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Journal of Electronic Science and Technology
Volume 18, Issue 4, December 2020, 100044

Review on dynamic bandwidth allocation of GPON and EPON

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Abstract

The passive optical network (PON) technology has been drastically improved in recent years. In spite of using the optical technology, the utilization of the entire bandwidth is a very challenging task. The main categories of PON are the Ethernet passive optical network (EPON) and gigabit passive optical network (GPON). These two networks use the dynamic bandwidth allocation (DBA) algorithm to attain the maximum usage of bandwidth, which is provided in the network dynamically according to the need of the customers with the support of the service level agreement (SLA). This paper will provide a clear review about the DBA algorithm of both technologies as well as the comparison.

Keywords

Dynamic bandwidth allocation (DBA); Ethernet passive optical network (EPON); Gigabit passive optical network (GPON)

1. Introduction

The information and communications network technology is fast growing nowadays. Due to the gradual growth in the cellular mobile subscription and the usage of online video streaming services like Netflix, video conferencing, online high definition television (HDTV), video games, and cloud computing trends, the bandwidth requirement is continuously increasing [1]. According to the latest International Telecommunication Union (ITU) statistics, the fixed broadband usage is increased by 13.1% while mobile service subscriptions by 52.2% and the individuals accessing the Internet have been raised by 46%. An ITU report states that 53.6% of people worldwide access the Internet from their homes and this rate in developed countries increases to 84.4% [2]. Due to such extensive usage of the Internet, the demand for high-speed broadband services has increased drastically [3]. The extensive increase in network traffic and applications has caused a delay between end users and the central office [4]. The passive optical network (PON), which was used earlier, had this problem, so nowadays fiber-to-the-home (FTTH) or fiber-to-the-premises (FTTP) is used effectively [5]. PONs only have passive components but no active components in the transmission path. The passive components are combiners, couplers, and splitters. Since PON has no active components, there is no need of the optical to electrical conversion [6]. The only demerit of PON is the small coverage area, which depends on the signal strength. In an active optical network, the network coverage range is around 100 km, but that in PON is only 20 km. PON mainly has three sections: The optical line terminal (OLT), splitter/combiner, and optical network unit (ONU).

The central office has OLT, which links the optical network to the Internet protocol (IP), asynchronous transfer mode (ATM), or synchronous optical network (SONET) background. The optical splitter is a passive device that splits the single optical signal from OLT into multiple equal but low power signals to ONUs located at the customer premises. The upstream direction is from multiple ONUs to OLT and the downstream direction is from OLT to ONUs [7]. PON has various types, of which the Ethernet passive optical network (EPON) and gigabit passive optical network (GPON) are the latest and familiar ones [8]. EPON and GPON are used for the Internet access, voice over Internet protocol (VoIP), digital TV, teleconferencing, collaborative gaming, and some applications used as backhaul connections for cellular base stations, Wi-Fi hot spots, and distributed antenna systems. The only difference is the protocol used for its upstream and downstream. The main challenges in the upstream transmission are the separation of signals from multiple ONUs which transmit the signals simultaneously to the combiner, so it must use the multiplexing technique to avoid collision between these ONUs signals.

1.1. EPON

EPON is a kind of PON that carries Ethernet traffic. EPON is a combination of Ethernet and time division multiplexing (TDM) [9]. Ethernet is perfectly accepted in EPON because of its broadcasting nature. Ethernet packets from OLT are broadcasted to proper ONUs by using the media access control (MAC) address, which is attached in the Ethernet packets in the downstream transmission. In the upstream direction, the TDM technology is used. If we consider N ONUs in the design model, the non-overlapping timeslot assigned to every ONU and the N ONUs' timeslots can be combined together to make a frame, which has small overhead for synchronizing the OLT and ONUs clocks. The traffic reaches ONU either from the single user or local area network (LAN). Packets are buffered in ONU until ONU gets its timeslot from OLT, and once it gets its timeslot all the buffered packets will be transmitted in the upstream direction.

