EPON performance optimization: an extensive comparative study for DBA algorithms

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This work provides a classification study and a detailed comparison for a large number of dynamic bandwidth allocation (DBA) algorithms with respect to time delay and throughput as performance indicators. The study shows that IPACT WITH CBR, UDBA, IPACT with two stages and CPBA are the best DBA algorithms regarding both time delay and throughput at highly loaded scenarios. These algorithms are enrolled in a parametric optimization process targeting performance enhancement. This process results in a reduction in time delay between 1.167 and 3.5% and an increase in throughput between 1.3% and 1.795%.

(Received December 31, 2015; accepted August 3, 2016)

Keywords: Ethernet Passive Optical Network (EPON), Dynamic Bandwidth Allocation (DBA), Time delay performance, Throughput, Optimization

1. Introduction

Fiber infrastructure is required in the access networks to provide the permit transmission over longer distances and at higher bandwidths (data rates), as well as more flexibility [1]. From the service provider perspective, access network links have different revenue dynamics than links in the wide area network (WAN) and Metropolitan area network (MAN). Whereas WAN and MAN links carry the bit streams of many revenue generating customers, access network links carry a single or only a few revenue generating bit streams. For this reason, access networks are very sensitive to cost [1]. Wide Area Network-Time Division Multiplexing (WAN-TDM) cost issues are slowing the deployment of a new physical plant in the access networks [1]. Deploying a passive optical network (PON) between service providers and customer premises can provide a cost efficient and flexible infrastructure that will provide the required bandwidth to customers for many years to come [3, 4, 6].

A PON is a network in which a shared fiber medium is created using a passive optical splitter/combiner in the physical plant. Sharing the fiber medium means a reduced cost in the physical fiber deployment, and using passive components in the physical plant means a reduced recurring cost by not maintaining remote facilities with power. These reduced costs make PONs an attractive choice for access networks, which are inherently cost sensitive [5, 6]. PONs provide a powerful point-to-multipoint solution to satisfy the increasing capacity demand in the access part of the communication infrastructure, between service provider central offices (COs) and customer sites [7]. A PON consists of an optical line terminal (OLT) located at the provider CO and a number of optical network units (ONUs) at the customer premises. At a top level, PONs are classified by the used link-layer protocol [8].

Different types of PON include an asynchronous transfer mode (ATM) PON (APON), an Ethernet PON (EPON), and a gigabit PON (GPON) [3]. The International Telecommunication Union (ITU) has generated standards for APONs: G.983 broadband PON (BPON), as well as GPONs: G.984 gigabit-capable PON (GPON). The IEEE has generated a standard for EPONs: IEEE 802.3ah Ethernet in the first mile [1].

Given the fact that 90% of data traffic originates and terminates in Ethernet frames, using an EPON can reduce the adaptation required to move data between the LAN and the access network [3, 9].

Furthermore, ATM creates inefficiencies in data transport as a result of its fixed data unit that requires most data packets to be segmented and reassembled at the end points of the network. This results in higher processing delays, as well as a reduced efficiency of error recovery techniques. For these reasons, EPONs appear to be more promising than APONs for data dominated networks [1]. Furthermore, the 10G-EPON shows significant merits over traditional GPON [2, 8, 9].

In a time-division multiplexing PON (TDM-PON), downstream traffic is handled by broadcasting from the OLT to all connected ONUs. 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 length of each upstream transmission time slot for each ONU is scheduled using a bandwidth allocation scheme. In order to achieve flexible sharing of bandwidth among users and high bandwidth utilization, a bandwidth allocation (BA) scheme is required that can adapt to the current traffic demand. Bandwidth allocation schemes can be divided into two categories: fixed bandwidth allocation (FBA) and DBA. DBA in Ethernet passive optical networks (EPON) presents a crucial issue and a key issue for providing efficient and fair utilization of the EPON upstream bandwidth while supporting the quality of service (QoS) requirements of different traffic classes.

DBA schemes have significant advantages over FBA regarding sharing of bandwidth among users and high bandwidth utilization [1, 2, 7, 9, 10].

In order to achieve an effective EPON bandwidth allocation and utilization, several algorithms have been proposed and evaluated in the last few years. This becomes a prominent concern in EPON research today, especially with the huge bandwidth demands and critical applications.

