Comparative Analysis of Algorithms for Bandwidth Allocation in EPON

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Abstract—**In this paper we compare the main algorithms used for bandwidth allocation in Ethernet Passive Optical Networks (EPON): Interleaved Polling with Adaptive Cycle (IPACT), Constant Cycle Time (CCT) and Static Bandwidth Allocation for High Priority Services (SBAHPS) algorithms. Computer simulations are executed to reproduce the behavior of these methods using powerful software tools. Some changes in the computational procedures have also been implemented. The ICCT (Improved CCT) and SBAHPS algorithms showed the best results.**

Keywords-EPON; bandwidth allocation;resource efficiency.

I. INTRODUCTION

Traffic in telecommunication networks grows steadily because of data-intensive applications and services. To tackle this fact, EPONs have gained popularity as a suitable infrastructure to support such huge traffic in the access segment. In EPONs several Optical Network Units (ONUs) share a common upstream channel for transmission. The bandwidth must be dynamically allocated among multiple ONUs to achieve an efficient use of resources. Allocation algorithms take into account the instantaneous bandwidth demand and Quality of Service (QoS) requirements.

Dynamic Bandwidth Allocation (DBA) is an active field of research [1], and many different approaches have been proposed [2]-[12]. In this paper, we compare the main algorithms for bandwidth allocation for data transmission upstream from multiple ONUs to the Optical Line Termination (OLT) in EPONs [1], such as: IPACT, CCT and SBAHPS. Several indicators on efficiency and fair utilization of the EPON upstream bandwidth, while supporting the Quality of Service (QoS) requirements of different traffic classes, are calculated. Several modifications in the computational procedures have also been carried out. The software simulation tools have been developed using Mathworks Matlab software.

The rest of the paper is organized as follows: in Section 2, we discuss recent literature on DBA for EPONs, Section 3 describe the algorithms to be compared, Sections 4 and 5 contain the results and discussion. We end with some conclusions and explain some future works.

II. STATE OF ART

There are research papers that apply techniques for DBA in EPON networks. In [3], the authors examine Passive Optical Networks (PON) architectures and DBA algorithms. The main branches of their classification for DBA methods are: grant sizing, grant scheduling, and optical network unit queue scheduling. They examine the topics of QoS support, as well as fair bandwidth allocation. The results are summarized and explicitly point to posible future avenues of research. In [4], an enhanced QoS-based dynamic bandwidth allocation (EQDBA) mechanism is proposed which incorporates with a prediction-based fair excessive bandwidth allocation (PFEBA) scheme to support differential traffic class in EPON. The proposed EQDBA mechanism divides a frame into two parts; one is the high priority traffic, which is always assigned in the fixed location of the frame to minimize the delay variation. The other kind of traffic, to solve the idle period problem, is dynamically adjusted in the transmission order according to an unstable degree list. The simulation results show that the proposed mechanism outperforms the PFEBA and QDBA mechanisms in terms of average end-to-end delay and high priority traffic delay to ensure QoS. In [6], the authors present a survey of the state of the art DBA algorithms for EPONs. They explain the main concepts and issues related to DBA in EPON systems. This paper justifies why IPACT, CCT and SBAHPS are the most suitable DBA algorithms. In [7], the authors show the differences between EPON and GPON (such as: bandwidth utilization, delay, and jitter) by means of simulations for the two standards. They take into account the evolution of both technologies to their next-generation counterparts with a bit rate of 10 Gbps and analyze the implications for the DBA. The authors propose a new GPON DBA method to study the GPON performance. It is shown that the length of the polling cycle is a key issue for the DBA within the two standards. Minor differences regarding DBA for current and next-generation PONs were also detected. In [12], the author emulates a 10Gbps next generation EPON network, which transmits voice, video and data packets, using the DBA-MAX, DBA-LINEAR and DBA-GATED algorithms. The performance is compared studying the variations of the average delay and the throughput with the traffic load. In [11], the authors provide a classification and a detailed comparison for a large number of DBA algorithms with respect to time delay and throughput parameters as performance indicators. The study explains that IPACT WITH CBR, UDBA, IPACT with two stages and CPBA algorithms show good results.

