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# FDMA-PON and NG-PON2: performance and cost comparison

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## ABSTRACT

FABULOUS is an EU project pertaining to the 7th framework program with the aim of proving the effectiveness of a Passive Optical Network adopting WDM FDM/FDMA approach, able to grant increased bandwidth, flexibility and cost savings with respect to the recently approved NG-PON2 architecture. In this paper we will show a system management, power and cost comparison among the FABULOUS and the NG-PON2 architectures.

**Keywords:** Optical Communications, PON, FTTH.

## 1. INTRODUCTION

The FABULOUS EU project, started on October 2012, proposes Passive Optical Network (PON) architecture compatible with current legacy infrastructure and based on two levels of multiplexing: Wavelength Division Multiplexing (WDM) in conjunction with Frequency Division Multiplexing and Multiple Access (FDM/FDMA) per wavelength. An innovative aspect of this architecture is the adoption of a Reflective Mach-Zehnder Modulator (R-MZM) making it possible to use source free all silicon integrated ONUs with low cost and mass manufacturability. The performance of FDMA PON has been assessed with commercially off-the-shelf components exhibiting close to 40 Gbps per wavelength downstream (DS) [1] and 20 Gbps upstream (US) [2]. The key idea of using FDMA is that each ONU can only access a fraction of the aggregated data rate, lowering drastically the DSP speed required and hence the cost and power consumption. At ONU side, a sampling speed of the order of 500 MHz is sufficient to provide any user with 1Gbps data stream [3]. The purpose of this paper is to compare, for an equal performance, the management, cost and power consumption of the FABULOUS FDMA PON architecture with the one chosen for NG-PON2 (G989.1) also known as Time and Wavelength Division Multiplexing (TWDM) PON [4].

It has to be noted that the commercial availability of NG-PON2 is expected to be in less than 5 years from now, whereas FDMA PON is not yet mature as it still requires a large effort in terms of technology and integration, effort that is assessed and progressed through the FABULOUS project. As a result, the idea in this paper is not to oppose the two solutions but rather to highlight what may be the advantages of FDMA as compared to the continued use of TDMA for a future release of PON transmission systems. We will first recall the architecture and main characteristics of TWDM PON and, in a second part, those of FDMA PON. Finally, we will summarize the different characteristics and highlight the potential advantages of FDMA with regards to TWDM.

## 2. NG-PON2 ASSESSMENT

The TWDM NG-PON2 architecture known as G989.1, represented in Figure 1, is based on at least [4]:

- 4 DS wavelengths each carrying 10 Gbps modulated in On-Off Keying (OOK) with Time Domain Multiplexing (TDM) in the upper L-band with 100 GHz spacing.
- 4 US wavelength each carrying 2.5 Gbps OOK with Time Domain Multiple Access (TDMA – burst mode) in the lower C-band also with 100 GHz spacing.
- Transmission over an infrastructure called Optical Distribution Network (ODN) based on different classes of optical budget with the most common one being the class B+ PON (13 to 28~dB of loss with 32 or 64 way splitters and 20 km passive reach).
- Coexistence with older PON generations such as G-PON and XG-PON over the same infrastructure by wavelength multiplexing through a Coexistence Element (CEX).

Considering this basic list of features, we can derive the cost of NG-PON2 from the cost of the previous generation called XG-PON1 (TDM/TDMA system with a single wavelength pair carrying 10Gbps DS and 2.5Gbps US OOK) to which we must add several key elements:

