Hybrid Dynamic Bandwidth and Wavelength Allocation Algorithm to Support Multi-Service Level Profiles in a WDM-EPON

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Abstract. A novel bandwidth assignment algorithm in WDM Ethernet Passive Optical Networks, called DyWaS-SLA, is proposed not only to provide service differentiation but also to offer subscriber differentiation. Simulation results show that DyWaS-SLA outperforms other bandwidth allocation algorithms in WDM-EPONs as it makes fairer bandwidth distribution than those methods. Consequently, it always insures a guaranteed bandwidth for every priority subscriber. Furthermore, DyWaS-SLA obtains lower mean packet delay and packet loss rate for the highest priority subscribers when compared with other bandwidth distribution schemes in WDM-EPONs.

Keywords: Wavelength Division Multiplexing (WDM), Dynamic Bandwidth Allocation (DBA), Ethernet Passive Optical Network (EPON), Service Level Agreement (SLA), CoS (Class of Service).

1 Introduction

Passive Optical Networks (PONs) are an excellent technology to develop access networks, as they provide both high bandwidth and class of service differentiation [1-2]. The PON technology uses a single wavelength in each of the two directions and such wavelengths are multiplexed on the same fiber by means of Wavelength Division Multiplexing (WDM). Since all users share the same wavelength in the upstream direction, a Medium Access Control (MAC) is necessary to avoid collision between packets from different Optical Network Units (ONUs). Time Division Multiple Access (TDMA) is the most widespread control scheme in these networks. However, it

is inefficient because the nature of network traffic is neither homogeneous nor continuous [3-4]. In this way, algorithms which distribute the available bandwidth in a dynamic way, called Dynamic Bandwidth Allocation algorithms (DBA), are necessary to adapt the network capacity to traffic conditions by changing the distribution of the bandwidth assigned to each ONU depending on the current requirements [3-8]. Therefore, the current MAC protocols are based on a dynamic distribution of the upstream bandwidth among the connected ONUs in the PON.

Although PON infrastructures are able to provide enough bandwidth for current applications, both the gradual increase of the number of users and the bandwidth requirements of the new emerging services, demand an upgrade of such access networks. The addition of new wavelengths to be shared in the upstream and downstream direction in PON infrastructures leads to the so-called Wavelength Division Multiplex PONs (WDM-PONs). The pure WDM-PON architecture assigns one dedicated wavelength per ONU, which implies more dedicated bandwidth and more security in the system. However, the related cost associated to such deployment makes pure WDM-PONs as the next-generation architectures. Hence, the combination of the WDM technology with Time Division Multiplexing (TDM) techniques is likely the best near future approach. These hybrid architectures exploit the advantages of wavelength assignment of WDM techniques and the power splitting of TDM techniques.

On the other hand, end users contract a Service Level Agreement (SLA) with a provider, which forces the access network to treat each SLA subscriber in a different way. Many studies are related to service providers, which offer multi-service levels according to subscribers' requirements [5-8]. The Bandwidth Guaranteed Polling (BGP) method proposed in [5] divides ONUs into two disjoint sets of bandwidth guaranteed ONUs and best effort ONUs. While the guaranteed ONUs receive the demanded bandwidth, the remaining bandwidth is delivered over the best effort ONUs. However, this scheme only differs between guaranteed ONUs and best effort ONUs, but it does not distinguish other profiles with specific restrictions. Hence, a typical way to offer customer differentiation is to use a fixed weighted factor assigned to each ONU associated to a specific SLA. Then, the bandwidth is allocated depending on these weights. In the method presented in [6], each ONU is assigned a minimum guaranteed bandwidth based on the associated weight, so that the upstream channel is divided among the ONUs in proportion to their SLAs. In the Dynamic Minimum Bandwidth algorithm (DMB) [7-8], the OLT distributes the available bandwidth by assigning different weights to each client depending on their SLA. Therefore, ONUs associated with a higher weight will be assigned more bandwidth.