There are also a few studies regarding IPACT and its variances. Some of them are:

- [8], where the authors propose a new DBA algorithm. The method provides constant and predictable average packet delay and minimizes the delay variation for the high and medium priority traffic, keeping the packet loss rate under control.
- [9], where the authors describe an improved weighted interleaved polling with adaptive cycle time (IW-IPACT) algorithm according to the QoS requirement for different kinds of traffic. Strict priority scheduling was applied to the expedited forwarding services and, the weighted fair queuing scheduling was used for the rest of the services.
- [10], where the authors present a dynamic bandwidth allocation model. They propose a local bandwidth allocation algorithm based on a bargain—bargain approach. Reordering the delivery date of each packet after bargaining it according to its user level, delay and size. The model improves the traditional IPACT algorithm which establishes the delivery date of each packet in the order of polling. The results show that the proposed model can effectively minimize the Unused Slot Remainder (USR), and improves bandwidth allocation efficiency.

As a novelty, we analyze the CCT algorithm, and carry out specific variations in the SBAHPS and IPACT methods. We also study among other parameters: the average cycle times, the cycle time standard deviation and the waste of channel capacity for the high and low priority traffics. These experiments (algorithms and parameters) have been chosen because IPACT, CCT and SBAHPS algorithms are considered as the most efficient methods in the scientific bibliography, and because these parameters allow to evaluate precisely the behavior of them.

III. BANDWIDTH ALLOCATION FOR UPSTREAM DATA TRANSMISSION

This section describes the main DBA algorithms that have been simulated: IPACT, CCT and SBAHPS methods. Simulation results are presented in Section 4.

In general, the OLT allocates the size of transmission windows for each ONU using the GATE message. This allocation is based on the information received from ONUs in the REPORT message.

A. Interleaved Polling with Adaptive Cycle

The OLT polls the ONUs individually and issues grants to them in a round-robin fashion [2]. At the end of a transmission window, an ONU reports its queue sizes. The OLT employes this data to establish the next granted transmission window. The knowledge of the distance between OLT and ONUs (*d*) allows the OLT to schedule transmission windows so that packages from different ONUs do not overlap in time.

The OLT controls and allocates a transmission window for each ONU at levels below an established maximum value (*TMax*) according to the Service Level Agreement (SLA). If the transmission window requested by an ONU is lower than *TMax*, the OLT will allocate this value to the ONU. If not, the OLT will allocate *TMax* as transmission window size.

B. Constant Cycle Time

This algorithm does not carry out a sequential pool of ONUs. The transmissions from each ONUs are undertaken in a cyclical manner. Once the transmission in the cycle $TCycle_j$ is finished, each ONU will have sent a REPORT message with the request related to the transmission window for the cycle $TCycle_{j+2}$. This method ignores the requested window size from each ONU and always grants the estimated *TMax* in a cycle as window size. The main disadvantage of this algorithm is that the cycle time is not used efficiently by those ONU with little information to tranmit.

*TMax*in cycle *j+2* is defined as:

$$TMax\text{ in cycle } j+2 = \sum_{k=1}^{k=N} (TCycle_{jk} - TAuto_{jk})/N \qquad (1)$$

Where:

- $TCycle_j$: Time needed by the ONUs to transmit the granted length of data together with their associated guard intervals in the cycle *j*.
- *TAuto*: Time required to detect newly-connected ONUs and handle the round-trip delay and MAC address of ONUs in the cycle *j*.

  We suggest raising the efficiency in the use of resources employing the ICCT algorithm, which is based on the following premises:

  - The OLT summarizes the unused transmission window time in cycle *j* (UT_{ij}) for all ONUs with a window size lower than *TMax*, The OLT grants this calculated value($t_{re\text{-}assignedj}$) to those ONUs that have requested a window higher than *TMax* (P_j).

  $$t_{re-assignedj} = \frac{\sum_{i=1}^{N} (UT_{ij})}{P_j} \qquad (2)$$

  - In the event that all ONUs request a window size higher than *TMax*, the allocations are equitably distributed in a manner similar to the CCT algorithm.

C. Static Bandwidth Allocation for High Priority Services

In relation to the SBAHPS method, based on the investigation [5], we suggest prioritizing delay-sensitive traffic (IP telephony, video-streaming, etc) by reserving a specific time slot. This time slot should be proportional to the allocated transmission window for each ONU. This procedure works similarly to the IPACT algorithm but booking a specific time slot for the high priority traffic in

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each ONU. However, this particular slot can be used inefficiently by an ONU has not enough traffic to fill it completely.

