Dynamic Bandwidth Allocation in GPON Networks

Joanna Ozimkiewicz, Sarah Ruepp, Lars Dittmann, Henrik Wessing
Technical University of Denmark
DTU Fotonik
Kgs. Lyngby
Denmark
ozimki@gmail.com, {srru,ladit,hewe}@fotonik.dtu.dk

Sylvia Smolorz
Nokia Siemens Networks
Munich
Germany
sylvia.smolorz@nsn.com

Abstract: Two Dynamic Bandwidth Allocation algorithms used for coordination of the available bandwidth between end users in a GPON network have been simulated using OPNET to determine and compare the performance, scalability and efficiency of status reporting and non status reporting dynamic bandwidth allocation. Results show that the status reporting is more efficiently using the bandwidth while non-status reporting provides better QoS for real time services.

Key–Words: GPON, dynamic bandwidth allocation (DBA)

1 Introduction

Ba ndwidth requirements for providing new services are increasing. Moreover, different types of users have varying needs regarding the amount of bandwidth and transmission delays. Network providers are forced to think about new mechanisms that will distribute the bandwidth among the users. That leads to the increased interest in the optical networks suitable for Fiber to the Home (FTTH) and Fiber to the Building (FTTB) solutions.

One of the technologies introducing high throughput, small delays and advanced bandwidth control is Gigabit Passive Optical network (GPON) [1]. GPON is designed to transport Ethernet packets over the optical medium using the GPON Encapsulation Method (GEM) [3]. The physical link is fragmented into GEM frames as specified in [1] [3]. Downlink frames distribute a Bandwidth map (BWMap) for the future uplink frame. Dynamic Bandwidth Assignment (DBA) is used to control access to the media by end nodes [3].

This paper introduces two different DBA algorithms designed for GPON, namely, status and non status reporting DBA [3] [4], respectively. DBA for GPON networks is not given in ITU-T GPON specifications, and hence often proprietary algorithms are used in OLT equipment. This paper provides a proposal for the DBA algorithms, together with the analysis of the impact of available configurations on the network performance, which has not been heavily researched until now. The remainder of this paper is organized as follows: Section 2 provides background knowledge of DBA and traffic types. In section 3, a DBA algorithm is proposed. In section 4, the simulation scenario is described and simulation results are presented in section 5. Section 6 concludes the paper.

2 Dynamic Bandwidth Assignment (DBA)

GPON uses point-to-multi-point connections between central Optical Line Termination (OLT), coordinating network resources and Optical Network Units (ONU). Due to the high available bandwidth in GPON, bandwidth allocation is based on the Service Level Agreements (SLA) where Quality of Service (QoS) can be granted according to the demand. Bandwidth is allocated per transmission container (T-CONT) which is a GPON mechanism for provisioning of differentiated QoS. Three different T-CONTs feasible for dynamic bandwidth allocation were evaluated:

1. **T-CONT type 2** for on-off type traffic with well defined rate bound and strict delay requirements is provisioned with assured bandwidth. This bandwidth has to be granted to the T-CONTs' traffic, if requested. If not used, bandwidth can be allocated to other T-CONTs, providing that it is available as soon as T-CONT type 2 requires it.

2. **T-CONT type 3** is provisioned with assured bandwidth and additionally, it can be granted non-assured bandwidth if the entire assured bandwidth is utilized. It is suitable for variable rate, bursty traffic with requirements for average rate guarantee.

3. **T-CONT type 4** has no bandwidth guarantee but it has eligibility in best effort bandwidth sharing.

It is suitable for variable rate, bursty traffic with no delay sensitivity.

To avoid collisions the OLT allocates bandwidth per T-CONT in a TDMA fashion. The DBA automatically adjusts bandwidth grants to the needs of a particular T-CONT. The DBA uses the T-CONT's activity status as an input to the scheduler, either explicit through buffer status reporting (SR), or implicit through transmission of the idle GEM frames in place of granted upstream allocations, referred to as non status reporting (NSR). Assured bandwidth is granted regardless of the overall traffic load. Additional non-assured and best effort bandwidth allocation depends on the available upstream capacity remaining after allocation of the granted bandwidth. Non-assured bandwidth is given higher priority than best effort bandwidth.

For both SR and NSR DBA, the OLT traces the activity status of each T-CONT and instantaneously updates size and number of allocation intervals granted per DBA cycle. Obtained information becomes input to the scheduler, which thereby allocates transmission opportunities.

