Status Reporting versus Non Status Reporting Dynamic Bandwidth Allocation

Moufida Feknous
Orange Labs and
Telecom Bretagne
2 Avenue Pierre Marzin
Lannion, France 22300
moufida.feknous@telecom-bretagne.eu

Annie Gravey
Telecom Bretagne
UMR CNRS 6074 IRISA
Technopole Brest-Iroise
CS 83818 Brest, France 29238
annie.gravey@telecom-bretagne.eu

Bertrand Le Guyader, Stéphane Gosselin
Orange Labs
2 Avenue Pierre Marzin, France 22300
bertrand.leguyader@orange.com
stephane.gosselin@orange.com

***Abstract*—Optical access technologies allow service providers to propose high bandwidth services in both directions (upstream and downstream) and thus to develop values added services. Passive Optical Network (PON) technologies offer, in the upstream, a controlled access to a shared media. Dedicated control mechanisms to the upstream channel have been proposed by ITU-T for Gigabit-capable Passive Optical Network (G-PON) and 10 Gigabit-capable Passive Optical Network (XG-PON1). Such mechanisms rely on Dynamic Bandwidth Allocation (DBA) procedures that manage bandwidth allocation according to customers requirements. This paper focuses on comparing two such DBA algorithms: Status Reporting (SR) in which the customer explicitly reports its backlog, and Non Status Reporting (NSR) in which the Optical Line Termination (OLT) infers customers' requirements by assessing how previously allocated resources were used. We develop several models in order to illustrate the respective performances of SR and NSR.**

I. Introduction

As specified by ITU-T G.984.3 [1], a dynamic upstream traffic control can be implemented in a GPON using either a Status Reporting (SR) Dynamic Bandwidth Allocation (DBA) procedure in which each customer explicitly reports its backlog, or a Non Status Reporting (NSR) DBA procedure in which the Optical Line Termination (OLT) infers customers' requirements by assessing how previously allocated resources were used. This paper compares SR and NSR DBAs using three complementary approaches:

- Control theory
- Matlab simulation
- OPNET simulation

Section I describes the main properties of SR and NSR DBA procedures as defined [1] and [2]. In Section II, Control theory is applied to assess how each DBA reaches a given fixed requested bit rate, assuming that resources are available. For the NSR DBA, this implies selecting the values of two parameters S and W used in NSR to increase (respectively decrease) the rate allocated to a customer. In Section III, we also assume that the customer requests resources that are available. We build a Matlab simulation to assess the impact of a real customer's demands on the behaviour of both SR and NSR DBA procedures. Section IV relies on an OPNET simulation to take into account the competition between Optical Network Units (ONUs). Experimental results obtained on commercial platforms are reported in Section V. Finally some conclusions are given in Section VI.

II. Dynamic Bandwidth Allocation mechanism

The dynamic control of upstream traffic in a GPON is based on DBAs. A DBA is controlled by the OLT and is designed to support different QoS levels, requested by each flow by the so-called Traffic CONTainers (T-CONT) [1]. A T-CONT allows different G-PON encapsulation Method (GEM) slots of an ONU to be aggregated and identified by a single Allocation Identifier (Alloc-ID). T-CONT traffic characteristics are Committed Information Rate (CIR), Assured Information Rate (AIR) and Excessive Information Rate (EIR), which are specified in the customer SLA. ITU-T G.984.3 defined five different T-CONTs types corresponding to different QoS classes [3].

The OLT allocates grants for upstream traffic to the ONUs with the Bandwidth (BW) Map field carried in downstream traffic frames. Each ONU can send upstream traffic within the limit of its grants. Each element inside the BW map corresponds to a T-CONT and a pair of start and stop pointers, defining the variable time slot in which packets from the assigned Alloc-ID can be sent in the upstream.

The OLT may change the grants for successive frames [3]. The DBA-cycle is the number of frames over which are distributed the grants. Instead of having one grant per T-CONT per frame, there would be a one grant per T-CONT per cycle, made of N frames. The DBA algorithm output is function of upstream bandwidth utilization as well as the CIR, AIR and EIR parameters of the T-CONT.

A. Status Reporting mode

In the SR mode, the OLT receives explicit requests by each customer that can send its current backlog in the Dynamic Bandwidth Report upstream (DBRu) fields of upstream frames [3]. In this mode, the OLT tries to satisfy the explicit ONUs' requests. It computes the number of grants for each T-CONT according to the backlogs reported in the upstream and thus builds the BW map sent to all ONUs.

