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Dynamic bandwidth allocation algorithm for long reach passive optical network

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ABSTRACT

Next generation broadband access networks are gaining more interests from many key players in this field. The demands for longer reach and higher bandwidth are among the driving factors for such network as it can reach wider area up to 100 km, even beyond; has enhanced bandwidth capacity and transmission speed, but with low cost and energy consumption. One promising candidate is long reach passive optical network, a simplified network with reduced number of network elements, equipment interfaces, and even nodes; which leads to a significant reduction in the network's capital expenditure and operational expenditure. Outcome of an extended reach often results in increased propagation delay of dynamic bandwidth allocation messages exchange between the optical line terminals and optical network units, leading to the degradations of bandwidth allocation and quality of service support. Therefore, an effective bandwidth allocation algorithm with appropriate service interval setup for a long reach network is proposed to ensure the delay is maintained under ITU-T G.987.1 standard requirement. An existing algorithm is improved in terms of service interval so that it can perform well beyond 100 km. Findings show that the improved algorithm can reduce the mean delay of high priority traffic classes for distance up to 140 km.

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1. INTRODUCTION

According to the current Cisco visual networking index (VNI), global internet protocol (IP) traffic will increase nearly triple from 2017 to 2022 [1]. Overall IP traffic is expected to grow from 122 exabytes in 2014 to 396 exabytes per month by 2022, a compound annual growth rate (CAGR) of 26% as shown in Figure 1. The number of devices connected to IP networks will be more than three times the global population by 2022 and global fixed broadband speeds will reach 75.4 Mbps, up from 39 Mbps in 2017.

For decades, fiber optical network has been providing the best services to the end users involving urban and rural areas. Fiber optical network, specifically passive optical network (PON) is widely known as the last mile solution due to its high bandwidth, long reach, low power consumption, easier deployment and upgradation [2]. It is reflected by the standards introduced by the full service access network (FSAN) group of International Telecommunication Union (ITU-T) which cover PON solutions operating at gigabit rates, especially gigabit PONs (GPONs) [3]. PON is named based on the fact that it functions only using passive elements in the distribution network [4], particularly a passive optical splitter, used to connect each subscriber to the main fiber. Thus, the network can minimize the operating and maintenance costs of the access network with the absence of active elements (eg. the optical amplifiers, signaling and management electronics, and power supplies) [5].

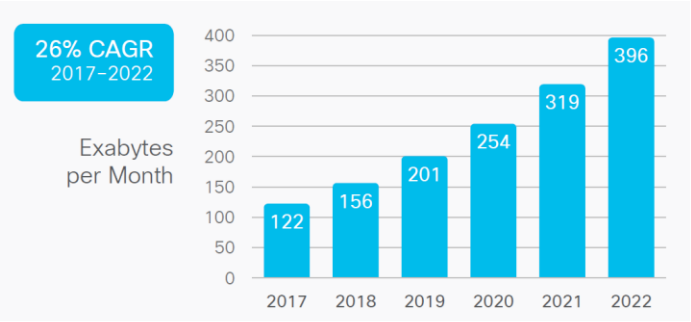

Figure 1. Cisco VNI forecasts 396 exabytes per month of IP traffic by 2022 [1]

Ethernet PON (EPON) and gigabit PON (GPON) are the main contributors in PON technology, standardized by Institute of Electrical and Electronics Engineer (IEEE) and ITU-T, respectively. Among these two systems, GPON surpasses EPON in terms of capacity, scalability, and splitter ratio [6]. EPON offers bit rate up to 1 Gbps, while GPON serves bit rate up to 2.4 Gbps for downstream transmission. EPON supports fiber split ratio up to 16 users, while GPON supports up to 64 split ratios which is much higher than EPON. This is due to the application of reach extender (RE) by GPON at the optical distribution network (ODN). The use of RE can increase the power budget and in the same time, increase the reach and the split ratio [6]. In terms of cost, GPON is more expensive than EPON as it requires tighter physical of the transport components due to its complexity. However, GPON has its own benefit in particularly of all the PON technologies, it has the best support for heterogeneous networking [7].

