New trends on Optical Access Networks: DBAs for 10G EPON and Long-Reach PON

(Invited paper)

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Abstract.- The access network infrastructure plays an important role in the overall performance of the network, next generation access networks (NGA) must be able to access diverse services, and should incorporate adequate architectures that include mechanisms for the integration of different technologies. New optical access technologies trends are: WDM, 10 Gb/s, and longer reach/higher splits. It is also important to take into account the evolution of the installed legacy PONs to the next generation optical access networks. The present paper goes through such topics, focusing on the research being carried out to develop dynamic bandwidth algorithms for the 10 Gb/s new EPON standard (IEEE 802.3av). We summarize results and point out issues that will require further investigation.

Keywords: Optical Access Networks, Broadband access networks, Scheduling Algorithms, EPON , 10GEPON, Long Reach PON

1. Introduction

It is widely accepted that Passive Optical access Networks (PON) are the most promising cost-effective and high-performance access network solution, they will support bandwidth-intensive applications in the near future. The FTTH (Fiber-to-the-Home) infrastructure, mainly in the form of PON networks, is being deployed on a large scale in Asia and the U.S, and is beginning to pick up pace also in Europe.

Operators need to consider the future migration from legacy PON systems to next generation access (NGA) systems upon the current PON fiber infrastructure (see figure 1). Not only such upgrade will provide higher bandwidths or further reduce the cost of delivering existing services, but also NGA will be the backhaul of mobile networks (WiFi, WiMAX); attaching the Base Station to the PON to access easily the metro and core networks.

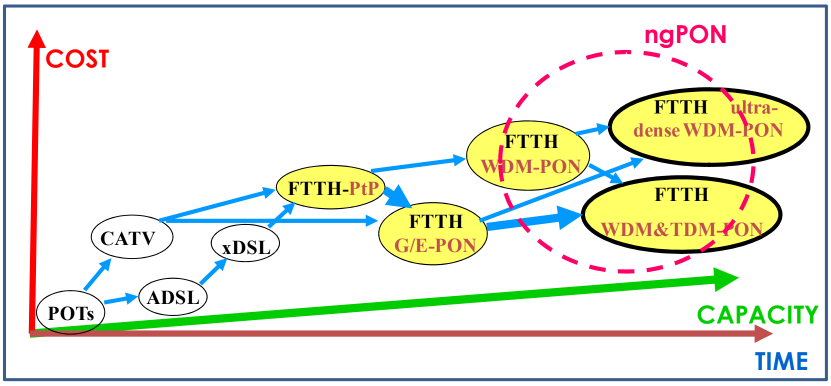

Fig 1. Optical networks evolution (from [1])

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The extant PON networks are TDM-PON with a single channel but the next generation - ng-PON - will be based on WDM techniques (WDM-PON. The goal is to migrate gradually from extant TDM-PON to the WDM-PON networks facilitating the operators to replace the users and network equipment. Such upgrade is driven by the IEEE and ITU-T, developing new standardization bodies.

The paper is organized as follows: section 2 is devoted to review the legacy PONs shortly; in section 3 we describe the next generation Access Networks (NGA), and the coming standards upgraded to 10 Gb/s; in section 4 we take a look to the trends in NGA and the evolution from TDM to WDM including new scheduling algorithms (DBA, Dynamic Bandwidth Allocation); and finally we conclude pointing out future topics of research.

2. Legacy TDM-PON's

A PON network is an FTTH (Fiber-to-the-Home) network, with no active equipment installed on the ground (very satisfying feature for TELCO's), distances covered as far as 20 Km., point-to-multipoint and it allows data and video broadcasting (digital and/or analogue).

There are two types of active terminals: the OLT (Optical Line Terminal) in the central office which is connected to multiple optical network terminations, so-called ONU or ONTs, in the customer premises via an optical distribution network (ODN) of fibers and passive splitters.