B. Non Status Reporting mode

In the NSR mode, inputs for the grant allocation mechanism are no more the ONU queue lengths, but the effective traffic received at the OLT. The OLT counts the number of idle GEMs in the upstream frame and infers current requests by assessing whether each customer has fully used, or not, its grants [4], [5]. S and W are parameters used in the NSR mode considered in the present paper. Multiplicative factor (S) is used to increase the bandwidth allocation in the current cycle when the bandwidth allocated in previous cycle was totally consumed. Multiplicative factor takes values between 1.1 and 1.9 which represent an increase between 10% and 90%. W parameter is only used to decrease the bandwidth allocation when the bandwidth allocated in the previous cycle was not totally consumed. W takes values between 0.1 and 0.9.

C. Intuitive assesment of SR versus NSR

The SR mode is potentially quite accurate, at the cost of explicit DBRu messages sent by the ONUs. The only cause for inaccuracy is the delay between the measurement at ONU side and resource allocation performed at OLT side. Also, the variation between successive grants may be quite large if DBRu requests are sent with high frequency and are automatically granted when resources are available, as application activity may change very quickly. The NSR mode is potentially simpler as the OLT only has to assess grant usage. Also, the multiplicative grant adaptation can dampen reaction especially for smaller values of S and larger values of W. On the other hand, as the OLT tries to guess ONUs' requirements, it may over- or underestimate the real requirements and thus wrongly allocate grants to inactive ONUs whereas active ONUs are starved. The present paper checks the validity of this intuitive assesment, and attempts to provide operational values for S and W.

III. Control theory model

Control theory is commonly used for understanding the features and behaviours of computing and telecommunication subsystems such as e.g. queuing systems, Random Early Detection (RED), etc [7], [8].

We assume that an ONU is controlled by an OLT in an uncongested upstream channel. Furthermore, the ONU's activity is constant, and therefore its bandwidth request is fixed. We use here control theory to assess how long it takes for the ONU to be granted its request in both SR and NSR modes. We assume that in the SR system, each DBRu request is granted by the OLT, and that in the NSR system, the OLT multiplicatively adapts its grants by comparing previously granted bytes and bytes actually used by the ONU.

The communication between the ONU and the OLT and the granting processes can be modelled as closed loop systems. This kind of system aims to adjust the measured value (bytes allocated by the OLT) by minimising the error value (increase the allocation to reach the ONU demand and eliminate the error). Hence, we can estimate the time that the system needs to minimize or eliminate the error value, which represents in our case the reactivity time of each DBA modes (response time). Applying control theory for DBA functions allows to identify two parameters: the time needed by the ONU to reach the demanded bytes and the "overshoot" which represents allocated bytes that are cannot be used by the ONU and are thus "wasted". The closed loop used to construct SR and NSR DBA modes are based on Single-Input, Single-Output (SISO) model and SASO properties: stability, accuracy, settling time, and overshoot as described in [7].

Figures 1 and 2 represent SR and NSR closed loop models. In these models, the impact of buffered traffic in the ONU's buffer is considered and the features described in II-A and II-B are implemented.

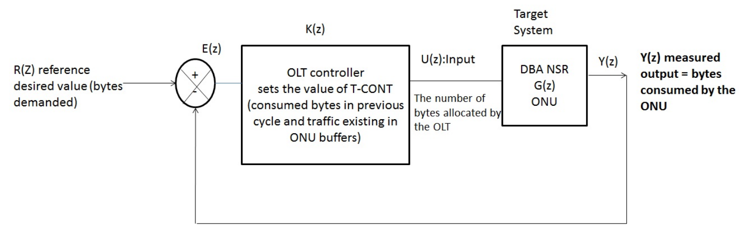

Fig. 1. Block diagram of NSR feedback control system

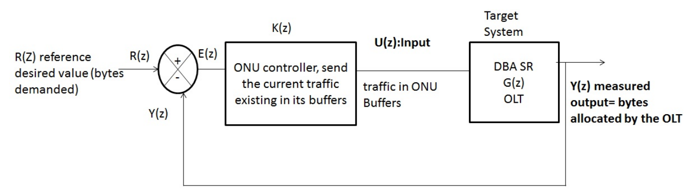

Fig. 2. Block diagram of SR feedback control system

To construct the DBA closed loop models, 3 stages are required:

- compute the transfer function G(z) of each DBA model. DBA models (SR and NSR) are based on a first principle approach to construct parameterized transfer function [7], [8];
- calculate the settling time parameter K_s, which represents the time that the system takes to converge to its steady state;
- select the type of controller and derive its parameters

DBA closed-loop models are based on Proportional Integral (PI) control. This kind of controller combines the advantages of integral control (zero steady-state error) with those of proportional control (increasing the speed of the transient response). In this case the control input is the sum of the proportional and integral terms. So, introducing this controller in DBA models requires to find the values of K_p and K_I which are the parameters that characterize PI controller.

