

Dynamic Bandwidth Allocation for Long-Reach PON: Overcoming Performance Degradation

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ABSTRACT

A passive optical network, with its inherent point to multi-point structure, allows for centralized placement of active equipment and possible extension of its boundary towards core networks. This property of the PON can be exploited for node consolidation where multiple central offices are replaced by a single one covering a larger service area. Such node consolidation is being particularly driven by the need for network operational cost saving, and is offering significant challenges to PONs. The degree of node consolidation that can be achieved is limited by the reach of conventional PON systems. In order to achieve a larger degree of node consolidation, an extension of the PON reach, beyond the conventional 20 km, is required. This article addresses the challenges of the dynamic bandwidth allocation, where increased reach results in a degradation of DBA performance and quality of service support. This degradation is a consequence of the increased propagation delay of the DBA messages exchanged between different PON elements. A potential solution to the performance degradation is the introduction of a multi-threaded DBA. In this article, we examine for both Gigabit PON and Ethernet PON, the extent to which DBA performance degradation can be reduced by exploiting multi-threading. It is found that for both standards, multi-threading, if done properly, can be used to mitigate the performance degradation due to the increased reach. To make bandwidth allocation efficient, new schemes for coordinating the multiple threads are required in long reach PON.

INTRODUCTION

An ongoing trend in fixed access network evolution is node consolidation where multiple central offices (COs) are being replaced by a single CO covering larger service areas. The

passive optical network (PON), has an inherent point to multi-point structure, where an optical line terminal (OLT) located at the provider CO connects a number of optical network units (ONUs) at the customer premises (CPs). This allows for centralized placement of active equipment in the access network and has been exploited for removing or avoiding active cabinet sites in the outside plant. This aspect of PON can be further extended to the consolidation of COs and the possible extension of the boundary of the access network towards the core network.

Such node consolidation is particularly driven by network operator concerns for reducing operational cost of the network, and it offers significant challenges to the PONs. The interest in long-reach PON as a means to this end is not uniform across all network operators, with European network operators evincing more emphasis on this approach. Some of the related research challenges have been summarized in [1]. For the conventional time-division multiplex TDM PON (e.g., Ethernet PON EPON [2] and Gigabit-capable PON GPON [3]) the degree of achievable node consolidation is limited by the 20 km physical reach due to the constraint from the optical power budget to support up to 32 optical network units (ONUs) at the customer premises. In order to cover larger service areas and higher number of the customers, both longer reach and higher splitting ratio at the remote node (RN) are required, causing larger propagation delay, and higher fiber and power splitter insertion loss respectively. Node consolidation by means of extended reach PON, here referred to as long reach PON (LR-PON), requires use of active elements in the PON to compensate for power loss.

Several types of active reach extenders (RE) for LR-PON have been considered such as semiconductor optical amplifiers (SOA), Erbium

doped fiber amplifiers (EDFA) and optical electrical optical converters (OEO). The SOA and EDFA solutions offer optical amplification of the optical signal. The OEO solution provides extensive reach extension through signal regeneration. Compared with the SOA and EDFA, the OEO solution is sensitive with the line rates, and consequently cannot flexibly support line-rate upgrade, e.g., to allow multiple line rates coexistence which has been ratified in both IEEE 802.3av [2] and ITU-T-proposed architectures (in Next-Generation Access 1 [NGA1]) [4]. The idea of introducing active elements is in a sense contradictory to the concept of PON. Note however that what is important for the evolution of access networks is not the presence or absence of active equipment but rather the properties of different active elements and how they affect costs as well as reliability and availability (e.g., during power outages). If placing simple active elements with high reliability in the outside plant can significantly increase the PON service area and enable node consolidation, then the ultimate goal of cost-efficient networks may still be achieved.

Reach extension also introduces challenges to the medium access control layer. In TDM PONs (including 10G EPON defined in [2] and XG-PON defined in [5]) traffic in the downstream direction is handled by broadcasts from the OLT to all the connected ONUs, while in the upstream direction an arbitration mechanism is required, so that only a single ONU is allowed to transmit data at a given point in time because of the shared upstream channel. The start time and the length of a transmission time slot for each ONU are scheduled using a bandwidth allocation scheme. In order to achieve flexible sharing of bandwidth among users and high bandwidth utilization, a dynamic bandwidth allocation (DBA) algorithm that can adapt to the changing traffic load is required. A comprehensive review of different DBA algorithms for EPON and GPON has been done in [6]. By extending the reach of the PON, the round-trip time (RTT) may grow from today's 200 μ s (20 km reach) to 600 μ s (60 km reach) or potentially 1 ms (100 km reach). In conventional DBA schemes for EPON and GPON, performance depends on the RTT as it affects the delay of the DBA control loop. With increased RTT, the performance is ultimately degraded. Hence, development of DBA schemes that can deliver adequate service despite increased RTT in LR-PON is highly desirable. To address this problem, a novel multi-thread polling DBA scheme for long-reach EPON was proposed in [7]. Three specific issues of the multi-thread scheme were addressed, namely the initiation and tuning of multiple threads, inter-thread scheduling and fairness among multiple threads. Regarding the first issue, key parameters were analyzed and optimized in [7]. Regarding the last two issues, the scheme presented in [7] is based on an idealization that updated and adequate buffer state information is available for the threads on time. More work is required regarding these two latter issues to improve the DBA performance for long-reach EPON. GPON faces a

series of distinct challenges due to the inherent framing structure. To the best of our knowledge, multi-thread DBA for long reach GPON has not yet been addressed.