IV. SIMULATION OF ALGORITHMS

The simulation environment should be suitable for the most usual applications. Its requirements are:

- EPON network with bidirectional 1 Gbps links ($C = 10^9$ bits/second) using 1490 nm wavelength for downstream and 1310 nm for upstream, with 1550 nm reserved for additional services. This network has a 1:32 split ratio.
- ONUs are located at a distance of *d* km from the OLT.
- The network is in a stable condition at the simulation time.
- The network should be characterized by the parameters indicated below, where:
- *N* is the total number of ONUs.
- *M* is the total number of ONUs transmiting low priority data traffic.
- Each ONU(*i*) processes data traffic according to a Poisson distribution, which has a mean arrival rate of λ_i packages every second. A package requires a mean service time$E(X)$. ONU*i* has a traffic load ρ_i.

$$E(X) = \frac{1}{\mu} = 8 . \frac{1518}{10^9} = 12.14 \, \mu seg \quad (3)$$

$$\rho_i = \frac{\lambda_i}{\mu}; \; i=1:N \quad (4)$$

- The OLT processes a total traffic load ρ_{Total}

$$\rho_{Total} = \sum_{i=1}^{N} \rho_i \leq 1 \quad (5)$$

$$\rho_i \in [0\,,1] \qquad \rho_i = \rho_i^{HP} + \rho_i^{LP} \quad (6)$$

$$\rho_{total} = \sum_{i=1}^{N} \rho_i = \sum_{i=1}^{N} (\rho_i^{HP} + \rho_i^{LP}) \leq 1 \quad (7)$$

- ρ_i^{HP} is the traffic load for packages related to high priority services (percentage of ρ_i).
- ρ_i^{LP} is the traffic load for pakages related to low priority services (percentage of ρ_i).
- For one ONU *i*, a cycle time *j*, $TCycle_j$, represents the elapsed time between transmission start times *j+1* and *j*.
- The average cycle time, $E(TCycle^{HP})$, for the packages related to high priority servicesis defined as:

$$E(TCycle^{HP}) = \frac{N.\ TCycle_0}{1-\rho} \quad (8)$$

- The average cycle time, $E(TCycle^{LP})$, for the packages related to low priority services is defined as:

$$E(TCycle^{LP}) = \frac{N}{M} \frac{N.\ TCycle_0}{1-\rho} \quad (9)$$

- The waste of channel capacity in the cycle *j*, $WCj(\%)$, is defined as:

$$WCj(\%) = TCycle_{jwasted} / TCycle_j \;.\ 100 \quad (10)$$

- The waste of channel capacity for the high priority services in the cycle *j*, $WCj^{HP}(\%)$, is defined as:

$$WCj^{HP}(\%) = TCycle_{jwasted}^{HP} / TCyclej^{HP} \;.\ 100 \quad (11)$$

- ρ_{Total} will have the values: 0.1, 0.3, 0.5, 0.7, 0.9.
- ρ_i^{HP} (percentage of ρi) will have the values: 0.1, 0.3, 0.5, 0.7, 0.9.

$$E(TCycle) = \frac{1}{\mu} \cdot \lambda \cdot E(TSim) + N \cdot E(TGuard) + N \cdot E(TRep) \quad (12)$$

$E(TSim)$ *is the* average time for the execution of the simulation scenario.

$E(TGuard)$ is the average guard time. (13)

$E(TRep)$ is the average required time for the transmission of the REPORT message (64 bytes).

$TReq_i$ is the requested transmission window.

$$TRep = \frac{\rho_{Total}}{N} \quad (14)$$

$$TReq_i = TCycle_0 + \frac{1}{\mu} NPaq_i \quad (15)$$

N_{paq_i} is the number of packages that ONU_i asks to transmit.

A. *Interleaved Polling with Adaptive Cycle*

Below, we explain the main simulation environments and the obtained results for the IPACT algorithm.

TABLE I. PARAMETERS USED IN THE IPACT ALGORITHM SIMULATION

N	*M*	ρ^{HP}
4	4	0.3

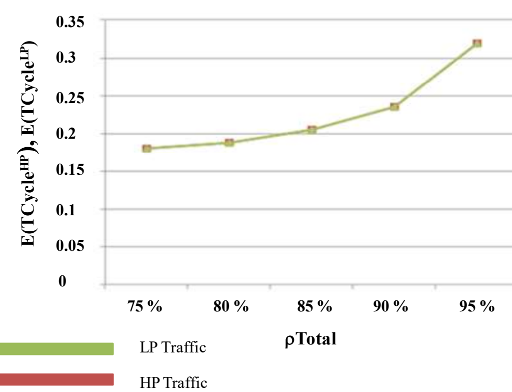

Figure 1. IPAC algorithm: $E(TCycle^{HP})$, $E(TCycle^{LP})$ in microseconds as a function of ρTotal forρ^{HP} = 0.3 [1].

