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Bandwidth Utilisation of PON Using PDF Based DBA Algorithm

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Abstract
Bandwidth allocation is very pivotal issue in the passive optical networks. By efficiently allocating bandwidth using the appropriate bandwidth allocation algorithm can significantly improve the network performance by guaranteeing the network availability to all the ONU's in the network. In this paper we proposed a efficient PDF based DBA algorithm which uses the last recent polling table for the current allocation of the bandwidth among the ONU's dynamically. This scheme allocates the bandwidth to the ONU's requesting bandwidth lower than minimum guaranteed bandwidth and ONU's demanding bandwidth greater than minimum guaranteed whose PDF in the last polling table is greater than threshold value at the starting of time cycle. It shares excess bandwidth of lightly loaded ONU's to the heavily loaded ONU's. This algorithm uses the early assignment concept thus incorporates the idle period. Through simulation experiments, it is shown that the proposed algorithm can significantly improve the network performance in terms of packet delay, queue length, and bandwidth utilization under high traffic load as compared with a well-known DBA algorithm in the literature.

Keywords
Line Termination (OLT), Optical Network Units (ONU), Passive Optical Networks (PON), Probability Density Function (PDF), Efficient Dynamic Bandwidth Allocation (E-DBA), Minimum guaranteed bandwidth, Requested bandwidth (), Excess bandwidth ()

I. Introduction

Telecommunications today is perhaps the fastest evolving field of study. It is continuously offering new challenges and opportunities to telecommunications network planners. Passive optical network is a very attractive solution to the bottleneck problem in the access networks [1].

Passive optical network consist of OLT and many ONU's consisting only the passive components like splitter all the way down from OLT to ONU. For the downstream direction it is like a point-to-multipoint network a passive splitter acts as a 1:N splitter. Downstream direction is like relay system in which information is broadcasted to all ONU the ONU keeps the information relating to it and discards everything else. But for the upstream direction the network is multipoint-to-point network. Thus all the ONU's shares the single medium to communicate with the OLT. According to the MAC currently for upstream direction it uses one wavelength (e.g. 1310) and another one for the downstream direction (e.g. 1550). Time division multiplexing is used in the upstream direction to separate the transmission of several ONU's to avoid collision. A particular time slot is allocated to the ONU only in which it can transmit its data frames [2].

That is why the bandwidth allocation is very important issue in PON. For a network to be efficient it should have a very efficient bandwidth allocation algorithm. Further the bandwidth can be allocated by two means static or dynamic. In the static bandwidth allocation fixed slots are allocated to the ONU's only in which they can transmit data packets. But in static bandwidth allocation scheme there is too much wastage of the bandwidth. But in the dynamic bandwidth allocation scheme the bandwidth allocated to the ONU in not permanent it can be changed according to the bandwidth requirement of the ONU [3].

According to the IEEE 802.3ah Task Force [4],the ONU can work in two modes: normal mode and auto discovery mode, which is a Multipoint control protocol. In normal mode the MPCP relies on two Ethernet control messages, GATE and REPORT, to allocate bandwidth to each ONU. A GATE message is used by the OLT to allocate a transmission window to an ONU. A REPORT message is used by an ONU to report its local conditions to the OLT. In the auto-discovery mode, the protocol relies on three control messages, REGISTER, REGISTER_ REQUEST, and REGISTER_ACK, which are used to discover and register a newly connected ONU, and to collect related information about that ONU, such as the round-trip time (RTT) and MAC address [4].

The rest of the paper is organized as follows. In Section 2, we introduce review related work. In Section 3, we present the existing Efficient DBA algorithm and proposed algorithm PDF polling using last recent polling table. In Section 4, we evaluate the performance of the proposed DBA algorithm through simulation experiments. In Section 5, we present our conclusions.