The remainder of this article is organized as follows. The next section discusses the core problem addressed in this work namely the performance degradation of DBA due to the extension of PON reach. We then build a case for multi-threading as a potential solution to this performance degradation. We then describe an evaluation of multi-threaded DBA for both GPON and EPON, and conclusions are presented in the final section.

PERFORMANCE DEGRADATION OF DYNAMIC BANDWIDTH ALLOCATION IN LR-PON

Dynamic bandwidth allocation (DBA) is essential for achieving high upstream bandwidth utilization in time-division multiple access (TDMA) PON. For both EPON and GPON, in the upstream direction the concept of logical queues associated with specific QoS requirements, are fundamental to the DBA operation. In the EPON standard the logical queues are referred to as logical links (LL) represented by an LLID. The bandwidth assignment in EPON DBA is done on a per LLID basis. In the GPON standard the logical queues are referred to as traffic containers (T-CONTs). The bandwidth assignment in GPON DBA is done solely on a per T-CONT basis. In general, for both EPON and GPON, the requirement on the DBA is to provide an overall efficient utilization of the shared upstream bandwidth while ensuring that each logical queue is allocated bandwidth according to its QoS requirements.

In order to implement DBA, a means for the OLT to communicate scheduling information to the ONUs is required. Both the EPON and GPON standards define grant messages used by the OLT to communicate scheduling information to the ONUs. For efficient operation, the DBA also requires detailed and up to date information on the bandwidth demand of the logical queues at the ONUs. Therefore, the PON standards also define report messages used to communicate instantaneous logical queue occupancy information to the OLT. In EPON the report and grant messages are referred to as, REPORT and GATE, respectively and encapsulated in special Ethernet frames. In GPON the report and grant messages are referred to as status reports (SR) and the bandwidth maps (BW map), respectively, and integrated in header fields of the GPON Transmission Convergence (GTC) frames. The propagation delay through the PON implies that there is a delay associated with the exchange of these messages between the OLT and ONUs.

The performance degradation due to extending the PON reach for traditional DBA (single thread) is illustrated in Fig. 1 for different types of traffic and traffic load. Results for a GPON system are based on simulations using a reactive

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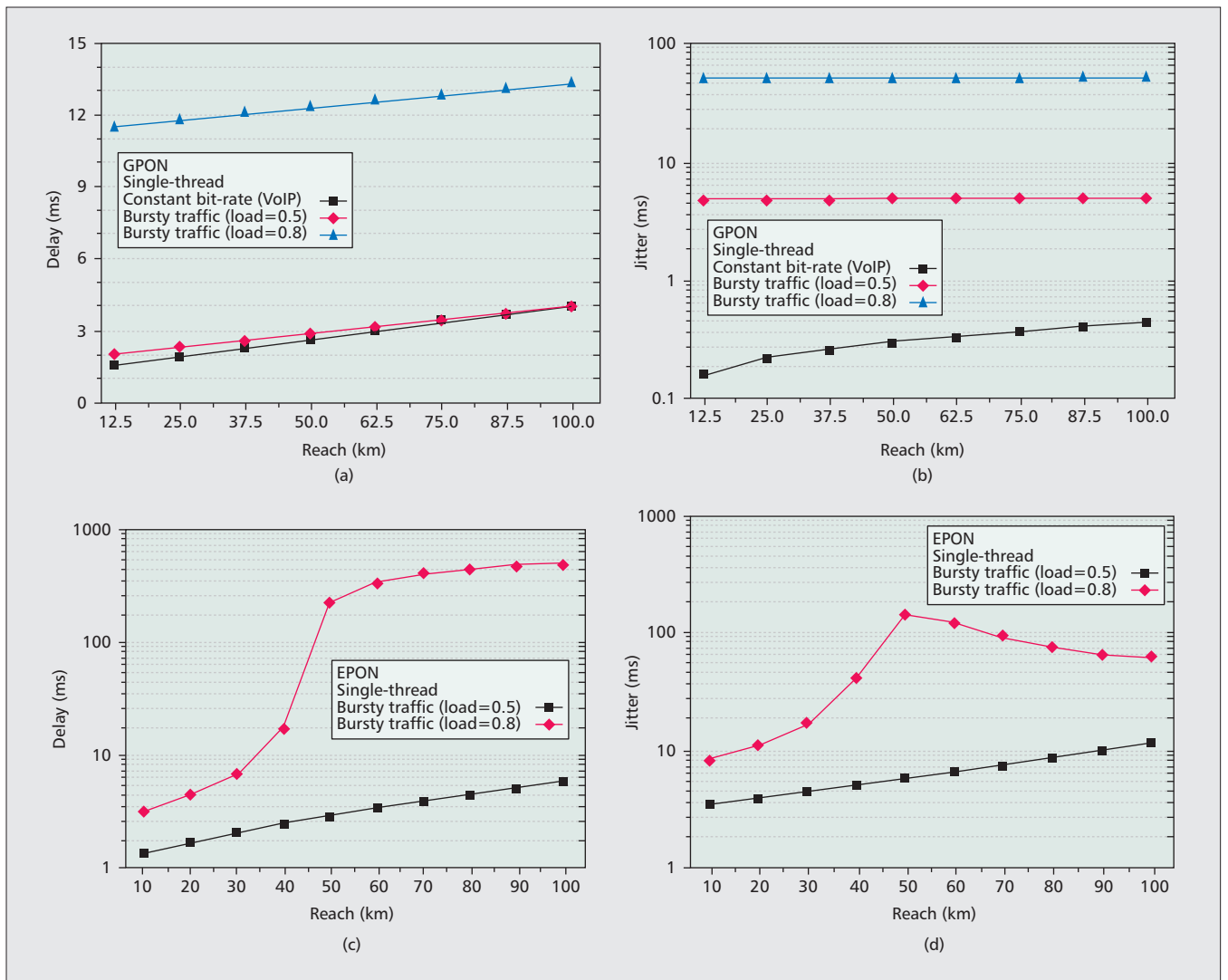