In this paper, we present a novel DBA algorithm applied to a hybrid WDM-TDM EPON architecture for a gradual upgrade of the existing TDM EPON infrastructures. Unlike other DBA algorithms proposed in WDM-EPONs, the new algorithm is able to differ between service level profiles with the aim to distribute the available bandwidth conscious of the requirements of every profile. Then, the algorithm is designed to insure a guaranteed bandwidth to every subscriber when the available bandwidth is not enough to support every bandwidth demand. Furthermore, the Ethernet protocol has been considered because it is a well-known inexpensive technology and interoperable with a variety of legacy equipment [1-2].

The paper is organized as follows. Section 2 describes the related work focus on WDM-PON deployment. Section 3 explains the new WDM-TDM algorithm. In Section 4 the environment and results achieved from simulations carried out are presented. Finally, in section 5, the most relevant conclusions obtained in this study are shown.

2   Related Work in WDM-TDM PONs

Several WDM-TDM architectures have been proposed recently, although the deployment of the WDM technology in the access network is still in its first stages. One extended WDM-PON approach employs one separate wavelength for the transmission between the OLT to each ONU. In general, this architecture does not allow bandwidth redistribution and presents high deployment cost. In order to reduce costs, the authors in [9] proposes a hybrid WDM-TDM access architecture with reflective ONUs, an arrayed-waveguide-grating outside plant, and a tunable laser stack at the OLT. This architecture decreases a lot the number of lasers at the OLT and also improves highly the security at each ONU. However, dynamic wavelength assignment is not permitted and it can not take advantage of the inter-channel statistical multiplexing to fairly redistribute the available bandwidth.

On the contrary, the WDM-PON architecture called SUCCESS [10] permits a gradual migration from TDM-PON to WDM-PON by adding tunable transmitters at the OLT. It allows that multiple tunable transceivers can be shared among several independent PONs. Furthermore, the SUCCESS prototype was improved by deploying a ring topology in the so-called SUCCESS-HPON [11]. Then, the OLT communicates with users using several distribution starts. The authors developed in [12] a scheduling algorithm applying dynamic wavelength allocation to allow bandwidth sharing across multiple physical PONs, by means of sharing the tunable transceivers at the OLT. It enhances the architecture performance and reduces the related costs.

The hybrid novel WDM-TDM architecture proposed in [13] uses a transmitter without wavelength selectivity based on an uncooled Fabry-Pérot Laser Diode (FP-LD). The study demonstrated that a single FD-LD can be used in any wavelength channel without wavelength tuning in a temperature range from 0 to 60ºC. The architecture has a double-star topology in a cascade of several arrayed-waveguide gratings (AWGs), and each of them is shared by a number of users by means of splitters via TDM techniques. However, no DBA algorithms were discussed for such architecture.

The architectures proposed in [14-16] consider a smooth upgrade of TDM-PONs, allowing several wavelengths for the upstream transmission. Authors in [14-15] proposed that the OLT consists of an array of fixed laser/receivers and the ONUs of either an array of fixed laser/receivers or one or more tunable laser/receivers. However, since the providers' point of view is more likely the utilization of either tunable laser/receivers or fixed laser/receiver arrays, but not both simultaneously. Moreover, the migration from TDM-PONs to WDM-PON would be upgraded gradually along the time depending on economical constrains.

In the prototype proposed in [16], every ONU employs one or more fixed transceivers, permitting a gradual upgrade depending on the traffic demand of the ONUs. Then, the OLT assigns the bandwidth to each ONU in those wavelengths they

support. In addition, the fixed transceivers at the ONU can be interchanged by a fast tunable laser. In that case, the OLT only can transmit in one single wavelength at any given time, which may lead to poor bandwidth utilization due to the dead tuning time every time there is a wavelength switch.

Finally, there are other architectures which propose to divide ONUs into multiple subsets [17]. As each subset is allocated a fixed wavelength channel for the upstream transmission, each ONU is equipped with a fixed transceiver and the OLT with a stack of fixed transceivers. However, this architecture is limited flexible as it does not allow dynamic wavelength allocation.