- The NG-PON2 ONU can operate over a set of four wavelength pairs while remaining achromatic i.e. it can tune to the correct set of wavelength. Hence, it must contain a tuneable laser on the transmit side and a tuneable filter on the receive side to isolate the dedicated wavelength. The most probable technology for the laser is a Distributed Feed-Back (DFB) chip with thermal tuning (heating only) [5]. The tuneable filter could be a Fabry-Pérot (FP) type filter with a thermo-optic actuator [6].
- A mechanism to reduce Coherent inter-channel crosstalk
- A mechanism to reduce interference on other wavelength due to Stimulated Raman Scattering [7] and coherent inter channel crosstalk must be enforced. This is especially important in order to minimise the impact on the RF video wavelength at 1550 nm [8]. Such mechanism is not available today although several solutions have been proposed such as additional line coding to suppress the lower part of the OOK RF spectrum [9] but the implementation cost of such mechanism is not known.
- A mechanism to ensure that the ONU transmitter emits light within its own allocated wavelength band (and there only) must also be implemented. It must be able to detect an ONU emitting outside of its wavelength window, then identify, among the 64 connected ONU, which one is to be re-tuned. A mechanism is proposed in [10]. One must also ensure that when an ONU switches from sleep to active mode, the DFB wavelength does not wander outside of the range.
- The equivalent range of optical loss that each individual NG-PON2 wavelength must transmit over is increased compared to XG-PON1 by at least the loss of the OLT wavelength multiplexer (WM) and the tuneable filter inside the ONU for the DS. In the US, only the WM is added. Note also that the differential loss between the former ODN initial wavelength coupler (denoted WDM1r in G-PON and XG-PON1) and now called Coexistence Element (CEX) should also be taken into account. This added loss will require higher power laser sources and higher sensitivity receivers in the termination modules. It also requires two additional optical amplifiers. A first one in the DS to reach a power of +10dBm per wavelength and a second one in the US to recover a suitable power level before the OLT receiver.
- All the downstream transmission chain works at a 10 GHz clock rate (eventual coding, forward error correction, decision circuits, clock recovery units, etc...) while the upstream chain operates at 2.5 GHz similarly to that of XG-PON1. This is source of cost and power consumption. The power consumption of an XG-PON1 ONU has been evaluated in [11] to be around 10 W. Some mechanisms have been proposed such as Bit Interleaved PON [12], reducing the downstream power consumption from 3.6 W to 0.1 W when the clock rate is reduced to 1 GHz. To our knowledge this mechanism is not forecasted for implementation in TWDM PON and, further, concerns only the downlink. The cost of an XG-PON1 ONU is evaluated also in [11] to be in the region of 1k\$US.

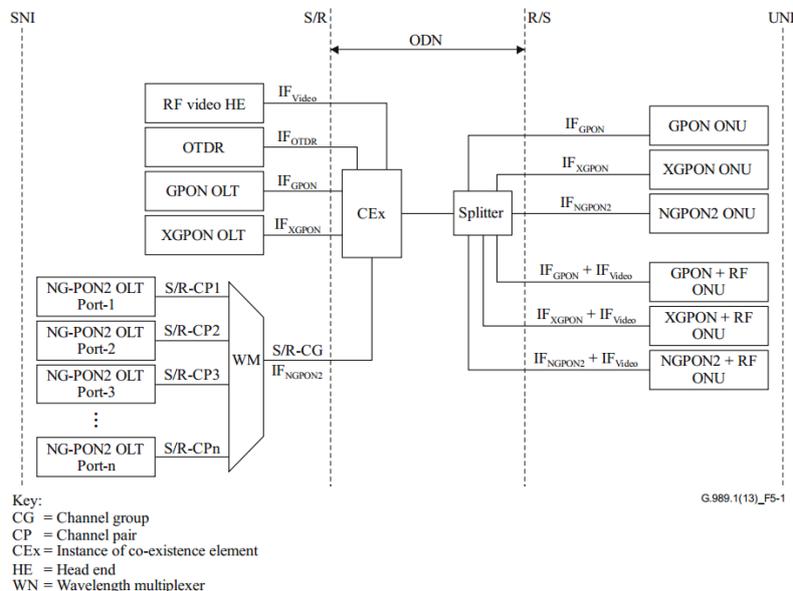


Figure 1 : NG-PON2 Functional Reference Architecture[4]

### 3. FDMA PON ASSESSMENT

In order to compare the FDMA PON architecture with the one above, we base ourselves on a system with similar performance i.e. we use a single wavelength pair leading to a transport capacity of 40 Gbps DS and 20 Gbps US:

- The upstream laser source is centralised in the OLT and is also used for homodyne coherent reception of the upstream signals. As thus, a low line width laser (<100KHz) must be used. This is a relatively

high cost device but is shared between the different ONU and also means that there is no need to implement a mechanism of surveillance of the emission spectras of the different ONUs (to avoid rogue ONU behaviours).