Figure 1. Degradation of average delay and jitter as a function of reach for different traffic patterns based on simulations of a GPON (a, b) and EPON (c, d) system.

DBA algorithm (MGTC) described in [8]. For EPON, we apply a general inter-ONU DBA described in [9]. The exact nature and extent of the performance degradation depends on the details of the employed DBA. In a relative sense, for GPON it is mostly the time critical traffic that is affected by the reach extension. The increased propagation delay leads to an increased DBA response time resulting in increased average delay. The average delay is increased by approximately twice the increase in propagation delay. In EPON results are less trivial. At heavy load (load = 0.8) there is a quite severe degradation of performance incurred by the reach extension. This is an effect of the increased propagation delay resulting in requirements of larger polling cycle in order for the DBA to remain efficient. If the variable polling cycle is smaller than twice the propagation delay, there will be a waiting time where the system waits for transmission of control messages to be completed. As shown in Fig. 1d, beyond 50 km, results are affected by the limited buffer sizes used in the simulation which leads to packet loss. This results in an apparent improvement in

jitter when the reach is extended to 50 km and beyond.

GPON DBA

This section presents an overview of DBA issues specific for GPON. The GPON protocol is based on a partitioning of the upstream and downstream transmission slots into 125 μ s GPON Transmission Convergence (GTC) frames. The GTC header of each downstream GTC frame carries an upstream (US) bandwidth (BW) map for an associated upstream GTC frame. The BW map contains exact T-CONT scheduling information for a particular upstream GTC frame. Hence, a BW map is broadcasted to the ONUs in every downstream GTC frame. The DBA algorithm is typically executed less frequently and as a result the bandwidth assignment must be scheduled over multiple GTC frames.

The GPON DBA process illustrated in Fig. 2a consists of a chain of events:

- 1 Sending of SRs from the ONUs to the OLT
- 2 Calculation of the bandwidth grants based on a DBA algorithm

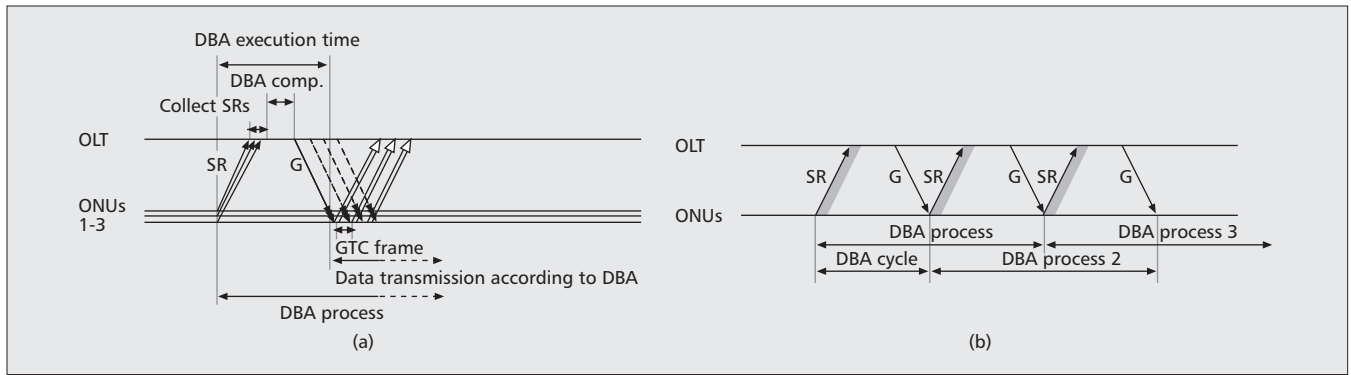


Figure 2. The left panel shows a single DBA process. SRs are sent from the ONUs and received by the OLT. DBA is calculated and the updated bandwidth allocation (G) is used in consecutive US BW maps until further updated. The right panel shows a schematic figure of a stacking of multiple DBA processes.