A. SR DBA model

1) Compute transfer function: The system is linearized by using the first order model

$$Y(K+1) = aY(K) + bU(K) \qquad (1)$$

Where Y is the output (such as the bytes allocated by the OLT), U represents the number of bytes existing in ONU buffers, a and b are linear coefficients .

Table I represents the first order model to data collected from SR model. The training data consists of a set of observations of the control input supplied to the system and the corresponding output. Let the raw data be presented by a sequence of tuples $(\tilde{U}(K), \tilde{Y}(K))$, $1 \leq K \leq N+1$, where $\tilde{Y}(k)$ is the number of bytes allocated by the OLT, and $\tilde{U}(k)$ is the content of the ONU's buffer. We begin by normalizing the input and output around their operating points. Let $\bar{U}$ be the mean input value and $\bar{Y}$ the mean output value. We assume that $(\bar{Y}, \bar{U})$ is the operating point. That is, if $\tilde{Y}(K+1) = f(\tilde{Y}(K), \tilde{U}(K))$, then, $\bar{Y} = f(\bar{Y}, \bar{U})$. The offset values are given by $Y(K) = \tilde{Y}(K) - \bar{Y}$ and $U(K) = \tilde{U}(K) - \bar{U}$.

Y and U are computed as shown in Table I. We denote the predicted value by $\hat{Y}(K+1)$. That is, $\hat{Y}(K+1) = aY(K) + bU(K)$. The (K+1)st residual is $e(K+1) = Y(K+1) - \hat{Y}(K+1)$ this is also known as the prediction error. We want to choose a and b so as to minimize the sum of the squared errors (residuals) which is called "least squares" method, detailed in [7]. We minimize the following function:

$$J(a,b) = \sum_{K=1}^{N} e^2(K+1) = \sum_{K=1}^{N} [Y(K+1) - aY(K) - bU(K)]^2 \quad (2)$$

From data presented in Table I, we obtain $a = 0.05$ and $b = 0.97$.

TABLE I. DBA-SR DATA MODEL

K	$\tilde{U}(K)$	$\tilde{Y}(K)$	U(K)	Y(K)
1	40	5	30.33	-2
2	40	5	30.33	33
3	5	40	-4.66	33
4	0	5	-9.66	2
5	0	0	-9.66	-7
6	5	0	-4.66	-7
7	10	5	0.33	-2
8	10	10	0.33	3
9	5	10	-4.66	3
10	0	5	-9.66	-2
11	0	0	-9.66	-7
12	5	0	-4.66	-7
13	10	5	0.33	-2
14	10	10	0.33	3
15	5	10	-4.66	3
16	0	5	-9.66	-2

After obtaining the values of a and b, we find the transfer function of the system by using z-transform properties described in [7].

The z-transform of a linear difference equation is:

$$G(Z) = \frac{0.97}{Z - 0.05} \quad (3)$$

The initial conditions are assumed null ($Y(0) = 0$) and $U(Z)$ is considered as an impulse with a magnitude of 1, $U(Z) = 1$.

2) Settling time parameter: In a second step, we can calculate the settling parameter value based on the definition described in [7]. For a stable system, settling time represents the time until the output is within 2% of its largest magnitude value [7]. K_s parameter is defined such that:

$$|a^{K_s}| = \frac{|Y(K_s)|}{|Y(0)|} \quad (4)$$

$$K_s = \frac{-4}{log(a)} \quad (5)$$

In SR model,

$$K_s = \frac{-4}{log(0.05)} = 2.86 \quad (6)$$

3) PI controller parameters: In order to integrate PI controller in SR model, we need to calculate K_P and K_I parameters. For this reason, the limitations of settling time (K_s^*) and maximum overshoot (M_p^*) are required. It is assumed that the value K_s^* parameter is 10 and maximum overshoot M_p^* of 30%. K_P and K_I parameters are calculated by applying "pole placement" method described in [7]. We find $K_P = -0.36$ and $K_I = 0.35$. 36000 bytes represent the number of bytes requested by the ONU or target value.

Figure 3 shows that the SR model converges and achieves the target value after 7 time slots (7× 125μs= 875μs) and does not exceed the reference input (36000 bytes). 7 time slots represent the convergence time (or settling times) to reach the steady state value.

