Performance of PON Dynamic Bandwidth Allocation Algorithm for Meeting xHaul Transport Requirements

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Abstract—**Passive optical networks (PONs) use dynamic bandwidth allocation (DBA) algorithms to assign upstream bandwidth for different types of traffic to transmission containers (T-CONTs) used by optical network units (ONUs). In this paper, we show that the performance of a PON DBA algorithm that incorporates a colorless grant can ensure that the average upstream delay and delay distribution of T-CONT frames fall within the latency requirements for different traffic types in an xHaul transport network. We evaluate the performance of two deployment scenarios for a 10-Gigabit-capable PON (XGS-PON) system using the OMNeT++ network simulator. The simulation results show that, when the delay distribution of frames is analyzed, more than 99% of fronthaul traffic at 80% load in both scenarios are below the 250 μs latency requirement. Overall, the results indicate that the latency requirements of fronthaul traffic can be met by over-allocating bandwidth to it relative to other types of traffic in the network.**

Keywords—passive optical network (PON), dynamic bandwidth allocation (DBA), 5G, cloud radio access network (C-RAN), functional split, fronthaul, midhaul, xhaul, fixed-mobile convergence

I. INTRODUCTION

Next-generation mobile networks (for 5G and beyond) will possess a dynamic and flexible network architecture to support diverse latency (delay), bandwidth and reliability requirements due to new use cases, defined generally by the enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (uRLLC) and massive machine-type communications (mMTC) service types [1]. Addressing these requirements led to the introduction of the cloud radio access network (C-RAN) and the virtualized RAN (vRAN) architectures. The use of the Common Public Radio Interface (CPRI) protocol was proposed for the transport of traffic between radio equipment and radio equipment controllers in a C-RAN [2], [3]. However, the use of CPRI leads to very high bit-rates and does not scale to meet the demands of 5G networks which will use wider carrier bandwidths and more antenna elements. The introduction of new functional splits in the C-RAN architecture and, for example, the use of an enhanced CPRI (eCPRI) protocol enables meeting the 5G requirements [4].

The 5G RAN's radio base station (known as a gNB) consists of three functional units: the Central Unit (CU), Distributed Unit (DU) and Remote Unit (RU). Although various terminologies are used in the literature, in this work the transport network segments connecting these units are referred to as the backhaul (connecting the 5G core, 5GC, to the CU), the midhaul (connecting the CU with the DU) and the fronthaul (connecting the DU with the RU) [5]. Together, we refer to the three network segments as an xHaul network. The split gNB architecture poses new challenges for the xHaul network since fronthaul, midhaul and backhaul traffic may need to meet different delay requirements both within the same physical network.

Passive optical networks (PONs) are fundamental to the implementation of 5G mobile networks and next-generation fixed networks [6], [7]. Time-division multiplexed (TDM) PONs are the most widely commercially deployed PON architecture due to their cost advantage when compared to a point-to-point architecture. However, the latency due to the dynamic bandwidth allocation (DBA) for upstream transmission in a TDM-PON is the major challenge in meeting the xHaul network requirements.

Much of the research on DBA algorithms for TDM-PON based mobile fronthaul has focused on IEEE PONs such as 10G-EPON [8], [9]. To the best of our knowledge, the following International Telecommunication Union (ITU) TDM-PON (GPON, XG-PON) DBA algorithms have been studied for use in the mobile fronthaul: Round Robin DBA (RR-DBA) [10], Group Assured GIANT (gGIANT) DBA [11] – based on the well-known GigaPON Access NeTwork (GIANT) DBA [12], [13] – and Optimized-Round Robin (Optimized-RR) DBA [14]. In [14], the authors improve the gGIANT and RR DBAs by redistributing unused bandwidth of lightly-loaded transmission containers (T-CONTs) equally to heavily-loaded T-CONTs, resulting in sub-300 μs upstream delays. The authors in [15] demonstrate sub-250 μs delay values for eCPRI functional split fronthaul traffic using the fixed-elastic DBA (FEDBA) algorithm, which exploits both the fixed and elastic bandwidth reservations in a TDM-PON. In order to provide low latency bandwidth assignment in a TDM-PON based fronthaul, the concept of coordinating scheduling between the 5G mobile scheduler and the PON OLT was proposed in [8] and has been recognized by the ITU-T as a DBA method known as the cooperative DBA (CO-DBA) [16]. The O-RAN Alliance [17] has also specified a corresponding bidirectional open interface used with the CO-DBA known as the cooperative transport interface (CTI).