II. Related Work

Dynamic bandwidth allocation for EPONs has been widely studied in the literature [5–12]. In [5], Krameret al. proposed an interleaving polling protocol called IPACT. In IPACT, a polling message is scheduled in an interleaved manner with data transmission, which largely reduces the bandwidth overhead caused by the propagation delay and thus increases the bandwidth utilization of the upstream channel. The authors also investigated several bandwidth allocation schemes with IPACT and indicated that the limited allocation scheme exhibits the best performance. In [6], Assi et al. proposed a couple of DBA algorithms to allocate fairly bandwidth for end users and support differentiated services. The proposed algorithms make use of the excessive bandwidth of lightly loaded ONUs to meet the bandwidth demand of heavily loaded ONUs in each transmission cycle and thus improve the performance of the limited allocation scheme. In [7], Luoet al. proposed a DBA algorithm to support differentiated services based on MPCP and busty traffic prediction, which enhances quality of service (QoS) performance over other existing algorithms. In [8], Luoet al. proposed another DBA scheme called limited sharing with traffic prediction (LSTP). LSTP enables dynamic bandwidth negotiation between the OLT and its associated ONUs, alleviates data delay by predicting the traffic arrived during the waiting time and preserving a portion of bandwidth for delivery, and avoids the aggressive bandwidth competition by upper bounding the allocated bandwidth to each ONU. In [9], Maet al. proposed a bandwidth guaranteed polling protocol, which allows the upstream bandwidth to be shared based on the service level agreement

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(SLA) between each subscriber and the operator. This protocol is able to provide bandwidth guarantee for premium subscribers based on SLAs while providing best-effort service to other subscribers. In [10], Anet al. proposed a MAC protocol based on per-subscription-rate queuing with round-robin scheduling and packet reclassification, which guarantees fairness among users by allocating excess bandwidth proportional to their subscription rates. In [11], Byun et al. proposed an estimation-based DBA algorithm to keep the queue length of each ONU low and to reduce the packet delay in the EPON. In [12], Xieet al. proposed a two-layer bandwidth allocation scheme that implements weight-based priority to support differentiated services. In [13], McGarry et al. presented a comprehensive survey of DBA algorithms already proposed in the literature. J. Zheng[14] In the paper, an efficient bandwidth allocation algorithm for an EPON system is proposed. The proposed algorithm uses the multipoint control protocol (MPCP) defined by the IEEE 802.3ah Task Force to arbitrate the transmission of multiple ONUs and incorporates a dynamic bandwidth allocation (DBA) scheme that makes use of the excessive bandwidth of lightly loaded ONUs to meet the bandwidth demand of heavily loaded ONUs

III. Existing Efficient DBA Algorithm

E-DBA algorithm improve the bandwidth utilization of the upstream transmission channel in an EPON system .We consider an EPON system with N ONUs. The transmission rate of both upstream and downstream links is R Mbit/s. The maximum transmission cycle is T cycle, which is the time during which all ONUs get a timeslot to transmit. The guard time between two consecutive time slots is Tguard, which is used to compensate for the fluctuation of the RTT of different ONUs [14]. Under these conditions, the minimum guaranteed bandwidth (in bytes) for ONU-I (i.e., the minimum bandwidth allocated to ONU-i) can be calculated as follows

$$B_{\min}(i) = \alpha_i \times \frac{(T_{cycle} - N \times T_{guard}) \times R}{8}, \quad \sum_{i=1}^{N} \alpha_i = 1 \quad .. \qquad [14]$$

Where α_i is the weight factor for ONU-i based on the service level agreement of the ONU. Owing to the busty nature of Ethernet traffic, however, in each transmission cycle some ONUs may have less traffic to transmit and thus need smaller bandwidth than the minimum guaranteed bandwidth (which are called lightly loaded ONUs), while other ONUs may have more traffic to transmit and need larger bandwidth (which are called heavily loaded ONUs). For this reason, those lightly loaded ONUs would result in an excessive bandwidth that is not needed and the total excessive bandwidth in each transmission cycle can be calculated as follows

$$B_{excess} = \sum_{i \in l} [B_{\min}(i) - B_{req}(i)], \quad B_{\min}(i) > B_{req}(i) \qquad [14]$$

Where Breq(i) is the requested bandwidth of ONU-i and L is a set of lightly loaded ONUs in a transmission cycle. Obviously, this excessive bandwidth can be exploited to meet the bandwidth demand of those heavily loaded ONUs and thus provide better network service to end users. For this purpose, Assi et al. proposed an allocation scheme that allocates the excessive bandwidth among the heavily loaded ONUs in proportion to the bandwidth demand of each of the ONUs [6], which is expressed as follows

$$B_{granted}(i) = B_{\min}(i) + B_{excess}(i)$$

$$B_{excess}(i) = \frac{B_{req}(i)}{\sum_{k \in H} B_{req}(k)} \times B_{excess} \qquad ..[14]$$