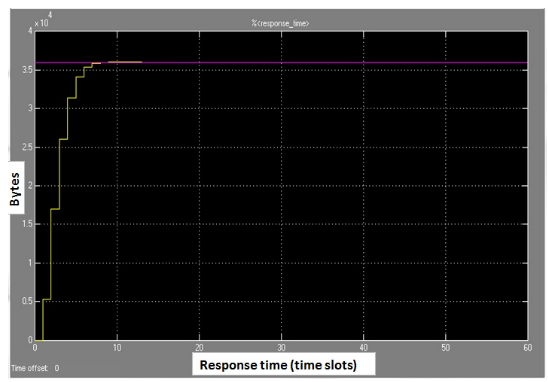

Fig. 3. Closed loop system for DBA SR model

B. NSR DBA model

In this section, we show the impact of two parameters introduced in DBA NSR mode (S and W) for increasing and decreasing the grant allocated by the OLT to the ONU. The successive steps used to build the SR model (transfer function, settling time and PI controller parameters) are also applied to construct the NSR model. The NSR system is linearized by using the first order model, where Y in this case represents the bytes consumed by the ONU and $U(Z)$ represents the content of the ONU's buffer.

Table II shows the impact of S and W on the response time and overshoot (wasted bytes). We see that increasing S and decreasing W leads to a shorter response time, while decreasing S and increasing W reduces the amount of wasted bytes. Therefore, the selection of S and W corresponds to a tradeoff between response time and overshoot.

NSR provides a reasonnable response time (smaller than 2.5ms) with moderate wasted bytes (less than 20%) for S between 1.4 and 1.6 as long as W is less than or equal to 0.4. With these parameter values, NSR is nevertheless slower

TABLE II. THE IMPACT OF S AND W PARAMETERS ON DBA NSR BEHAVIOUR

W=0.4	**S=1.1**	**S=1.4**	**S=1.8**
Response time	4.37 ms	2.25 ms	1.875 ms
Wasted bytes (overshoot)	8%	18%	30%
S=1.4	**W=0.1**	**W=0.4**	**W=0.8**
Response time	1.625 ms	2.25 ms	3.75 ms
Wasted bytes (overshoot)	7%	18%	22%

than SR, and wastes some bytes whereas SR does not waste any. In the constant traffic scenario, it seams that selecting a small W value is a good choice, as it limits wasted bytes in this scenario. However, we shall see in the next section that selecting a very small W value may present drawbacks in other traffic scenarios.

IV. MATLAB SIMULATION

In this Section, we still consider a single ONU in isolation, controlled by an OLT when there is no congestion.

In order to further study the SR and NSR mode, we build simple Matlab models implementing representing the evolution of the allocated grants in both modes, in successive slots (slot duration= 125μs). $A(k)$ and $S(k)$ respectively represent the number of bytes arriving in the ONU during slot k, and the number of grants that can be used by the ONU during slot k. $N(k)$ is the number of bytes in the ONU at the beginning of slot k. These models are illustrated in Figures 4 and 5.

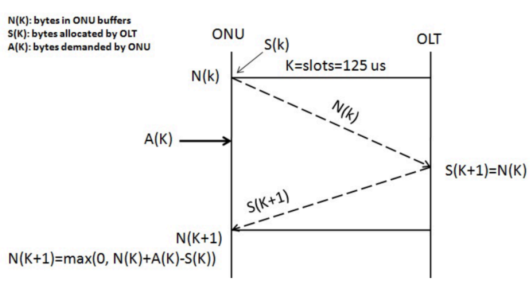

Fig. 4. Evolution of allocated grants in SR mode

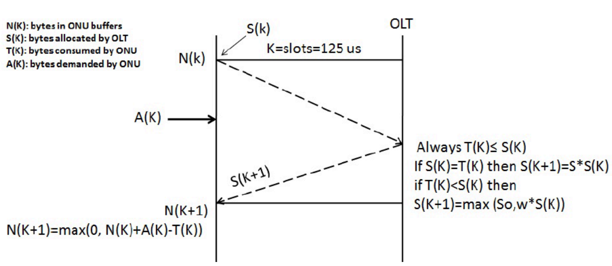

Fig. 5. Evolution of allocated grants in NSR mode

We assume that in the SR mode, the OLT exactly grants what is requested by the ONU, i.e. $S(k+1) = N(k)$. In the NSR mode, $S(k)$ varies either increases with factor S or decreases with factor W depending on whether the ONU used all its grants or not in the previous slot. It is also possible to set a minimum threshold for $S(k)$.

A. SR and NSR applied to a constant traffic profile

Table III displays the response time and the amount of wasted bytes for both modes, for NSR, $W = 0.4$ and S takes several values. Table III shows that the SR mode empty its buffers afer 5 slots (875 μs) which represent the time that the OLT takes to allocate the bytes demanded by the ONU. As shown with the previous model, we can see that for a fixed value of W in the NSR mode, the response time decreases and the amount of wasted bytes increases when S increases.