Regarding DBA algorithms developed in WDM-PONs, the algorithm proposed in [16] presents three variants in order to allocate the excess bandwidth among ONUs with great traffic demand (high loaded ONUs). Among these three schemes, namely controlled, fair and uncontrolled methods, the former improves the bandwidth utilization and therefore the overall network performance. In the controlled variant, the OLT waits until all reports messages from one cycle are received in order to apply the allocation algorithm for the next cycle. However, in the other two approaches the OLT permits that ONUs with low traffic demand can transmit before the reception of every report. Moreover, the dynamic channel allocation is based on the first-fit technique (i.e. the first available free wavelength).

The algorithm proposed in [18] is an extension of the Interleaved Polling Adaptive Cycle Time (IPACT) for EPON access networks. Similar to the previous method [16], it also applies the first-fit technique to dynamically select each channel wavelength. Besides, it also provides Class of Service (CoS) differentiation by means of the extended strict priority queue scheme.

The algorithm proposed in [15] developed an extension to the Multi-Point Control Protocol (MPCP) for WDM-PONs in order to support dynamic bandwidth allocation. They implemented two scheduling paradigms for WDM-EPONs, namely online and offline. In the former, the OLT applies bandwidth and wavelength allocation based on the individual request of each ONU. However, in the offline policy the OLT applies scheduling decisions taking into account the bandwidth requirements of all ONUs. The simulations demonstrate that online scheduling obtains lower delays than offline scheduling, especially at high ONU loads.

Finally, the algorithm presented in [19] supports Quality of Service (QoS) in a differentiated services framework. The algorithm allows each ONU to simultaneously transmit at two channels, where each channel is dedicated to a different type of traffic.

The WDM-PON architectures and the WDM-DBA algorithms for such architectures are being strongly studied nowadays. However, it does not exist a predominant or imposed architecture. Therefore, the gradual WDM upgrade would be limited by technological costs and based on the necessity of service providers. It is preferable flexible WDM-PON architectures which could be upgraded in a cost-effective way. We agree with these flexible architectures which allow both time and wavelength dynamic allocation. In order to share several wavelengths for the upstream transmission, each ONU will be equipped with several fixed transceivers or a tunable transceiver. However, the utilization of a tunable transceiver may provide less bandwidth due to the dead tuning time necessary to switch wavelengths. Therefore, it is necessary to have transceivers with a tuning speed at least of microseconds.

3   DyWaS-SLA Algorithm

In order to distribute the available bandwidth among users there are two essential approaches which can be applied: the separate wavelength and time allocation, or the joint wavelength and time assignment. Most of the proposed studies [15, 18-19] consider the joint time and wavelength assignment as it permits multidimensional scheduling.

Furthermore, there are multiple schemes to assign wavelengths and some of them are extensively used in the transport network, such as the fixed, the random, the least assigned, the least loaded or the first fit allocation. Then, the OLT keeps track of the utilization of each wavelength and uses this information to decide on which ONUs the wavelength assignment changes. In the fixed scheme, once a wavelength has been assigned for the transmission of one ONU, this assignment is never changed. This makes the wavelength allocation very simple to implement but it lacks of the statistical wavelength-domain multiplexing advantages. On the other hand, the random, the least assigned and the least loaded methods tend to excessively overload certain wavelengths, as it is demonstrated in [15]. Therefore, the online scheduling wavelength scheme in which ONUs are able to transmit in the first free wavelength, leads to an efficient solution [18]. Then, in this simulation study it is assumed the first fit method to dynamically assign the wavelengths.

In order to allocate bandwidth at each separate wavelength channel, polling algorithms are a good choice as they can improve the channel utilization. Among the different bandwidth allocation schemes which may be used in polling methods, the limited scheme offers the best performance, as it is demonstrated in [19, 21]. In this scheme, the OLT gives the required bandwidth to each ONU as long as the demand is lower than a maximum bandwidth imposed. When the demand is higher than this bandwidth, the OLT gives this latter maximum. This behaviour makes the cycle time to be adaptive depending on the updated demand of each ONU. The cycle time is the total time in which all ONUs transmit in a round robin discipline.

As the network allows different service levels profiles, it is necessary to treat subscribers differently depending on their priority. In order to do that, it is applied the method based on assigning a fixed weight to each profile [9, 14-15] depending of its priority. Then, the OLT uses these weights to allocate the available bandwidth at each channel.