3 Proposed Dynamic Bandwidth Assignement Algorithms

3.1 Non Status Reporting DBA

In the NSR algorithm, the OLT estimates bandwidth allocation for the next DBA cycle $B_a(c)$, required by each T-CONT t, on the basis of the bandwidth usage during the previous DBA cycle $B_u(c-1)$.

At first the OLT assigns assured bandwidth (B_aAsr). Remaining bandwidth is divided between non assured traffic (B_aNasr) and best effort traffic (B_aBE). The assured bandwidth granted for T-CONTs type 2 and 3 for the new cycle $B_aAsr(c)$ is based on the activity in the previous cycle $B_u(c-1)$, as shown in eq. 1. The expansion factor (EF) is used to provide fast response for variation in traffic, and to ensure that assured bandwidth is always allocated when required by a T-CONT. An EF of 1.25 is used to keep assigned 25% more bandwidth than T-CONT used in the previous cycle. This value has been obtained from previous simulations [6].

$$B_aAsr^t(c) = \begin{cases} Max^t_{asr} & \text{if } B^t_u(c-1) = Max^t_{Asr} \\ Min^t_u & \text{if } B^t_u(c-1) \leq Min^t_{Asr} \\ B^t_u(c-1) * EF & \text{otherwise} \end{cases} \tag{1}$$

Equation 1 verifies that $B_aAsr(c)$ does not exceed the maximum allowed bandwidth Max_{Asr} for T-CONT t and is never lower than the minimum bandwidth Min_{Asr}.

Assignment of additional non-assured grants $B_aNasr(c)$ eligible for T-CONTs type 3 depends on $B_u(c-1)$ and already assigned $B_aAsr(c)$ (eq. 2). It is limited by the total allowed bandwidth Max^t_{Total}, and no minimum bandwidth assignment is guaranteed.

$$B_aNasr^t(c) = \begin{cases} Max^t_{total} - Max^t_{Asr} & \text{if } B^t_u(c-1) * EF > Max^t_{total} \\ B^t_u(c-1) * EF - Max^t_{Asr} & \text{if } B^t_u(c-1) > Max^t_{Asr} \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

When the non-assured bandwidth is overbooked, non-assured bandwidth assignments are scaled proportionally to fit into the total link capacity C for each T-CONT (eq. 3)

$$\begin{gathered} if: (\textstyle\sum_t B_aAsr^t(c) + \sum_t B_aNasr^t(c)) > C \\ than: \\ B_aNasr^t(c) = \frac{B_aNasrt(c)*(C-\sum_t B_aAsr^t(c))}{\sum_t B_aNasr^t(c)} \end{gathered} \tag{3}$$

Best effort bandwidth is assigned proportionally to $B_u(c-1)$ scaled by EF(eq 4) and limited by Max_{total}. Additionally zero bandwidth in the previous cycle indicates that the link was too congested to serve the best effort traffic. Therefore $B_aBe(c)$ is set to infinity, and scaled equally for all T-CONTs of type 4 (eq. 5).

$$B_aBe^t(c) = \begin{cases} Max^t_{total} & \text{if } B^t_u(c-1) = Max^t_{total} \\ \infty & \text{if } B^t_u(c-1) = 0 \\ B^t_u(c-1) * EF & \text{otherwise} \end{cases} \tag{4}$$

$$\begin{gathered} if: (\textstyle\sum_t B_aAsr^t(c) + \sum_t B_aNasr^t(c) + \sum_t B_aBe^t(c)) > C \\ then: \\ B_aNasr^t(c) = \\ \frac{\sum_t B_aBe^t(c)*(C-\sum_t B_aAsr^t(c)+\sum_t B_aNasr^t(c))}{\sum_t B_aBe(c)} \end{gathered} \tag{5}$$

When the DBA cycle ends, the scheduler is provided with assignments for a new cycle (eq.1 to eq.5) and creates a bandwidth map for each frame in the new DBA cycle. Assured traffic is allocated for each T-CONT once per millisecond, thereby once in every 8 upstream frames(eq. 6).

$$B_{frame}Asr^t(c) = ceil(\frac{B_aAsr^t(c)*8}{\text{frames per DBA cycle}}) \tag{6}$$

Non-assured and best effort traffic grants are served at most every third frame in order to maximize throughput. Allocations are served in a cyclical way according to eq. 7 and starting from the T-CONT that was last granted bandwidth in the previous upstream frame.

$$B_{frame}Nasr^t(c) = \frac{B_aNasr^t(c) * \text{frames since last alloc}}{\text{frames per DBA cycle}} \tag{7}$$

3.2 Status Reporting DBA

In the SR scheduling, the OLT requests the buffer occupancy status from each T-CONT indicating the number of bytes waiting for transmission. At the beginning of a new frame, one T-CONT of each type gets a token. The T-CONT possessing a token is granted allocation slots according to the request, providing that it does not exceed its maximum bandwidth. At first, requests for assured allocations are served. Later, bandwidth allocations are given to consecutive non-assured bandwidth requests. In the end, best effort requests are served. After each T-CONT is served, the next in order T-CONT receives the token. At the beginning of a new frame, T-CONTs with tokens received in the previous uplink frames are served first.