This paper presents the use of the Immediate Allocation with Colorless Grant (IACG) DBA algorithm [18], which is an extension of the GIANT DBA [12], [13] in meeting the latency requirements for different traffic types in a PON-based xHaul network with both midhaul (CU – DU) and fronthaul (DU – RU) segments. The colorless grant process in IACG allows for a more efficient allocation of bandwidth. In contrast to other works, we not only show results for the average upstream delay but examine the delay distribution of the T-CONT frames to determine the proportion of frames that meet the latency requirements. Although we use lower upstream rates, the results obtained could be scaled to PONs with higher upstream rates,

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such as NG-PON2 (1 – 4 x 10 Gbit/s) and 50/100 Gbit/s PONs [19], as the emphasis in this paper is on queuing delay versus normalized load. We also investigate the effect of three different frame sizes (1500, 1000 and 500 bytes) on meeting the latency requirement. In addition, we utilize multiple T-CONTs in order to meet the requirements of each of the fronthaul, midhaul, backhaul and fixed access traffic that would be found in a converged and mixed functional split scenario. The remainder of this paper is organized as follows: Section 2 introduces the functional split options in 5G radio access networks, while Section 3 provides some necessary background on the operation of an ITU-T PON DBA. The system being modeled is described in Section 4. Section 5 describes the performance evaluation and simulation results for the queuing delay and queuing delay distribution for various T-CONTs, in addition to the comparison of performance for different frame sizes. A conclusion is provided in Section 6.

II. RAN FUNCTIONAL SPLIT OPTIONS

The Third Generation Partnership Project (3GPP) standards organization defined eight functional split options for the 5G NR protocol stack [20]. Two split option categories were identified, a high layer split (HLS) point and a low layer split (LLS) point, as the preferred split options, and are shown in Fig. 1. Option 2 was selected as the HLS point [20] while the sub-options of Option 7 (7.x) are considered for the LLS point, e.g., Option 7.2x [21]. Table I summarizes the latency requirements for the two split options in xHaul, as defined by 3GPP [20]. The LLS point is located within the real time functions of the RAN, so has stringent latency requirements. The HLS point has relaxed latency requirements, which are more similar to those of backhaul traffic [22].

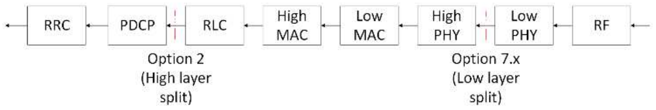

Fig. 1. Functional Split Options. RRC: radio resource control, PDCP: packet data convergence protocol, RLC: radio link control, MAC: media access control, PHY: physical layer, RF: radio frequency [20].

TABLE I. 5G LATENCY REQUIREMENTS

Split option	**One-way latency**
Option 2 (HLS)	1 – 10 ms
Option 7.x (LLS)	< 250 μs

III. ITU-T PON DYNAMIC BANDWIDTH ALLOCATION (DBA)

In TDM-PONs, upstream bandwidth is assigned to ONUs by a DBA algorithm at the optical line terminal (OLT). Based on the bandwidth grants received from the OLT, each ONU can begin to transmit their frames using T-CONTs. There are five types of T-CONTs with each serving a different bandwidth type and quality of service (QoS). T-CONT type 1 (T1), with the highest priority, supports fixed bandwidth only and T-CONT type 2 (T2) supports assured bandwidth. T-CONT type 3 (T3) supports both assured and non-assured (or surplus) bandwidth while T-CONT type 4 (T4), which has the lowest priority, supports only best-effort bandwidth. T-CONT type 5 (T5) supports a combination of one or more of the other four bandwidth types [23], [24]. The two main parameters for the T-CONTs, which are used to allocate the available bandwidth, are the service interval (SI) and the allocation bytes (AB). The SI, specified in multiples of the frame duration (125 μs), dictates how often the T-CONT is served, while the AB determines how many bytes on the upstream frame can be assigned to the T-CONT during its service interval. The allocated bandwidth is thereby calculated as the number of AB divided by the SI. The service interval for assured bandwidth and surplus/best-effort bandwidth is SI_{max} and SI_{min}, respectively while the allocation bytes for assured and surplus bandwidth is AB_{min} and AB_{sur}, respectively.