The most famous DBA algorithms in previous researches that will be investigated and tested through this work are: 1) Arishtat: auction based DBA [11], 2) IPACT with CBR Credit [12], 3) IPACT with two stage queue [12], 4) CPBA [12], 5) n-DBA [14], 6) e-DBA [14], 7) TLBA [30], 8) TWO STAGE QUEUE [15], 9) TCP-DBA-APC [20], 10) EBDBA [19], 11) YDBA [19], 12) SDBA [19], 13) ADBA [19], 14) IFLDBA [16], 15) IPACT [18], 16) CDBA QOS 31 dB [18], 17) CDBA QOS 26 dB [18], 18) TWO STAGE QUEUE [11], 19) FSD-SLA [11], 20) Limited Services IPACT [11], 21) UDBA, 22) MSARF, 23) CPBA-SLA [17].

Several evaluation factors and parameters are introduced in literature to evaluate the performance of the DBA algorithms and test their ability to meet EPON bandwidth allocation/utilization requirements. The most important factors and parameters are : 1) Average waiting delay, 2) Average buffer occupancy, 3) Average loss rate, 4) Upstream channel utilization, 5) Maximum waiting delay, 6) Jitter, 7) Line utilization, 8) Throughput rate, 9) Average execution time, 10) Average upstream data rate, 11) Average queue length [1-21].

Among these parameters, throughput and time delay are considered the most famous metrics in evaluation and judgment process [22]. Also, these factors provide critical information about average time measured in seconds between the generation of packets and their arrival in an OLT and the sum of the bits arriving at an OLT in 1 s for the algorisms under test.

In the present work, a comparative study between previously mentioned famous DBA algorithms based on throughput and/or time delay is carried out. Preferable algorithms resulting from this study showing acceptable performance regarding both throughput and time delay undergo a parametric optimized process targeting performance enhancement.

This work is organized as follows: Section 2 provides a review on famous DBA techniques, algorithms and specifications. The simulation method and parameters are presented in Sec. 3. Throughput and time delay performance evaluation, is carried out in Sec. 4 together with a comparison and a parametric optimization process. This is followed by the main conclusions in Sec. 5.

2. Review on famous DBA techniques, algorithms and specifications

This section provides useful essential information about famous DBA algorithms. Characteristics of techniques are also summarized. Many DBA algorithms have been developed especially for EPONs to cope with the challenges of high bandwidth utilization and QoS provisioning. However, it is difficult to pick a single algorithm due to the multidimensional performance requirements expected of a DBA algorithm. In addition, some algorithms introduce increased complexity when supporting higher traffic demand, QoS, fairness, and so on. So, one needs a very detailed classification and a comparative study between recent DBA algorithms. This will be the main concern of this work regarding time delay and throughput as evaluating factors.

One can classify DBA algorithms into two categories: the algorithms supporting QoS and ones that do not support QoS [23]. Then, algorithms that support QoS can be divided into two types: the one supporting QoS locally and the other supporting QoS universally.

The algorithms that locally support QoS contain nine branches: 1) Limited scheduling adaptive cycle time, 2) Limited with non-strict priority scheduling, 3) Limited with strict priority scheduling [24-27], 4) Traffic prediction [28], 5) Excessive bandwidth [29], 6) Excessive bandwidth with non-strict priority Scheduling [30], 7) Excessive bandwidth with strict priority scheduling [31], 8) Excessive bandwidth in intra ONU allocation [32], 9) Fuzzy logic [33]. The algorithm that supports QoS universally is performed by Y. Yang [34]. This algorithm consists of two parts. The first part is inter-ONU scheduling, which is a delta DBA based on burst polling. The second part is OLT based intra-ONU scheduling that is responsible for a differentiated priority queuing.

3. Evaluation method and simulation parameters

In this section, the mathematical models used to calculate [delay/throughput] for different DBA algorithms under test are extracted from literature. The evaluation method is based on (OPNET/C++) calculation for these algorithms/models. The parameters and their corresponding values are applied to the mathematical models to generate the targeted comparative study. As the first aim of this work, a comparison between DBA algorithms with respect to throughput and time delay will be carried out targeting the choice of the top four performance algorithms. These selected four top performance algorithms will undergo an optimization parameter process targeting: 1) enhancing the performance, 2) choosing the optimum DBA algorithms among all evaluated ones with respect to time delay and throughput.