TABLE III. SR VERSUS NSR DBA MODE

	NSR, $W = 0.4$			**SR**
	S**=1.1**	S**=1.4**	S**=1.8**	
Response time	4.87 ms	2.25 ms	1.875 ms	875 μs
Wasted bytes	2600	15500	50000	0

Figure 6 shows how the OLT overallocates bytes to the ONU versus time, for S equal to 1.4 and several W values. The time needed to the ONU empty its buffers is the same (2.25 ms) for all W. However, we confirm here that the smaller W is, the quicker the OLT provides the requested resources to the ONU.

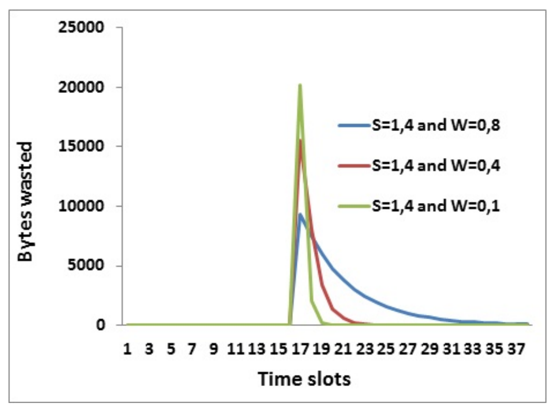

Fig. 6. Wasted bytes of DBA NSR mode with constant traffic profile

B. SR and NSR applied to a real traffic trace

As our Matlab models take into account the sets $A(k)$ of arrivals during successive time slots, we can use them for more complex scenarios. In particular, we apply these models here to a real traffic trace obtained on an operational FTTH network in Orange.

A real traffic trace of an FTTH heavy user has been captured on the Orange FTTH network. As many heavy users, this particular customer uses the maximum allocated bandwidth to upload P2P traffic. The trace is given in Table IV.

We first show on Figure 7, that, as expected, the SR mode ensures a very short reaction time to the highly dynamic traffic

TABLE IV. UPSTREAM REAL TRAFFIC TRACE OF A FTTH HEAVY USER

Time (ms)	Bytes	Throughput (Mbit/s)
10	11928	9.54
20	43176	34.5
30	56892	45.5
40	62312	49.8
50	61860	49.4
60	56588	45.2
70	67324	53.8
80	61656	49.3
90	47124	37.69
100	18208	14.5
110	0	0
120	3116	2.49
130	3656	2.92
140	27328	21.8
150	0	0
160	10796	8.6
170	9540	7.6
180	3040	2.43
190	76	0.06
200	3108	2.48
210	24444	19.5
220	76	0.06
230	6548	5.2
240	0	0
250	1852	1.48
260	0	0
270	76	0.06
280	0	0
290	1596	1,27
300	16384	13,1

profile. This is because we assume that the OLT directly allocates what is requested by the user in the SR mode.

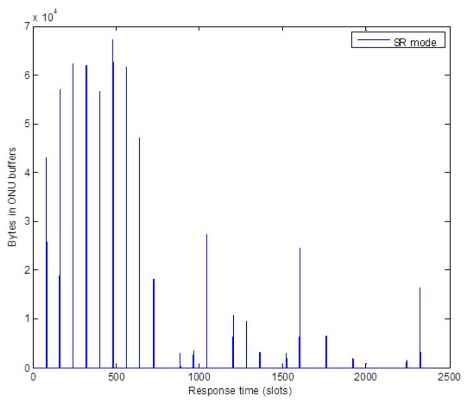

Fig. 7. ONU buffer for SR and a real traffic trace

We now address the behaviour of the NSR mode for the real traffic trace. Figure 8 represents the amount of wasted bytes for $W = 0.6$ and different values of S. It shows that, as for the constant traffic profile, the amount of wasted bytes increases with S.