The new algorithm called Dynamic Wavelength aSsignment to support multi- Service Level Agreement (DyWaS-SLA) has been designed taking into account the previous ideas. In contrast to other existing DBA algorithms applied to WDM-PONs, the new algorithm distinguishes between profiles with different requirements, insuring a guaranteed bandwidth when every profile demand excesses the available bandwidth. Therefore, DyWaS-SLA sets different maximum bandwidths $\left(B_{max}^{sla_k}\right)$, one for each priority SLA. Therefore, the allocated bandwidth in one cycle time for each ONU ($B_{alloc}^{onu_i}$) can be defined by Eq. 1:

$$B_{alloc}^{onu_i} = \begin{cases} B_{demand}^{onu_i} & \text{if} \quad B_{demand}^{onu_i} < B_{max}^{sla_k} \\ B_{max}^{sla_k} & \text{Otherwise} \end{cases} . \tag{1}$$

where $B^{onu_i}_{demand}$ is the aggregated bandwidth demand of all supported services in the ONU i . The term $Q_{i,j}$ is the demanded bandwidth for the class of service j in the ONU i (Eq. 2) reported in the last control message.

$$B^{onu_i}_{demand} = \sum_j Q_{i,j} \ .$$

(2)

The maximum allocated bandwidth permitted for each ONU depending on its SLA at each cycle time, $B^{sla_k}_{max}$, is calculated using the Eq. 3. In this equation W^{sla_m} represents the weight associated to the SLA m, $B_{cycle\_available}$ the available bandwidth at each maximum cycle (i.e. maximum cycle time of 2 ms set by the EPON standard). The term $N^{sla_m}_{onus}$ is the number of ONUs associated to SLA m in the network and λ_n represents each supported wavelength.

$$B^{sla_k}_{max} = \frac{B_{cycle\_available} \cdot W^{sla_k} \cdot \sum_n \lambda_n}{\sum_m W^{sla_m} \cdot N^{sla_m}_{onus}} \ .$$

(3)

4 Simulation Results

4.1 Simulation Scenario

Simulations were made considering an WDM-EPON with 32 ONUs and one user connected to each ONU using OPNET Modeler 14 [20]. The transmission rate of the upstream link between ONUs and the OLT is set to 1 Gbit/s and the access link from the user to each ONU to 100 Mbit/s [6, 22-23]. The distance between ONUs and the OLT is set to 20 km, which is near the maximum permitted distance for a typical PON [6, 23]. In order to avoid collisions between adjacent ONUs, a guard time of 1 μs is chosen, a value within the limits specified by the standard IEEE 802.3ah D1.414 [24].

Moreover, the WDM-EPON network copes with a variety of traffic streams with different requirements. Then, taking into consideration the ITU-T G.1010 [25] and G. 114 [26] Recommendations and other related works [3, 6, 23], it is assumed that three of these classes of service, P_0, P_1 and P_2 are supported by the network. They respectively represent Real-Time, Responsively and Best effort traffic. In addition, it is considered that the highest priority service P_0 represents 20% of the ONU load, while P_1 and P_2 priority services get equal shares of the remaining ONU load [3, 23]. Hence, each ONU is equipped with three queues, one for each class of service, all of them sharing the same buffer of capacity 10 MB like in [6, 22].

As the WDM-EPON network also contemplates subscriber differentiation, it is presented a scenario with three priority SLAs: SLA_0 for the highest priority service level, SLA_1 for the medium priority service level and SLA_2 for the lowest priority service level. In general, only very few conventional users contract high level

agreement conditions, whereas users tend to contract medium or low priority service level profiles. As a consequence, it is assumed that one ONU contracts the highest priority service level agreement SLA_0, five ONUs contract the medium priority service level SLA_1 and ten ONUs the lowest priority service level SLA_2. Related to the assigned weights to each SLA (W^{sla_k}), it is set the values $W^{sla_0} = 4$, $W^{sla_1} = 3$ and $W^{sla_2} = 2$ as well as other other published studies [7-8]. These weights are considered to comply with the NTT DSL service plans (50/70/100 Mbit/s) [27], also used by the algorithms proposed in [7-8]. Therefore each SLA should be offered this guaranteed bandwidth when the bandwidth demand of every SLA exceeds the available bandwidth. Furthermore, it is considered 3 supported wavelengths in the WDM-PON in order to increase the total capacity of the shared upstream channel.