The simulation parameters used are extracted from the published work in this field [24-34]. The values of these parameters are as follows:

1. For all algorithms:
   Number of ONUs =16
   Distance between OLT and ONUs = 20 km
   Packet size = 12000 bits
   Ethernet overhead bits =304 bits
   Upstream bandwidth = 1 Gbps
   Max cycling time = 2 ms
   Buffer size = 10 Mbyte
2. Amount of bit rate for ONU to OLT (Mb/s) = 5 to 57.5 for Arishtat and FSD SLA and = 62.5 for n-DBA and e-DBA.
3. Windows size for report message (Byte) = 64 for IPACT Fixed, IPACT Limited, DBA 2, SC-DBA, Sort-DBA.
4. Request message size (bits) = 570
5. Maximum transition window (Packets) = 10 for Arishtat, FSD SLA, CDBA QOS 31 dB, CDBA QOS 26 dB.
6. Guard time (μs) = 1 for TLBA, IPACT Fixed, IPACT Limited, DBA 2, SC-DBA, Sort-DBA, WE-DBA, DBA-APC, IPACT with CBR, CPBA, IPACT with Two Stage Queue, EDSA and = 1.5 for CDBA QOS 31 dB, CDBA QOS 26 dB and = 1.6 for ADBA, YDBA, EBDBA, SDBA and = 5 for Arishtat, FSD SLA, n-DBA, e-DBA, UDBA, MSARF, CPBA-SLA.

4. Numerical results and discussion

The throughput performance and time delay for the DBA algorithms under evaluation is presented to specify the optimum DBA algorithms that achieve a remarkable throughput and time delay performance among all DBA algorithms under evaluation. Then, a parametric optimization process for algorithms is carried out to enhance the performance of these algorithms regarding time delay and throughput.

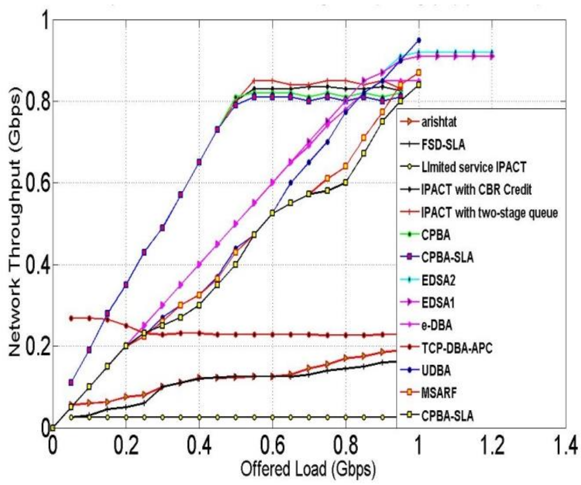
4.1 Throughput performance

In this section, the parameters and their corresponding values are applied to the mathematical models to generate the following throughput performance for the DBA algorithms under evaluation.

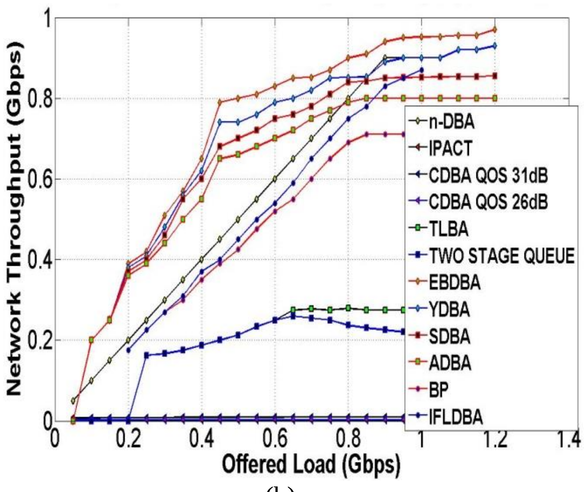
Fig. 1(a, b) represents the network throughput performance as a function of offered load for different algorithms.

Due to the high bandwidth demand required by modern life applications and personal digital assistance (PDAS), this work will concentrate on the order that achieves a remarkable performance at high offered load (i.e. 0.8-1 Gbps) scenario.

This means that this work selection will be: 1) EBDBA, 2) YDBA, 3) IPACT WITH TWO STAGE, 4) n-DBA, 5) SDBA, 6) IPACT WITH CBR, 7) e-DBA, 8) UDBA, 9) CPBA and 10) IFLDBA.



(a)



(b)

Fig. 1. Network throughput for different DBA algorithms

Table 1 represents the order of DBA algorithms according to their throughput performance as a function of offered load as extracted from Fig. 1.