The key advantages that the IACG DBA [18] has over the GIANT DBA [12], [13] is that (i) it sends bandwidth grants to the ONUs in every downstream frame during a SI and (ii) it assigns the unallocated remainder of the upstream PON frame equally to each ONU. The bandwidth scheduling mechanism of IACG consists of three phases: the guaranteed phase allocation (GPA), surplus phase allocation (SPA) and colorless grant (CG) phase. IACG uses two counters to monitor: (i) the available bytes that can be allocated to ONUs within the SI (available byte counter for the assured bandwidth, V_a, or surplus bandwidth, V_s), and (ii) the remaining duration of the SI itself (down counter for assured bandwidth, SI_{max_timer} or surplus bandwidth, SI_{min_timer}). A summary of the service parameters and counters for each T-CONT type can be found in [18].

The DBA process is described as follows: if the available byte counter (V_a or V_s) and available frame bytes (FB) are greater than zero, then each ONU is granted a bandwidth allocation specified by the minimum of its request, the maximum allocation bytes of the T-CONT and the available frame bytes in the order of the assured bandwidth of T2, assured bandwidth of T3, surplus bandwidth of T3 and best-effort bandwidth of T4. The available byte counter is decreased by the grant amount and recharged to the allocation bytes ($V_a = AB_{min}$ or $V_s = AB_{sur}$) when its down counter (SI_{max_timer} or SI_{min_timer}) reaches 1. At the end of the bandwidth allocation, any unallocated remainder of the available frame bytes is distributed equally to all ONUs using T5 (colorless grant). The maximum value of the available frame bytes in every cycle (125 μs) is 155,520 bytes for a 10 Gbit/s upstream rate. A PON with 16 ONUs and similar traffic demands for each ONU will, on average, be allocating approximately 622 Mbit/s of the upstream bandwidth per ONU for a fully loaded network.

IV. SYSTEM MODEL

The network architecture being modeled is illustrated in Fig. 2. It represents a PON-based 5G xHaul transport network with both high layer and low layer functional split configurations. A mixed functional split scenario such as this may represent a network in which there is a need to provide for legacy and new deployments and differentiated services, e.g., dense small cells, business and residential broadband services. It could also provide for functions such as co-ordinated multipoint, interference cancellation, and differing degrees of RAN centralization [7], [25]. The PON elements (OLT, ONU) are deployed to connect the RAN elements (CU, DU, RU). The

PON must then meet the throughput and latency requirements of the CU-DU midhaul and DU-RU fronthaul transport. In addition, to provide for comprehensive convergence possibilities, it is assumed that backhaul and fixed access traffic may be carried over the same PON.

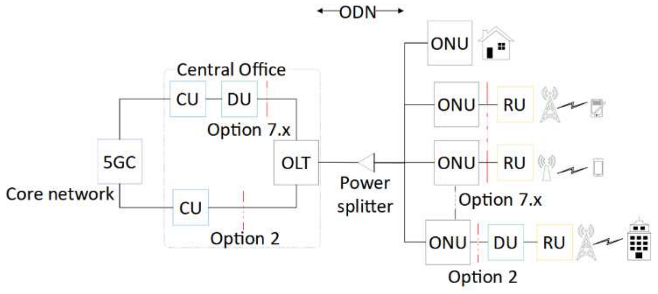

Fig. 2. PON-based 5G xhaul transport network architecture.

Two deployment scenarios are analyzed. Common to both scenarios is the use of multiple T-CONTs (T2, T3 and T4) in each ONU for various types of traffic in the network. T1 is not considered in either scenario since it is mainly suited for constant bit-rate traffic, and would result in inefficient bandwidth utilization in a network with varying user traffic. In the first scenario, we have fronthaul traffic with the highest priority being placed in T2, midhaul traffic with medium priority placed in T3 and backhaul & fixed access traffic with the lowest priority placed in T4. The amount of fronthaul traffic generated by the users is made larger due to higher overheads and the possible need to transmit multiple antenna streams. In the second scenario, T2 carries control and signaling traffic, T3 carries fronthaul traffic and T4 carries midhaul traffic. The amount of traffic generated by the users in scenario 2 is tied to the amount of overhead and number of antenna streams for LLS traffic. Furthermore, the LLS traffic is split between user plane (fronthaul and midhaul) and control & signaling traffic.