Packet generation follows a Pareto distribution with a Hurst parameter, H, equal to 0.8, considering them of fixed length (1500 bytes plus additional headers, i.e., 1538 bytes). This length was assumed because it is the MTU of the standard IEEE 802.3. Moreover, the maximum cycle time is set to 2 ms, limited by the standard IEEE 802.3ah D1.414 [24].

Related to the evaluation of algorithms, DyWaS-SLA is compared with WDM-IPACT [18] as the original algorithm IPACT [22] is a very efficient method even when it does not differentiate priority profiles. Finally, both algorithms support service differentiation by means of the strict priority queue method. This method achieves the best performance for the highest priority services and it is easy to implement.

4.2 Simulation Results

Fig. 1 represents the mean packet delay versus the ONU load, when WDM-IPACT and DyWaS-SLA algorithms are compared for the three service level agreements (SLA_0, SLA_1 and SLA_2) and for the highest priority service P_0. As it can be noticed, there are slight differences between both algorithms for every ONU load, obtaining all of them values under 1E-3 seconds. Furthermore, this value is under the maximum limited imposed in the access by the Recommendation ITU-T G. 114 [31] for such applications, that is 1.5 ms. However, DyWaS-SLA achieves lower delay than WDM-IPACT for every subscriber at high ONU loads, although the differences between them are very small. Regarding the packet loss rate, both algorithms do not permit packet losses for such priority service P_0, therefore it has not been represented in any graph.

Fig. 2 represents the mean packet delay versus the ONU load, when WDM-IPACT and DyWaS-SLA algorithms are compared for the three SLAs and the medium priority service P_1. It can be observed that WDM-IPACT does not differ between subscribers with different priority, achieving the same delay for every SLA. In contrast to WDM-IPACT, DyWaS-SLA obtains lower mean packet delay than WDM-IPACT for the two highest priority subscribers (SLA_0, SLA_1). It can be noticed that DyWaS-SLA keeps the mean packet delay for such priority subscribers near the values obtained for the highest priority service P_0. Regarding packet losses, these algorithms do not allow losses for such priority service and it has not been represented in any graph.
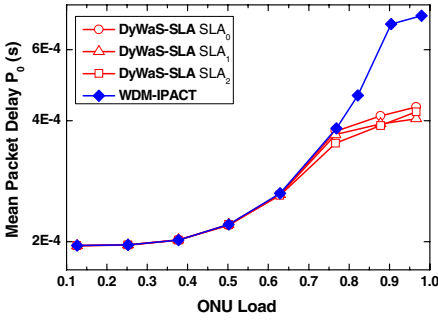
Fig. 1. Mean packet delay versus ONU load of WDM-IPACT and DyWaS-SLA algorithms for every SLA subscriber and class of service P_0
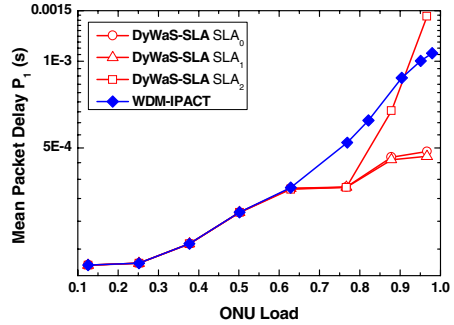
Fig. 2. Mean packet delay versus ONU load of WDM-IPACT and DyWaS-SLA algorithms for every SLA subscriber and class of service P_1

Related to the lowest priority service P_2, Fig. 3 represents the mean packet delay versus the ONU load, when WDM-IPACT and DyWaS-SLA are compared for the three SLAs. One more time, it can be seen how WDM-IPACT treats subscribers in the same way. On the contrary, DyWaS-SLA achieves a great reduction in the mean packet delay when compared with WDM-IPACT for the two highest priority subscribers (SLA_0, SLA_1). The most noticeable improvement appears for the highest priority subscribers (SLA_0), where DyWaS-SLA is able to keep their mean packet delay under or around 1E-3 seconds for every ONU load. Therefore, it has been demonstrated that this profile achieves very low delays for every supported service. Furthermore, differences between WDM-IPACT and DyWaS-SLA for SLA_0 and SLA_1 subscribers reach more than two orders of magnitude when the ONU load is higher than 0.8.