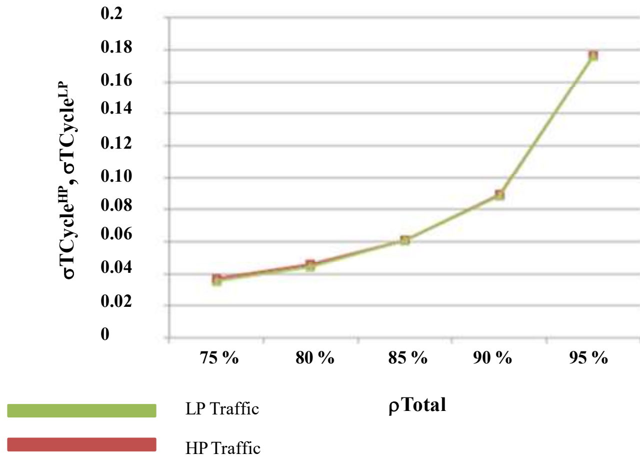

Figure 2. IPAC algorithm $\sigma TCycle^{HP}$, $\sigma TCycle^{LP}$ in microseconds as a function of ρTotal for $\rho^{HP} = 0.3$ [1].

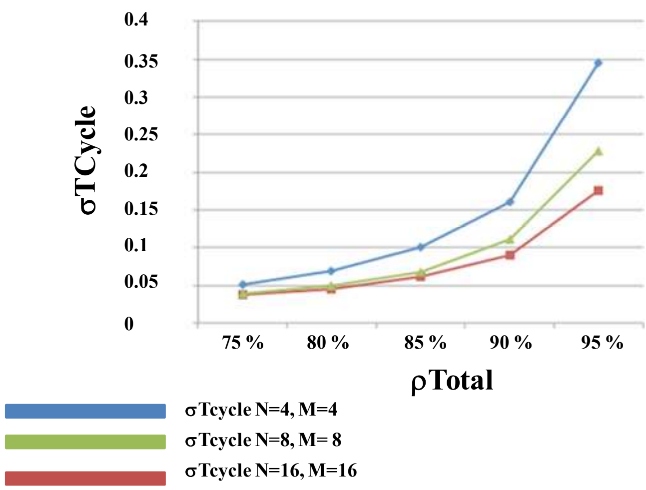

Figure 3. IPAC algorithm: σTCycle in microseconds as a function of ρTotal with $\rho^{HP} = 0.3$ for several values of N and M [1].

Figure 1 shows that there is not a clear distinction between the average cycle times for high and low priority traffic when the relation between *N* and *M* parameters is 1. Figure 2 shows the progressive growth of the cycle time standard deviation when the total traffic, ρ_{Total}, increases. Figure 3 displays how the cycle time standard deviation increases as the number of ONUs raises, this fact is particularly relevant for high traffic demands (i.e., in $\rho_{Total} = 95\%$, $(\sigma(T_{ciclo}^{N,M=16}) \approx 2 \cdot \sigma(T_{ciclo}^{N,M=4}))$.

The results show that IPACT algorithm carries out an efficient use of resources; however, is very sensitive to fast traffic changes or unstable traffic flows.

B. Constant Cycle Time

Below, we describe the main simulation environments and the obtained results for the CCT algorithm.

TABLE II. PARAMETERS USED IN THE CCT ALGORITHM SIMULATION

N	*M*	*ρHP*	*TMax (msecond)*
4	4	0.1	0.05

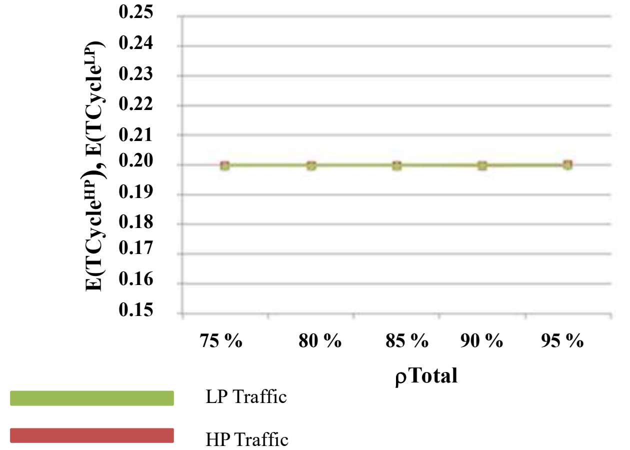

Figure 4. CCT algorithm: $E(TCycle^{HP})$, $E(TCycle^{LP})$ as a function of ρ_{Total} for $N= 4$, $M= 4$, $\rho^{HP} = 0.1$ and $TMax = 0.05$ [1].

