Multi-NGPON: Stacking of PON Systems in the Fiber Spectrum

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Abstract: We propose a method for stacking fully-independent NG-PON systems over the same optical distribution network by wisely sharing the optical-fiber spectrum. Possible addressed use-cases for this technique are: unbundling of optical access, optical fronthauling.
OCIS codes: (060.4258) Networks, network topology; (060.4264) Networks, wavelength assignment.

1. Introduction

Several different types of bandwidth-hungry applications and services, including multimedia oriented applications, are driving to upgrade the access network to provide broader bandwidth for subscribers [1]. To satisfy this growing demand, Passive Optical Networks (PONs) has emerged as flexible, scalable, and future-proof optical access technology [2]. Under the pressure for more bandwidth, the standardization bodies involved in PON enhanced the protocol from GPON to NGPON2, to achieve a global throughput at the OLT of 10 Gbit/s (X-GPON), and up to 40 or 80 Gbit/s (TWDM-PON). Although such capacity is remarkable for most residential and even business applications, there are cases in which it may be not sufficient. We have identified two use-cases: i) multiple operators have to share the same Optical Distribution Network (ODN) in unbundling; ii) the ODN is used for radio backhauling for advanced LTE or for "fronthauling" in a Cloud Radio Access Network (C-RAN).

In case i) it is important that the different PON systems multiplexed on the same ODN can operate and be managed independently one of each other, while at the same time each operator is able to serve any number of user terminations, up to the splitting factor of the ODN. Case ii) is justified by the bandwidth required by the Radio-over-Fiber (RoF) service when the ODN connects the central office to LTE antennas: the bit-rate estimated for each antenna for CPRI in the most advanced implementations, is between 2 and 4 Gbit/s [3]. This quickly saturates the capacity of a single PON system (even a TWDM-PON), leading to the necessity of stacking multiple PONs on the ODN. For both use-cases, standardization is still non-existing or still under development.

Without loss of generality, in this paper we will consider the case of ODN unbundling, being understood that what presented can be equally applied to the C-RAN. In order to freely exploit the optical spectrum, we will assume a green-filed deployment in which there is no need to guarantee backward compatibility with older PON systems on the same ODN (GPON, BPON, etc.). This assumption is realistic in many countries in which fiber access has not yet got off the ground so much (e.g. Italy).

2. Method

All the solutions here presented follow a method characterized by three main steps: spectrum partitioning, spectrum characterization, and slot assignment.

Grid type	CWDM	DWDM
Reference	ITU-T recommendation G.694.2	ITU-T recommendation G.694.1
Slot width	20nm	0,6 or 0,1 THz
Number of slots	18 slots	88 or 534 slots

Table 1. Standard grids for Spectrum Partitioning

Spectrum Partitioning (SP)
SP is done by defining a grid of spectrum slots, where each slot is specified by its central frequency and its spectral width. A safe-guard band-gap between adjacent slots may also be specified. Referring to standardized grids is a great advantage, because off-the-shelf components are available at the appropriate wavelengths. In particular, we consider the CWDM and DWDM grid partitions (Table 1), that are both suitable to accommodate X-GPON and TWDM-PON systems. CWDM is potentially the least-expensive, because of the availability of cheap optical components off-the-shelf. On the other hand, DWDM offers a higher number of slots and thus leaves more ground to better-optimized solutions in slot assignment (see below).

Spectrum Characterization (SC)

We assume that the ODN is implemented by full-spectrum optical fiber: this ensure the possibility of extending the range of channels over the full CWDM and DWDM grids. Nevertheless, channels are not homogeneous in terms of transmission features. Therefore, SC is necessary at the physical layer. The main goal is to evaluate the wavelength dependent impairments that affect the different channels. In this initial work we have built a power-penalty curve $C(\lambda)$ (one for each direction, up- and down-stream) taking into account the simple set of impairments shown in Eq. (1): c_a accounts for the attenuation due to propagation, c_d accounts for the chromatic dispersion effect and c_s represents receiver sensitivity. It is understood that other impairments can be considered in a follow-up, provided that they can be modeled in terms of power penalty.

$$C(\lambda) = c_a(\lambda) + c_d(\lambda) + c_s(\lambda) = L \cdot \alpha(\lambda) + c_d(\lambda) + \left[S(\lambda) - \min_{\lambda} S(\lambda)\right]\ [dB] \quad (1)$$

$$c_d(\lambda) = 5\,log_{10}[(1 + 8C\beta_2 B^2 L)^2 + (8\beta_2 B^2 L)^2],\ \text{with}\ \beta_2 = -\frac{\lambda^2}{2\pi c} D(\lambda) \quad (2)$$

$$S(\lambda) = \left[SNR \cdot I_{N,RMS} \cdot (r_e + 1)\right] / [2R(\lambda) \cdot (r_e - 1)] \quad (3)$$

Parameters are defined as follows: λ = central wavelength of the channel, L = propagation distance, α = fiber loss per unit length, C = chirp parameter of the laser, B = baud-rate, D = fiber dispersion coefficient, SNR = signal-noise ratio needed to achieve a given threshold BER and for a given modulation format or line coding, $I_{N,RMS}$ = input equivalent RMS noise current of the trans-impedence amplifier, r_e = extinction ratio, R = photodiode responsivity.

Eq. (2) is the Agraval's formula [4] [5]. Values for the parameters and functions used in this paper are taken from literature and component datasheets: they shall be substituted by measured or specific values in a real application case. Also, BC can be done using other analytical methods or including more impairments.