In order to analyze the packet losses of the service P_2, Fig. 4 represents the packet loss rate versus the ONU load, when WDM-IPACT and DyWaS-SLA are compared.
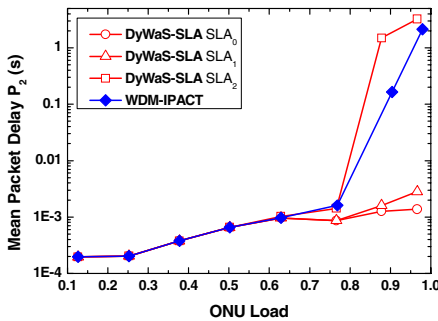

Fig. 3. Mean packet delay versus ONU load of WDM-IPACT and DyWaS-SLA algorithms for every SLA subscriber and class of service P_2
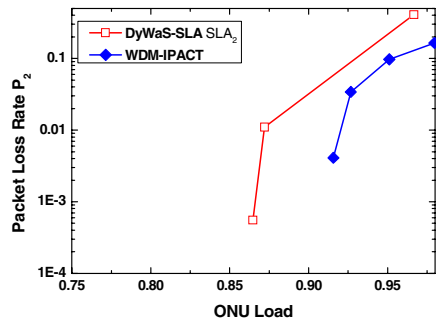
Fig. 4. Packet loss rate versus ONU load of WDM-IPACT and DyWaS-SLA algorithms for every SLA subscriber and class of service P_2

It can be observed that WDM-IPACT presents losses for every subscriber independently of its priority. However, DyWaS-SLA differs between SLAs and performs better for the two highest priority subscribers (SLA_0 and SLA_1), as it does not permit losses for such subscribers. Consequently, DyWaS-SLA presents packet losses for the lowest priority subscribers (SLA_2), in order to avoid losses for SLA_0 and SLA_1 profiles.

On the other hand, one important characteristic of DBA algorithms is the offered bandwidth to each priority subscriber. Then, Fig. 5 shows the offered bandwidth to one ONU of each SLA versus the ONU load when WDM-IPACT and DyWaS-SLA are compared for 32 ONUs. As all ONUs have the same traffic distribution, all of them demand the same bandwidth (B_{demand}), as it is shown in the figure. As it can be seen in Fig. 5 the demanded bandwidth follows a linear function until the maximum user transmission rate of 100 Mbit/s. In the same way, the represented offered bandwidth to one ONU of each SLA is the same for all ONUs belonging to such SLA.

It can be noticed that WDM-IPACT offers the same bandwidth to every SLA as it does not take into consideration the priority of the subscriber. On the contrary, DyWaS-SLA differs between profiles and it offers more bandwidth than WDM-IPACT for the two highest priority subscribers (SLA_0 and SLA_1). Then, DyWaS-SLA outperforms WDM-IPACT as it always insures the guaranteed bandwidth when the total capacity is not enough to cover the bandwidth demand of every profile. On the contrary, WDM-IPACT does not offer the guaranteed bandwidth to the highest priority subscribers SLA_0 (100 Mbit/s) when the ONU load is higher than 0.9.