- 3 Sending of upstream bandwidth maps from the OLT to the ONUs
- 4 Sending of data from the ONUs to the OLT according to the US BW maps

The DBA process is executed in regular intervals which we refer to as the DBA cycle (Fig. 2b). Here, we use the term *DBA execution time* to denote the delay due to events 1, 2, and 3, and which mainly depends on the round trip time (RTT) and DBA computation time. Let us define the entire DBA process to also include the phase for the data transmission according to the DBA assignment as shown in Fig. 2. The length of the data transmission phase is equal to the DBA cycle and can only be defined when there are multiple DBA processes. Figure 2b shows DBA where the DBA cycle is set to the same length as the DBA execution time.

Based on this simple illustration of the DBA, we can estimate the average response time (Fig. 3) of the DBA as equal to the sum of the DBA cycle and the DBA execution time. In a single threaded scheme as in Fig. 3, it is the increased response time due to the extended reach that results in DBA performance degradation. Details of how the increased response time affects DBA performance depends on the implementation.

Let us now consider the DBA computation at the OLT in detail. The computation contains three important steps:

- 1 Calculation of bandwidth demand for the T-CONTs based on SR information
- 2 Assignment of bandwidth based on service and fair-share policies
- 3 Scheduling of the upstream traffic through the construction of upstream bandwidth maps

It is the first step which is affected by the extended reach. We use the terms reactive and pre-emptive to differentiate between two different ways of estimating bandwidth demand. A reactive algorithm assigns bandwidth per request based on the report message. A pre-emptive algorithm assigns bandwidth based on predictions, which in turn are based on assumptions as well as report messages. For a reactive DBA algorithm we can expect an increased delay for all packets incurred by the increased reach, whereas jitter is unaffected. For a pre-emptive

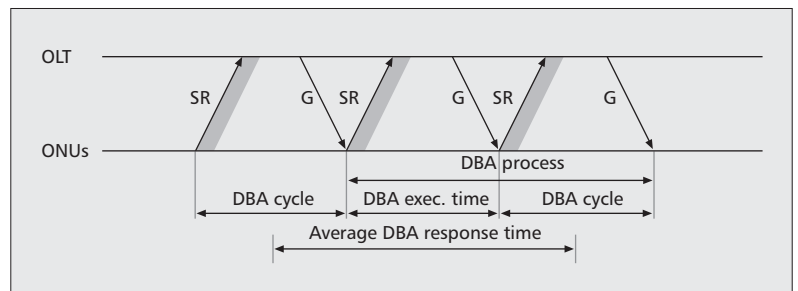


Figure 3. On average an Ethernet frame needs to wait half a DBA cycle before the DBA algorithm is executed and half a DBA cycle from the arrival of an updated US BW map until transmission. The average DBA response time is equal to the DBA execution time + DBA cycle.

algorithm the behavior will depend from case to case, but in general as a result of the increased propagation delay, the report messages from the logical queues are less accurate. Inaccurate information and assumptions of the bandwidth demand lead to occasional over-granting of bandwidth, resulting in increased average delay and increased jitter.

EPON DBA

The EPON standard provides a lot of flexibility for designing the DBA algorithm since protocol specifications are not part of the standard. Large burst transmission overhead and absence of Ethernet frame fragmentation in the EPON standard, introduce more complexity to the EPON DBA.

There are several ways of categorizing DBA algorithms. One important distinction relates to whether the DBA algorithm is online or offline. In an offline scheme the DBA is executed after reception of all required report messages (Fig. 4a) as in GPON. In an online scheme, the DBA is executed per ONU upon reception of an ONU report at the OLT (Fig. 4b). In the former case there is typically one common DBA process for all ONUs in each polling cycle. In the latter, there is one DBA process per ONU and polling cycle. Due to the overhead structure most well-known implementations for EPON DBA are online and have a variable DBA cycle. Since the execution time of the DBA (including OLT-ONU communication) is non-negligible, it is