The multi-point control protocol (MPCP) arbitration is a mechanism that supports the timeslot management of OLT [10]. Various kinds of dynamic allocation in EPON are serviced by MPCP, although it does not have any direct relations with the bandwidth. MPCP performs two-way communications between OLT and ONUs along with the simultaneous transmission of multiple ONUs to OLT [11]. MPCP is composed of five messages: GATE, REPORT, REGISTER REQUEST, REGISTER, and REGISTER_AC [12]. The functions of the GATE and REPORT messages are to carry out normal operations during the normal mode. The GATE message is sent to proper ONU along with starting transmission time and length after receiving the data request. The auto discovery mode uses the remaining three-message frame to identify recently connected ONUs, round trip time, and MAC address, respectively [13].

1.2. GPON

The GPON standard is defined in ITU-T G.984.x [14]. The data rates for downstream and upstream are 2.488 Gbps and 1.244 Gbps, respectively. The split ratio using a single fiber is 1:32 or 1:64 or sometimes 1:128, which means every fiber can serve up to 32, 64, or 128 users. In the data format, the GPON packets have 53 bytes in which 48 bytes are used for data and 5 bytes for overhead. GPON using a generic encapsulation method (GEM) to handle the other protocol like Ethernet, IP, transmission control protocol (TCP), user datagram protocol (UDP), T1/E1, video, VoIP, and other protocols for the data transmission. The GPON packet size ranges from 53 bytes to 1518 bytes [15].

In the 10-gigabit passive optical network (XGPON or 10GPON), the maximum downstream rate is 10 Gbps and that of upstream is 2.5 Gbps [16]. The downstream wavelength is 1577 nm and the upstream wavelength is 1270 nm. It can serve up to 256 connections. The latest version is 10-gigabit symmetrical passive optical network (10 XGSPON) which provides downstream and upstream with a same data rate of 10 Gbps. The next generation passive optical networks (NG-PON1 and NG-PON2) fulfill the need of the wide bandwidth from end users. NG-PON1 was developed to achieve a data rate up to 10 Gbps/2.5Gbps and NG-PON2 was developed to achieve that of 40 Gbps/10 Gbps.

2. EPON and GPON standards and comparison

EPON carries naturally Ethernet frames, thus there is no need for extra adaptation methods or encapsulation [17]. In GPON Ethernet, the frame is encapsulated into the GEM frame and then it is modified into the SONET/synchronous digital hierarchy (SDH) frame, in the upstream and downstream directions. The EPON frame is either synchronous or fixed length or commonly normal operation using two messages: GATE and REPORT. In the same format of GPON for the upstream and downstream operations, GPON upstream and downstream frames are synchronized with the length of 125 ms. In EPON, ONU is addressed by the logical link identifier (LLID) during the transmission from OLT to ONU, OLT adds the preamble at the starting of the frame to identify destined ONU among multiple ONUs, but in the GPON traffic container (T-Cont) it is virtually connected to OLT and ONU. T-Cont has PORT IDs to identify proper ONU, which is assigned to ONU during the initialization by OLT. Both EPON and GPON support ONU discovery, initialization techniques and dynamic bandwidth allocation (DBA) methods. The EPON DBA algorithm is not suitable for GPON, because the frame structure of GPON is entirely different due to the significant difference of the MAC layer.

EPON and GPON standards have different guard time, overhead, and parameters which influence the bandwidth utilization. Both EPON and GPON standards define a) ONUs to convey the current buffer size to OLT by the REPORT message and b) OLT to convey bandwidth information back to ONUs by the GRANT message [18]. This communications mechanism is vibrant for the operation of DBA. EPON messages have larger overhead associated with them compared with GPON messages. The EPON standard provides more flexibility in the design of the DBA algorithm than GPON. The comparison between EPON and GPON is tabulated in Table 1 [19].

Table 1. Comparison between EPON and GPON.