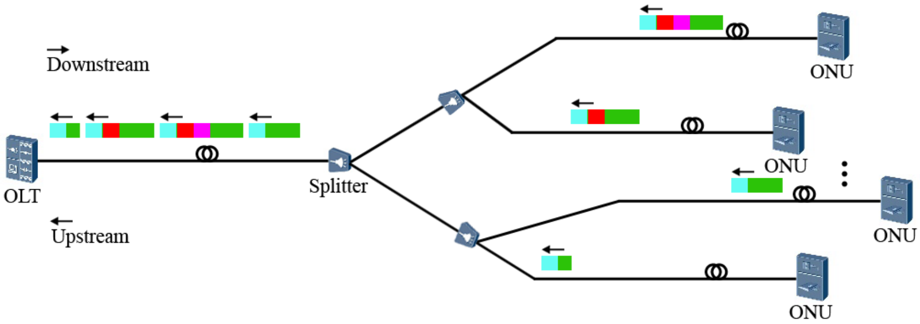

Figure 2. TDM operation concept in upstream transmission of GPON

As shown in Figure 2, in the downstream operation, GPON is a point-to-multipoint network in which data is broadcasted to all optical network units (ONUs) while in the upstream transmission; each ONU will have to send the data in time-division-multiplexing (TDM) manner. To control the upstream bandwidth transmission between ONUs, a bandwidth allocation algorithm is used in the optical line terminal (OLT) so that the collision of the data between ONUs can be avoided [8]. According to [9], there are two main methods of bandwidth allocation in GPON, which are static bandwidth allocation (SBA) and dynamic bandwidth allocation (DBA). SBA is a TDM-like allocation where each ONU gets its predefined bandwidth allocation whether it uses it or not. This method is suitable for network which requires constant bandwidth allocation such as voice over IP (VoIP) or TDM. If no congestion occurs in the transmission and the total required upstream bandwidth is less than the standard upstream bandwidth value for GPON (1.24 Gbps), the upstream channel available bandwidth is sufficient to service all ONUs with virtually no queuing. The unused bandwidth of certain ONUs could be utilized by other ONUs to offer high speed connections and better upstream quality of service (QoS) to the end users, thus also reduce over-granting problem [10]. The DBA mechanism is required to fulfil this objective.

Throughout this paper, some related works on DBA Algorithms for next generation broadband access network are discussed in section 2, further study on long reach passive optical network (LR-PON) is explained in section 3, and the significance of service interval (SI) in LR-PON is elaborated in section 4. The simulation setup using OMNet++ is described in section 5 and the results are then analyzed in section 6, while section 7 concludes this paper with recommendation of future works.

2. RELATED WORK ON DBA ALGORITHMS

Many PON DBA algorithms have been proposed, such as in [3, 10-27], but there were only a few articles on GPON FSAN-compliant DBA algorithms which have been physically implemented, named as GigaPON access network (GIANT), immediate allocation colourless grant (IACG) and efficient bandwidth utilization (EBU) algorithms. GIANT [3] is the first physically implemented DBA algorithm which introduced a down counter for bandwidth allocation. The OLT can assign bandwidth to a queue only when the down counter of the queue has expired. GIANT is indeed simpler and more feasible, but it causes higher delay since a request of a queue cannot be granted until the down counter expired. This degrades the overall performance of a GPON system.

Then, IACG algorithm is introduced where each queue has an available byte counter in addition to a down counter [11]. The available byte counter with positive value allows the OLT to immediately allocate a bandwidth to a queue without having to wait for the down counter to expire. The available byte counter is decreased by the grant amount and recharged when its down counter has expired. It was proven that IACG surpasses GIANT in [3], but on the contrary of its good performance, it does not effectively utilize the unused bandwidth of queues. The unused bandwidth of a queue cannot be used by other starving queues. It is necessary that the unused bandwidth is utilized by queues whose request sizes are greater than their reserved service.

Thus, EBU algorithm is introduced to efficiently overcome the unallocated bandwidth problem of IACG [12]. Like IACG, every queue has an available byte counter and a down counter. The minor change is, the available byte counter can be negative in EBU. Furthermore, at the end of scheduling, the unused remainder of the available byte counter is added to the negative available byte counters. EBU is proven to increase the utilization of the unallocated bandwidth compared to IACG.