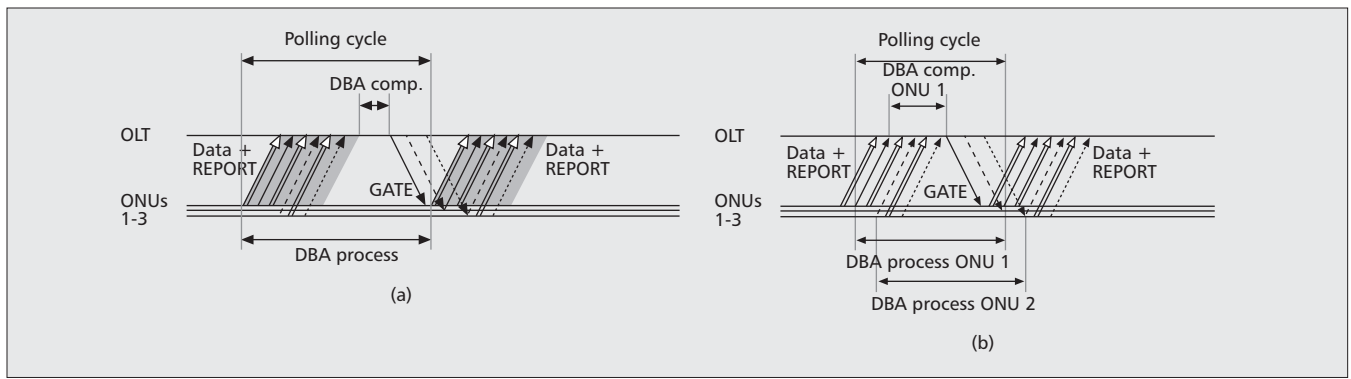


Figure 4. Schematic figure of an EPON DBA algorithm: a) offline; b) online.

necessary to interleave several DBA processes in order to avoid ONU idle time.

One of the most well-known scheduling algorithms for EPON is the interleaved polling with adaptive cycle time (IPACT) algorithm [10]. In IPACT, the OLT polls and issues transmission grants to the ONUs cyclically in an interleaved fashion. The polling cycle is defined as the time between two consecutive report messages sent from the same ONU to the OLT. In IPACT the polling cycle is variable and adapts to the instantaneous bandwidth requirements of the ONUs.

The interleaved polling of ONUs, entails that the OLT must inform the $(i + 1)$ st ONU of grant information, including the start time and the size of the granted window, during or before the time that the i th ONU is transmitting Ethernet frames in the upstream direction. For efficient bandwidth utilization, the grants for the $(i + 1)$ st ONU must be received before the data transmission of the i th ONU is completed and the transmission slots must be scheduled in such a way that the first bit from the $(i + 1)$ st ONU arrives at the OLT right after the OLT receives the last bit from the i th ONU. IPACT is most commonly used together with the limited service discipline. Under this discipline, the slot size assigned by the OLT to the ONU is equal to the requested size in a previous REPORT message, up to some predefined maximum limit. This limit is needed in order to place an upper bound on the polling cycle and to avoid bandwidth hogging by greedy ONUs. This scheme has been shown to efficiently share bandwidth while still maintaining fairness among ONUs.

The burstiness of traffic arriving at the ONUs can cause a shrinkage of the polling cycle in IPACT with the limited service discipline. This leads to a degradation of bandwidth utilization. A generic weighted DBA adopted in [9] can alleviate this problem. In this scheme ONUs are partitioned into two groups, namely, underloaded and overloaded. Underloaded ONUs are those which request bandwidth below the guaranteed minimum, and hence their unused capacity is shared in a weighted manner amongst overloaded ONUs. However, in this weighted inter-ONU scheduling, an overloaded ONU may get more bandwidth than the requested, and thus some bandwidth may be

wasted. With this in mind, [9] proposed a scheduler based on recursive calculation to guarantee that no ONU gets more bandwidth than the requested. Therefore, we adopt this algorithm for the intra-thread scheduling of the EPON multi-thread DBA presented in next section.

MULTI-THREADED DBA

There are two ways of reducing the response time of the DBA in a PON. One way is to reduce the DBA execution time also allowing for reduced DBA cycle or polling cycle. However, in LR-PON the DBA execution time may not be significantly reducible due to the large contribution from the propagation delay. The other way, illustrated in Fig. 5, is to execute the DBA algorithm more frequently. In GPON this means reducing the DBA cycle and increasing the overlap of the DBA processes. In EPON this means introducing multiple DBA threads.

For both GPON and EPON, the DBA consists of the execution of DBA processes. In EPON, the DBA processes are connected together to threads in the sense that the bandwidth granted by a DBA process through a GATE message carries the REPORT message for the next DBA process of the thread. Increased overlapping of EPON DBA processes is achieved by introducing multiple threads running in parallel, which is the concept of multi-threading. In GPON, the DBA processes are not as clearly connected together to well-defined threads as in EPON. In GPON, the granted bandwidth is communicated to the ONUs through a series of US BWmaps in the downstream GTC frame headers during the data transmission phase. The SRs, i.e., the starting point, for the next DBA process of the thread could be scheduled anywhere within this data transmission phase. What is important for the GPON DBA is the degree to which the DBA processes overlap.