In the upstream direction, we assume that the PON transports Ethernet frames for the various types of traffic, such as fronthaul, midhaul, backhaul and fixed access. The upstream delay of the frames will consist of delay components such as propagation delay (fixed), serialization delay (fixed, for a fixed frame length) and queuing delay (variable). According to 3GPP, the delay threshold for 5G fronthaul traffic is set at 250 µs [20]. In our case, we define an upstream delay which deducts the following delays – propagation delay of a 10 km optical fiber link (50 µs), DBA processing time (~ 40 µs), optical-electrical-optical (OEO) conversion delay (~ 15 µs) and FEC coding/decoding (~ 5 µs) [26] – from 250 µs to arrive at a new delay threshold of 140 µs for the queuing delay. The queuing delay is the only variable delay component of the upstream delay, and is thus the focus of this paper. Ethernet frames can vary in length but we first assume a 1500-byte fixed length in order to have a fixed serialization delay value.

The queuing delay is the waiting time of a frame in the ONU buffer from its arrival at the ONU buffer ingress to its departure from the ONU buffer egress. The granting of bandwidth in IACG results in 1500-byte frames being fragmented and split over one or more upstream transmissions. So for each T-CONT, we only consider the queuing delays of the last frame fragments leaving the ONU buffer of each 1500-byte frame arriving at the ONU buffer. In the simulation model, we achieved this by using a counter at the ONU to keep track of all the frame fragments of each 1500-byte frame sent from the ONU to the OLT.

To compute the ONU upstream delay of each T-CONT at the OLT, the serialization delay is added to the queuing delay. As the packet serialization delays generally decrease with increasing line rates, it is expected that a 10 Gbit/s PON would have the greatest challenge in meeting the delay requirement in a fronthaul network. To transmit a 1500-byte packet on a 10 Gbit/s interface, it would take 1.2 µs to serialize [27]. Using the ONU upstream delays for many frames, we compute the average ONU upstream delay, and obtain its cumulative distribution function (CDF). This is done for each T-CONT aggregating the upstream delays obtained at all ONUs.

V. PERFORMANCE EVALUATION AND RESULTS

A. *Simulation Environment*

An XGS-PON network of 16 ONUs with downstream and upstream line rates of 10 Gbit/s [28] is implemented in the OMNeT++ open-source discrete event network simulator [29]. We have chosen a 10 Gbit/s upstream line rate instead of the 2.5 Gbit/s upstream line rate used in the IACG DBA model in [18], because it is the minimum line rate required for fronthaul networks [21]. By examining the queuing delay against normalized load, the results can be made more generally applicable, especially for higher upstream line rates, such as 40 Gbit/s. The simulation model is depicted in Figure 3. The ONU-OLT distance is 10 km and each ONU has a buffer size of 1 MB. The traffic generation uses an exponential distribution for the inter-arrival times, as the load varies from 0.1 to 0.9. The simulation parameters are listed in Table II.

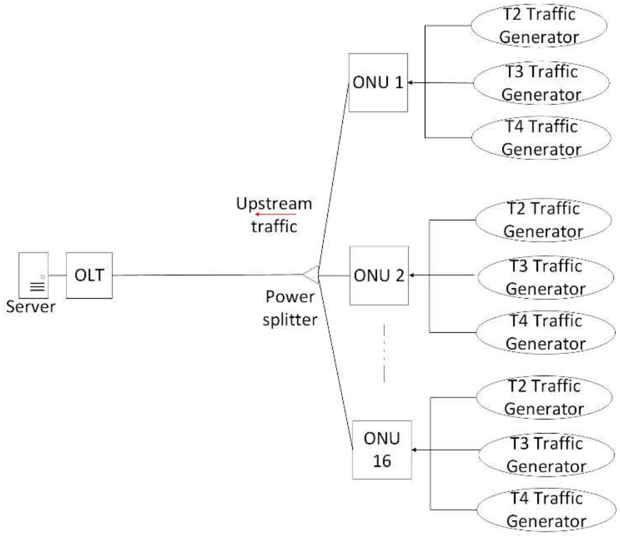

Fig. 3. Simulation model as implemented in OMNeT++.