2.1 GPON / EPON review

The PON standards being currently deployed around the world are: BPON; GPON (Gigabit capable PON) born in 2.003 (ITU G.984 [2]); and EPON (Ethernet PON) born in 2.004 (IEEE 802.3 ah [3]). The basic physical features are very close to each other but what differences them more is the encapsulation of the information carried by the network: while the GPON carries the information using ATM or GEM (Generic Encapsulation Method) frames whereas the EPON carries bursts of pure Ethernet frames.

Current TDM-PON are single channel networks, the downstream is a broadcast channel but the upstream channel is a multi-access channel shared among the ONUs. Each ONU transmits a burst of data which could not be interfered by any other burst of a different ONU in the window allocated to it (see figures 2 and 3).

The main challenge is to develop appropriate scheduling algorithms to allocate efficiently the bandwidth of the upstream channel to the ONUs. Such issue was an important topic of research in the past; the scheduler must be efficient, support the QoS each traffic flow requires, as well allocate fair bandwidth to users reducing delay and jitter, and finally be computationally simple enough. Such process runs usually centralised at the OLT but it is also possible to develop distributed scheduling algorithms running at the user equipment [4]. A survey of the most relevant algorithms is available at [5], among others the IPACT (Interleaved Polling Adaptive Cycle Time) is a key one among others [6].

Each ONU performs the intra-scheduling to provide the QoS each traffic type demands. The QoS in the GPON is based in 5 categories as the ATM model but in the EPON standard there are up to 7 queues of priority, and the transmissions are ordered from the higher to the lower following the IEEE 802.1P/Q standards.

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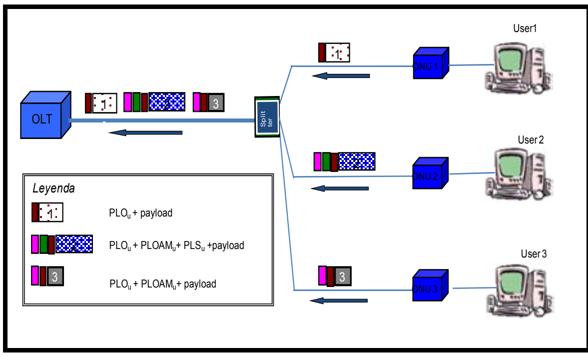

Figure 2. Upstream GPON

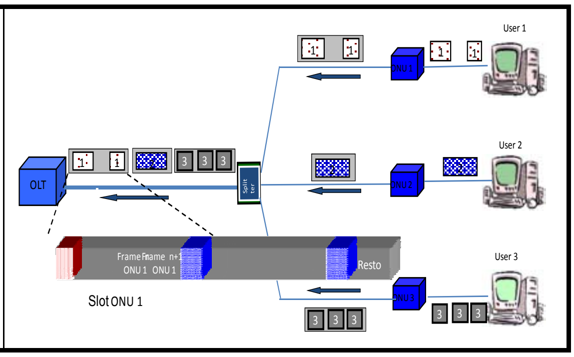

Figure 3. Upstream EPON

2.2 *GPON / EPON comparison*

Table I summarizes such information about both standards. There is a common concern that the ATM-oriented technology – APON, GPON – performs very well when the traffic is CBR type, and widely to real time traffic; while Ethernet-oriented networks performs better when the traffic is mostly composed by Internet applications. Anyway, it is not such simple to make a definitive statement about the performance because the data collected depends on many parameters. For instance, a detailed performance comparison between the GPON and EPON with real traffic traces and simulation settings is presented in reference [7], where the authors state that EPON is more efficient in the setting evaluated.

Table I. GPON / EPON

		GPON		**EPON**
Standard		ITU G.984		IEEE 802.3 ah
Downstream (Mbps.)		1.244		1.250
Upstream		155/ 622/ 1.244/ 2.488		1.250
DS/US wavelength (nm.)		1.490 / 1.310		1.490 // 1.310
Split		1:64		1:16 / 1:32
Distance (Km.)		10 / 20		10 / 20
Power Budget		15 / 20 / 25		15 / 20
Data rate (Gb/s)		2,5		1
Cost per ONU ($)		100		78
MAC (Framing)		ATM /GEM		Ethernet
Avg Bandwidth (Mbps.)		40		60

3. Next Generation Access networks (NGA)

Technological advances especially in optical transmission devices boost the upgrading of current TDM-PON to the next generation access networks.

