EPON CWDM Optical Light Expander with Adaptive Prediction Scheduler

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***Abstract*—Fiber To The Home (FTTH) Passive Optical Networks (PON) are widespread in modern access networks. Among PONs, Ethernet-PON (EPON) networks stand out, as they have the advantage of combining simplicity and low cost devices with a wide bandwidth provision. As a matter of fact, the Epon Optical Light Expander (OLE) has been designed to improve the scalability and cost issues of EPON networks, adding, in this way, CWDM bandwidth enhancements without extra costs per subscriber. In this article, we empower the OLE with a new Adaptive Prediction Algorithm (APA) that allows for better performances in terms of per-user bandwidth assignment efficiency. Our algorithm shows an average packet delay that is 18% less than the standard Interleaved Polling Adaptive Control Protocol (IPACT) algorithm, simulated for medium traffic load conditions.**

Keywords-FTTH;EPON; CWDM; Scheduler; Adaptive

I. INTRODUCTION

Ethernet Passive Optical Network (EPON) is a promising solution for the last mile access network, as they allow for cost savings in terms of: cable deployment, components usage, network maintenance, and management. In order to manage the user's bandwidth, EPON uses the Multi Point Control Protocol (MPCP) to manage the bandwidth allocation among subscribers. We have some experience on the field as we have implemented it in a hardware processor, [1]. Interleaved Polling Adaptive Control Protocol (IPACT) [2], prediction based algorithms [3], adaptive Dynamic Bandwidth Allocation (DBA) algorithms [4], and service priority-based algorithms [5] aim to optimise the matching between requested and assigned bandwidth. However, these scheduling algorithms perform correctly only in low and medium traffic load conditions, while for heavy loads, the bandwidth per user saturates to its minimum value. Furthermore, since MPCP acts on a shared medium, the single user bandwidth decreases linearly with the number of users. Two kinds of solutions of this problem are emerging:

- Increasing the bit rate up to 10 GBPS;
- Wavelength Division Multiplexing (WDM) solutions;

The first solution [6] increases the bandwidth per user by increasing the baud rate per time slot but introduces electronic complexity and costs.

WDM solutions [7] allow us to overcome this constraint by assigning different wavelength to the users. Hence, the cost of Coarse Wavelength Division Multiplexing (CWDM) and WDM using either active or passive interfaces makes this solution at the Customer Premise Equipment (CPE) unfeasible. This paper proposes a solution to optimize the bandwidth per subscriber in an EPON network. Moreover, a new Adaptive Prediction Algorithm (APA) has been designed in order to be integrated in a novel network topology based on CWDM Optical Light Expander (OLE) [8] units, allowing the scheduler working in optimal conditions without saturation. The rest of the paper is organized as follows. Section II describes the existing prior art , what is missing and what we aim to improve, Section III describes the OLE implementation and advantages and proposes an OLE-based network architecture. Section IV presents a detailed description of the new APA algorithm, while in Section V the simulation results have been represented and analyzed.

II. STATE OF THE ART

With reference to the existing prior art, the proposed solution has many advantages in terms of simplicity and cost. We are aiming to design a subscriber-shared device, fully compatible with the existing ONUs, whose cost falls entirely on the subscriber. The scheduler has been implemented by a hardware accelerator. Indeed the algorithm must be simple and compatible with the existing hardware basic blocks (adders, multipliers, memories). We aimed to improve the IPACT algorithm [2], decreasing its protocol overhead and increasing the bandwidth utilization. The APA algorithm works only at the OLE side, without overloading the Optical Network Units (ONUs) with extra scheduling features and costs, introduced in previous adaptive DBA schemes like [3] or service-based schemes like [5]. These algorithms add computation complexity to the ONU blocks, increasing the cost of Customer Premise Equipment (CPE) and loosing the compatibility with the existing devices. The APA's *online* scheduling framework, with real-time and fast bandwidth assignment calculation is a further advantage over existing adaptive algorithms like [4], that needs previous knowledge of all the ONUs queues and have big computation latency. All the scheduling algorithms work effectively only in medium traffic load conditions, since in high traffic condition saturation comes out, due to the shared physical medium. For the first time with reference to the existing prior art, we also inserted the scheduler in the novel OLE CWDM architecture that ensures a better network segmentation and avoids network saturation.