Parameter	**GPON**	**EPON**
Standard	ITU T	IEEE
Carried services	ATM, Ethernet, and TDM	Ethernet and TDM
Data rate (Gbps)	2.488/1.244	1.244/1.244
Grant schedule	T-Cont	LLID
Split ratio	1:32, 1:64, and 1:128	1:32
QoS	Very good, including Ethernet,TDM, and ATM	No inherited QoS capacity
Protocol conversion	Required	Not required
Operation and management	Strong	Weak
Bandwidth efficiency (%)	92	72
DBA	Standard format	Defined by vendors
Optical budget	Class A/B/B$^+$/C	Power × 10/ × 20
Communications with ONUs	ONT management control interface	Not supported

3. DBA

In earlier days, the bandwidth is allocated to a user at a constant rate. If the user needs more bandwidth, it will not be feasible. Then most of the bandwidth will be wasted because of non-usage. This is usually said to be static bandwidth allocation, later several developments occurred in the evolution of optical fibers, which increased the speed of the network. DBA is the latest technique where the bandwidth allocated for the user can be varied according to the usage of the user. In DBA, each user buys fixed bandwidth, if the user needs more than the existing, it will be allocated. If any user is not using the allocated bandwidth, the excess bandwidth will be taken and allocated to the needed user. So many techniques and algorithms have been introduced based on DBA and each of them has its own advantage. However, the main motive of any of these algorithms is the same, which is the sharing of bandwidth. The heavily loaded units have to be allocated bandwidth as soon as possible by collecting the excess bandwidth from the lightly loaded units. The classification of the DBA algorithm is shown in Fig. 1 [20,21].

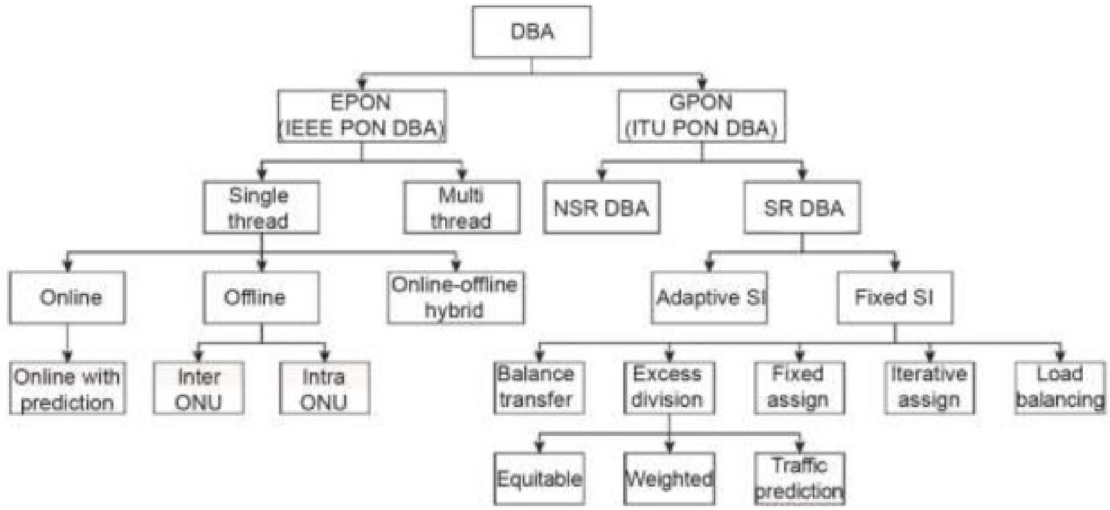

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Fig. 1. Classification of the DBA algorithm.

4. DBA algorithms for EPON

In EPON, during the upstream transmission, all ONUs use a single channel. To avoid the traffic collision and to fairly allocate the channel bandwidth while transmitting data from multiple ONUs to OLT, it should use the MAC arbitration mechanism. It will provide the non-overlapping timeslot window to every ONU either statically or dynamically.

In [22], to avoid data collision in the upstream direction, the author experimented on the fixed bandwidth assignment algorithm. Entire ONUs have fixed bandwidth allocation without service differentiation. The bandwidth given to lightly loaded ONUs is not optimized properly, which leads to a delay and deteriorate throughput of the system.

Interleaved polling with adaptive cycle time (IPACT)[23] focuses on the polling process by overlapping the requests from ONUs to OLT. OLT knows every bit of the first ONU as it is authorized to do that. It will not wait for every ONU's request to reach OLT. OLT sends the GRANT message before itself by proper scheduling of requests to save the waiting time. The drawback in this algorithm is the longer waiting time for small workloads.