Let us now assess the impact of W for a fixed value of S; for a constant traffic profile, we had identified that the smaller W, the shorter the time to reach the requested bitrate. Now, for a customer that requests a highly varying amount of resources as is the case for the FTTH traffic trace, we assess how buffer size varies with time for different values of W. Note that the maximum buffer size in Figures 9 and 10 significantly differ: it is close to 10^5 bytes in Figure9, whereas it is more than 210^5 bytes in Figure10. We observe on these figures that the

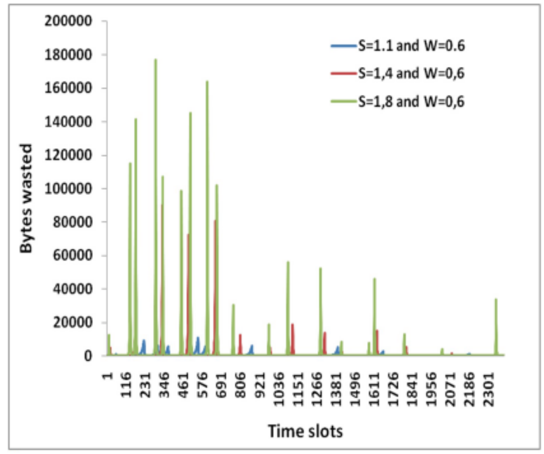

Fig. 8. Wasted bytes for the real traffic trace, W fixed, S variable

buffer size is lower for the larger value of W.

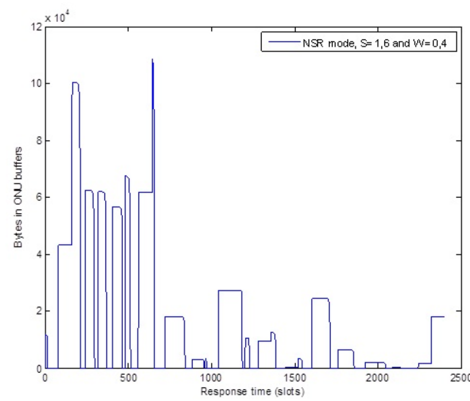

Fig. 9. ONU buffer for NSR (S=1.6 and W=0.4) and a real traffic trace

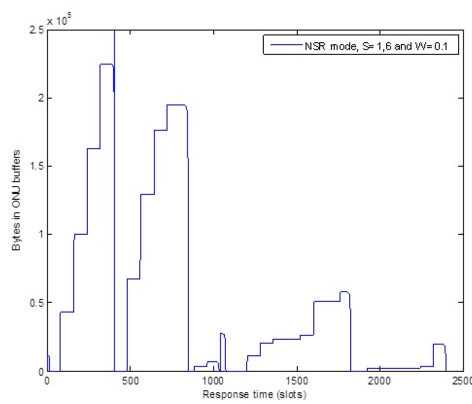

Fig. 10. ONU buffer for NSR (S=1.6 and W=0.1) and a real traffic trace

C. First assesment of SR versus NSR

Up till now, we have considered a single ONU in isolation, also assuming that the OLT is always able to satisfy the ONU's explicit or implicit requests (the upstream channel is not congested). Under these assumptions, we have shown that

SR fully supports both constant and variable traffic profiles with a better performance than NSR, which should ideally operate with intermediate S and W values (i.e. S between 1.4 and 1.6 and W between 0.4 and 0.6) in order to provide a short response time, with a limited amount of wasted bytes while limiting the ONU's buffer size.

V. OPNET MODEL

In a GPON, resource allocation for the upstream differs from what has been considered previously for a ONU in isolation. This is because the OLT has a fixed amount of grants to allocate per slot: if the sum of the ONUs' requests is less than this fixed amount, the ONUs may receive more than what is requested, whereas if the sum of the ONUs' requests is more than this fixed amount, the ONUs will usually receive less than what is requested. The ideal models of SR and NSR grant allocation processes shown in Figures 4 and 5 should be revised to reflect reality.

In this Section, we use an OPNET simulation model complying with [1] and providing a realistic sharing process for both SR and NSR modes.

In the scenario under study, 4 ONUs are used. The first three ONUs represent customers with a constant traffic profile which do not congest the upstream channel while ONU4 has negotiated a T-CONT4 to support the traffic profile described in IV-B and defined by a maximum bandwidth of 100 Mbit/s (EIR= 100 Mbit/s).

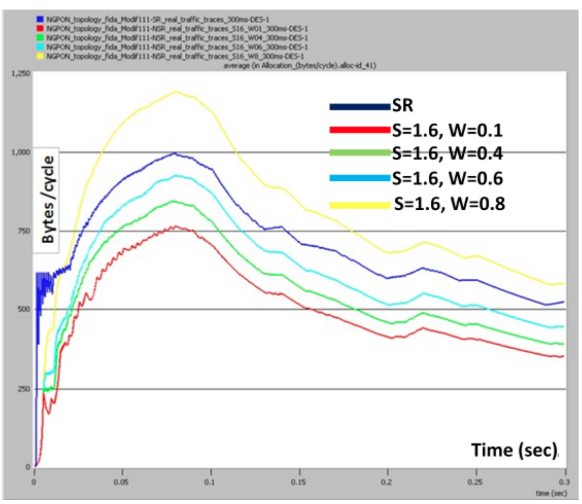

Fig. 11. T-CONT4 allocation (bytes /cycle) for DBA SR and NSR with $S = 1.6$ and different W