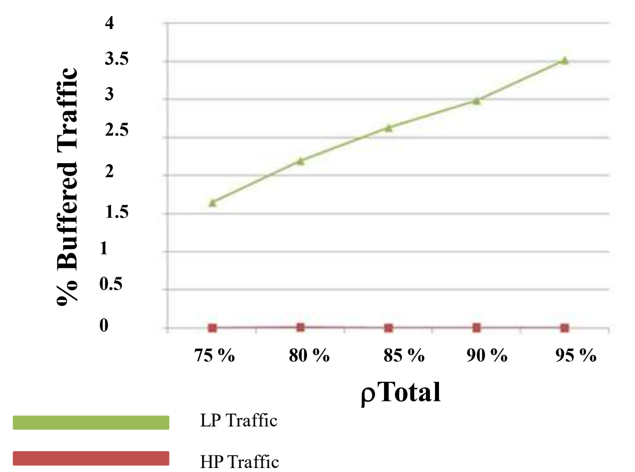

Figure 5. CCT algorithm: % Buffered HP and LP traffic as a function of ρ_{Total} for $N= 4$, $M= 4$, with $\rho^{HP} = 0.1$ and $TMax = 0.05$ [1].

Figure 4 shows that the algorithm works properly, since it allocates a constant cycle time for each simulation scenario.Several values for ρ_{Total} are tested.

In Figure 5, it can be noted that the package prioritization works properly as the traffic load (ρ_{Total}) increases –even if the low priority traffic data stored in the buffer increases.

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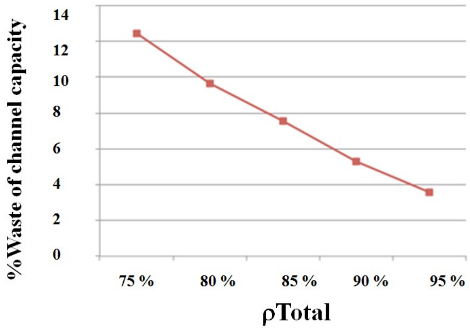

Figure 6. ICCT algorithm: Waste of channel capacity as a function of ρ_{Total} for N= 4, M= 4, with ρ^{HP} = 0.1 and $TMax$ = 0.05 [1].

Figure 6 shows that there is not a significant waste of the channel capacity and its value decreases as ρ_{Total} grows. The same pattern with very slight variations in the value of the waste has been observed for ρHP = 0.3, 0.5, 0.7 and 0.9.

TABLE III. PARAMETERS USED IN THE ICCT ALGORITHM SIMULATION

N	*M*	ρ^{HP}	*TMax(msecond)*
4	4	0.1	0.05

In Figures 7, 8, and 9, it can be noted that the algorithm works properly, the high priority traffic is adequately prioritized and there is no waste in the allocated time. However, the low traffic data stored in the buffer increases as the total traffic load raises, although lower in magnitude than in the CCT algorithm. Figure 10 shows the average cycle time for several values of M and ρ^{HP} = 0.1. It should be noted that a decrease in the number of ONUs transmitting low priority data traffic implies a considerable increase in the average cycle time for this kind of traffic. Figure 11 shows that the low traffic stored in the buffer increases as the total load traffic grows for all M values.

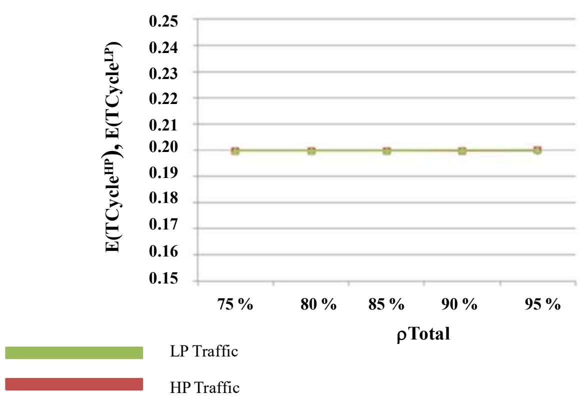

Figure 7. ICCT algorithm: $E(TCycle^{HP})$, $E(TCycle^{LP})$ in microseconds as a function of ρ_{Total} with ρ^{HP} = 0.1 [1].