3.1 10G GPON

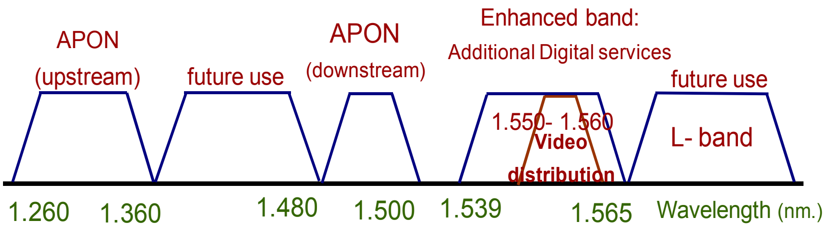

Fig. 4. WDM enhancement G.983.3.

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The FSAN group is upgrading the former GPON to 2 to 10 Gb/s. The first enhancement of the GPON was the recommendation G.983.3 which allocated some space in the optical spectrum to host video services or additional digital services by using appropriates subcarrier multiplexing techniques [see figure 3]. The video distribution goes in the downstream direction only.

The current upgrade goes in the three directions: [8]

- Higher data rates: The downstream rate would likely be 10 Gb/s, but the upstream rate is still an open question of 2.5, 5, or 10 Gb/s.
- Blocking filters to be supported at G-PON ONUs to ensure that next-generation ONUs could be installed on currently deployed G-PON side by side with legacy G-PON ONUs.
- Finally, the extension of a G-PON's optical budget. Such enhancement will allow the deployment of longer reach and higher split ratio in current PONs.

3.2 Next Generation 10G EPON. IEEE 802.3av

The TDM-EPON is being upgraded also to 10 Gb/s by the IEEE 802.3av TG, the standard is expected to be finished this year 2009. Its market potential is very wide and the standard goes after the objectives listed below [9]:

- Support subscriber access networks using point to multipoint topologies on optical fiber.
- Two different data rate channels: 10 Gb/s dn/1 Gb/s up, single SM fiber, or PHY for PON, 10 Gb/s dn/10 Gb/s up, single SM fiber.
- Define up to 3 optical power budgets that support split ratios of 1:16 and 1:32, and distances of at least 10 and at least 20 km.

The goal is to upgrade the channel capacity for both upstream and downstream channels gracefully, while maintaining the logical layer intact, taking advantage of the already existing MPCP and DBA agent specifications, which will remain compatible with legacy 1 Gb/s EPONs. Moreover, it is expected that the 10G EPONs will keep on utilizing the analog video delivery systems before the network is upgraded before such delivery shifts gradually to IP-based distribution system.

The selected solution presents a number of technical hurdles which will have to be overcome, we describe them briefly below: a) DBA mechanisms, it will not change in most cases when the transition between the 1 Gb/s to 10 Gb/s; b) security considerations; and finally, 1G and 10G EPON coexistence on the same PON plant, thus resulting in the need to share both downstream and upstream channels. It might be possible to deploy the first 10G in an asymmetric mode 10 Gb/s downstream/1 Gb/s upstream.

3.3 Long-Reach-PON (LR-PON)

The next step in future NGA is the so-called Long Reach PON (LR-PON). The LR-PON can simplify the network, reducing the number of equipment interfaces, network elements, and even nodes, thus the LR-PON is very cost-effective solution. Basically, the strength of an LR-PON is its ability to displace electronics and simplify the network. The access and metro networks can be combined into an integrated system through the use of an extended backhaul fiber, possibly 100 km

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in length, increment drastically the split ratio of up to 1.024 ONUs, and incorporate protection paths and mechanism. Moreover the overhead at the interface between access and metro could be reduced significantly, the PON head-end and all higher-layer networking functions can now be located further upstream.

LR-PON is being investigated recently, but LR-PON are not commercially available yet although many experimental networks are already being developed.