TABLE II. PON SIMULATION PARAMETERS

Parameter	Value
Upstream rate	10 Gbit/s
Downstream rate	10 Gbit/s
Number of ONUs	16
OLT-ONU distance	10 km
Ethernet frame size	1500 bytes

B. *Scenario 1*

The bandwidth for scenario 1 was initially allocated to each ONU as follows: 400 Mbit/s (at 100% load) to T2, 180 Mbit/s to T3 and 40 Mbit/s to T4. The average ONU upstream delay for T2 was 65 µs at 80% load. However, from the results obtained, it was found that only 99.81% of T2 frames were meeting the 140 µs latency requirement at 80% traffic load while 100% of T3 and T4 frames were meeting the less stringent 1 ms latency requirement. Some 5G services may require a packet reliability of 99.9% or higher [30].

TABLE III. BANDWIDTH ALLOCATION PER ONU IN SCENARIO 1

Parameter	Value
T-CONT 2 (T2)	$AB_{min2} = 43748$ bytes, $SI_{max2} = 5$ (≈ 560 Mbit/s assured bandwidth)
T-CONT 3 (T3)	$AB_{min3} = 1560$ bytes, $SI_{max3} = 5$ (≈ 20 Mbit/s assured bandwidth); $AB_{sur3} = 1560$ bytes, $SI_{min3} = 5$ (≈ 20 Mbit/s non-assured bandwidth)
T-CONT 4 (T4)	$AB_{sur4} = 1560$ bytes, $SI_{min4} = 5$ (≈ 20 Mbit/s best-effort bandwidth)

Therefore, the bandwidth allocation of T2 was increased to 560 Mbit/s to ensure that T2 frames access the network with minimal delay. The bandwidth allocations to T3 and T4 were lowered to 40 Mbit/s and 20 Mbit/s, respectively. Table III lists the bandwidth allocations for T2, T3 and T4 in each ONU for scenario 1. We assume that the latency requirements will be met in the downstream direction, so only concentrate on traffic sent in the upstream direction.

Even though, the average ONU upstream delay of T2 indicates that the latency requirement is being met, there may be a significant number of frames that do not meet it. This requires further investigation by examining the distribution of delay for T2 in order to get a realistic analysis of the situation. Using the new bandwidth allocation values in Table III, it was observed that 99.96% of T2 frames at 80% traffic load meet the 140 µs queuing delay requirement. The results also shows that the average ONU upstream delay of T2 at all traffic loads does not exceed 70 µs. At 80% load, the average ONU upstream delay of T3 and T4 is 69.46 µs and 71.37 µs, respectively, thus satisfying the 1 ms requirement for midhaul and backhaul traffic. Therefore, the over-allocation of bandwidth to fronthaul traffic (T2) shows an increased improvement in performance for meeting the 140 µs queuing delay requirement at 80% load.

In order to replicate a mixed functional split scenario, instead of sixteen ONUs transmitting all three types of T-CONTs as described above, specific ONUs are chosen to transmit T2, T3 and T4 separately. Therefore, nine of the sixteen ONUs (56.25%) transmit only T2, four ONUs (25%) transmit only T3 and three ONUs (18.75%) transmit only T4. In the case where there is no over-allocation of bandwidth, 98.42% of T2 frames at 80% traffic load meet the 140 µs queuing delay requirement. However, when there is an over-allocation of bandwidth for T2, 99.18% of T2 frames meet the requirement with an average ONU upstream delay of 66 µs. Fig. 4 shows the CDF of the queuing delay at 80% traffic load, with the vertical purple line showing the 140 µs queuing delay requirement.

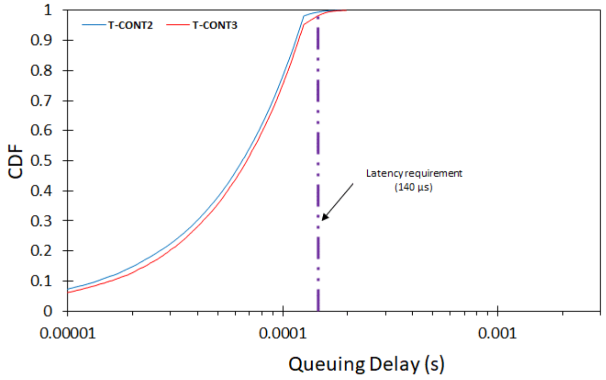

Fig. 4. CDF of queuing delay at 80% traffic load for scenario 1 with frame size of 1500 bytes.