But in both IACG and EBU algorithms, the OLT is not aware of the complete grant to each traffic class and thus does not completely subtract all previous grants sent to ONU from the received queue reports. As a result, the excess bandwidth is wasted and over-granted, which leads to higher upstream delay. Thus, GPON redundancy eraser algorithm (GREAL) is introduced in 2014, where the remainder unassigned bandwidth is left unused, but a constant bandwidth demand is added to each high priority traffic classes' queue reports [22]. This method unfortunately restricts bandwidth assignment to lower priority traffic classes.

In 2017, Butt *et al*. introduced an improved DBA scheme named as CBA-LR algorithm to overcome the problem in GREAL [2]. This method focuses solely on long reach PON, specifically XG-PON; fixing the fairness issue of unused bandwidth assignment by eliminating the borrowed bandwidth refund process from EBU algorithm, and improves the polling mechanism of existing ITU compliant DBA schemes by fixing the static report inconsistency (SRI) problem. CBA-LR implements comprehensive polling and scheduling mechanism where the excess bandwidth is allocated to each traffic class completely at the OLT instead of granting them to each ONU. The algorithm allocates DBRu slot in odd cycles only during a service interval (SI). To date, CBA-LR is the most reliable DBA scheme, which is fully compliant to the delay requirements specified in ITU-T G.987.1 recommendations, but the range of the fiber can only reach up to 100 km for the algorithm to perform effectively.

According to ITU-T Recommendation G.114, the mean delay of the access network (i.e., the digital local exchange system) should be lower than 1.5 ms [28, 29]. Simulating the CBA-LR algorithm with SI set to 10, T-CONT types 3 and 4 for all distances from 60 to 120 km perform well under 1.0 ONU offered load. For T-CONT type 2, the algorithm failed when the distance exceeds 100 km as the delay impossibly decreases drastically for 120 km fiber distance. It is observed that the mean delay of T-CONT type 4 has exceeded the standard and is extremely high even under light traffic approaching ONU offered load 1.0. These show that the DBA algorithm still needs improvements in handling T-CONT types 2 and 4 for XG-PON system with extended reach beyond 100 km.

As reaching longer coverage and wider subscribers are the main focuses of LR-PON, it is important for a network system to be able to perform well beyond 100 km, specifically in practical ONU deployment scenarios. Thus, in this study, the SI is improved to cover longer distance of an LR-PON, concerning the least mean delay during bandwidth allocation process among traffic transmission containers (T-CONTs). There are also other works on LR-PON which focuses on polling and scheduling algorithm such as in [14, 21, 27, 30-34] but most of them are on E-PON and some are not GPON-FSAN compliant.

3. LONG REACH PASSIVE OPTICAL NETWORK

As the work of DBA grows rapidly, the demand for further coverage yet cost-effective network also increases. Here came the efforts to improve the existing system either by modifying the physical layer or the network layer technology. There is a proposal to extend PON towards next generation-PON to get higher bandwidth capacity and to serve larger number of subscribers. Long reach PON (LR-PON) is one of the next generation-PON technologies which aims to extend the optical access network up to 100 km. LR-PON is a term that refers to the consolidation of the metro and the access networks in the traditional PON, which also means the consolidation of the multiple optical line terminals (OLTs) and the central offices (CO) where they are located in the network [35], as shown in Figure 3.