Algorithm	Minimum Cost (MC)	Maximum Fairness (MF)
Common data	W = set of available slots (each represented by its central wavelength); P = set of operators; nso_i = number of slots requested by each operator $i \in P$ c_j = cost associated to each slot $j \in W$ (from BC)	
Goal	Minimizing the total cost of wavelength selection	Maximizing treatment equality between the operators
Decision variables	$x_{ij} \in \{0,1\},\ \forall i \in P, \forall j \in W :\ x_{ij} = 1$ if wavelength j is assigned to operator i	$x_{ij} \in \{0,1\},\ \forall i \in P, \forall j \in W :\ x_{ij} = 1$ if wavelength j is assigned to operator i $z \geq 0$: maximum cost difference
Objective function	$min\left\{\sum_i x_{ij} \cdot c_j\right\}$	min{z}
Constraints	Operators requests are satisfied $\sum_j x_{ij} = nso_i\,, \quad \forall i \in P$ Each slot is assigned only once $\sum_i x_{ij} = 1\,, \quad \forall j \in W$	Operators requests are satisfied $\sum_j x_{ij} = nso_i\,, \quad \forall i \in P$ Each slot is assigned only once $\sum_i x_{ij} = 1\,, \quad \forall j \in W$ Maximum fairness $\boldsymbol{z \geq (x_{ij} \cdot x_{kl}) \cdot \lvert c_j - c_l \rvert}$ $\forall i, \forall k \in P, i \neq k\ and\ \forall j, \forall l \in W, j \neq l$
Variables domain	$x_{ij} \in \{0,1\}, \quad \forall i \in P, \forall j \in W$	$x_{ij} \in \{0,1\}, \forall i \in P, \forall j \in W$ $z \geq 0 \in \mathbb{R}$

Table 2. Optimization models in SA's process

Slot Assignment (SA)

The main goal of slot assignment is to allocate spectrum slots to the different operators in order complete a wavelength allocation plan. Note that each operator needs at least two slots (one for up- and the other for down-stream), but it may require more than two, according to its bandwidth needs and the type of PON system it wants to deploy. As slots have different transmission performance (depending on their central wavelength), the assignment becomes an optimization problem. BC provides the cost of each slot in terms of impairments, while from BP we know number of slots and their spectral features (central wavelength and width).

The objective function to be optimized can be different, according to the criterion adopted to design the network. In this paper we have considered two possible objectives: “Minimum Cost (MC)” tends to exploit the best regions of the ODN spectrum, while “Maximal Fairness (MF)” tends to enforce a fair treatment for all operators. Table 2 shows the two corresponding formulations.

Both previous formulations may assign to each operator slots that are not adjacent. To have a contiguous slot assignment per operator, we need an additional proximity constraint:

$$(x_{ij} \cdot x_{kl}) \cdot |f_j - f_l| \leq (nso_i - 1) \cdot cw, \qquad \forall i, \forall k \in P, i \neq k \; and \; \forall j, \forall l \in W, j \neq l.$$

Function f_j represents the frequency value associated to each wavelength $j \in W$ and the scalar variable cw is the channel-width value, both in THz.

3. Example of assignment: stacked TWDM-PONs on a DWDM grid

As sample use-case, we have considered 4 operators sharing an ODN, each one aiming at deploying a TWDM-PON (NGPON2) system. Each TWDM-PON requires four upstream channels at 2.5 Gbit/s each and four downstream channel at 10 Gbit/s each. SP is based on a DWDM-grid with 0.6 THz channel spacing. The total ODN distance (OLT-to-ONU) is 20 km with a splitting ratio at least 1:64, scalable to 1:128 and 1:256. Transceiver characteristics are derived from the NGPON2 standard (up- and down-stream sources are Directly Modulated (DM)-DFB and Externally Modulated lasers, respectively).

Figure 1 and Figure 2 shows the results of the solution of the optimization SA problems using the two objective functions (MC and MF) previously described.

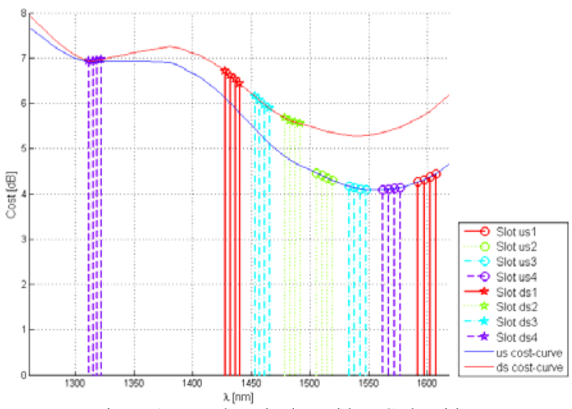

Figure 1. Wavelength plan with MC algorithm

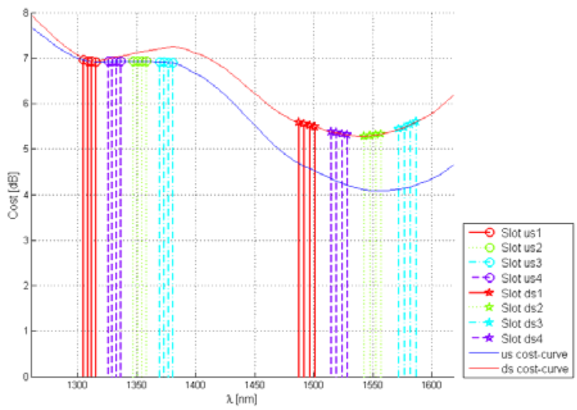

Figure 2. Wavelength plan with MF algorithm

We notice that the MF method leads to a better equalization of the operators, even if the ODN spectrum is used less effectively, as the best slots of the spectrum remain unassigned. We have applied our technique also to other use-cases, adopting the CWDM grid and with operators demanding for XGPON deployment. Results are omitted here for brevity and will be presented in a full-paper version. As next step, we will apply the presented technique to the optical fronthauling use-case.

4. Acknowledgements

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5. References

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