III. OPTICAL LIGHT EXPANDER ARCHITECTURE

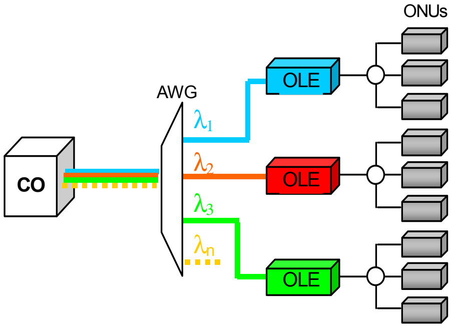

Fig. 1: OLE Network topology

In order to enable a CWDM feature without increasing the subscriber costs, a novel OLE architecture has been proposed in Figure 1. Since the subscribers share the same CWDM deployment, its cost is shared as well. From Central Office (CO) to OLEs the network is a CWDM Giga ethernet network, while from OLE to Optical Network Units (ONUs) the topology is a typical tree topology that uses MPCP protocol. The cost advantages of this layout can be quantified in comparison with an ONU-based CWDM scheme. The dominant ONU cost is due to the optical transceiver, accounting for up to 30 % of the Bill of Materials (BOM). Actually burst-mode WDM ONU optical transceivers are not standard products but considering the Continuous Wavelength (CW) optical transceiver prices, we could forecast a 30 % extra cost for the CWDM feature. Total ONU BOM would cost around 10 % more per subscriber. We must add a 10 % extra price to the OLT, since a CWDM Burst Receiver must be kept in account. The total devices extra cost per subscriber would be around 10 % due to the CWDM feature. Considering the OLE scheme of Figure 1, we won't have any extra cost at the ONU BOM, while we should need to add a CW CWDM optical transceiver to the OLT BOM. Considering the actual OLT cost, around USD 900, and a CW CWDM bi-directional transceiver cost around 55 USD, adding extra costs due to the Media Access Control (MAC) extra logic, we could forecast an OLE price of 1000 USD, with around 11 % extra cost over a standard OLT. Considering a 10,000 subscribers network with 16 ONUs OLE subnets, the OLE devices extra cost in the whole network would be 3.96 %, instead of 10 %, as for ONU CWDM enhancement. In Table I we estimated the total devices costs for a 10,000 subscribers, 16 ONU-nodes, standard EPON network, CWDM ONUs network and OLE-based network. From a technical point of view, the OLEs convert the point-to-point Ethernet protocol into EPON protocol at the second layer of the OSI stack by adding scheduling-and-registering functionality. The incoming Ethernet frame, from the CO, is received in a CWDM transceiver and then passed to the Ethernet physical layer, where it is parsed in order to extract the data and header. OLEs don't limit their functionality to packet forwarding, like in Remote Node Units (RNU) [9] or previous decentralized architectures [10] but also they implement a remote Optical Line Terminal unit with scheduling and registering capabilities. Furthermore RNUs require wavelength-dedicated OLTs to enable CWDM capability, while OLEs interface the existing point-to-point CWDM equipment.

TABLE I.

Network Type	**OLT Cost (USD)**	**ONU Cost (USD)**	**ONU OLT/OLE Number**	**Tot. Costs (USD)**
Standard EPON	***900***	***100***	***10,000*** ***625***	***1,562,500***
ONU CWDM EPON	***990***	***110***	***10,000*** ***625***	***1,718,750***
OLE EPON	***1000***	***100***	***10,000*** ***625***	***1,624,937***