4 Simulations

Three series of simulations were made using OPNET [7], to evaluate the efficiency of SR and NSR DBA algorithms for varying GPON networks scenario. All GPON physical layer properties [5] together with framing and protocol overheads were accurately modeled. The transmission timing highly affects the results, especially on the SR algorithm, where negotiation between OLT and ONU has to be performed before calculation of bandwidth grants.

The simulation scenario consists of the central OLT connected to 48 office networks interfaced by ONUs, each consisting of six workstations used to model traffic load, as shown in figure 1. The distance between OLT and each of the ONUs is the maximum allowed GPON distance of 20 km.

Three different simulations scenarios were evaluated. Simulation parameters were chosen according to simulations results from [6]. Simulations were performed using GPON 2.48832 Gbps links and two workstations per one T-CONT. In the first scenario, low network load was simulated. In the second scenario, a network with a traffic load of 89% of the link capacity and high load of assured traffic with Max_{Asr} for all T-CONTs equal to 82% of total traffic was simulated. Max_{Asr} was set to 125% of generated traffic. The third scenario modelled a network with total traffic load of 90% of the link capacity and high best effort traffic load. Additionally Max_{Asr} was lowered to 110% of T-CONT generated traffic.

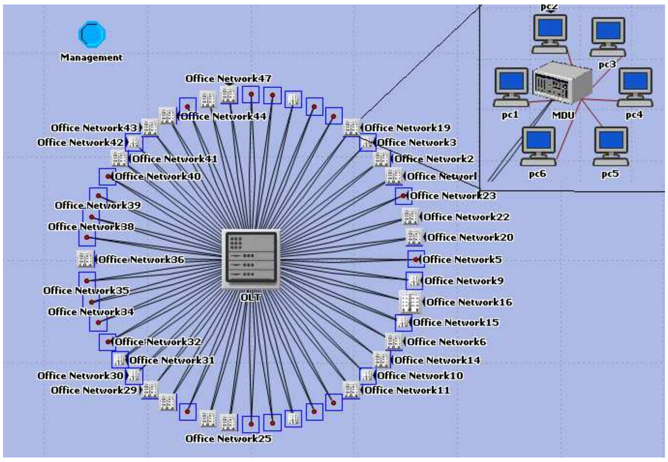


Figure 1: Simulated network.

5 Results

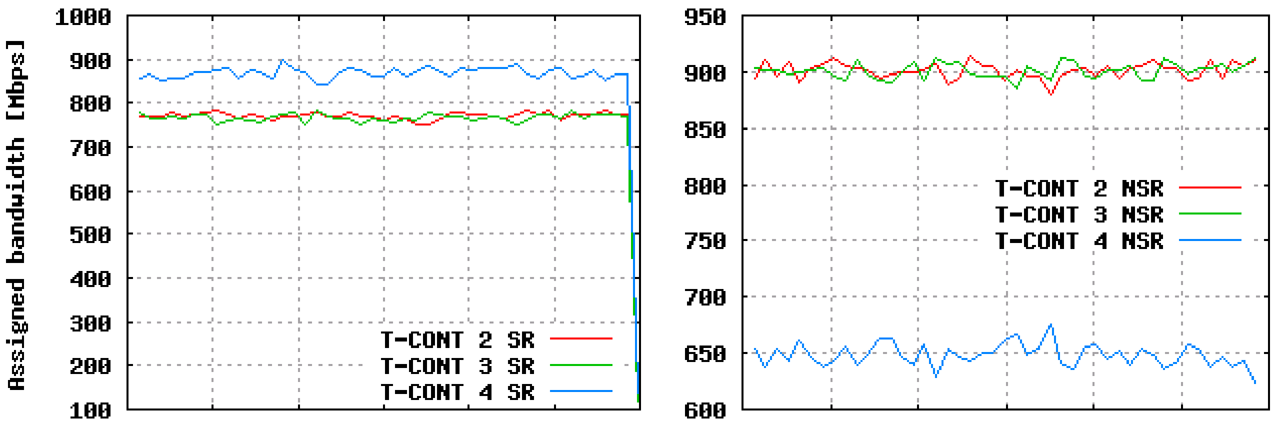
Simulation results show that for the low traffic load of scenario 1, both NSR and SR algorithms serve all T-CONTs well with the SR average uplink delay of 0.6 ms and NSR of 1.6 ms for all T-CONT types.