Among others the SUPERPON [ref] is the most well-known successful prototype of an LR PON, developed under the European PLANET project in the mid-1990s. It targets 100 km and 2048 ONUs. There are some more recent developments also under the European projects, i.e.: the PIEMAN and MUSE II, both prototypes target similar figures, including additionally the WDM dimension. Finally, recent developments points to extending the G-PON physical layer to its logical reach of 60 km and split ratio of 128 ONUs.

And finally, the current FP7 framework of the CE is funding the project so-called Single-fiber Advanced Ring Dense Access Network Architecture (SARDANA). Its goals are quite ambitious: up to 1.024 users per PON and 10 Gb/s data rate, remote passive amplification and wavelength-agnostic customer equipment [1].

4. New Trends in next Generation Access networks (NGA)

4.1 <u>New Trends: WDM – PON</u>

A WDM-PON enhances a single fiber single channel TDM-PON by using multiple wavelengths. The overlay of new wavelengths on a working TDM-PON, however, requires an upgrade of the network infrastructure. The different realizations being proposed focus on the network architecture, e.g.: the first step would be to substitute the current passive splitter by a passive wavelength router.

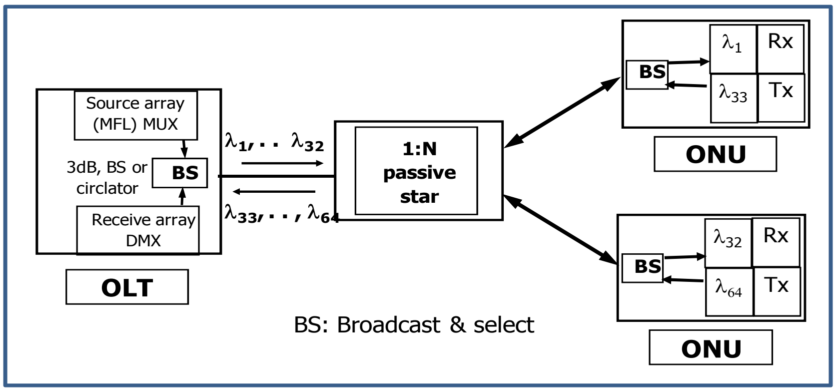

Figure 5. WDM-PON first generation network

Each OLT-ONU pair in the figure has a dedicated and permanent wavelength assignment, and requires two transmitter/receivers. Such architecture is not satisfactory enough for future implementations because each ONU must be tuned to a specific wavelength thus increasing the maintenance and replacement costs. It is much more desirable to use when possible wavelength-agnostic equipment, thus eliminating the issues related to inventory, maintenance, and installation associated with individual DWDM transmitters. The successful solution to upgrade extant PON is based mainly on colorless ONUs rather than any other enhancement.

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In an overlay network the new and existing signals need to be separated. Three major techniques can be applied to achieve such goal: launch the upgrade signal at new wavelengths; use subcarrier multiplexing technique (SCM); and finally, use the spectral line-coding technique to minimize its interference on the existing signal.

But in the future, the throughput of the network will be many times higher than today's PON, we expect to achieve several gigabits per second per user by developing new disruptive architectures. The WDM-PON of the future will be based on highly enhanced optical devices such as: tunable components; spectral Slicing; Injection Locking, and Centralized Light Sources [10].

4.2 From TDM to WDM

There were early WDM-PON developments, the first a Hybrid WDM/TDM-PON with wavelength-selection-free transmitters [11], LARNET, RITENET; and a recent WDM-PON so-called SUCCESS network [12]. The SUCCESS-HPON architecture is based on a topology consisting of a collector ring and several distribution stars connecting a central office (CO) and optical networking units (ONUs). Each ONU has its own dedicated wavelength for both upstream and downstream transmissions) on a DWDM grid to communicate with the OLT. The communication is half-duplex communications because the tunable transmitters at the OLT are used for both downstream frames and CW optical bursts to be modulated by the ONUs for their upstream frames.