where is Bexces(i) is the excessive bandwidth allocated to ONU-i, Bgranted(i) is the bandwidth granted to ONU-i, and H is a set of heavily loaded ONUs in a transmission cycle. To improve bandwidth utilization, an early allocation mechanism was proposed in [6],

which schedules a lightly loaded ONU instantaneously without any delay, whereas schedules those heavily loaded ONUs after the OLT receives all REPORT messages and perform computation for bandwidth allocation. However, this scheduling mechanism may not be able to make sufficient use of the idle period in many cases, which can be observed in Fig3.1. Moreover, while it can significantly improve bandwidth utilization under low and medium traffic load [14], it is unable to make use of the idle period under high traffic load. This is because under high traffic load all ONUs may have a bandwidth demand larger than the minimum guaranteed bandwidth,

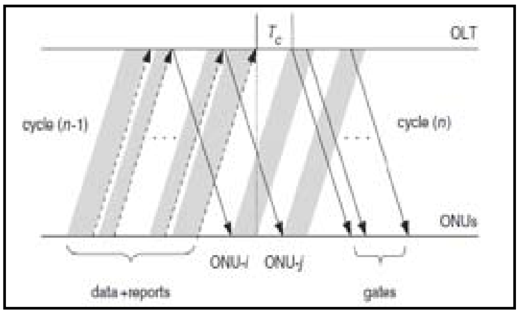

Fig. 3.1 : E-DBA under low load conditions [14]

As shown in Fig.3.2. In this case, the idle period is still wasted, which would degrade the network performance under high traffic load. To further improve bandwidth utilization under high traffic load, we propose a new scheduling control mechanism to address the idle period problem. With this mechanism, the OLT still employs an early allocation mechanism which schedules a lightly loaded ONU instantaneously without any delay [14]. At the same time, it accumulates the excessive bandwidth contributed by each lightly loaded ONU. For those heavily loaded ONUs, the OLT normally waits until all REPORT messages are received to perform the computation for bandwidth allocation and send GATE messages to the ONUs. To ensure that the idle period is not wasted, the OLT maintains a tracker that records the ending time of the timeslot for the last scheduled ONU and updates the tracker every time the next ONU is scheduled [14].

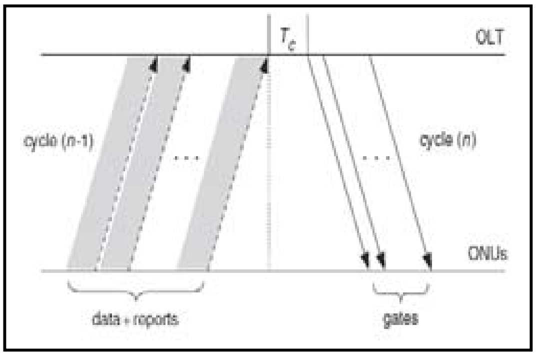

Fig. 3.2 E-DBA under high load conditions [14]

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E-DBA uses the following equation for the distribution of bandwidth among the ONU's.

$$grgranted\ bandwidth(n) = \begin{cases} (req_{bw}(n)_t & if(\ req_{bw}(n) < \min g_{bw}\ ) \\ Wait\ for\ the\ end\ of\ cycle_{(t)} & else \end{cases}$$

This algorithm efficiently utilizes the idle period which results in the lesser delay in the packet delivery. This scheme describes the use of tracker to each assignment to keep the record of the last assignments.

A. Limitations of E-DBA

It is seen at the time of simulation that at the medium loads there is a huge amount of the bandwidth remains unallocated while at the medium loads it has been found that a few number of ONUs can request the bandwidth greater than the minimum guaranteed bandwidth. The existing algorithm does not consider the request those are demanding greater bandwidth than the minimum guaranteed bandwidth yet there is a massive amount of excess bandwidth is present. Thus the ONUs demanding more bandwidth has to wait till the end of the cycle to get demanded bandwidth which leads to the packet delivery delay. To improve the bandwidth utilization at the moderate traffic load we propose a new DBA algorithm that is probability density function based efficient dynamic bandwidth allocation algorithm as given below.