For the congested networks, SR is more efficiently using network resources due to the high EF used in NSR DBA andMax_{Asr} set as high as 125% of generated traffic. NSR DBA on average assigns more than 900Mbps for each T-CONT of type 2 and 3 to serve 744Mbps generated traffic load, while T-CONT type 4 lacks bandwidth. SR DBA grants all T-CONTs sufficient amount of bandwidth as shown in figure 2(a). The corresponding uplink transmission delay is acceptable for all T-CONTS only in SR DBA, as shown in figure 2(b). The transmission delay for T-CONT type 4 using NSR exceeds 100 ms. Despite SR allocates the highest amount of bandwidth for T-CONT type 4 it experiences the highest delay due to the small and frequent bandwidth grants resulting in high packet fragmentation.

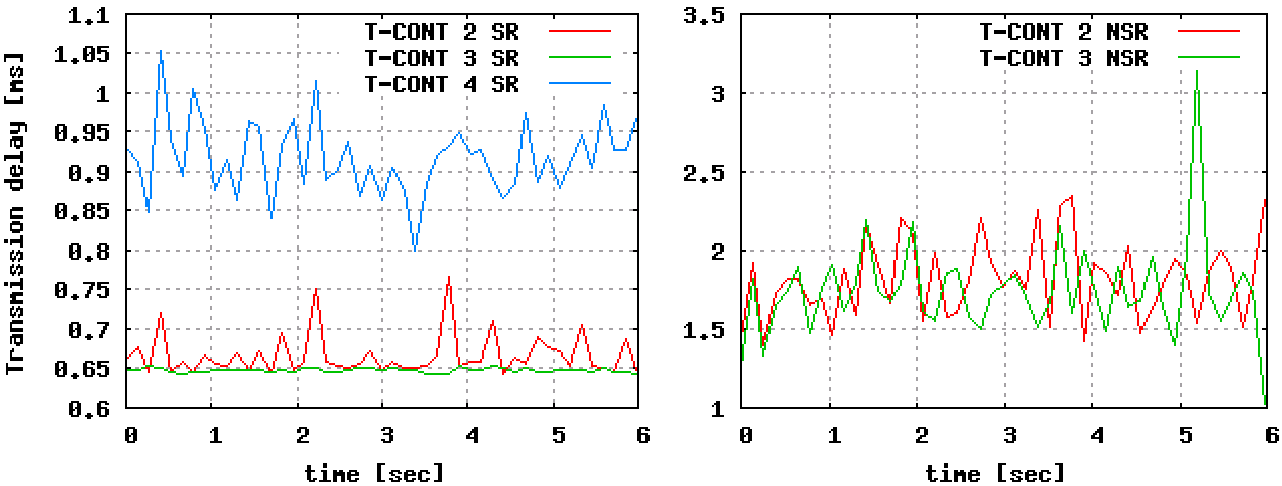
In the third scenario Max_{Asr} was decreased to 110% of source bandwidth to minimize the assignment of unused bandwidth grants. As a result all traffic obtains enough bandwidth using both SR and NSR DBA. The bandwidth allocation is much smoother with NSR DBA, as shown in figure 3(a). Bandwidth grant variation using NSR is especially high for T-CONT type 4, which results in high delays reaching 10ms as illustrated in figure 3(b).

The SR algorighm does not allocate many unused grants for high priority traffic due to the decreased Max_{Asr} compared to the previous scenario. It increases QoS for best effort data. The drawback of SR is that it did not manage to guarantee the required QoS in the last scenario for high priority data. The delay varies between slightly less than 4ms and 7ms, which does not always meet the 5ms required for real-time traffic.

The performance of the NSR algorithm is highly dependent on the algorithm configuration values. With high EF and Max_{Asr} lower than 110% of the source load, it handles all kinds of traffic efficiently, keeping uplink transmission delay below 5ms for all



(a) Assigned bandwidth



(b) Uplink transmission delay

Figure 2: Simulation results for Scenario 2.

real-time traffic types, while keeping a reasonable delay for best effort traffic. High EF and Max_{Asr} results in an obvious favoring of high priority traffic, neglecting best effort services with basically non QoS.