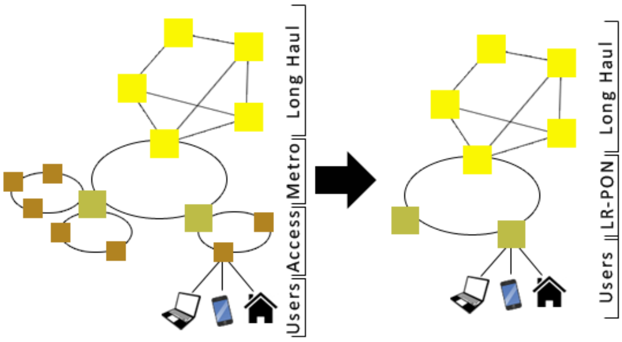

Figure 3. Consolidation of the metro and access network in long reach PON

According to Skubic *et al.*, node consolidation of PON is significant in reducing cost and components. However, it is limited by the reach of conventional PON system due to optical power budget constraint to support up to 32 ONUs. To achieve larger degree of node consolidation, extended reach beyond 20 km is needed [36]. Reaching longer coverage and wider subscribers are the main focuses of LR-PON. On the other hand, extending the reach creates serious challenges at the MAC layer. As the reach is extended beyond 100 km, the Round-Trip-Time (RTT) also grows. In a traditional PON, RTT is only 0.1 ms with 10-km span, while in a LR-PON, the RTT is increased to 1 ms with 100 km of OLT-ONU distance, which results in 10 times the idle time in a traditional PON [35].

DBA performance relies on the RTT. There will be impact on the delay of the DBA control loop as the reach increases. The growth of the RTT will degrade the system performance. Increased reach results in increased propagation delay of DBA messages exchange between OLT and ONUs [37], which then leads to degradation of DBA and QoS support, plus inefficient utilization of upstream channels. As described in [2], the upstream delay of PON depends mostly on idle time (T_{Idle}) and queuing time ($T_{Queuing}$), where

$$T_{Idle} = RTT + T_{OLT} + T_{ONU} + T_{Queuing} \tag{1}$$

Referring to Figure 4, the delays involved in a DBA cycle of LR-PON are RTT, T_{ONU}, T_{OLT} and T_{Idle}, where T_{ONU} is the sum of ONU processing and equalization delay (T_E) at the ONU. For ITU PONs, the standard value of T_{ONU} is taken as 35 µs + T_E [38]. T_{OLT} is the grant sending delay at OLT, where it is varies based on T_{POLL} and DBA processing time ($T_{DBA\_Process}$).

The ITU PONs are synchronous with a fixed frame length of 125 µs. T_{POLL} is the time grants sent to ONUs. It is typically measured in number of downstream frames for ITU PONs, while in IEEE PONs it is variable and depends upon ONU traffic load. In (1) to (4) from [2] show the expressions for D_{US}, T_{Idle}, T_{OLT} and T_{DBA_Cyle}. The T_{OLT} can be at minimum equal to one downstream frame duration. RTT mainly depends upon the length of optical fiber between ONU and OLT. T_{ONU} is normally fixed while $T_{Queueing}$ depends on the traffic arrival rate (λ) and upstream service rate (µ) as evident from (5).

$$D_{US} = T_{Idle} + T_{Queueing} \tag{2}$$

$$T_{OLT} = T_{DBA\_process} + T_{POLL} \tag{3}$$

$$T_{DBA\_Cycle} = RTT + T_{OLT} + T_{ONU} \tag{4}$$

$$Q_D = \frac{\lambda}{2\mu^2(1-\rho)} \tag{5}$$

Therefore, minimization of T_{Idle} and thus the D_{US} is only achievable through minimization of T_{OLT} and $T_{Queueing}$ which are reliant on DBA scheme. Thus, some modifications are needed to improve the existing DBA algorithm to ensure that the algorithm can properly allocate bandwidth to the end users accordingly while minimizing the upstream delays.

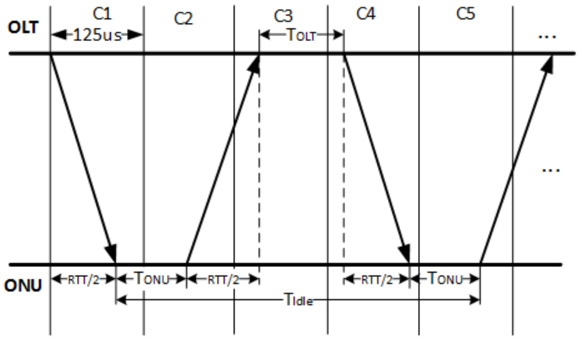

Figure 4. Delays involved in DBA cycle [2]

4. SERVICE INTERVAL IN DBA ALGORITHM FOR LONG REACH PON

In a basic GPON system, the ONU has a transmission container (T-CONT) for each service class to support multiple service classes [11]. This T-CONT is identified by its unique allocation identifiers (AllocIDs). Depends on their assignable bandwidth, T-CONTs are classified into five types, which are:

- T-CONT type 1 supports fixed bandwidth only.
- T-CONT type 2 supports assured bandwidth only.
- T-CONT type 3 supports assured bandwidth and non-assured bandwidth.
- T-CONT type 4 supports best-effort bandwidth only.
- T-CONT type 5 supports all types of bandwidth.