Figure 11 shows the allocated grants versus time for TCONT-4 in case of SR and NSR allocation processes. For NSR, we assume that $S = 1.6$ and consider several values of W. We see that the SR process behaves very similarly to the NSR processes, as the shapes of their respective curves are identical. SR allocates bytes to the TCONT-4 even in slots where the requests are very small. This is because the OLT has more grants than requested in those slots. For NSR, as expected, the larger W is, the larger is the allocation; in particular, $W = 0.8$ makes NSR allocate significantly more bytes than SR, whereas smaller values for W (e.g. $W = 0.4$ or $W = 0.6$) make NSR allocate less bytes than SR.

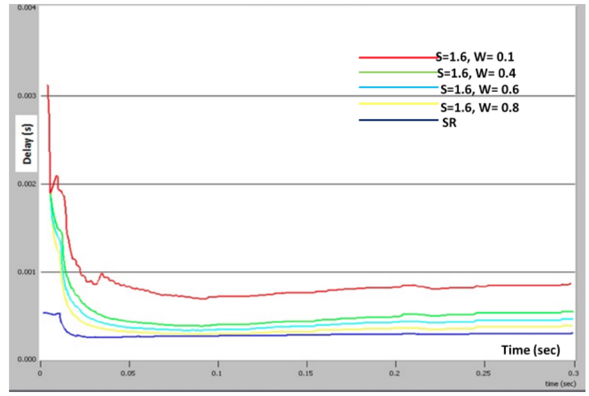

Fig. 12. Buffer size in ONU4 for DBA SR and NSR with $S = 1.6$ and different W

Figure 12 shows the buffer size in ONU4 versus time for TCONT-4 in case of SR and NSR allocation processes, in the same cases addressed in the previous figure. The buffer size is the smallest for SR, whereas for NSR, larger values of W correspond to smaller buffer sizes, which is logical as we have seen that the larger W is, the larger is the allocation. $W = 0.4$ or $W = 0.6$ yield buffer sizes close to the buffer size for SR.

OPNET results show that in the case of competition between the ONUs, resources can be allocated by SR even when the ONU is inactive as the OLT has a given amount of grants to distribute for any slot. Moreover, extensive simulations (only some of them have been reported above) have shown us that values of S (resp. W) greater or equal to 1,4 (resp. greater or equal to 0,4) allow an efficient use of the upstream PON capacity. These results show also that whatever the values of W and S implemented in DBA NSR mode, DBA SR mode represents more efficient use of the PON capacity than NSR mode.

VI. REALITY CHECK OF DBA MODELING

Equipment manufacturers of GPON optical access systems provide OLTs, ONUs together with proprietary methods for controlling upstream traffic. This is because ITU standards do not mandate any specific algorithm, but only specifies how control messages can be exchanged between ONUs and the OLT. Moreover, the implemented controls are not usually fully documented; in particular, the DBA process is not fully specified by the manufacturer.

This is why we checked our assesments of DBA SR and NSR by testing commercial equipment from two different manufacturers.

We consider an OLT controlling 9 ONUs. The configuration is as follows:

- 5 ONUs with CIR=AIR=EIR=100 Mbit/s; these ONUs are used to load the PON.
- 3 ONUs with CIR=AIR=5Mbit/s, EIR=100 Mbit/s
- 1 ONUs with CIR=AIR=50Mbit/s, EIR=100 Mbit/s
- 1 ONUs with CIR=AIR=150Mbit/s, EIR=350 Mbit/s

Each ONU attempts to transmit at its EIR. One of the ONUs with CIR=AIR=5Mbit/s, EIR=100 Mbit/s is stopped, and then restarted. We want to compare SR and NSR in this scenario, and to measure how long it takes for the ONU to reach its grants after having been restarted, i.e. compute its “Reaction Time”. Tests performed with the equipment of manufacturer 1, implementing SR, are reported in Figure 13 and those performed with the equipment of munufacturer 2, implementing NSR with $S = 1.1$ in Figure 14.