The results show that ICCT method prioritizes the high priority traffic with an insignificant impact on the low priority traffic delay. However, the low priority traffic stored in the buffer increases as the total traffic flow grows.

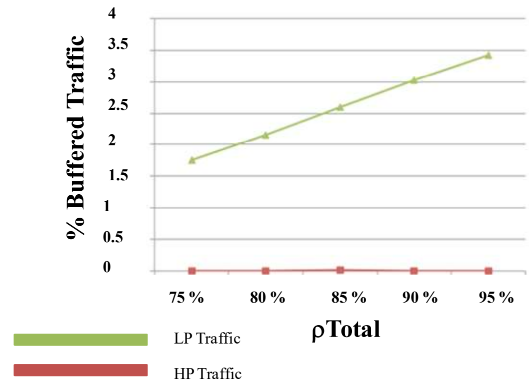

Figure 8. ICCT algorithm: Buffered HP and LP traffic as a functionρ_{Total} for ρ^{HP} = 0.1 [1].

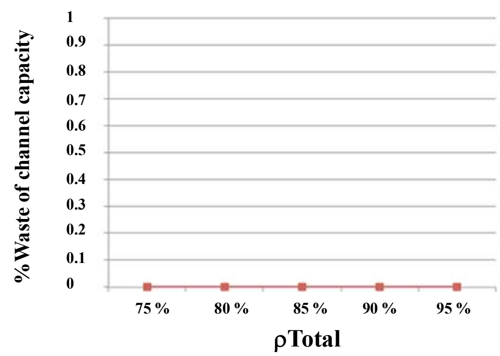

Figure 9. ICCT algorithm: Waste of channel capacity as a function of as a function of ρ_{Total} for N= 4, M= 4, ρ^{HP}= 0.5, TR = 0.2 and $TMax$ = 0.05 [1].

C. Static Bandwidth Allocation for High Priority Services (SBAHPS)

Below, we explain the main simulation environments and the obtained results for the SBAHPS algorithm.

TABLE IV. PARAMETERS USED IN THE SBAHPS ALGORITHM SIMULATION

N	*M*	ρ^{HP}	*TR*	*TMax (msecond)*
4	4	0.5	0.2	0.05

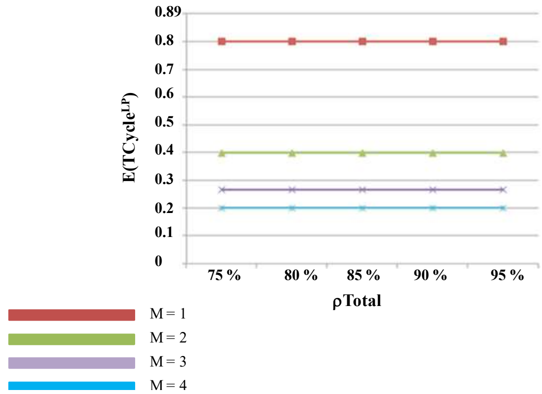

Figure 10. ICCT algorithm: E(TCycleLP) in microseconds as a function of ρ_{Total} for several values of M, , HP = 0.1 and TMax = 0.05 [1].

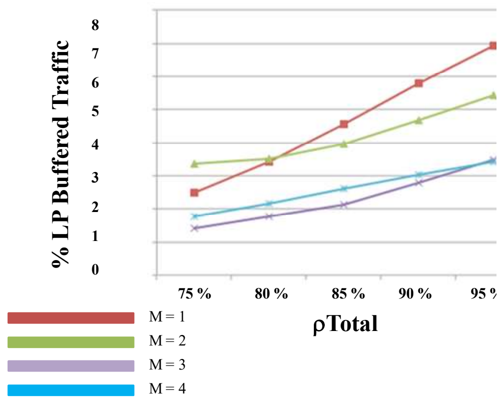

Figure 11. *ICCT: algorithm: %Buffered LP traffic* as a function of ρ_{Total} for *several values of M,* , $\rho^{HP} = 0.1$ and *TMax* = 0.05 [1].