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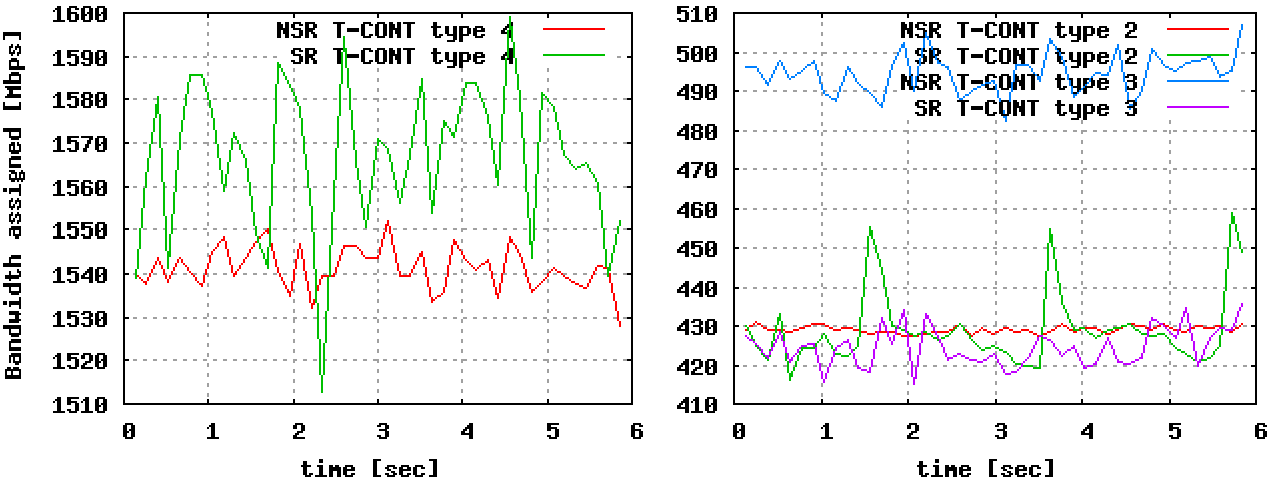
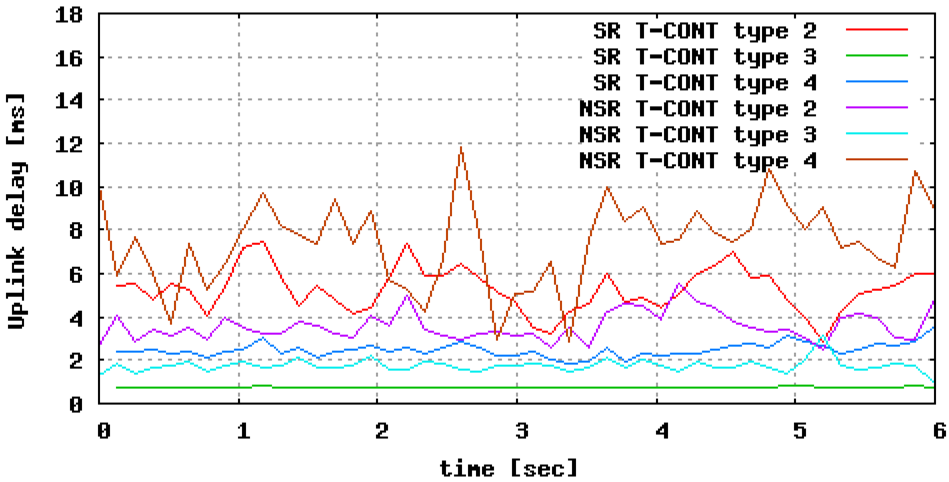


(a) Assigned bandwidth



(b) Uplink transmission delay

Figure 3: Simulation results for Scenario 3.

6 Conclusion

Based on the simulation results, it can be observed that NSR DBA is more reliable in providing agreed QoS, and, with appropriate network configuration optimized for amount of connected ONU's and their traffic requirements, it can sufficiently serve all traffic types. The SR algorithm does not provide and guarantee QoS in all network configurations, but it is efficiently using available resources. NSR is more recommended for networks, where transmission delay has to be maintained below a specified minimum level. This solution however requires more bandwidth due to the over allocated bandwidth. The choice of the algorithm should be made depending on the QoS SLAs agreed upon with particular customers and the dominant traffic type in the network.

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