In [24], the authors combined the limited service scheme and priority queuing called priority scheduling with DBA, to avoid the light load penalty, and the two-stage buffer and constant bit rate (CBR) credit were introduced. The earlier one increases the delay while reducing the light load penalty and the latter one partially reduces the penalty with some external inputs. In Ref.[25], the authors introduced the DBA algorithm for multimedia services, which is based on strict priority queuing. Furthermore, there is a control message format to manage the bandwidth classification. It provides low cost deployment between the central office and user end. Bandwidth guaranteed polling (BGP) works when it divides a time window into slots of fixed size, which is equal to every ONU number of slot allocation. The number of slots allocated to BGP [26] depends upon the customer's SLA on ONU. Lightly loaded ONU reassigns the remaining timeslot to another ONU. However, it is not feasible with MPCP. The light load penalty free bandwidth allocation algorithm [27] upgrades the limited service scheme and it has the ability of queue management with priority scheduling. It supports differentiated services also to share the extra bandwidth to heavily traffic ONUs from lightly traffic ONUs. For the instant bandwidth grants, the estimation based DBA [28] utilizes previous values of GRANT size and queue length to reduce the waiting delay which is not useful approximation for buffer occupancy in the case of polled ONU.

In [29], the authors proposed two methods, Proposed Scheme 1 and Proposed Scheme 2, which give concession for the maximum timeslot size and make smart changes in bandwidth allocation with the help of other ONU's details. To utilize the maximum bandwidth, Proposed Scheme 1 uses previous GATE information and Proposed Scheme 2 uses previous REPORT information. In Refs. [30], the limited sharing with traffic prediction (LSTP) scheme, while calculating the bandwidth requirements, predicted the data which would arrive at the waiting time to reduce the data delay and loss. The timeslot for next ONU is appended into the current timeslot. The two-layer bandwidth allocation algorithm [31], as its name suggests, works in two layers. The transmission cycle is partitioned into two layers; upstream bandwidth allocation is in the first layer. In the second layer, the upstream bandwidth is allocated to entire ONUs. Under the high traffic load, it guarantees the minimum bandwidth. In Ref.[32], the authors introduced IPACT with the smallest available report first algorithm, which is similar to IPACT apart from the concept of allocating the GRANT message. It will not send the GRANT message immediately after ONU requests. Instead of that, it will postpone the grant transmission to the grace time without changing the idle time. In Ref.[33], the three priority based DBA algorithm was proposed for the emergency state network. It prevents non-priority ONUs from starving. The IPACT with grant estimation (IPACT-GE) [34] algorithm is an enhancement of IPACT. It estimates the newly arrived packets between two consecutive polling and granting ONUs along with the extra estimated amount. In low traffic conditions, the data packets transmit the consecutive cycle, thus reducing the waiting delay. The multi thread polling algorithm uses the modified version of short range PON architecture and long range PON. ONU sends REQUEST before the previous GATE message is received. Thus the thread cycle time is created between ONU and OLT. In this algorithm [35], OLT can make use of subsequent threads. In Ref.[36], the online and offline DBA algorithms were used independently. In online DBA, the entire bandwidth along with idle time periods was used, but not for unbalance traffic. Reference [37] implemented the online-offline DBA algorithm that inherited the advantages of both online and offline algorithms. It operates according to the traffic on upstream in the light load; it will use offline DBA and the heavy load will switch to the online DBA mode. Zheng proposed the efficient DBA algorithm [38], which could provide the extra bandwidth required for heavy traffic ONUs from light traffic ONUs and the idle period problem could be solved by the control mechanism.

In [39], the authors implemented the sort DBA algorithm, which sorted the report length. After that, it will transmit the transmission grant at the next cycle. It eliminates the idle time during the traffic load. In the long-term proportional fair DBA algorithm [40], for a different bandwidth requirement and variable traffic load, this algorithm takes account of the surplus bandwidth proportional factor and makes sure that the allocated bandwidth is not greater than the bandwidth requested, to avoid the bandwidth misuse. In the dynamic wavelength and bandwidth allocation (DWBA) algorithm [41], to reduce the transmission latency and moderate the frame resequencing problem, transmitting the data frames from ONU is on a single wavelength channel in the single grant allocation. It aims to rectify the non-efficient bandwidth utilization and provides a lower average delay and better dealing of the resequencing issue. In Ref.[42], the authors explained the partially online DBA algorithm, after receiving the bandwidth request from heavily loaded ONUs and the algorithm provided the bandwidth by summing up the minimum bandwidth and extra bandwidth from lightly traffic ONUs. Heavily loaded ONUs will not wait until the end of the cycle. The flexible wavelength (FW) allocation algorithm [43] adaptively allocates the wavelengths and bandwidth depending on the traffic offered by ONUs. The operation of the grant is given to each considered wavelength. Some of the EPON algorithms and their characteristics are tabulated in Table2.