The same behaviour can be observed in Fig. 6, when it is assumed that 48 ONUs are connected to the WDM-EPON. In the figure, it can be noticed that differences between both algorithms are much higher. DyWaS-SLA can offer the demanded bandwidth for the highest priority subscribers SLA_0 for every ONU load. Related to the SLA_1 priority profile, DyWaS-SLA offers the demanded bandwidth up to ONU loads around 0.75. Meanwhile, WDM-IPACT algorithm does not distinguish between priority SLAS and it only offers the demanded bandwidth for the two highest priority subscribers for lower ONU loads than DyWaS-SLA, that it is, loads lower than 0.6. This means that for the two highest priority profiles SLA_0 and SLA_1, DyWaS-SLA supports efficiently higher loads than WDM-IPACT does.
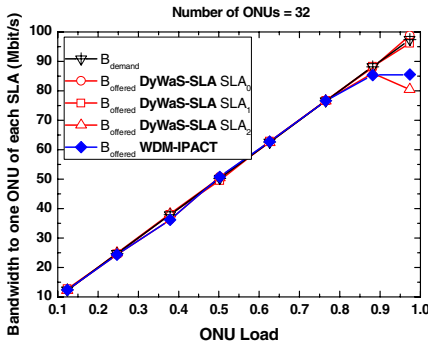

Fig. 5. Demanded and offered bandwidth to one ONU of each SLA versus ONU load for WDM-IPACT and DyWaS-SLA for 32 ONUs
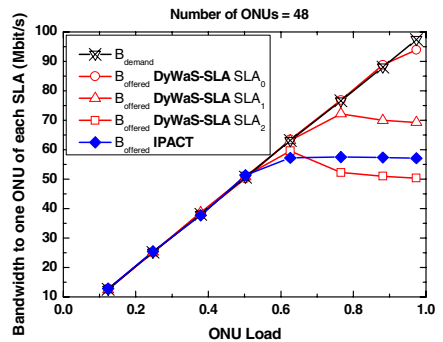
Fig. 6. Demanded and offered bandwidth to one ONU of each SLA versus ONU load for WDM-IPACT and DyWaS-SLA for 48 ONUs
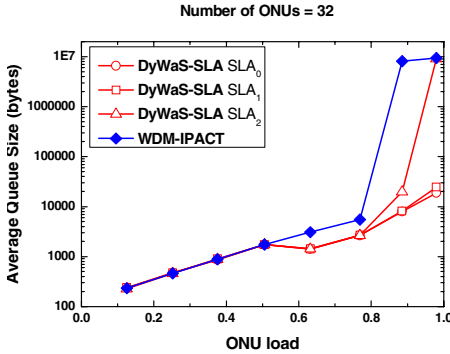
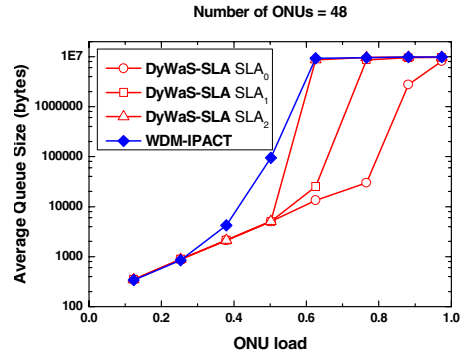**Fig. 7.** Average queue size versus ONU load for WDM-IPACT and DyWaS-SLA for 32 ONUs

Fig. 8. Average queue size versus ONU load for WDM-IPACT and DyWaS-SLA for 48 ONUs

Regarding the guaranteed bandwidth to each profile, in Fig. 6 it is shown that DyWaS-SLA is able to insure the guaranteed bandwidth for every SLA and every ONU load. However, WDM-IPACT can not offer the guaranteed bandwidth for the most important priority subscribers SLA_0 (100 Mbit/s) and SLA_1 (70 Mbit/s). This behaviour means that DyWaS-SLA efficiently complies with the bandwidth restrictions imposed by the service provider.

In Fig. 7 and Fig. 8 it is represented the average queue size versus the ONU load in order to compared DyWas-SLA and WDM-IPACT for 32 and 48 ONUs. In both figures it can be seen how WDM-IPACT keeps the same queue size for every SLA. On the contrary, DyWas-SLA maintains lower queue size than WDM-IPACT for the two highest priority profiles SLA_0 and SLA_1.

In particular, in Fig, 7, when the number of ONUs is set to 32, WDM-IPACT keeps the queue of every profile nearly full (10 Mbytes) for ONU loads higher than 0.8. This behaviour provokes that the highest priority subscriber SLA_0, cannot comply with its guaranteed bandwidth for such loads, as it has been demonstrated in Fig. 5. When the number of ONUs is increased to 48, Fig. 8 shows how WDM-IPACT keeps the queue nearly full for every SLA when the ONU load is higher than 0.6. Therefore, it makes that SLA_0 and SLA_1 subscribers cannot have insured their guaranteed bandwidth for such loads, as it can be seen in Fig. 6.

