the ONU. Type II Rayleigh backscattering should also not represent a problem using the FABULOUS architecture thanks to the higher tolerance provided by the subcarrier modulation and by the Faraday rotation in the reflective modulator.



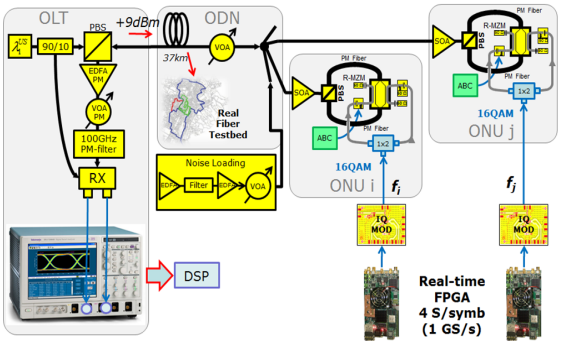
Different types of Rayleigh backscattering in reflective PONs

Giuseppe Talli
Tyndall National Institute, University College Cork

32^3: 32 users, 32 Gbps, 32 dB

One of our ambitious goals is the demonstration of the FABULOUS system full-compliance with the standardized ODN loss and upstream capacity NG-PON2 requirements.

The system is based on an innovative reflective PON approach for the upstream transmission employing a Reflective Mach-Zehnder Modulator at the ONU side, whose two electrodes are independently driven with a 16-QAM modulating signal, generated by an electrical IQ modulator. This device combines the In-phase and Quadrature baseband 4-PAM components generated by a real-time FPGA, and outputs the 16-QAM signal centred at the RF frequency set by a local oscillator. The Optical Distribution Network (ODN) is made of 37 km of real installed metropolitan buried SMF fibers plus an optical attenuator, to change the ODN loss, and a 1x4 optical splitter, in order to connect 2 active ONUs. Thanks to a noise loading system placed inside the ODN, a variable amount of ASE noise has been added in order to emulate the noise generated by the SOAs of other ONUs in the network.



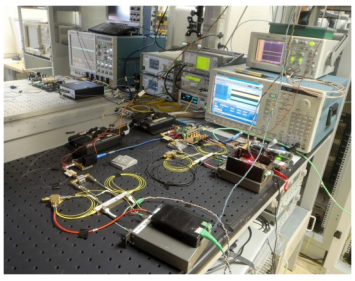
FABULOUS system setup for the upstream

Acting on the central frequency of the 2 active ONUs, the penalties due to adjacent channels and to the second and third harmonic interference have been evaluated. At the Central Office side, the upstream signal is demodulated by means of a single polarization optical self-coherent receiver, whose outputs are sampled by a real-time oscilloscope and off-line processed with a digital signal processing consisting of a feed-forward adaptive equalizer and a Carrier Phase Estimation and recovery. This part will be replaced, by the end of the project, by an electrical IQ demodulator and a real-time FPGA.

The performances of the system have been evaluated as pre-FEC BER as function of the ODN loss and the number of interfering ONUs, demonstrating the feasibility of a FDMA reflective PON with 32 ONUs, a bit rate per user of 1 Gbps and a total capacity of 32 Gbps per wavelength with an ODN loss of over 32 dB. The FABULOUS system is therefore fully compliant with the standardized ODN loss requirement while outperforming NG-PON2 with a tenfold increase in the upstream capacity.

Stefano Straullu
ISMB

> "The introduction of the balanced self-coherent detection and FDMA modulation has a positive impact on tolerance to Rayleigh back-scattering noise"



The FABULOUS experiment at the ISMB premises

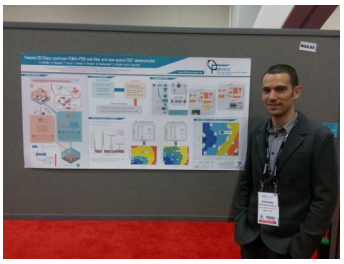
info@fabulous-project.eu
+39 011 2276 302

A flexible architecture, compatible with current infrastructures, and low cost components and network units based on silicon photonics: the keys for mass Fiber-To-The-Home deployment.

The FABULOUS Project has been conceived and is being carried out by a balanced mix of *universities, research centers, industries and operators*; such a consortium is very heterogeneous, in order to cover all the many different technological aspects required by the work-plan. In particular, two main different category of aspects can be identified in the project structure:

- **System aspects**, main duty of Istituto Superiore Mario Boella, Politecnico di Torino and France Telecom
- **Optoelectronic, silicon photonics and packaging aspects**, main duty of CEA-LETI, II-V Labs, University of Pavia, Tyndall National Institute, STMicroelectronics.

www.fabulous-project.eu



Poster session at OFC 2014

III-V booth at OFC 2014, with FABULOUS roll-up poster

EVENTS and DISSEMINATION

The partners of the FABULOUS consortium have been really active from the point of view of scientific dissemination. We count more that 10 peer-reviewed papers, even if the project has just reached half period and the most promising parts, the components, are yet to come. For the last nine months, it is of particular interest to mention a pubblication by the University of Pavia that appeared on Optix Express, a prestigious journal by OSA, and a few papers presented at ECOC 2013 (September, in London) and OFC/NFOEC 2014 (March, San Francisco), the most important conferences for Optical Communications. Moreover, two partners (III-V and CEA-LETI) had a booth at the OFC/NFOEC exhibition, and both widely advertised FABULOUS.

Where to see FABULOUS next? A demonstration booth, in which the working principle of the architecture will be presented by researchers of Orange France Telecom, is foreseen at EUCNC 2014 (European Conference on Networks and Communications), in Bologna from the 23rd to the 26th of June, where also two scientific papers have been submitted. Two invited presentations will be held at ICTON (International Conference on Transparent Networks) in Graz, from the 6th to the 10th of July.

ECOC 2014 will be an important step for FABULOUS: we expect again a few papers to be accepted, but most of all we expect to be important actors in a workshop about optical access.