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An auto-tuning PID control system based on genetic algorithms to provide delay guarantees in Passive Optical Networks

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ABSTRACT

Passive Optical Networks (PONs) are the most important access architectures since their deployment is massive all around the world. However, the QoS (Quality of Service) and the efficient management of the network resources have become the key point, especially with the new emerging services and applications. In particular, the delay and the bandwidth are becoming important limiting factors for the user experience. As a consequence, in a previous research we proposed the implementation of PID (Proportional-Integral-Derivative) control strategies to manage these networks parameters in PONs, demonstrating higher efficiency and more robustness than other previous existing algorithms. It is worth emphasizing that this is the first time to apply this control strategy in PONs access networks. However, in this paper we improve the PID control strategy by automating the tuning process with a genetic algorithm. Indeed, we have developed a novel automatic tuning technique based on genetic algorithms to tune a P controller that provides delay guarantees. Simulation results show that the control strategy reduces the tuning time up to 64% in comparison with the Ziegler–Nichols manual technique (ZN). On the other hand, it is demonstrated that our proposal is more accurate and robust that ZN since the genetic algorithm automatically evolves to the best solutions of the tuning parameters in contrast to the manual experiments required for the ZN method. Furthermore, we have complemented the use of the P controller with a new dynamic Admission Control (AC) module. This module implements a policy to selectively transmit or drop packets and leads a better delay control. The simulation analysis reveals that the real time evolution of the delay with the dynamic AC is more stable when compare to a conventional and simple fixed AC, reaching differences near one order of magnitude in the delay fluctuations.

1. Introduction

The most deployed access networks, called Passive Optical Networks (PON) and Long-Reach-PON networks, are showing a high penetration impact in the last mile deployment with more than 80 million subscribers in Asia Pacific, 11 million in America (Ahl, 2013) and 41.5 million households expected in Europe at end of 2017. PONs and Long-Reach PONs are Point-to-MultiPoint (P2MP) high capacity access networks based on a tree topology between the Optical Line Terminal (OLT) and the Optical Network Units (ONUs), as it is shown in Fig. 1.

To achieve bidirectional transmission, two different wavelengths are used and combined by means of WDM, one for the downstream direction (from the OLT to the ONUs) and the other for the upstream transmission (from the ONUs to the OLT). In the downstream direction, the OLT uses all the available bandwidth since it broadcasts the messages to every ONU, but only the designated ONU will deliver the received traffic to its end users. In contrast, in the upstream channel, every ONU shares the channel, so a Medium Access Control (MAC) mechanism is needed to avoid collisions between data from different ONUs. Then, Dynamic Bandwidth Allocation (DBA) algorithms, based on Time Division Multiplexing Access (TDMA), are the most popular algorithms to manage the upstream channel in PONs and LR-PONs (Assi, Sudhir & Ali, 2003; Can Turna, Muhammed Ali, Halim Zaim, & Atmaca, 2015; Chang, Merayo, Kourtessis, Senior, & Lorenzo, 2010; Chen, Kuo, & Yan, 2009; Herrería-Alonso, Rodriguez Pérez, Fernández Veiga, & López García, 2015; Jiunn-Ru & Wen-Ping, 2015; Kantarci & Mouftah, 2011; Mcgarry, Reisslein & Maier, 2008; Merayo et al., 2010; Murayama, Oota, Suzuki, & Yoshimoto, 2013; Wati & Hidayat, 2013).

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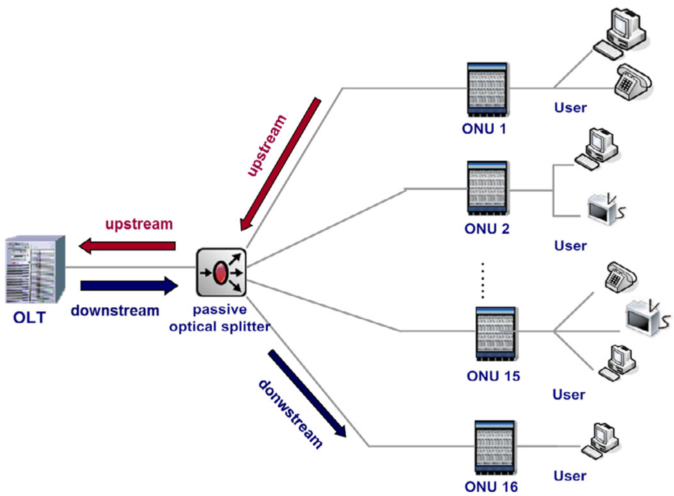

Fig. 1. PON architecture with a typical tree topology.