Assured bandwidth means fixed average bandwidth over a specified time interval. The assured bandwidth is dynamically allocated, whereas the fixed bandwidth is statically allocated. As T-CONT type 1 supports fixed bandwidth only, it is served by SBA, thus we do not consider this T-CONT hereafter as in [3, 11]. In the GIANT MAC algorithm, one of the parameters in T-CONT is service interval (SI), while another one is allocation byte (AB). These two parameters play important role in allocated bandwidth (VB) calculation where:

$$VB = \frac{AB}{SI} \tag{6}$$

The SI is expressed in multiples of the frame duration, i.e. 125 µs, and the AB is expressed in bytes. In the T-CONT type 4, SI_{max} and AB_{min} are used only for the DBRu field to report the queue length of T-CONT type 4, where SI_{max} is the polling period and AB_{min} is the same as the size of the DBRu field. For T-CONT types 2 and 3, SI_{max} is also used for the polling period.

According to Leligou *et al.* [3], AB-SI pairs can provide the required rate in allocated bandwidth, but high SIs increase delay while low ABs cause inefficiency. To attain the best trade-off between transport efficiency and delay, the higher SI that satisfies the maximum tolerated delay (with some safety margin) has to be used and then the AB value can be calculated. To calculate the SI_{max} as a function of the maximum access delay (D_m) the application tolerates, the relation between them is expressed as follows:

$$D_m = 2(SI_{max} + T_p + T_{pr}) \tag{7}$$

where T_p is the fixed propagation time required for the DBRu field to reach the OLT (also the fixed propagation time of the grant to reach the ONU) and T_{pr} is the time required for the transmission and decoding of the messages in each node. In the worst case, the maximum polling period can be SI_{max} for an ONU. Also, in the worst case, at the scheduling stage, the ONU has to wait the SI_{max} time to get a data transmission time.

From information of related works in section 2, the SI which denotes by the down counter is very crucial during bandwidth allocation process as ONU and OLT depend on it. Based on this, we suggest to increase the SI value from 10 in [2] to 12 so that the algorithm works better for longer fiber distance, but still in compliant with FSAN-GPON standard, which is proposed as Service Interval-Based Allocation (SIBA) algorithm for LR-PON. The simulation setup for SIBA is explained in the next section.

5. SIMULATION SETUP

Simulation has been done on OMNet++ platform for XG-PON system of distance varied from 60 km to 140 km to demonstrate the improvement of mean delay, specifically T2 traffic. Referring to previous work on the algorithm [11], a system with 16 ONUs, a line rate from users to an ONU link of 100 Mbits/s, an upstream rate of 1.24416 Gbits/s, a T-CONT buffer size of 1 Mbyte, and two frame durations of RTT are considered. The Ethernet frame length size ranges from 64 bytes to 1518 bytes.

Equally distributed traffic is assumed where each ONU has an identical load. Also, the traffic load distribution among T-CONTs in an ONU is set to be uniform. The service interval (SI) is increased in this simulation to improve the mean delay performance of the system. For the T-CONT type 2, we set AB_{min}=15625 and SI_{max}=12, for the T-CONT type 3, AB_{min}=7812, SI_{max}=12, AB_{sur}=7812, and SI_{min}=12. For the T-CONT type 4, AB_{sur}=15625 and SI_{min}=12. Increasing the incoming traffic load of each ONU from 5% to 95%, the algorithm is simulated, and the performance is evaluated.