Multi-threading or overlapping of DBA processes requires some adjustments to the DBA algorithm. The problem with overlapping DBA processes is that each process by default does not have full information on the impact of other overlapping DBA processes. There is an obvious risk of duplicated traffic reporting resulting in a large degree of over-granting. This problem is accentuated as the DBA process overlap is increased. In

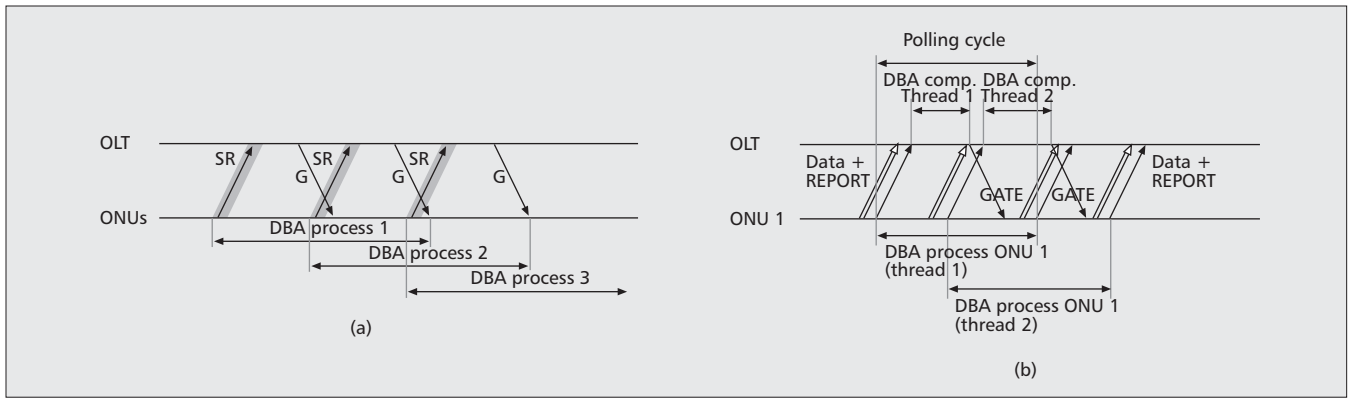


Figure 5. The left panel shows a GPON algorithm where the DBA process overlap has been increased by reducing the DBA cycle. The right panel shows an online EPON algorithm where a second DBA thread has been introduced.

this work we propose a scheme for coordination between DBA processes. The scheme is applicable to both EPON and GPON. We will first describe the general idea of the scheme followed by a more detailed description of the adaptation of this scheme to GPON and EPON.

The scheme used in this work for coordinating between DBA threads will be referred to as the newly arrived frames plus (NA+) scheme. The general idea of the NA+ scheme is that each DBA process is primarily responsible for allocating bandwidth to newly arrived frames, i.e., frames that have arrived since the last previously initiated DBA process. The idea provides a way of partitioning the workload among overlapping DBA processes. Let R_i denote the value of the report for a logical queue issued at time t_i from which the i th DBA process starts and let G_i denote the resulting grant. Furthermore, let $g_i = g(t_{i-1}, t_i)$ denote the bandwidth allocated to the same logical queue for transmission between t_{i-1} and t_i , where t_{i-1} is the time for the previously issued report. The traffic, $I_i = I(t_{i-1}, t_i)$, that entered the logical queue between t_{i-1} and t_i can be calculated from $I_i = R_i - R_{i-1} + g_i$. The term g_i can be written as a function $g_i = f(G_j)$, where G_j is the grant corresponding to some previous DBA process $j < i$.

Due to the fact that a DBA process may not be able to cater for the full bandwidth request of all newly arrived traffic, a mechanism is required in order to allow bandwidth to be granted to backlogged traffic. Within the NA+ scheme the bandwidth demand for a logical queue is calculated as $B_{dem,i} = I_i + C_i$, where C_i is a term to compensate for backlogged traffic. The relative shape and relative size of this term is important. If the term is too small, backlogged traffic will block newly arrived traffic. If the term is too large, the workload partitioning between overlapping DBA processes is effectively reduced, increasing the risk of over-granting.

In this work we calculate the backlog term by the exact amount of backlogged traffic for some previous completed DBA process for which all required information is available. The backlog term is calculated as, $C_i = B_{dem,i-n} - g_{i-n}$, where n is an integer ≥ 1 determining which trailing DBA process the correction is calculated for.

Adapting the NA+ scheme to GPON is

straightforward. The DBA cycle as well as the DBA execution time is a fixed number of GTC frames. The relative size of these parameters determines the overlap and the fixed function $g_i = f(G_j)$.

Adapting the NA+ scheme to EPON is less trivial since EPON frames cannot be fragmented, and unused time slots (UTS) [10] may occur when the bandwidth assigned by the OLT is not equal to the bandwidth reported from ONUs. By applying the NA+ scheme to EPON, if the OLT is not aware of the occurrence of UTS at the ONUs, the buffer at the ONUs will be fully occupied by the backlogged traffic due to the UTS. Therefore, the backlog term is modified to the following form: $C_i = B_{dem,i-n} - g_{i-n} + U_{i-n}$ where U_{i-n} stands for the UTS which occurred during the $(i-n)$ th DBA process.

EVALUATION OF THE MULTI-THREAD DBA FOR GPON AND EPON

In this section the assessment method for the considered multi-thread DBA in GPON and EPON is described followed by the simulation results.