IV. ADAPTIVE PREDICTION SCHEDULING ALGORITHM

In Addition to the proposed OLE architecture a novel Adaptive Prediction Algorithm (APA) has been developed to minimize the average packet delays of the Upstream Traffic at the OLE-ONU sides of the network. Typical function of DBA schedulers is to efficiently determine the ONUs granted *Slot Starting Time* and the granted *Slot Length*. To determine the *Slot Starting Time*, APA is based on the same principle as IPACT algorithm [2], since it supplies the most efficient way to both maximize the upstream bandwidth utilization and minimize the average packet delays. Our contribution aims to determine the *Granted Slot Length*. We use the following formula to model the problem:

$$GrantedSlotLength=Min(MaximumSlotLength;\ PredictedRequest) \tag{1}$$

Limiting the *Granted Slot Length* by using the parameter *Maximum Slot Length* in (1) is important to achieve the isolation objective which prevents heavily loaded ONUs of reducing the QoS guaranteed to lightly loaded ONUs. IPACT limited service [2] uses fixed *Maximum Slot Length*, which may lead to very short Cycle Times when there is only few number of active ONUs. Excessive short Cycle Times should be avoided to decrease the protocol overhead and increase the bandwidth utilization.

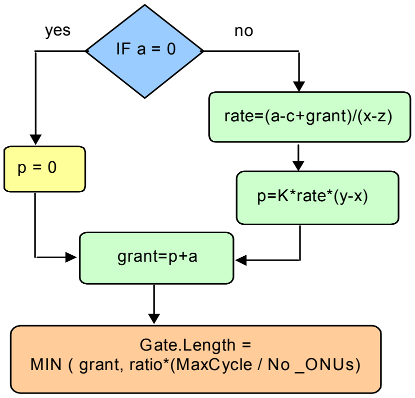

Fig. 2: APA Gate Length Calculation

Another proposed service in IPACT [2], Elastic service, dynamically sets the *Maximum Slot Length* but does not allow fairness since it may assign all the extra Bandwidth to a single ONU. Our algorithm calculates a dynamic *Maximum Slot Length* that enlarges the Cycle Time within its limit and achieves fairness and isolation as well. This scheme accumulates the extra bandwidth at the end of each Cycle and equally distributes it to the active ONUs in the next Cycle. During the next cycle the maximum allowed length for each ONU would be increased according to the variable

$$ratio = Maximum\_Allowed\_Cycle/total\_granted \qquad (2)$$

where total_granted is the sum of single ONU grants. This approach is correct on condition that the changes in active and idle ONUs between successive Cycles are negligible. APA may fail and lead to very long Cycle Times if several idle ONUs became suddenly active at the same Cycle. Practically this scenario may not be faced and indeed the simulations on LRD (Long Range Dependency) traffic proved that the Cycle Time never goes more than 10% over the maximum allowed value.

The *Predicted Request* is calculated based on a simple linear predictor, which can be easily implemented on hardware. Estimating of the next requests of the ONUs can greatly contribute in decreasing the average Packet Delays. As shown in Figure 3, the requested bandwidth of ONU 1 at time t=x is (a) bytes, however the next available *Slot Starting Time* decided by the pipelined scheme is at time t=y. This means that the real need for ONU 1 will be (a+b) bytes.

The algorithm calculates the rate of packets arriving at the ONU 1 queue in the time range from t=z to t=x in order to be able to estimate the amount of arriving packets in the time window from t=x to t=y. The predicted bandwidth request of ONU 1 at *Slot Starting Time* becomes (a+p) Bytes, which is the requested packets + the predicted packets.

The predicted Packets are finally re-tuned based on Histogram study of Ethernet Upstream traffic, which states that 60% of packets are of sizes 1,500 Bytes or 40 Bytes, hence the predicted numbers are always rounded to numbers with higher probability in Histogram. The APA algorithm has been represented by a flow diagram in Figure 2 with final *Granted Slot Length* calculation. The *ratio* variable is the weighting factor pre-calculated by (2), that keeps in account the available extra bandwidth.