B. New Proposed Algorithm PDF Based DBA Using Last Recent Polling Table

In order to resolve the above mentioned problem we introduced the new DBA algorithm which uses the last recent polling table to assign the bandwidth to those ONU's who continuously demanding the larger bandwidth. In this way the ONU who is heavily buffered can transmit their frames as soon as possible. In this algorithm the ONU's demanding the bandwidth lower than the minimum guaranteed bandwidth and the ONU's demanding the greater bandwidth than the minimum guaranteed bandwidth whose PDF (t-1) in the last recent polling table is greater than the threshold value both are assigned the bandwidth immediately. But the ONU's whose bandwidth request is for higher bandwidth but having PDF (t-1) lower than the threshold value has to wait for the end of the cycle. Thus this scheme allocates the bandwidth to the heavily loaded ONU's immediately this result in the less packet delivery delay hence improves the network performance. The proposed algorithm uses the following equation for the allocation of the bandwidth among the ONU's.

$$granted\ abndwidth(n) = \begin{cases} (req_{bw}(n)_t & if(\ pdf_{t-1}(n) > Threshold\ ) \\ (req_{bw}(n)_t & if(\ req_{bw}(n) < \min g_{bw}\ ) \\ Wait\ for\ the\ end\ of\ cycle_{(t)} & else \end{cases}$$

The formula to measure the excess bandwidth is same as used in the existing algorithm but to allocate the bandwidth to the ONU who is demanding more bandwidth the following formula is used.

$$granted\ bndwidth(n)_t = \begin{cases} (req_{bw(n)})\ \ if\ (Excess\ badwidth > req_{bw}(n) - \min g_{bw})\ ) \\ \min g_{bw} \qquad else \end{cases}$$

The formula to calculate the PDF of the nth ONU in the T-1 cycle is given by as below

$$pdf(n)_{t-1} = \frac{granted\ bandwidth(n)_{t-1}}{\sum total\ bandwith\ allocated\ in(t-1)}$$

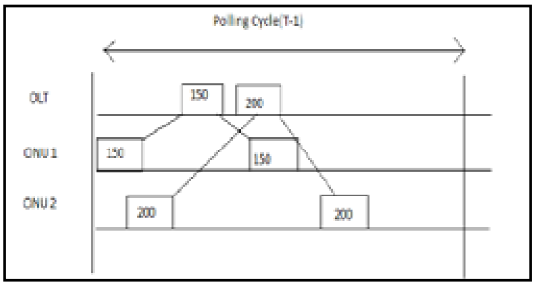
This above formula is used for the allocation of bandwidth to the ONU whose PDF(t-1) is greater than threshold value. Let's understand the working of this new proposed algorithm with a example as given below consider a polling cycle in which there are three ONU's demanding bandwidth 150,200. If the total bandwidth is 1024 and the third ONU just registered in the network which means the PDF of the third ONU in the last polling table is zero as given in the table below

Table 3.1 : Polling table at cycle(t-1)

ONU	requested bandwidth
1	150
2	200

If the minimum guaranteed bandwidth is 300 than the allocation of bandwidth will be according to the existing algorithm will be as shown in diagram below.

Fig 3.3 Polling in cycle (T-1)



Now consider that after the cycle (T-1) Ranging window took place and a new ONU joined and registered in the network as ONU 3 demanding bandwidth 500. Assume that for a next polling cycle that is T ONU1 and ONU2 requesting band width 110 and 250 respectively and their PDF(T-1) are .42 and .58 because in cycle (T-1) total bandwidth allocated is 350. The PDF(T-1) of the third ONU is not available till this cycle thus initialized as zero.

Table 3.2 : Polling table at cycle (t)

ONU	requested bandwidth	PDF in cycle(t-1)
1	110	.42
2	250	.58
3	500	0

Now new proposed algorithm comes in action the polling process in cycle (T) will be as shown in diagram given below.

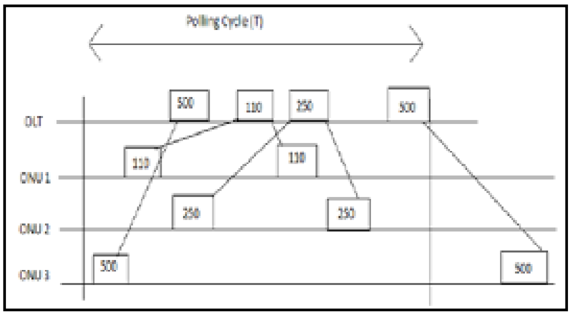


Fig 3.4 : Polling in cycle (T)

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As you can see in the above diagram the given above the third ONU was demanding bandwidth greater than the minimum guaranteed bandwidth but as it was having zero PDF in (T-1) cycle thus it has to wait until the end of the polling cycle for the transmission of its packets. Now consider the cycle (T+1) in which the polling table will be

Table 3.2 : Poling table t cycle (T+1)

ONU	requested bandwidth	PDF in cycle (T)
1	120	.13
2	290	.29
3	320	.58

Here in the cycle (T) total bandwidth allocated 860. Now if the threshold level is above than .3 than the polling process in the cycle (T+1) will be as shown in diagram below.