Multi-threaded DBA performance is evaluated by means of simulations. For GPON the evaluation is performed using a complete DBA algorithm presented in [11]. For the performance evaluation we utilized an event driven C++ based GPON simulator developed at Ericsson Research where we have modeled a 32 ONU GPON system at 2.48832 Gb/s upstream rate at varying reach.

For EPON the evaluation is performed using an inter-ONU DBA algorithm presented in [9] assuming one logical queue per ONU. Included in the REPORT message, the ONU reports the UTS in the previous DBA process and the amount of the traffic that arrived since the previous DBA process started. Performance evaluation is done using an event driven C++ based EPON simulator where we have modeled a 32-ONU EPON system at 1 Gb/s upstream rate with reach ranging from 10km to 100km.

For traffic modeling we use the traffic generator provided by Kramer [10] to model self-similar traffic conditions. We used 256 pareto sub-streams with a Hurst parameter of 0.8 and a

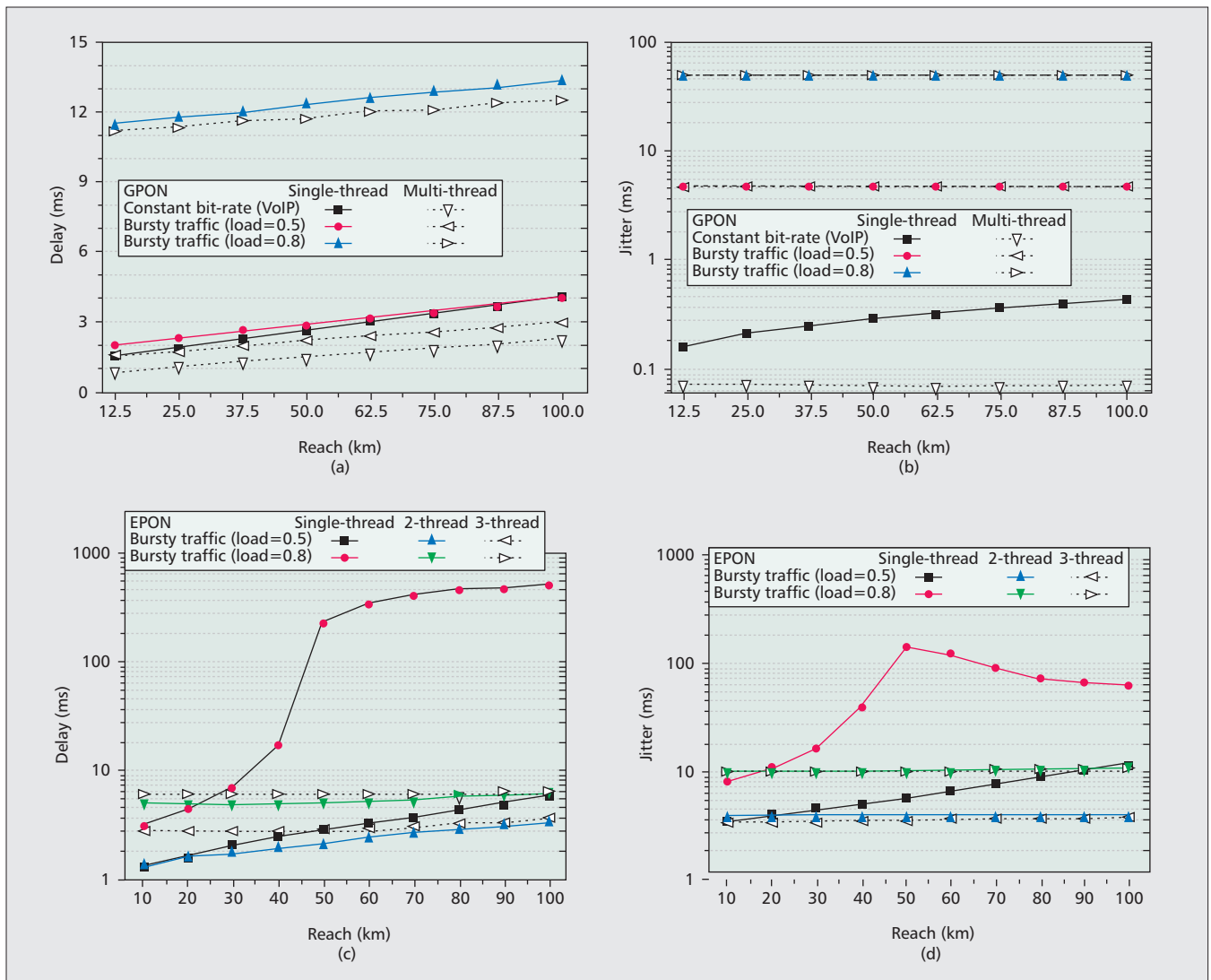


Figure 6. a) Average delay for GPON; b) jitter for GPON; c) average delay for EPON; d) jitter for EPON.

packet size distribution taken from traffic measurements by Broadcom [12]. In GPON, we emulate the constant bit rate output from the G.711 voice codec for voice traffic. In GPON, simulations have been performed with infinite logical queue buffers while in EPON, the buffer sizes were set to 10 Mb which is of the same order of magnitude as in commercial PON products.