C. *Scenario 2*

Scenario 2 is much more challenging for the PON since both T2 and T3 carry fronthaultraffic that must meet stringent latency requirements. In this scenario, nine ONUs (ONU 0 to 8) transmit both control and signaling traffic (T2) and fronthaul traffic (T3). The total traffic generated by the users for ONU 0 to 8 is split between T2 and T3 and allocated as 22% (136.84 Mbit/s per ONU, at 100% load) to T2 and 78% (485.18 Mbit/s) to T3. The remaining seven ONUs (ONU 9 to 15) transmit only T4 with 100% (622.08 Mbit/s) of the traffic generated by the users allocated to T4.

As shown in Table IV, T3 is allocated the highest amount of bandwidth since it carries fronthaul traffic. However, T2 has higher priority but requires less bandwidth to transmit control and signaling traffic. The midhaul traffic carried in T4 has a less stringent latency requirement (1 ms) to meet so it is allocated the least bandwidth. Although the T4 bandwidth allocation is low, it is expected that T4 will use the colorless grant (T5) to transmit its frames. The CDF shows that at 80% traffic load, 100% of T2 frames and 98.97% of T3 frames meet the 140 µs queuing delay requirement, as indicated with the vertical purple line in Fig. 5.

TABLE IV. BANDWIDTH ALLOCATION PER ONU IN SCENARIO 2

Parameter	Value
T-CONT 2 (T2)	$AB_{min2} = 9372$ bytes, $SI_{max2} = 5$ (≈ 120 Mbit/s assured bandwidth)
T-CONT 3 (T3)	$AB_{min3} = 35936$ bytes, $SI_{max3} = 5$ (≈ 460 Mbit/s assured bandwidth); $AB_{sur3} = 1560$ bytes, $SI_{min3} = 5$ (≈ 20 Mbit/s non-assured bandwidth)
T-CONT 4 (T4)	$AB_{sur4} = 1560$ bytes, $SI_{min4} = 5$ (≈ 20 Mbit/s best-effort bandwidth)

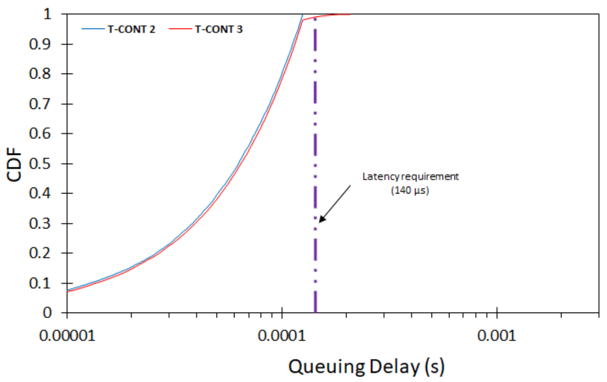

Fig. 5. CDF of queuing delay at 80% traffic load for scenario 2 with frame size of 1500 bytes.

Meeting the delay requirements largely depends on the amount of bandwidth allocated to each T-CONT and the traffic load. As stated previously, the IACG DBA [18] provides lower delay values for T2, T3 and T4 at all loads by sending bandwidth grants every downstream frame and assigning the unallocated bandwidth of the upstream frame at the end of the DBA cycle to each ONU equally (colorless grant phase). In comparison, the GIANT DBA [12], [13] does not have a colorless grant phase and only grants bandwidth once during a SI, so it was found to give higher delays for the traffic classes at all loads [10], [14]. Also, the RR DBA [10], gGIANT DBA [11] and optimized RR DBA [14], which all use a 2.5 Gbit/s upstream line rate, show average upstream delay values at slightly less or higher than 300 µs at the same per-ONU traffic load [14]. Our results show, when using a 2.5 Gbit/s upstream rate, an average upstream delay of 90.89 µs (below 100 µs) is obtained. However, our emphasis is on the percentile delay result which shows that 86.06% of T2 frames at 80% traffic load meet the 140 µs queuing delay requirement in scenario 1. As has been discussed in subsections V.B and V.C, the percentage of frames meeting the 140 µs queuing delay requirement is significantly higher when the upstream rate is 10 Gbit/s. Note that the authors in [14] did not simulate traffic for the optimized RR DBA in the LLS point (fronthaul I interface) but used a delay requirement for the HLS point (fronthaul II interface).