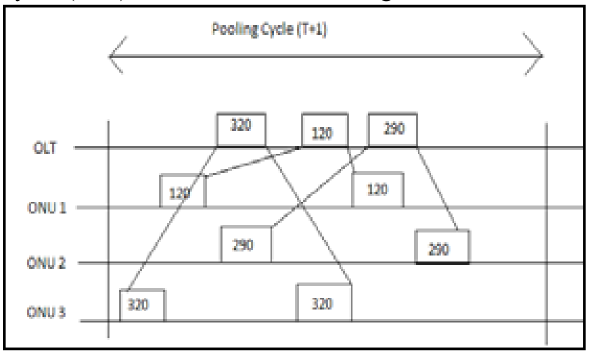

Fig 3.5 : Polling Process in cycle (T+1)

In the above diagram the third ONU 3 demanding the bandwidth greater than minimum guaranteed bandwidth and the PDF of the third ONU in last recent polling table is greater than the threshold level thus it was allocated with the demanding bandwidth instantly. In this proposed algorithm the threshold value is to be assigned so that the average queue length at the ONU is least possible. For the higher value of PDF(T-1) there will be a very few ONU's exceeding that value thus there will be not much improvement. But also if the value of PDF(T-1) is kept very low there will be so many ONU's those can have the value greater than it. Thus lower value will lead to the dead lock where new ONU will never get that bandwidth at medium and higher loads. Thus a intermediate value should be chosen so that algorithm can work at its maximum potential.

IV. Performance Evaluation

In this section we will evaluate the performance of our new proposed algorithm with the existing algorithm. For the general notification the E-polling will represent the efficient algorithm and PDF-polling will represent the new proposed algorithm. We used the maximum packet delay, bandwidth utilization and average queue length at deferent threshold value as the performance parameters. Maximum packet delay is the maximum delay occurred to the packets at the given load. Bandwidth utilization is amount of bandwidth allocated out of total available bandwidth at given load.

A. Simulation Model

In the simulation, we assume that there are 16 ONUs in the system. The upstream and downstream line rates are 1Gbit/s. The distances between the OLT and ONUs are about 20km, corresponding to a propagation delay of about 100ms. According to the IEEE 802.3, the size of an Ethernet packet is variable between 64 and 1518 bytes. For simplicity, we consider packets with a fixed size of 1000 bytes. The traffic load ranges from 0.1 to 1. In addition, we assume that the maximum cycle time is .02ms, and the guard time between two consecutive timeslots is .05ms.ONU get a minimum guaranteed bandwidth of about 62.5Mbit/s.

B. Simulation Results

Fig 4.4 shows the maximum packet delay among the existing and proposed algorithm. In fig 4.4 at the low traffic load as expected there not much difference between two schemes because at the very low loads the bandwidth request is mostly below the minimum guaranteed bandwidth thus both algorithm works in the same way. But at the medium load the maximum delay of new proposed scheme s much lesser as compare to the existing scheme because at the medium loads some of the ONU starts to demand greater bandwidth where the existing schemes doesn't considers them new algorithm acknowledges the higher bandwidth demands those are having sufficient PDF in last recent polling table. As you can see at the higher loads again the performance of the both algorithms is almost same. This is because as the traffic load increases the excess bandwidth decreases thus as most of the ONU's getting almost same bandwidth thus the PDF of the all ONU according to last polling table comes to the almost same level which is less than the threshold value of PDF which is adjusted for the optimum performance at the moderate loads. Thus at the higher loads the proposed and existing algorithm works in same fashion. at different threshold values of PDF(T-1) Fig 4.5 shows the bandwidth utilization among the two schemes. As expected for medium traffic load the new proposed algorithm utilizes more bandwidth as compare to the existing scheme. Fig 4.6 shows the average queue length against traffic loads at different threshold values of PDF. As expected the algorithm performs well at the medium value of half range of the probability density function