In order to understand the performance gains that are achievable by means of multi-threading we present results for both GPON and EPON comparing conventional DBA schemes with multi-threaded versions in Fig. 6. The aim of this study is to try to illustrate the maximally achievable performance gain when exploiting multi-threading.

For GPON, results are presented for a conventional DBA algorithm as well as a version with a very high degree of DBA process overlap employing NA+. For the conventional algorithm, the DBA cycle is set to the DBA execution time, which is assumed to be equal to the double propagation delay plus 0.5 ms (to cater for other delays such as DBA computation time, etc.). For the multi-threaded version, the DBA

cycle is set to 250 μ s and the backlog term is calculated for $n = 1$. Performance degradation due to moderately larger n is found negligible. Considering Fig. 6, we see a general performance improvement of using multi-threading. The performance improvement is larger for longer reach. We see that multi-threading to a large extent can compensate for the performance degradation of average delay. For non-infinite buffers and high load traffic, one may expect a reduced average delay to translate into higher throughput. Another interesting observation is that the relative delay improvement is larger for low load traffic. Low load constant-bit rate traffic shows the highest relative performance improvement. Low load bursty traffic contains brief periods of high load traffic and for this reason improvement is less significant compared to the constant bit-rate traffic. For the considered algorithm, there was no implication on the jitter, neither by increased reach nor by multi-threading. For a GPON system with multiple traffic classes of different priorities, lower priority traffic has no effect on higher priority traffic as it could have in various EPON algorithms. Hence the results for low load traf-

fic are valid also for the low load high priority traffic in a fully loaded multi-class system. In a multi-class system, DBA process overlapping leads to a reduced average delay for high priority traffic and an increased overall capacity of the system.

From the results shown in Fig. 6, it can also be observed that for EPON the performance improvement is more tangible for longer reach. However, there is a performance hit due to multi-threading through the increased overhead associated with report and grant messages in EPON. When the reach is relatively short (e.g., 10 km), the average delay and jitter for the multi-thread scheme is even worse than for the single-thread scheme. Furthermore, we can observe that there is a trade-off between the number of threads employed to increase the DBA performance and extra message exchange overhead generated by them. According to the results shown in Figs. 6c and 6d, we find that two is the optimal number of threads for this scheme in order to obtain the best delay and proper jitter. However, this value is sensitive to system characteristics (number of ONUs, line rate, etc.) and traffic characteristics (load, burstiness, etc.).

CONCLUSIONS

LR-PON was identified as a potential candidate for future broadband access infrastructure. One of the most important challenges of LR-PON is resource scheduling which suffers from increased response time due to the increased propagation delay. Multi-threading was identified as plausible solution to the increased response time. By means of multi-threading, the frequency with which the DBA algorithm is executed can be increased, reducing the waiting time for incoming upstream traffic, from the arrival of traffic to the execution of the DBA algorithm and also potentially from the arrival of a upstream BW map to the upstream data transmission of traffic. However, for conventional DBA, multi-threading or increased DBA process overlap, results in an increased degree of overgranting, which effectively decreases DBA performance. The NA+ scheme was introduced in this article and adapted to both GPON and EPON in order to eliminate the overgranting associated with multi-threading. NA+ coordinates work between the DBA processes. As a result, the advantages of multithreading can be fully exploited without the conventional side-effects. Simulation results show that for both GPON and EPON, multi-threading employing the proposed NA+ scheme, provides an avenue for mitigating the performance degradation of DBA in LR-PON.

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BIOGRAPHIES

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Simulation results show that for both GPON and EPON, multi-threading employing the proposed NA+ scheme, provides an avenue for mitigating the performance degradation of DBA in LR-PON.

transmitters/receivers, which were commercialized successfully. Since 2000, he joined Zhejiang University, Hangzhou, China, where he has been engaged in research on metropolitan- and access-area network technologies. From 2008–2009 he worked as a visiting professor in the Next Generation Optical Networks (NEGONET) group at the Royal Institute of Technology (KTH), Sweden. His current research interest is in Optical Code Division Multiple Access, Passive Optical Networks (PONs) and Radio over Fiber Systems.

LENA WOSINSKA [M] (wosinska@kth.se) received her Ph.D. degree in photonics and Docent degree in optical networking from KTH. She joined KTH in 1986, where she is currently an associate professor in the School of Information and Communication Technology (ICT), heading a research group in optical networking, and coordinating a number of national and international scientific projects. Her research interests include optical network management, reliability and survivability of optical networks, photonics in switching, and fiber access networks. She has been involved in a number of professional activities including guest editorship of the following special issues that appeared in *OSA Journal of Optical Networking: High Availability in Optical Networks*; *Photonics in Switching*; *Reliability Issues in Optical Networks*; and *Optical Networks for the Future Internet*. From 2007–2009 she was an Associate Editor of *OSA Journal of Optical Networking* and since 2009 she is an Associate Editor of *IEEE/OSA Journal of Optical Communications*

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