Virtual Dynamic Bandwidth Allocation Enabling True PON Multi-Tenancy

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Abstract: We propose a virtual-DBA architecture enabling true PON multi-tenancy, giving Virtual Network Operators full control over capacity assignment algorithms. We achieve virtualization enabling efficient capacity sharing without increasing scheduling delay compared to traditional (non-virtualized) PONs.
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1. Introduction

Passive optical networks (PON) are considered as one of the prominent access network solutions due to the high capacity and coverage they can provide. Meanwhile, the high Capital expenditure (CAPEX) required for PON deployment has been an obstacle to large-scale adoption, especially in rural areas with a lower number of users and bandwidth demand. To this point, multiple solutions have been proposed in the past to improve the business case of access fiber deployments, stemming from changes in the overall network architecture [1], to the development of cost effective transceivers for multi-wavelength PONs [2]. A complementary approach to economic sustainability is to increase the revenue generated by the PON by increasing the number and types of services that can be supported, for example including mobile backhaul [3] and fronthaul [4], in addition to the enterprise and residential applications. Therefore, a scenario in which all the aforementioned services can coexist and operate on the same PON infrastructure is pivotal in increasing the utilization of the infrastructure, thus generating new revenue streams. A set of suitable multi-tenancy oriented solutions is then required to enable coexistence of multiple service providers offering services with diverse requirements. While multi-tenancy of access network has been developed through techniques like Next Generation Access (NGA) bitstream and Virtual Unbundled Local Access (VULA), many operators believe these high level virtualization tools do not give the ability to control capacity scheduling that can be necessary to satisfy strict Quality of Service requirements needed by 5G applications.

True Multi-Tenant PON (MT-PON) requires full virtualization of the PON network, giving Virtual Network Operators (VNOs) the ability to control the PON protocol, and the capacity scheduling in particular, as if they owned and had full control of the physical OLT devices [5], [6]. Indeed, the concept of virtual OLT (vOLT) is already a foundation stone of the Residential-CORD (R-CORD) strand of the OpenCORD project [7].

In this paper, we extend the idea of vOLT, by proposing the concept of virtual DBA (vDBA), a virtualization technique that allows each VNO to deploy its own virtual DBA algorithm of choice on top of a shared PON infrastructure. To the best of our knowledge, this is the first time that the possibility of having multiple virtual DBAs in a PON is being considered for multi-tenancy.

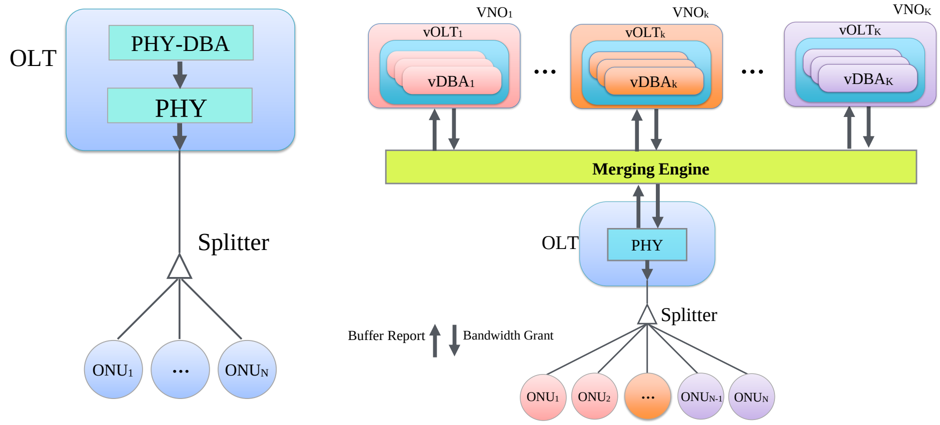
2. Multi-Tenant PON Architecture

Fig. 1 shows a comparison between the traditional PON and our virtualized MT-PON. In traditional PON, a single DBA scheme is implemented on OLT hardware. From hereafter, we will refer to the DBA scheme implemented on hardware as PHY-DBA. The problem with that architecture is that only a single operator can control the PHY-DBA process. The other virtual operators will not be able to control the upstream DBA process of their own customers/services, and at best only work on an assured rate service, without the ability to schedule the burst allocation of their customers ONUs.

In order to enable multiple VNO coexistence on PON, we propose a Multi-Tenant architecture. The architecture consists of three layers explained in the following subsections.

2.1 PHY Layer

The physical layer remains the same as in traditional PONs. The only exception is that it directs the DBRu (we consider the ITU XGS-PON protocol) from the ONU T-CONTs to the merging engine, which directly forwards them to the vDBA engines that are in charge of assigning capacity to them. While in this paper we target ITU standards, the same mechanism can be applied to (10GE-PON) report frames.



(a) (b)

Fig. 1: PON Layout (a) Traditional PON (b) Multi-Tenant PON

2.2. Merging Engine Layer

The merging engine layer has two main tasks. First, it is responsible for communications with the vDBAs controlled by the VNOs. It passes the upstream buffer reports (DBRus or report frames) to vDBA and it receives the corresponding virtual bandwidth grants (virtual bandwidth maps or virtual gate messages). Second, it analyzes the virtual bandwidth grants from all vDBAs, merging them into one physical bandwidth grant (bandwidth maps or gate frames). Within the context of XGS-PON, the merging engine layer is responsible for merging virtual bandwidth maps generated from virtual DBAs. We have defined two merging policies:

- Sharing Capacity: in this policy, each vDBA can act over the entire upstream frame, assigning capacity (assured, noon-assured and best effort) up to the maximum amount that has been pre-established with the PON infrastructure owner. The merging engine layer will merge the virtual bandwidth maps from all VNOs according to the following conditions:
    1. If all bandwidth grants can be accommodated, then no changes will be done to all virtual bandwidth maps.
    2. If some bandwidth grants cannot be accommodated, the bandwidth grants of overloaded VNOs are to be reduced in order to be fitted in the next upstream frame. In order to reduce bandwidth grants, the merging engine layer starts reducing best effort traffic grants first. If still not enough, non-assured traffic bandwidth grants are also to be reduced. Assured capacity will always be allocated as far as it has not been over-subscribed by the infrastructure owner and the VNOs have not exceeded their allocation.
- Non-Sharing Capacity: in this policy, each vDBA shall produce virtual bandwidth maps not exceeding its fixed allocated share of the upstream frame: for example in the case of two VNOs, one could be allocated the first half of the upstream frame and the other the second half. The merging engine layer simply concatenates the virtual bandwidth maps. This simple policy does not allow the unused capacity of one VNO to be shared with the other VNOs and is used as a baseline to evaluate the performance of the capacity sharing algorithm.

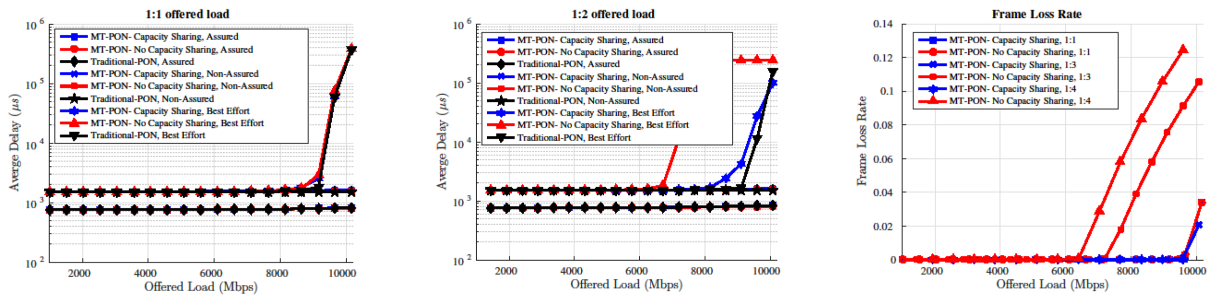
Although in this paper we carry out an analysis based on a single-wavelength system, the concept can be easily extended to multi-wavelength systems, where for example the total PON capacity across multiple wavelengths can be virtualized into slices of arbitrary capacity (for example virtual slices do not need to operate as 10G PONs, but could be assigned as 6G PONs or 15G PONs, as required). In addition, the idea can also be easily adapted to applications requiring very low latency, like fronthaul. For example, the BBU could embed the vOLT and control the vDBA generating the bandwidth map without waiting for DBRu messages, thus enabling tight synchronization between BBU and OLT as proposed in [8].

2.3. Virtual DBA Layer

This is the layer controlled by the VNO, which has full control over the choice of the most appropriate virtual DBA algorithm to run on its virtual PON slice. The vDBA calculates the bandwidth map for its PON slice and delivers it to the merging engine.

3. Performance Evaluation

We developed a C++ XGS-PON simulator (e.g., using 10G upstream rates) and we considered an XGS-PON with single OLT and 64 ONUs with maximum physical distance of 40 Km. The upstream capacity was set to 9.95328 Gbps. The Ethernet frame size for generating traffic load ranges from 64 to 1518 bytes with the packet size distribution reported in [9]. We employed self-similar traffic with long range dependence (LRD) and Hurst parameter 0:8. The number of VNOs was set to two with equal number of ONUs and both employ GIANT [10] as vDBA with three T-CONTs, namely: assured, non-assured and best effort. We considered service intervals of 4, 8, and 8 frames respectively. The offered load is uniformly distributed among ONUs and T-CONTs. We assume the two VNOs have each 5 Gbps of assured traffic, but are allowed to exceed this figure with non-assured and best effort traffic. We considered two scenarios for offered load. First, the offered load is equal (1:1) between the two VNOs. Second, the offered load is divided on a 1:2 ratio between the two VNOs.



(a) (b) (c)

Fig. 2: (a) Average delay, load divided by 1:1 (b) average delay, load divided by 1:2 (c) frame loss rate

The aim of our analysis is to show that the vDBA mechanism we propose does not cause additional delay to the capacity scheduling, while it gives full control to VNOs over their vDBA algorithm and is able to re-assign unused capacity among the VNOs. Fig. 2 shows the average delay versus the offered load for the sharing capacity, non-sharing capacity and traditional (non-virtualized) PON as well as the frame loss rate. From Fig. 2.a and Fig 2.b, we can see that employing virtualization in the DBA does not affect the delay of the assured and non-assured bandwidth performance. For these two cases the plots show the same constant delay performance both for the traditional PON and the two virtualized PONs. Assured bandwidth is the most important to consider as it is the most likely to carry traffic with higher QoS requirements. Regarding best effort traffic, in Fig 2.a we see that when the load increases towards saturation this experiences delay, which however is similar across traditional and virtual PONs (red, black and blue curves increase together). From Fig 2.b however we can see that when the traffic is unbalanced between VNOs, MT-PON with capacity sharing (blue) outperforms MT-PON with non-sharing capacity (red) and it performs similarly to a traditional PON (black). This advantage is also clear from Fig 2.c, showing that MT-PON with capacity sharing does not experience any noticeable frame loss when the load is unbalanced. On the other hand the non-sharing capacity MT-PON experiences noticeable loss rate (here we also show the case where the traffic is unbalanced by a factor of 3). In conclusion, our approach to DBA virtualization has shown that it is possible to achieve true multi-tenancy in PONs, giving operators full control over capacity scheduling, without increasing delay performance and without wasting PON capacity when the load is unbalanced among the VNOs.

4. Acknowledgements

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