Table2. EPON DBA algorithms and their characteristics.

Algorithm	Year of publication	Characteristics
IPACT	2002	Reduce overhead, but longer waiting time for smaller workload.
BGP	2003	Provide guaranteed bandwidth provided by SLA, but not feasible with MPCP.
Efficient DBA	2006	Provide extra bandwidth needed for heavily traffic ONUs and the idle problem has been solved.
IPACT-GE	2008	Under a low traffic condition, the waiting time is reduced.
Two-layer bandwidth allocation	2010	Under a high traffic load, it guarantees the minimum bandwidth.

5. DBA algorithms for GPON

In the GPON upstream direction, the bandwidth is dynamically assigned to the users by using T-Cont. T-Cont is the class, which depends on the traffic. Totally, there are five types of T-Cont (T-Cont 1, T-Cont 2, T-Cont 3, T-Cont 4, and T-Cont 5). Alloc_ID identifies each T-Cont and each T-Cont bandwidth is assigned differently according to DBA and SLA.

GIANT (GigaPON access network DBA algorithm) [44] is the first DBA algorithm for GPON. T-Cont is prioritized by the weighted round robin with weights following SLA and service interval (SI). It only uses the down counter to allocate the bandwidth to the queues; OLT will assign the bandwidth only when the down counter expires. The immediate allocation with the colorless grant (IACG) algorithm [45] uses the available byte counter and down counter. Even if the down counter is expired, it will assign the bandwidth immediately to needed ONUs. OLT distributes the unused bandwidth to all ONUs equally without knowing the priority of T-Cont. In Ref.[46], two approaches are proposed. The first one is status reporting DBA; OLT demands the buffer status of T-Cont to check the bytes waiting for the transmission. The second one is non-status reporting DBA; OLT estimates and allocates the bandwidth for the next cycle based on the bandwidth usage of the previous cycle. The status report is more efficient in the bandwidth usage than non-status reporting DBA. Non-status reporting DBA is more reliable based on its quality of service (QoS). In the immediate allocation with the reallocation (IAR) algorithm, after the first scheduling, if there is any unused bandwidth, it will iterate the scheduling again. In the second time iteration, it will assign the polling bandwidth to a queue to increase the system efficiency [47]. Because of more scheduling in this algorithm, the queuing delay will be increased.

This paper [48] proposes an efficient bandwidth utilization (EBU) algorithm using the unused bandwidth in DBA. In EBU, if the available byte counters of a queue are negative then the unused bandwidth can be used by the other queues and additionally it collects the request from ONUs during SI by using the novel polling technique. It gives more priority towards T-Cont 4, compared with T-Cont 2 and T-Cont 3 during scheduling.

In the long reach network, the round trip time will be large, because that OLT will get the REPORT message redundantly from ONUs, which leads to the bandwidth wastage. This problem is eliminated by using the GPON redundancy eraser algorithm for long reach (GREAL) [49]. This algorithm will remove the request immediately after sending the GRANT message to ONU from the pending data buffer. The simple and feasible DBA (SFDBA) algorithm [50] uses one available byte counter and a down counter for several queues of a single class. Since the queues use the common available byte counter, the unused bandwidth of the queue is transferred to the needed queue. In the hybrid slot-size/rate (HSSR) DBA algorithm [41], the total transmission timeslot is divided into two parts. The first part is distributed equally among all ONUs for high priority traffic and the second part is for the best effort traffic, but in modified HSSR [51] the first part is the bandwidth dynamically divided and shared to all ONUs and the second part is like HSSR. The given paper talks about a concept of H-DBA [52], in which ONU sends the report including the data needed for the present time, the data stored in the queue, and the data arrived during the waiting time to OLT. It will decrease the data delay during the waiting time, boost the real time performance, and decrease the packet loss rate. The improved bandwidth utilization (IBU) [53] algorithm has the scheduling mechanism which is better than EBU and immediate allocation with the colorless grant DBA algorithm. It gives more priority to the assured traffic class bandwidth than the best effort traffic. It has the polling mechanism to collect the queue report from proper ONUs. The multi-partition DBA algorithm [54] divides the number of ONUs into four parts. It allocates the excess bandwidth to another ONU with specific priority. The total delay is reduced and this algorithm improves the DBA computation time.