On the contrary, DyWaS-SLA keeps lower queue size than WDM-IPACT for SLA_0 and SLA_1 subscribers, which allows these profiles to achieve their guaranteed bandwidth for every ONU load.

If we analize the wavelength utilization, Fig. 9 represents the percentage of the wavelength utilization along the time when WDM-IPACT and DyWaS-SLA are compared. As it can be seen, both algorithms use every wavelength in the same way. Also this figure demonstrates that the first fit method does not overload one particular wavelength, as it distributes the wavelength allocation fairly between every supported wavelength. This behaviour can be seen in Fig. 10, which represents the wavelength allocation at one particular ONU along the time for the DyWaS-SLA algorithm. It is shown that one ONU is assigned the three supported wavelengths in the same proportion along the simulation time.
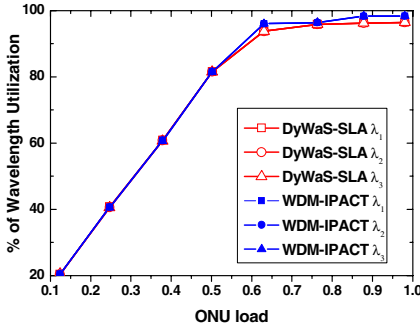
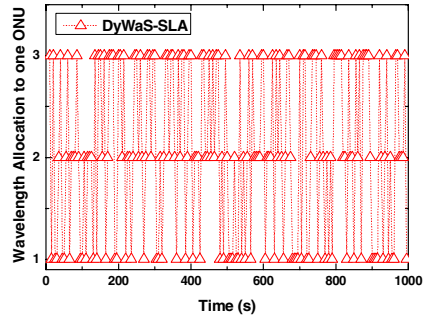**Fig. 9.** Percentage of the wavelength utilization along the time when WDM-IPACT and DyWaS-SLA are compared

Fig. 10. Wavelength allocation at one particular ONU versus the time for DyWaS-SLA algorithm

5 Conclusions

A novel polling algorithm called DyWaS-SLA to provide service and subscriber differentiation in WDM-EPONs has been proposed. DyWaS-SLA distributes the bandwidth according to a set of weights in order to offer a guaranteed bandwidth to each priority profile when the available bandwidth is not enough to cover the demand of every subscriber.

DyWaS-SLA has been compared with WDM-IPACT as it is a very efficient method even when it does not differentiate service level profiles. Simulation results show that DyWaS-SLA makes subscriber differentiation as the delay and the packet loss rate for the highest priority subscribers are lower than methods which do not offer subscriber differentiation, such as WDM-IPACT.

Related to the mean packet delay, the differences between WDM-IPACT and Dy-WaS-SLA for SLA_0 and SLA_1 subscribers reach more than two orders of magnitude when the ONU load is very high. Furthermore, it is demonstrated that DyWaS-SLA achieves very low delays for every supported service, under or around 1E-3 seconds for the highest priority subscriber SLA_0.

Regarding packet losses, WDM-IPACT presents losses for every subscriber independently of its priority for the service P_2. In contrast to WDM-IPACT, for such service, DyWaS-SLA differs more efficiently between priority SLAs and it does not permit losses for the highest priority subscribers (SLA_0 and SLA_1).

DyWaS-SLA makes a more conscious bandwidth distribution when it is compared with WDM-IPACT, as DyWaS-SLA insures a predetermined guaranteed bandwidth to every subscriber (SLA_0, SLA_1 and SLA_2) even when the number of ONUs is highly increased to 48. On the contrary, WDM-IPACT always offers the same maximum bandwidth to every SLA independently of its priority. Then, WDM-IPACT does not insure the guaranteed bandwidth to the SLA_0 subscribers when the number of ONUs is 32 and for the two highest priority profiles SLA_0 and SLA_1 when the number of ONUs is increased to 48.

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