On the other hand, PON and LR-PONs have to support different user profiles that sign specific Service Level Agreements (SLA) with providers, each of them with different priority Classes of Services (CoS) or applications. Therefore, a PON network has to provide Quality of Service (QoS) requirements typically regarding minimum bandwidth levels or maximum threshold delays. As a consequence, DBA algorithms should efficiently comply with the stipulated QoS requirements since very popular services with high QoS constraints are strongly emerging (live video broadcast, video on demand or video conversation (Wang, Kwon, Choi, Chen, & Zhang, 2012)). In addition, it is essential that DBA algorithms fulfill these QoS restrictions by means of a real time and automatic readjustment, so that the network becomes independent of its state. Many existing algorithms focus on providing QoS requirements in PONs and LR-PONs (Nikoukar, Hwang, Tanny Liem, & Wang, 2015). In fact, latency or delay is becoming an important limiting factor for the user experience since a lot of latency-sensitive web and cloud based applications are strongly increasing (Briscoe et al., 2015). In (Kantarci & Mouftah, 2012) authors proposed a DBA algorithm with delay constrains for different priority profiles (SLA, Service Level Agreements) but not for their supported services. Moreover, authors in (Assi, Maier, & Shami, 2007) control the maximum delay bound for voice traffic applications (1.5 ms), but the algorithm does not control the performance of other sensitive services. The approach presented in (Berisa, Fouli, & Maier, 2014) develops a real time signaling mechanism in PONs, outlining several emerging low-latency applications. However, these strategies do not consider different delay bounds for services depending on the priority of the profile (SLA). In this way, authors in (Berisa, Bazant, & Mikac, 2009) proposed a DBA algorithm that ensures delay bounds and bandwidth guarantees for users with high SLA priority, but only for their highest priority service. In contrast, the algorithm presented in (Dixit et al., 2013) controls the maximum delay bound of two highest priority services but also taking into account the priority of the profile (SLA). However, this algorithm only differs between residential and business customers (only two profiles). In (Merayo et al., 2009), it is also presented an algorithm which controls that the high and medium priority services fulfill packet delay requirements according to its SLA. This algorithm constantly modifies the allocated bandwidth (associated with a weight) to keep the mean packet delay below a maximum, by reducing or incrementing a fixed quantity its associated weight. However, this algorithm shows a great dependence on this fixed factor to guarantee the delay requirements. Therefore, to overcome these limitations we proposed in a previous research some algorithms that integrate a novel strategy to control QoS parameters in PON networks using the well-known PID technique (Jiménez et al., 2012; Jiménez et al., 2014a). Proportional-Integral-Derivative (PID) controllers are well-known control techniques which allow an automatic and reliable control of different parameters. They are extensively used in industrial systems, since they provide high robustness, clear functionality, effectiveness and good performance (Ang, Chong, & Li, 2005 and Aström & Hägglund 2006; Ilyas Menhas, Wang, Fei, & Pan, 2012; Vicente Hultmann Ayala H. & dos Santos Coelho L., 2012). Although PID systems are implemented in many fields, their use in optical networks to control network parameters has recently come up. In this way, authors in (Tachibana & Sugimoto, 2009; Tachibana, Kogiso, & Sugimoto, 2008) proposed a PID to control the tasks in optical grid networks and the establishment of ligthpaths in WDM networks. Moreover, authors in (Bianciotto, Puttnam, Thomsen, & Bayvel, 2009) designed a theoretical model of a wavelength-locking loop for stabilization of the output wavelength in tunable lasers for dynamic optical burst-switched networks using PID strategies. Therefore, it is worth mentioning that this is the first time to use these techniques to control network parameters in PONs access networks (bandwidth, delay). The results in Jiménez et al., 2012 and Jiménez et al., 2014a demonstrated that the designed and implemented PID strategies permits to control QoS parameters but in a more robust, efficient and fast way than other previous existing algorithms. In particular and regarding the delay control, our proposal, presented in Jiménez et al., 2014a, is the first one that relies on a robust and efficient technique based on the rigorous control theory of PID controllers to guarantee delay bounds.

On the other hand, PID controllers have to be tuned in an efficient way to provide a reliable response according to the process scenario. Most of the PID tuning techniques are manual and based on experiments (such as the well-known Ziegler–Nichols frequency response), so they become difficult, very time-consuming and quite tedious. Therefore, the development of fast and optimal tuning methods is an important research field in PID controllers, in order to overcome these limitations. In this way, expert systems or artificial intelligence try to simulate the knowledge and judgment of humans. Therefore, many proposals apply these computational intelligence approaches to deal with the tuning process of PID controllers, such as fuzzy logic, neural networks or genetic algorithms (Rodriguez, Rodrigues, & dos Santos, 2010). Among every alternative, in this approach we have chosen genetic algorithms because they are robust, easy to understand and to implement and they are based on biological organisms such as natural selection and reproduction. Furthermore, they find a population of solutions instead of a unique solution and they do not require much information about the system (except for the fitness function) (Keshari & Mehetab, 2011), that is, they does not require any gradient information and inherent parallelism in searching the design space, thus making it a robust adaptive optimization technique (Vicente Hultmann Ayala H. & dos Santos Coelho L., 2012). In contrast, neural networks need to be provided with good examples to be trained and the learning process could become quite long, because their performance highly depends on the amount of data they are trained with (Keshari & Mehetab, 2011). The fuzzy logic sometimes bases the reasoning and decisions on incomplete information similar to that of human beings (Keshari & Mehetab, 2011). Moreover, if the complexity of the system increases, the selection of the fuzzy rules and the membership functions could become quite tedious (Lakhmi & Martin 1998). On the other hand, there are a lot of recent proposals that implement genetic algorithms to tune expert PIDs (Ali & Wadhwani, 2015; Canto dos Santos, Farias, & Nogueira, 2015; Hussain, Allwyn Rajendran Zepherin, Shantha Kumar, & Giriraj Kumar, 2014; Ilyas Menhas et al., 2012; Kozeny, 2015; Neath, et al., 2014; Rajabi-Bahaabadi,Shariat-Mohaymany, Babaei, & Wook Ahn, 2015; Vicente Hultmann Ayala H. & dos Santos Coelho L., 2012; Wati & Hidayat, 2013; Yuan, Changuan, Zhou, Huang, & Yang, 2015) in many research fields. Hence, our algorithm has been designed using the GA