D. *Frame Size Comparison*

In subsections B and C, a fixed frame size of 1500 bytes was assumed for all traffic generated by the users. Here, in order to study the effect of the frame size on the queuing delay, we investigate two other frame sizes (1000 and 500 bytes) using a 10 km ONU-OLT distance in both scenarios.

Fig. 6 shows the CDF of the queuing delay at 80% traffic load for a frame size of 500 bytes in scenarios 1 and 2. It can be observed that 100% of T2 and T3 frames in both scenarios meet the 140 µs queuing delay requirement, as indicated with the vertical purple line, and 100% of T3 frames meet the 1 ms requirement, respectively.

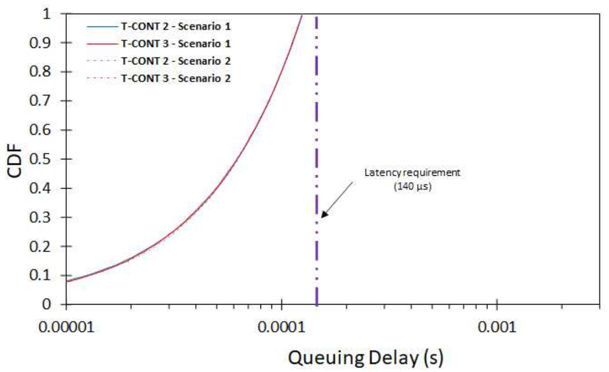

Fig. 6. CDF of queuing delay at 80% traffic load for scenarios 1 and 2 with frame size of 500 bytes.

A summary of the results for the different frame sizes in scenario 1 and 2 at 80% traffic load are shown in Table V and Table VI. The results show that as the frame size decreases from 1500 bytes to 500 bytes, the percentage of frames meeting the 140 µs queuing delay requirement increases while the average ONU upstream delay decreases. The reason for the steady increase of T-CONT frames meeting the delay requirement is that during the transmission of frames from the ONU to the OLT, a lot more frames avoid the need for fragmentation and are being transmitted in one upstream cycle leaving fewer frame fragments waiting for subsequent upstream cycles to be transmitted. In a case where different frame sizes are generated; the maximum Ethernet frame size of 1500 bytes will be the worst-case scenario. For 500-byte frames sizes, 100% of T2 frames will meet the 140 µs queuing delay requirement, as shown in both cases above.

TABLE V. FRAME SIZE COMPARISON FOR SCENARIO 1 AT 80% LOAD

T2		
Frame Size (bytes)	CDF (%)	Average Delay (µs)
1500	99.18	66.00
1000	100	63.66
500	100	63.52

TABLE VI. FRAME SIZE COMPARISON FOR SCENARIO 2 AT 80% LOAD

	T2		**T3**	
Frame Size (bytes)	CDF (%)	Average Delay (µs)	CDF (%)	Average Delay (µs)
1500	100	63.94	98.97	66.05
1000	100	63.94	100	63.71
500	100	63.94	100	63.71

VI. CONCLUSION

In this paper, we have presented the performance of a IACG PON DBA algorithm in meeting the latency requirement of an XGS-PON-based xHaul transport network. The IACG algorithm is used because of its colorless grant process which allocates unassigned bandwidth equally to ONU T-CONTs at the end of a DBA cycle, thereby ensuring higher bandwidth efficiency. We analysed the delay distribution of T-CONT frames in a mixed functional split scenario with different traffic priorities to show the proportion of frames that meet the different latency requirements. It was observed that over 99% of fronthaul traffic in both scenarios met the 140 µs queuing delay requirement. This was achieved by making a tradeoff between the different traffic types whereby fronthaul traffic is given a proportionally much higher bandwidth allocation, as midhaul, backhaul and fixed access traffic have less stringent latency requirements and can be assumed that they would make use of the colorless grant to access unused bandwidth. The results obtained can be adapted for higher upstream line rates of 40 Gbit/s, where there will be a higher proportion of frames meeting the queuing delay requirement and the delays are likely to be lower.

We have shown through simulation that the PON DBA algorithm is suitable for meeting the latency requirement in an xHaul transport network, provided an adequate allocation of bandwidth is made available for fronthaul traffic. In future work, we will focus on reducing the upstream latency further by implementing a cooperative DBA based on the IACG DBA algorithm in order to coordinate scheduling between a 5G mobile scheduler and PON OLT. This can be achieved by having the 5G mobile base station share the mobile scheduling information with the DBA at the PON OLT in advance of the arrival of uplink data.

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