And finally, a scheduling algorithm has been developed to keep track of the status of all shared resources and arrange them properly in both time and wavelength domains, including the control of both tunable transmitters and tunable receivers. The research is also focused on the evaluation performance of two new scheduling algorithms: 1) batching earliest departure first (BEDF); and 2) sequential scheduling with schedule time framing (S3F).

4.3 Dynamic Bandwidth Algorithm (DBA) for WDM-PON and LR-PON

The new challenge of a DBA is to allocate bandwidth to ONUs in both time and wavelength, maximizing the whole efficiency of the network. Two main approaches are possible: improve the former DBA's, e.g.: SIPACT; or develop new mechanisms, as for instance applying the well-known scheduling theory. [13]

The backward compatibility of the MPCP is mandatory but some extensions must be implemented to run the upgraded DBA, i..e.: the discovery process; or the GRANT message that should carry the information of the window allocated and the wavelength assigned.

The scheduling DBA's is usually broken into two separate problems: a) grant sizing, and b) bandwidth assignment.

Grant sizing: on-line / offline scheduling
Online and offline scheduling are the two broad paradigms to allocate the bandwidth dynamically for upstream transmissions [14]:

Offline Scheduling

Offline scheduling means that the ONUs are scheduled for transmission once the OLT has received current MPCP REPORT messages from all ONUs before the computation of the allocation to each ONU takes place. This requires that the

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scheduling algorithm be executed after the OLT receives the end of the last ONU's gated transmission window, which means that a gap between scheduling cycles is introduced, so-called inter-scheduling cycle gap (ISCG). The length of the ISCG on a wavelength channel is computed by adding: a) the computation time of the schedule; b) the transmission time for the grant; and c) the RTT to the first ONU scheduled on the wavelength in the next round. It is well-known that the ISCG impacts negatively on the efficiency of the algorithm.

Online Scheduling

On the other hand the online scheduling policy is an on-the-fly method, thus the ONU is scheduled for upstream transmission as soon as the OLT receives the REPORT without waiting to receive the request from the rest of the ONUs. In many settings the online performs better than the offline scheduling but with less control of the channel transmission times.

Wavelength assignment t LFJ vs NASC

The simplest policy is to assign the next available supported channel (NASC) to the ONU. On the other hand, the scheduling theory may help us to make a better decision when assigning the wavelength [15].

The LFJ schedules first transmissions to the ONUs that support the fewest wavelength channels at the earliest available time on the supported channels. The Least First Job (LFJ) policy is optimal in that it minimizes the length of the schedule under certain conditions and thus is the better candidate to be the scheduling policy applied; but nevertheless, there are many more applicable scheduling algorithms, i.e.: SPT (Shortest Path First), LPT (Longest Path First), in an online or offline setting. [13]

Online Just-in-Time (JiT) scheduling

Finally, the so-called online just-in-time (JIT) scheduling is a new enhancement hybrid between offline and online scheduling. The ONUs not yet allocated are scheduled together across all wavelengths as soon as a wavelength becomes available. The online JIT scheduling framework gives the OLT more opportunity to make better scheduling decisions. Outlined below we summarize some of algorithms developed for WDM-EPON. Some of them claim to be backward compatible with the legacy PON.

- The reference [16] presents the WDM IPACT with a single polling table (WDM IPACT-ST), it is basically an upgrade of the former IPACT.
- The reference [17] presents the Simultaneous and Interleaved Polling with Adaptive Cycle Time (SIPACT) which is also an algorithm derived from the former IPACT.
- The reference [18] presents different algorithms: Static (SWDT) and Dynamic Wavelength Dynamic Time (DWDT) for the WDM-EPON architecture. But in fact they are also an upgrade of the former DBA's developed in the past for the TDM-EPON.
- The reference [15] presents the online and Just-in-time (JiT) scheduling algorithms previously discussed.
- Finally, the reference [19] presents the algorithm so-called Byte Size Clock (BSC). It claims to be backward compatible with both: APON and EPON.

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In a Long-Reach scenario the algorithms might not be directly applicable since the waiting times need to start running the DBA algorithm could be relatively long. The DBAs at this level might face efficiency problems, since the RTT (round trip time) will be longer.