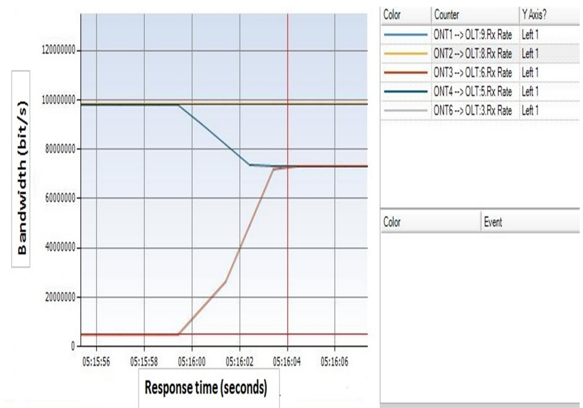

Fig. 13. Reaction Time for DBA SR

We first note on Figure 13 that bandwith allocation is not instantaneous, as the response time once the ONU is restarted is roughly 4 seconds. This is either because grants are not recomputed at each time slot, or because the operational SR algorithm dampens grant variations, in order to avoid oscillations.

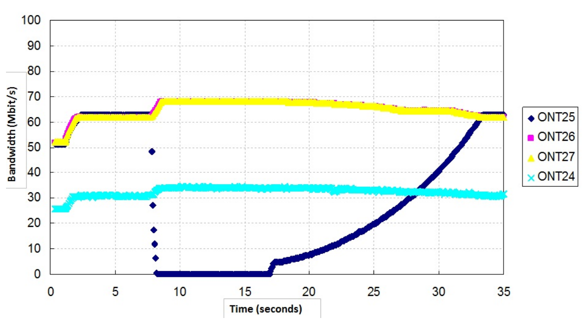

Fig. 14. Reaction Time for DBA NSR [9]

In Figure 14, we see that the ONU takes more than 15 seconds to reach its final rate after being restarted. This is in particular because the manufaturer has set $S = 1.1$, which precludes a quick rate adaptation, but also dampens the impact of highly varying traffic.

VII. Conclusion

We have shown that DBA SR reacts quickly when the ONU’s control is modelled in isolation, whereas when several ONUs are simultaneously controlled, grant variation is slower, as the OLT attempts to allocate as many grants as possible. However, even in this case, as we have shown with our experimental tests, SR reacts more quickly than NSR for traffic scenario where an ONU is stopped before being restarted.

The results for NSR depicted in this paper show that our intuitive assesment given in II-C needed to be completed by an analysis of the impact of the values taken by S and W, parameters of the NSR mode. We have shown, using several models, that whatever the traffic type (constant, real traffic trace, competition between ONUs), taking S between 1.4 and 1.6 and, and W between 0.4 and 0.6, allows to limit the time that the OLT takes to meet the ONU demand, limits the amount of wasted bytes while maintaining the ONU’s buffer rather small.

The NSR mode is slightly less efficient, and adds more latency to the customer’s traffic, than the SR mode but it automatically implements grant allocation smoothing meacanisms, which are also usually implemented in the SR mode to avoir oscillations and may also slow down the SR reaction time and degrade latency performance.

Therefore, the present study cannot provide a hard conclusion on the relative qualities of SR and NSR which both perform correctly, even in presence of highly varying traffic.

Acknowledgment

This work was partially funded by the FP7 European project COMBO (Convergence of Fixed and Mobile Broadband access/aggregation networks) under grant agreement n°317762.

References

[1] ITU-T G.984, *Gigabit capable Passive Optical Networks (G-PON)*, 2008.

[2] ITU-T G.984, *10 Gigabit capable Passive Optical Networks (XGPON)*, 2010.

[3] H.C. Leligou, CH. Linardakis, K. Kanonakis, J.D. Angelopoulos and Th. Orphanoudatis, *Efficient medium arbitration of FSAN compliant GPONs*, National Technical University of Athens, November 2005.

[4] O. Haran and A. Sheffer, *The Importance of Dynamic Bandwidth Allocation in GPON Networks*, White paper, January 2008.

[5] J. Ozimkiewiez, S.R. Ruepp, L. Dittmann, H. Wessing and S. Smolorz, *Dynamic bandwidth allocation in GPON networks*, 4th WSEAS International Conference on Circuits, Systems, Signal and Telecommunications, January 2010.

[6] H. Bang, S. Kim, D.S. Lee and C.S. Park, *Dynamic bandwidth allocation method for high link utilization to support NSR ONUs in GPON*, The 12th International Conference on Advanced Communication Technology (ICACT), February 2010.

[7] J.L. Hellerstein, Y. Diao, S. Parekh and D.M. Tilbury, *Feedback control of computing systems*, John Wiley & Sons, 2004.

[8] T. Abdelzaher, Y. Diao, J.L. Hellerstein, C. Lu and X. Zhu, *Introduction to control theory and its application to computing systems*, Performance Modeling and Engineering, 2008.

[9] F. Payoux, *Analysis of Dyanmic Bandwidth Allocation Function for GPON : Industriel Implementation*, Technical report, Internal Orange Labs document, 2007.