- In both FDMA and TWDM PON, a downstream EDFA is needed at the OLT side to boost the optical power sent to the Optical Distribution Network to +10 dBm. This is however lower than the required +10 dBm per wavelength of TWDM PON. No upstream EDFA shall be needed in FDMA PON due to the coherent upstream receiver.
- The FDMA ONU optical front end is fully integrable in Silicon. The components needed in the ONU are a US/DS filter, a high speed photo-detector with TIA, a pair of semiconductor optical amplifiers, a Mach-Zenhder modulator and its driving circuitry as well as its monitoring photo-detectors [2] (Figure 2). The cost of this integrated device whose demonstration is the goal of the FABULOUS project, must be inferred from different studies. If we refer to [13], the cost of a photonic chip with 10 Lasers and 10 photo-receiver hybridly integrated with the wavelength multiplexer and de-multiplexer is evaluated to be \$54/unit for 3 million unit production per year. Our photonic chip shall contain only two SOAs (equivalent to two lasers) with a single modulator and single high speed photo-receiver. We can assume that the ONU front end chip shall cost in the region of US\$10/unit in similar production volumes.
- The PHY/MAC chip for FDMA PON is similar to the ones used for UWB short reach radio i.e. capable of generating and receiving a RF channel of 500 MHz bandwidth. The cost of this chip is extremely low (<10US\$) and its power consumption is 0.4 W when transmitting and 0.7 W when receiving (measured at the +5V USB supply).
- The use of a single wavelength pair rather than four will also lead to a decrease of the Stimulated Raman Scattering effect described in [7]. Another positive point for FDMA is the fact that the modulating signals do not contain any low frequencies ( $f_{min}>1\text{GHz}$ ) so the crosstalk on the RF Video wavelength at 1550 nm will be much reduced [8].

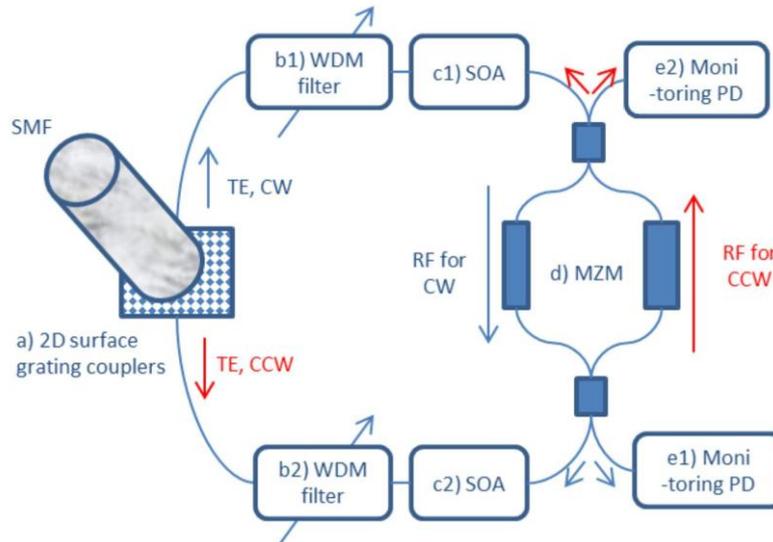


Figure 2 : FDMA PON uplink reflective transmitter in Silicon [2]

#### 4. COMPARISON TABLE

	TWDM-PON	FDMA-PON
ONU Cost	>1000US\$ (Based on XG-PON1 1000 US\$ [11] plus additional features such as tuneable front end)	<50US\$ (equivalent UWB module plus photonic integrated chip)
ONU Power consumption	>10 W (XG-PON1 ONU consumes 10 W [11], additional requirements for higher power/sensitivity components due to higher power budget)	<3 W (UWB transceiver plus photonics integrated chip, drivers and possibly temperature control)
G-PON coexistence	Impact of Stimulated Raman Scattering [7]	Reduced impact of SRS due to lower DS launch power (6dB less than NG-PON2 as single wavelength)

RF Video coexistence	Mitigation scheme required [8]	No impact (lower RF spectrum not used)
Rogue ONU	Control scheme required [10]	All wavelength controlled from OLT, single DS wavelength, single US wavelength

The OLT cost comparison is beyond the scope of this paper and shall be performed in a future edition.

## 5. CONCLUSION

For an equivalent transport capacity, the FDMA approach brings a consequent power and cost saving as compared to TWDM PON. It also solves many issues, whose cost and complexity is yet to be fully appreciated, brought by the use of several high power wavelengths transmitted over the trunk fibre in parallel and at the same time as older generation systems. On the other hand, the technology required to support FDMA PON is not ready yet and shall be demonstrated within the scope of the FABULOUS project. If successful, the benefits of FDMA PON in terms of manufacturability, system management, operation, cost and power consumption detailed here shall ensure a suitable long term solution for PON.

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