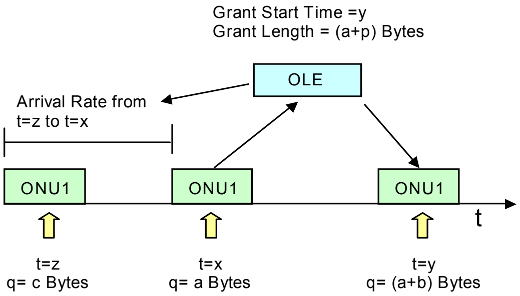

Fig. 3: OLE Predicted Value

V. SIMULATIONS RESULTS

The APA algorithm has been simulated in an OLE CWDM architecture and compared to an IPACT algorithm.

TABLE II.

Target Load	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**
IPACT (ms)	*0.4*	*0.4*	*0.7*	*8.5*	*24.4*	*127.9*	*145*
APA (ms)	*0.3*	*0.3*	*0.4*	*1*	*16.2*	*127.1*	*144.4*
Improv.nt	*5.6 %*	*10.5 %*	*47.1 %*	*88.9 %*	*33.5 %*	*0.6 %*	*0.4 %*

The algorithm shows great improvement in average packet delay compared to the limited service scheme in IPACT as shown in Figure 4. The simulation set up includes 16 ONUs with 100 MBs as maximum ONU traffic.

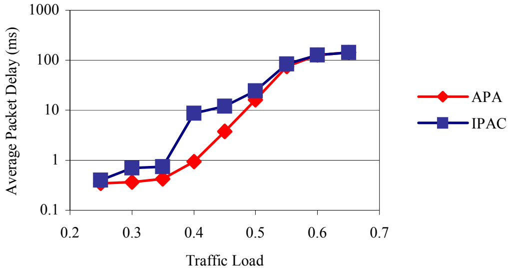

Fig. 4: APA Average Delay: 16 ONUs

The traffic is modeled as a Long Range Dependent (LRD) traffic, which is a very close model to the real characteristics of Ethernet Upstream traffic. We are analyzing the results in the region at loads from 0.2 to 0.7 as for the light load below this region and for the heavy saturating loads above this region; all algorithms almost show the same behavior. On the other hand, this region shows the abrupt increase in the average packet delay, which we are trying to mitigate in our algorithm.

TABLE III.

Target Load	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
IPACT (ms)	*0.35*	*0.35*	*0.35*	*0.35*	*0.35*
APA (ms)	*0.31*	*0.31*	*0.31*	*0.32*	*0.32*
Improv.nt	*10.7 %*	*10.6 %*	*10.8 %*	*10.9 %*	*33.5 %*

The simulations results, averaged on multiple samples, have shown in average a 18 % packet delay reduction in comparison with the IPACT algorithm in the considered Traffic Load condition. The numerical result has been reported in Table II with percentage improvement on IPACT. It may be noted that the improvement is substantial for average traffic loads while decreases for low or high traffic load conditions where the incidence of algorithms is less. Indeed, low traffic conditions allow low packet delays anyway, while high traffic conditions bring to the network saturation, where bandwidth allocation algorithms become useless.