Many of the DBA algorithms for the legacy PONs require that the ONU (user device) indicates the bandwidth need instantaneously. In such case online performs better than the offline algorithms.

We leave to further publication important topics such as the Dynamic Bandwidth Allocation for Quality-of-Service over WDM-PONs, and a detailed analysis of the performance evaluation.

5. Conclusions

The present paper has surveyed the next generation access networks (NGA) that are an evolution of the legacy TDM-PON to 10 Gbps, they will be a reality in a short term period. Then we have also reviewed how the WDM techniques can be used to enhance drastically current PON's, the NGA WDM-PON will become a revolutionary and scalable broadband access technology t. Finally, we also have explained the research carried out in LR-PON to extend the physical reach and increase the splitting ratio in a PONs. One of the keys of the NGA development is the huge enhancements of the optical devices and in particular the development of colorless ONU's.

Another interesting topic in current research is the definition of new dynamical bandwidth allocation algorithms (DBA'S). We have analyzed the online and offline scheduling mechanisms to perform such allocation in the most efficient way, and we have pointed out that it seems that online scheduling suits better the challenges arising from the NGA and LR-PON.

Further research should be carried out in such topics as to apply the scheduling theory and also to evaluate the performance of such DBA algorithms.

References

[1] Josep Prat. *Next-Generation FTTH Passive Optical Networks*. Springer, 2008. [book]

[2] GPON. ITU-T G.984.1, SG 15. *Gigabit-Capable Passive Optical Networks (G-PON): General Characteristics*. March 2003.

[3] Available at: http://ieee802.org/3/. Standard June 2004.

[4] Marilet De Andrade, Lluís Gutiérrez, Sebastià Sallent. *DDSPON: A Distributed Dynamic Scheduling for EPON*. Proc. of the IEEE- ICSPC, 2007.

[5] Michael P. Garry, et al .*EPON Architectures and DBA Algorithms*. IEEE Communications surveys, 3RD QUARTER 2008, VOL. 10, NO. 3

[6] Glen Kramer et al. *IPACT: A Dynamic Protocol for an Ethernet PON*. IEEE Comm. Magazine, Feb. 2002

[7] Marek Hajduczenia et al. *EPON versus APON and GPON: a detailed performance comparison*. Journal of Optical Networking, Vol. 5, nro. 4, April 2006

[8] Frank Effenberger et al. *An Introduction to PON technologies*. IEEE Comm. Magazine, March 2007.

[9] Available at: http://ieee802.org/3/av/index.html802.3av.

[10] Leonid G. Kazovsky et al. *Next-Generation Optical Access Networks*. Journal of Lightwave Technology, Vol. 25.

[11] Dong Jae Shin t al. *Hybrid WDM/TDM –PON with Wave length- Selection-Free Transmitters.* IEEE 2005.

[12] Kyeong Soo Kim et al. *Design and Performance Analysis of Scheduling Algorithms*. Journal of Light Wave Technology, vol. 23, nº 11, Nov. 2005

[13] M. Pinedo. *Scheduling: Theory, Algorithms, and Systems.* Prentice Hall, 2nd ed., 2002. [book]

[14] Michael P. McGarry et al. *WDM EPON*. IEEE Optical Communications, Feb. 2006

[15] Michael P. McGarry et al. *Just-in-Time Scheduling for Multichannel EPONs*. IEEE JLT, vol. 26, nº 10.

[16] Kae Hsiang Kwong et al. *DBA For Diffserv over W-EPON*. IEEE- ICCS 2004

[17] Frederick Clarke et al. *Simultaneous and Interleaved Polling: An upstream Protocol for WDM-EPON*

[18] Ahmad R. Dhaini et al. *Dynamic Wavelength and Bandwidth Allocation in Hybrid TDM/WDM EPON Networks*. Journal of Lightwave Technology, vol. 25, Nº 1, Jan. 2007.

[19] Chunpeng Xiao et al.. *An Efficient Reservation MAC Protocol with Preallocation for High-Speed WDM Passive Optical*. IEEE 2005.

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