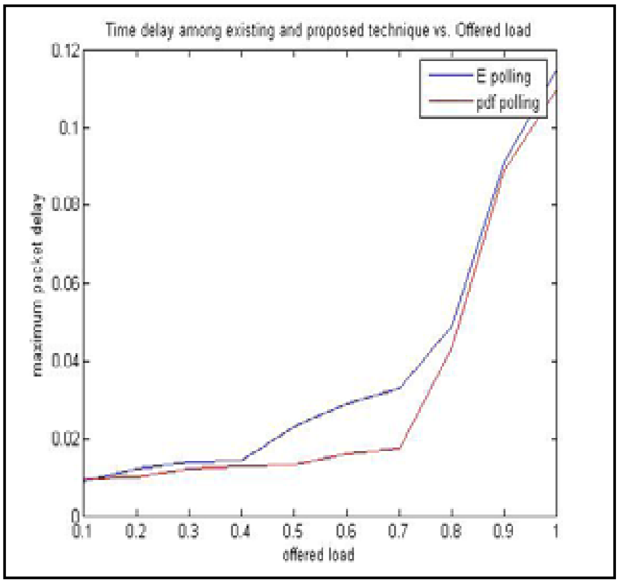

Fig 4.1 : Maximum Packet Delay against traffic load

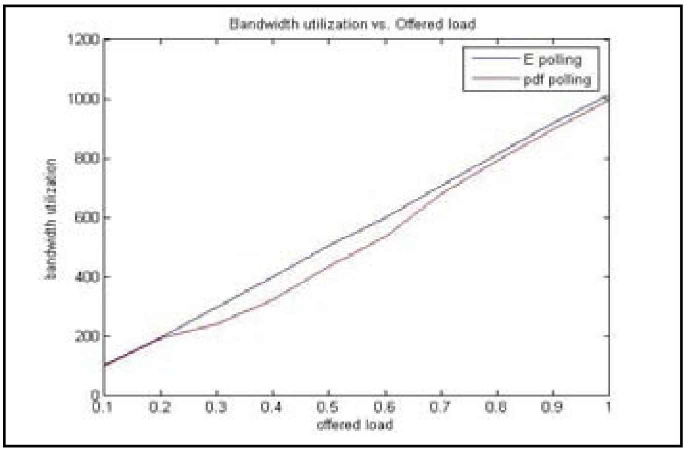

Fig 4.2 : Bandwidth utilization against traffic load

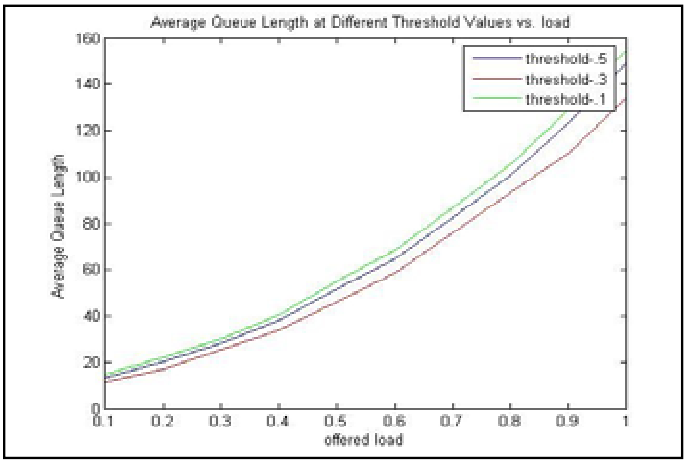

Fig 4.3 : Average queue length against traffic load

V. Conclusion

In this paper, we presented a PDF-polling bandwidth allocation algorithm for EPONs. Based on MPCP, the proposed algorithm incorporates a DBA scheme that makes use of the excessive bandwidth of lightly-loaded ONUs to meet the heavily loaded ONUs in addition to an effective scheduling control mechanism to address the idle period problem. Through simulation results, we showed that under medium traffic load the proposed algorithm can significantly improve the network performance in terms of packet delay, queue length, and Bandwidth utilization as compared with a well- known efficient DBA algorithm proposed. We expect this algorithm will improve the Qos and support the different type traffic loads.

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