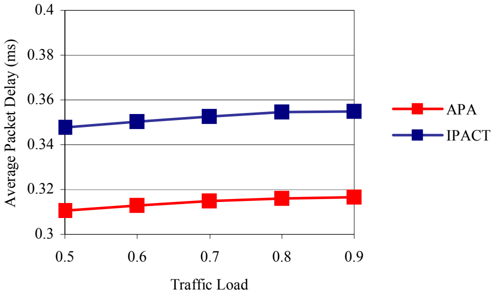

Fig. 5: APA Average Delay: 8 ONUs

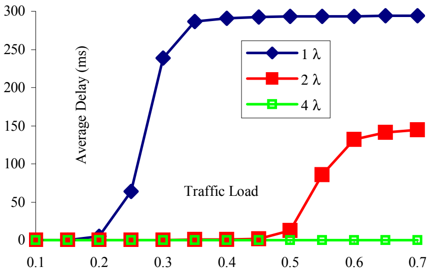

Fig. 6: 32 ONUs CWDM Expander:32,16,8 ONUs per OLE

To make the algorithm working anyway, the APA scheduler can be profitably coupled to the CWDM feature of OLE. In this case the total number of ONUs can be split on different CWDM wavelengths, in order to maintain a number of ONUs per OLE that never saturates the network over all the traffic conditions. In Figure 5 APA has been tested with only 8 ONUs at 100 MBs and traffic load between 0.5 and 0.9. In Table III the numerical-10 times averaged-packet delay values have been reported. Even with a smaller number of ONUs, and in light traffic condition, APA shows a 10 % improvement over IPACT. In Figure 6 a 32 ONUs subnet is scaled using one, two or four CWDM OLEs. The CWDM enhancement avoids traffic saturation allowing APA working in optimal traffic load conditions where it shows real advantages on IPACT.

VI. CONCLUSION AND FUTURE WORKS

The paper has introduced a new EPON prediction based scheduler scheme in order to improve the shared PON network bandwidth per user while a CWDM OLE allows extending the number of subscriber per CO. The proposed design has been modeled, simulated and compared with relative techniques in order to prove the enhancements. This scheme showed in average a 18 % packet delay improvement over IPACT for a 16 ONUs EPON subnet, running at 100 MBPS. We see the future trend for this work is to integrate this new algorithm in our MPCP VHDL implementation [1], in order to improve the bandwidth performances

REFERENCES

[1] *A. Mady and A. Tonini*, "A VHDL Implementation of ONU Auto-discovery Process for PON" Int. Conference on Networking and Media Convergence (ICNM09), pp. 36-41, 2009

[2] *G. Kramer, B. Mukherjee, and G. Pesavento*, **"**Interleaved Polling with Adaptive Cycle Time (IPACT): A Dynamic Bandwidth Distribution Scheme in an Optical Access Network", Photonic Network Communications, vol. 4, no. 1 pp. 89-107, January 2002

[3] *Y. Zhu and M. Ma*, "IPACT With Grant Estimation (IPACT-GE) Scheme for Ethernet Passive Optical Networks," J. Lightwave Technol. **26**, pp. 2055-2063, 2008

[4] *D. Nowak, J. Murphy, and P. P*erry, "Adaptive Dynamic Bandwidth Allocation Algorithm for Ethernet PONs," in Proceedings of 30th European Conference on Optical Communication, vol. 3, pp. 740-741, Sept., 2004

[5] *B. Chen, J. Chen, and S. He*, "Efficient and Fine Scheduling Algorithm for Bandwidth Allocation in Ethernet Passive Optical Networks", IEEE Journal of Selected Topics in Quantum Electronics, Vol. 12, No. 4, pp. 653-660 , 2006

[6] *G. Kramer*, "From 1 to 10 Gb/s in five years: The EPON Story", Joint ITU-T/IEEE Workshop on Carrier-class Ethernet, Geneva, Switzerland, May 31 - June 1, 2007

[7] *A. Banerjee, Y. Park, F. Clarke, H. Song, S. Yang, G. Kramer, K. Kim, and B. Mukherjee*, "A review of WDM-PON Technologies for Broadband Access" OSA Journal of Optical Networking, vol. 4, no.11, pp. 737-758, 2005

[8] *A.Tonini*, "CWDM Ethernet PON Optical Light Expander" IPCOM000191669D, IP.com Prior Art Database Disclosure, 2010

[9] *C. A. Chan*, M. *Attygalle*, and A. Nirmalathas, "Active remote node with layer two forwarding for improving performance of EPON," Journal of Optical Communications and Networking, Vol. 2, Issue 1, pp. 28-37, 2010

[10] *S. R. Sherif, A. Hadjiantonis, G. Ellinas, C. Assi, and M. A. Ali, "*A Novel Decentralized Ethernet-Based PON Access Architecture for Provisioning Differentiated QoS", Journal Of Lightwave Technology, Vol. 22, No. 11, pp. 2483-2497, 2004