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# A PID-based algorithm to guarantee QoS delay requirements in LR-PONs

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ABSTRACT

In this paper a novel algorithm with delay guarantees for high priority traffic based on a Proportional (P) controller for Long-Reach Passive Optical Networks (LR-PONs) is proposed. We have recently demonstrated that Proportional–Integral–Derivative (PID) controllers are quite effective when controlling guaranteed bandwidth levels and in this paper this functionality is adapted to jointly deal with Class of Service (CoS) and client differentiation in order to fulfill delay requirements. Therefore, it leads to an efficient control of the mean packet delay which enhances the provided Quality of Service (QoS) inside the LR-PON. Simulation results have exhibited that the bandwidth allocation process made by the P controller achieves this objective faster than other existing proposals. In fact, it stabilizes the priority delays in less than 2 min comparing with 5 or 6 min obtained by other proposals. Furthermore, it has been demonstrated that its performance is more robust than other proposals since it is independent of the initial network conditions, adapting very efficiently the available resources in order to comply with the established delay bounds of the most restrictive services.



## 1. Introduction

The new optically amplified Passive Optical Network (PON) architectures, called Long-Reach PONs (LR-PONs), are a promising technology in the short term deployment. These networks exhibit many advantages since they highly extend the reach and the split ratio of traditional PONs while being a cost effective solution [1]. LR-PONs significantly reduces the network complexity as it combines the optical access and the metro segment into an integrated system. Therefore, cost savings are achieved because the traditional Synchronous Digital Hierarchy (SDH) is replaced with a simple shared optical fiber and part of the shared equipment is reduced. Furthermore, as it is an optically amplified technology, it extends the reach to distances higher than 100 km and thus allows an important increase in the number of potential users [1,2]. Although LR-PONs can be combined with several complex technologies, in the protocol layer they can be simplified by one or several independent Point to Multipoint networks, typically based on a tree topology between the Optical Line Terminal (OLT) and the Optical Network Units (ONUs). As a consequence, their performance can be compared with a traditional PON, so the main problem occurs in the upstream channel, from the ONUs to the OLT, since all ONUs share the same access channel. Therefore, it is essential to implement a Medium Access Control (MAC) protocol to deal with possible collisions in the shared channel. In this way, Dynamic Bandwidth Allocation (DBA) algorithms, based on Time Division Multiple Access (TDMA), are the most popular solutions, as they dynamically

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distribute the available bandwidth depending on the current demand of ONUs and some Quality of Service (QoS) requirements [3–6]. However, in LR-PONs the increment of the distance and the appearance of long idle times may provoke an inefficient performance of the network. Therefore, a great number of DBA algorithms for LR-PONs are being designed to manage this phenomenon. Authors in [2,7,8] propose DBA algorithms which use the idle time between transmissions to poll the ONUs' requests by running multiple threads. Indeed, in [7] the algorithm incorporates a Gate optimization process applying ILP formulation techniques based on the ONUs' requests to calculate appropriate credit ratios for overloaded ONUs. Moreover, authors in [9] discuss and compare multi-thread and online polling strategies. Authors demonstrated that the first technique decreases the queuing delays. In contrast, online polling techniques achieve higher throughput and lead a better delay performance. On the other hand, other approaches focus on designing scheduling techniques to improve the network performance. Authors in [10] implement a DBA algorithm to enhance the network performance by firstly scheduling ONUs with small propagation delay. Moreover, the algorithm proposed in [11] improves bandwidth utilization and packet delay by classifying ONUs in different groups. Then, the OLT schedules the bandwidth assignation of one group, when another group is sending its data to the OLT. Meanwhile, the OLT tries to decrease the mean packet delay applying the Smallest Available Report First (SARF) to allocate bandwidth to each group of ONUs.

Regarding the QoS, service providers should face multi-profile access networks, with users and traffic of different priorities and requirements. Nowadays, very popular services with high QoS constraints are emerging. Indeed, Internet video streaming services, such as live video broadcast, video on demand or video conversation are becoming very popular [12]. Together with interactive voice applications and real-time gaming, all of them require some kind of performance predictability in terms of end-to-end transfer delays [13]. Consequently, in a typical access network, end users contract a Service Level Agreement (SLA) with a service provider. In this contract, some parameters, normally related to a minimum guaranteed bandwidth or a maximum delay for high priority CoS, are specified and they must be fulfilled. Then, DBA algorithms have to be designed to optimally deal with both subscriber and class of service differentiation. In the literature many proposals can be found which guarantee a minimum bandwidth to a variety of service levels in PONs and LR-PONs [4–6,14], but there are only a few algorithms which provide delay guarantees. In [15,16] an algorithm is presented for LR-PONs with SLA delay constraints by means of an admission control, but it does not ensure delay requirements for the supported CoS. On the other hand, in [17,18] algorithms with multiple supported services are proposed, but they only take into account bounds for only the most priority traffic (1.5 ms for voice traffic following the ITU-T Recommendations). However, with the emergence of many applications it is necessary to provide delay guarantees not only for the most priority traffic, but also for several priority services, likewise the algorithm described in [19]. Nevertheless, none of them supports client differentiation. In contrast, the algorithm presented in [20] allows SLA differentiation, providing bandwidth and delay guarantees for certain priority ONUs, but only for the highest priority service Constant Bit Rate (CBR). To the best of our knowledge, only two algorithms have been developed to control the mean packet delay of high and medium priority traffic while considering also client differentiation. In fact, this double differentiation is crucial in an access network since the most restrictive services have to comply with the stipulated maximum requirements depending on the SLA contracted. In [21], an algorithm with class of service differentiation, which meets the SLA agreements of users, is presented. This algorithm ensures delays for different CoSs and SLAs by establishing the cycle length to the most stringent delay bound and by polling high priority SLAs ONUs more frequently than less priority ONUs. In [22], an algorithm is also presented, called DySLa, which dynamically controls the mean packet delay and it guarantees that the high and medium priority services fulfill the packet delay requirements in a PON, according to its contracted SLA. This algorithm initially assigns different weighted factors to each SLA subscriber depending on its priority and then it constantly modifies the allocated bandwidth to each ONU to keep the mean packet delay for the most sensitive services below a maximum bound, by reducing or incrementing a fixed quantity its associated weight. As a consequence, the algorithm exhibits a great dependence on this fixed factor to guarantee the delay requirements of every class of service.

On the contrary, Proportional–Integral–Derivative (PID) controllers and its variants (P, PI) are widespread control techniques that can allow an automatic and reliable control of different parameters [23–25]. Although they are implemented in many fields, their use in optical networks to control network parameters has recently come up. In this way, authors in [26,27], have designed a PID to control the number of tasks in optical grid networks and the establishment of lightpaths in WDM networks. In the field of PON networks, a PID controller to efficiently guarantee minimum bandwidth levels to different SLA subscribers in a LR-PON was proposed in [28]. The performance of this algorithm was so satisfactory that this strategy can be viewed very promising for its extended use in PONs. Therefore, we consider the implementation of PID techniques to control other important parameters, such as the delay in PONs and LR-PONs, an interesting and appealing option to jointly deal with client and CoS differentiation. Contrary to the previous existing DBA algorithms, our proposal is the first one that relies on a robust and efficient technique based on the well-known and rigorous control theory of PID controllers to guarantee delay bounds. Therefore, it will provide a more stable and efficiently response when conducting the control process. Consequently, in this article a DBA algorithm is proposed based on PID controllers to automatically control the mean packet delay of high and medium priority traffic in Ethernet based LR-PONs, in order to keep the mean packet delay of the most sensitive services below a maximum upper bound for every supported SLA.