6. RESULTS AND DISCUSSION

Comparing with previous simulation focusing on mean delay of the high priority class of G-PON, the results are compared between IACG, EBU, CBA-LR and SIBA with fiber length ranging from 60 to 140 km at maximum traffic load of 1.0, and plotted on the graph in Figures 5-7. According to the results plotted in Figure 5, for T-CONT type 2 under SIBA algorithm, the bandwidth is scheduled accordingly when the distance exceeds 100 km as the mean delay increases after 100 km fiber distance. The mean delay performance also surpasses IACG and EBU with large improvement while CBA-LR shows instability after 100 km fiber range. Thus, the DBA algorithm works fine with SI set to 12, both for short and long distance.

From the data collected in Figure 6, T-CONT type 3 also performed better in terms of mean delay while for T-CONT type 4 in Figure 7, the results for SIBA algorithm show a slight degradation. This is due to the priority the SIBA algorithm gave to T-CONT type 2 and T-CONT type 3, which has higher traffic over other T-CONTs, thus maintaining the delay of the higher traffic under 1.5 ms of ITU-T G.987.1 standard requirement.

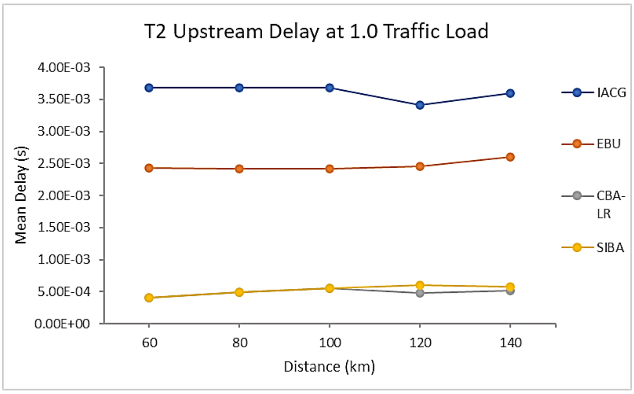

Figure 5. T2 Upstream delay at 1.0 traffic load for IACG, EBU, CBA-LR and SIBA

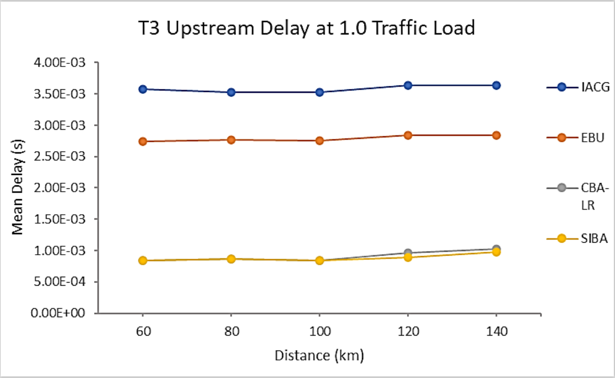

Figure 6. T3 Upstream delay at 1.0 traffic load for IACG, EBU, CBA-LR and SIBA

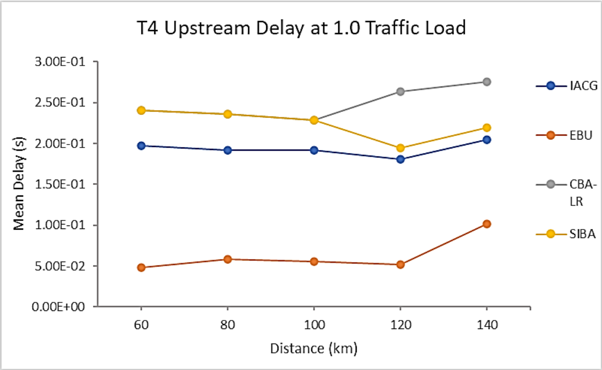

Figure 7. T4 Upstream delay at 1.0 traffic load for IACG, EBU, CBA-LR and SIBA

7. CONCLUSION

This paper presents the improved SI-based algorithm for DBA in LR-PON with fiber distance beyond 60 km, until 140 km in length. The proposed SIBA scheme improves the mean delay for traffic class T2, T3 and T4, specifically when the system reach maximum offered load. The results also show that the assigned number of SI is significant in DBA algorithm for LR-PON to ensure stability of the allocation process. From the results, it is proven that the proposed SIBA algorithm is most stable and efficient as the length of fiber increased, compared to the existing DBA in the field. In our future work, we will study on the adaptive-SI for various fiber distance for an LR-PON.

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