Table 1. DBA algorithms according to throughput performance in a descending order. The time delay values are taken around 0.9 Gbps offered load

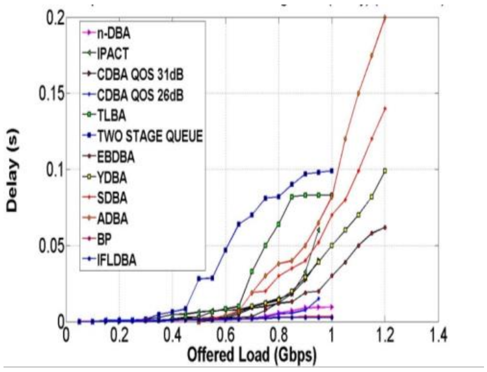
no.	Algorithm	Throughput (Gbps)
1	EBDBA	0.9200
2	YDBA	0.8650
3	IPACT with two stage	0.8500
4	n-DBA	0.8500
5	SDBA	0.8450
6	IPACT WITH CBR	0.8325
7	e-DBA	0.8150
8	UDBA	0.8113
9	CPBA	0.8100
10	IFLDBA	0.7900
11	ADBA	0.7900
12	CPBA-SLA	0.7063
13	BP	0.7000
14	MSARF	0.6750
15	TLBA	0.2760
16	TWO STAGE QUEUE	0.2325
17	DBA-APC	0.2250
18	ARISHTAT	0.1775
19	FSD-SLA	0.15
20	LIMITED SERVICE IPACT	0.1375
21	CDBA QOS 26 dB	0.0090
22	CDBA QOS 31 db	0.0029
23	IPACT	0.0010

4.2. Time delay performance

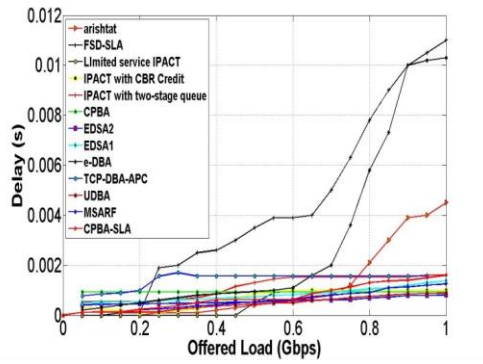
The procedure of throughput is repeated here for time delay performance.

Fig. 2(a) represents the time delay performance as a function of different offered load for the following algorithms (n-DBA, IPACT, CDBA QOS 31dB, CDBA QOS 26dB, TLBA, TWO STAGE QUEUE, EBDBA, YDBA, SDBA, ADBA, IPACT-fixed, IPACT-limit, DBA2, SC-DBA, and Sort-DBA).

Fig. 2 (b) represents the time delay performance as a function of different offered load for the following algorithms (arishtat, FSD-SLA, Limited service IPACT, IPACT with CBR Credit, IPACT with two-stage queue, CPBA, EDSA2, EDSA1, e-DBA, TCP-DBA-APC, UDBA, MSARF, CPBA-SLA).



(a)



(b)

Fig. 2. Network time delay for different DBA algorithms

Table 2 represents the order of DBA algorithms according to their time delay performance as a function of offered load as extracted from Fig. 2.

Table 2. DBA algorithms according to their time delay performance in a descending order. The time delay values are taken around 0.9 Gbps offered load

no.	Algorithm	Time delay (s)
1	UDBA	0.00085
2	CPBA	0.000925
3	IPACT WITH CBR	0.001
4	Limited Services IPACT	0.001
5	MSARF	0.001125
6	CPBA-SLA	0.0014
7	DBA-APC	0.00152
8	IPACT with Two Stage	0.00153
9	IFLDBA	0.0024
10	BP	0.0031
11	ARISHTAT	0.0039
12	CDBA QOS 26 dB	0.0075
13	n-DBA	0.009
14	FSD-SLA	0.01
15	e-DBA	0.01
16	EBDBA	0.019
17	CDBA QOS 31 dB	0.0275
18	YDBA	0.029
19	SDBA	0.04
20	ADBA	0.05
21	TLBA	0.0825
22	Two Stage QUEUE	0.097
23	IPACT	0.323

4.3 Selection of optimum DBA algorithms

Based on the illustrated results in Figs. 1 and 2, the target now is the choice of four optimum DBA algorithms that achieve acceptable throughput and time delay performance simultaneously for more processing.

Two important observations can be extracted from Tables 1 and 2. First, it is difficult to obtain a clear order for DBA algorithms that achieve remarkable throughput and time delay performance simultaneously. This is because the DBA algorithms that achieve a remarkable throughput performance have a lower quality for time delay performance and vice versa. Second, the DBA algorithms in time delay or throughput performance are very close which makes the selection operation more difficult.

However, we try to extract the optimum four DBA algorithms that can achieve acceptable rather than remarkable throughput and time delay performance simultaneously. Accordingly, the order of selection will be: 1) IPACT with two stage, 2) IPACT with CBR, 3) UDBA and 4) CPBA. This selection was made based on approximately the same delay performance for these algorithms so throughput performance takes the priority in the order selection.