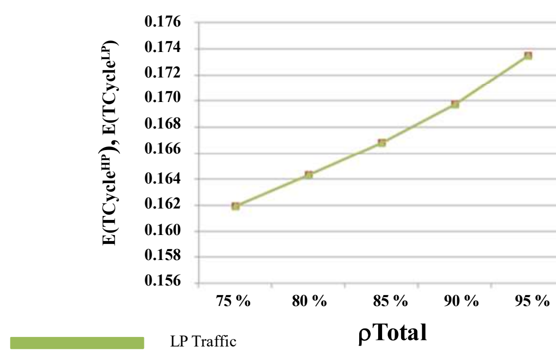

Figure 12. SBAHPS algorithm: $E(TCycle^{HP})$, $E(TCycle^{LP})$in microseconds as a function of ρ_{Total} for N= 4, M= 4, ρ^{HP}= 0.5, TR = 0.2 and$TMax$ = 0.05 [1].

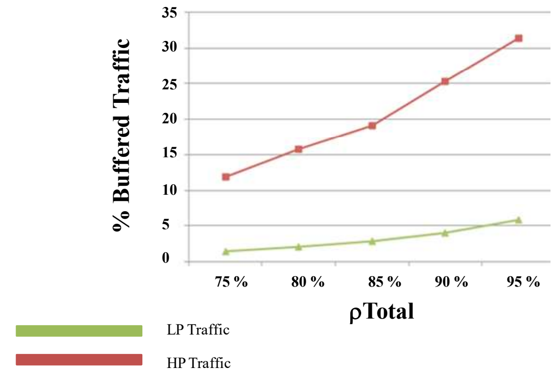

Figure 13. SBAHPS algorithm: % Buffered HP and LP traffic as a function of ρ_{Total} for N= 4, M= 4, ρ^{HP}= 0.5, TR = 0.2 and $TMax$ = 0.05 [1].

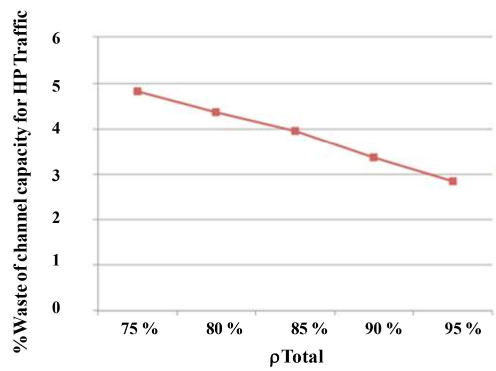

Figure 14. SBAHPS algorithm: Waste of channel capacity as a function of ρ_{Total} for$N$= 4, M= 4, ρ^{HP}= 0.5, TR = 0.2 and $TMax$ = 0.05 [1].

Figure 12 shows that the growth of the average cycle time is connected to the increase of the total traffic load. In Figures 13 and 14, it can be noted that the high priority data traffic stored in the buffer is much higher than the low priority traffic. There is not a significant waste of reserved capacity. This waste is slightly decreased if the total traffic increases.

The results show that the SBAHPS algorithm gets suitable constant cycle times and low priority buffered traffic flows. However, it has an inefficient bandwidth usage for the high priority traffic.

V. CONCLUSIONS AND FUTURE WORKS

We have analyzed the main algorithms utilized for the bandwidth allocation in EPON: IPACT, CCT and SBAHPS methods. Several computer simulations were carried out to reproduce the behavior of these algorithms and study their characteristics.

IPACT algorithm could be easily implemented and showed a good performance. However, due to the impact on the time-length cycle variations, caused by requests of big transmission windows from any ONU, it was difficult to achieve a minimum guarantee quality service when a specific delay was required (audio streaming, VoIP, video conference, etc.). The ICCT algorithm, which we use instead of the CCT method to raise the efficiency in the use of resources, had an important computational complexity. However, its capability to assign unused capacity intransmission windows, caused that the resources were more efficiently used for the data transmission upstream. The SBAHPS algorithm booked a transmission time for the high priority traffic, which was proportional to the allocated window for the rest of traffic. The control performed with the aim of limiting the maximum transmission window in each ONU, allowed to guarantee a QoS. Additionally, its configuration could be adapted to work in a similar way to IPACT and ICCT algorithms.

Our future research will build a proof of concept based on the simulation, which will test several real scenarios.

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