The prediction method used in the IRIS DBA algorithm depends on T-Cont priority to make sure the fair distribution of the bandwidth among the users to satisfy the condition of SLA [55]. The modified GIANT algorithm [56] allocates the redundant bandwidth of one T-Cont to another one. All ONUs will receive the bandwidth for T-Cont 1. Suppose if ONU has one more Alloc_IDs, then it will take the guaranteed and surplus bandwidth to service T-Cont 3 and T-Cont 4 traffic.

In the modular DBA algorithm of [57], the DBA function was separated from OLT and kept as a different module with a specified interface to link. This will allow even the live changes in ONUs, because this OLT will do the operation remotely or in the accessible location. The comprehensive bandwidth utilization and polling mechanism (CBU) algorithm [58] improves the drawbacks in the polling and scheduling mechanisms of EBU and IACG. In this algorithm, the entire bandwidth is allocated to T-Cont by OLT than ONU. The borrow refund method is omitted to avoid the bandwidth wastage. The extra bandwidth is transferred to T-Cont only through OLT. In the demand forecasting DBA algorithm [59], it predicts the future demand from ONU using statistical modeling of the demand pattern. It stores the demand values of the last 100 cycles, into a circular buffer, and predicts the demand for the next cycle using these data. This algorithm reduces the delay by a significant amount. A few of the basic GPON DBA algorithms are compared and tabulated in Table 3.

Table 3. Comparison between GPON algorithms.

Parameter	Year of publication	Polling	Scheduling	Working	Throughput	T-Cont priority	End to end delay
GIANT	2006	Only once during SI	Round robin method.	Distribute the bandwidth equally based on T-Cont priority.	Poor	T-Cont 4 will be starving.	Very high
IACG	2008	Multiple times in SI	Unused bandwidth shared among all ONUs.	Unused bandwidth is distributed equally to all ONUs T-Cont.	Poor	Priority to T-Cont 4.	High
EBU	2013	Multiple times in SI	Unused bandwidth assigned to needed ONU belonging to the same traffic.	Unused bandwidth is used for the overloaded ONU belonging to the same traffic.	Medium	Priority to T-Cont 4.	High
IBU	2017	Multiple times in SI	ONUs subtract the remaining unused grant of current SI	Unused bandwidth is used for the T-Cont 4.	High	Will not affect T-Cont 3 and T-Cont 2.	Medium

Parameter	Year of publication	Polling	Scheduling	Working	Throughput	T-Cont priority	End to end delay
			from the queue size.				
DFDBA	2019	–	–	Predict the future ONU demand by statistical modeling.	High	Will not affect T-Cont 3 and T-Cont 2.	Low

6. Conclusions

In this paper, we have described the differences between the EPON and GPON standards and DBA algorithms according to the standard, traffic nature, and service requirement. In both standards, DBA has so many advantages, while comparing both DBA, GPON has a better performance, even though EPON is a simple, cheap, time consuming, and straight forward solution. GPON is the solemn solution of the future networks, because of its bandwidth, high QoS, and security. Most of the dynamic bandwidth algorithms used in the GPON technology are based on the request grant procedure. This means that after the request from ONU has been sent, OLT provides the GRANT message back to ONU. The demand forecasting dynamic bandwidth algorithm (DFDBA) helps in predicting the ONUs future demand in time by statistical modeling. Although DFDBA leads to the well-managed delay, the risk of reduced throughput is still possible, because of the small over-allocation. Hence, the polling and scheduling method should be employed as it will remove over-allocation and regulate throughput. Hence, emphasis should be made on the polling and scheduling procedure based DBA algorithm.

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