5. Optimization process

In this section, the four selected DBA algorithms are enrolled on a parametric optimization process targeting enhancing the performance in each algorithm.

Our strategy for optimization and enhancing throughput and time delay is a numerical iterations process that changing some of parameters to get better result in time delay and throughput performance, for example we try to change and increase line up streaming rate as much as possible, the same for line down streaming rate increasing it as much as possible. Changing the size of Ethernet packets to get it large as possible. Trying to control and change guard time between time slots. This iterations changes give us small enhancing in throughput and time delay performance.

Table 3 contains the parameters of each algorithm with the original values (i.e. default values extracted from literatures as Sec. 2) and the optimized values that are used to enhance the time or throughput performance. Note that, this work will present the enhancement at highly loaded scenarios (load) since acceptable performance for both throughput and time delay is targeted for today and future bandwidth demand as mentioned previously.

A parametric optimization process achieves a reduction in time delay around (3.5% in IPACT WITH CBR), (1.725% in UDBA), (1.167% in IPACT with two stage) and (1.167% in CPBA) and an increase in the throughput by (1.3% in IPACT WITH CBR), (1.795% in UDBA), (2.5% in IPACT with two stage) and (1.684% in CPBA).

Concerning the throughput performance, Fig. 3 represents original values and optimized values. On the other hand, Fig. 4 represents the original values of time delay performance and optimized values.

The increased propagation delay has led to an increased idle time for interleaved-based Dynamic Bandwidth Allocation schemes resulting in poor bandwidth utilization [35].

Table 3. Original values (O) and optimized values (P) of the performance enhancement optimization process

Algoritm	IPACT with two stage		IPACT with CBR		CPBA		UDBA	
	O	P	O	P	O	P	O	P
Parameter								
upstream line rates (Gbps)	1	1.25	1	1.25	1	1.25	3	
down stream line (Gbps)		1.25	1	1.25	1	1.25		
distances between OLT and ONUs (km)	20	15-20	20	15-20	20	15-20		
rate from end user to ONU (Mbps)	100		100		100		1	1.25
size of Ethernet packet (bytes)	1000	1500 582/592	1000 Bytes	1500 bytes 582/592	1000 bytes	1500 bytes 582/592		
max. cycle time (ms)	2	1					2	1
guard time between time slots	1	3.5	2ms	1 ms	1	3.5 ms	5 µs	(1.5-5)

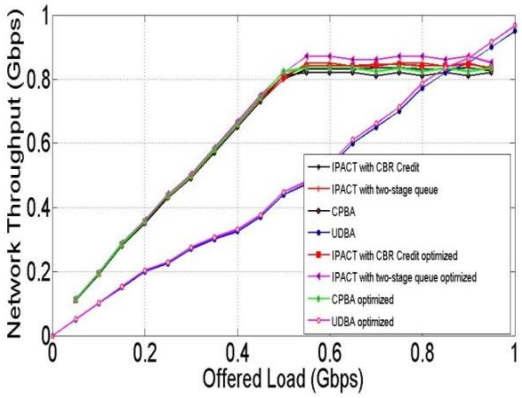


Fig. 3. Original and optimized values of throughput for different DBA algorithms

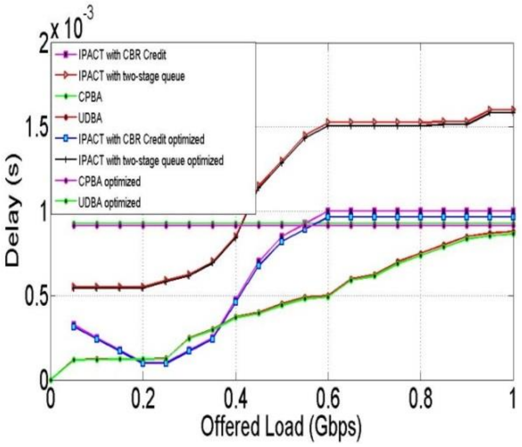


Fig. 4. Original and optimized values of time delay for different DBA algorithms

6. Conclusion

In this work, EPON and its protocols are explained. The classification of famous DBA algorithms regarding throughput and/or time delay is carried out, followed by an extensive comparative study. After that, an optimization process is done on the best algorithms (regarding throughput and delay time) to enhance the performance at highly loaded demands. This process reduces time delay around 3.5% for IPACT WITH CBR, 1.725% for UDBA, 1.167% for IPACT with two stages and 1.167% for CPBA). The optimization increases throughput by 1.3% for IPACT WITH CBR, 1.795% in UDBA, 2.5% for IPACT with two stages and 1.684% for CPBA.

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