Efficient Decentralized Dynamic Bandwidth Allocation in EPON

S.K. Sadon[1], N.A. Radzi[2], N. M. Din[3], M.H. Al-Mansoori[4]

Abstract— **Bandwidth allocation is a critical issue in the design of an Ethernet Passive Optical Network (EPON) system since multiple Optical Network Units (ONUs) share a common upstream channel. Traditionally, bandwidth allocation schemes relied on centralized Dynamic Bandwidth Allocation (DBA) and considered that the Optical Line Terminal (OLT) is the only device that can assess dynamic bandwidth allocation based on Time-Division Multiple Access (TDMA) for the shared upstream channel. This paper proposes an Efficient Distributed DBA (EDDBA) that supports differentiated services and ensures Quality of Service (QoS) for both inter and intra ONU allocation. The proposed mechanism introduces an identical DBA algorithm running simultaneously in each ONU. The simulation performance for the proposed DBA was conducted using prolog and shows more flexibility, reliability and more proper handling for data, voice, and video.**

Index Terms—**decentralized Dynamic Bandwidth Allocation, EPON, and Passive Optical Network.**

I. INTRODUCTION

The anticipated increase in internet usage will not only create more opportunities in distance learning, electronic commerce, and multimedia communication, but it will also create more challenges in organizing information and facilitating its efficient retrieval. From the network perspective, there will be additional challenges and problems in meeting bandwidth requirements and network management. If it is assumed that all users belong to the same administrative domain (say a corporate or campus network), network administrators would like to get most out of the available bandwidth [1], [2].EPON system typically employs TDMA for data transmission in the upstream direction. For this reason, bandwidth management becomes critical in order to efficiently utilize the bandwidth of the shared upstream wavelength [3].

Therefore, a decentralized control is needed to tailor to user's specific needs, eg, emergence of voice, video and peer to peer applications.

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Previously, it was obvious that the EPON bandwidth allocation schemes were relying on centralized architecture and consider that the OLT is the only intelligent device that can arbitrate time-division access to the shared channel[1], [4].

Few researches deal with the decentralized approaches for the EPON. However, most of the solutions provided added additional cost and complexity to the original architecture proposed by IEEE 802.3ah, where the original EPON architecture has to be modified such that each ONU's upstream transmission is echoed at the splitter to all ONUs, each equipped with an additional receiver to receive the echoed transmission. In doing so, all ONUs are able to monitor the transmission of every ONU and to arbitrate upstream channel access in a distributed manner [5]. Note that in such alternate EPON solutions, differentiated QoS is supported by using two independent bandwidth allocation mechanisms, inter-ONU allocation, where the OLT is the only device that can control the upstream transmissions by allocating an appropriate Transmission Window to each ONU. In this case, the OLT passes the request messages to a dynamic bandwidth allocation module (collocated with the OLT) that performs the bandwidth allocation computation and generates grant messages. And an Intra-ONU allocation where the queue management and priority queuing are used to divide the bandwidth allocated by the OLT to a given ONU among the different Class Of Services (COSs) based on their priorities supported by that ONU [3],[6].

In general, combining both allocation mechanisms is required to enable centralized EPON networking architectures to support differentiated QoS. However, since the two allocation schemes are independent of each other, the final bandwidth allocated to a particular QoS for a given ONU may not be the optimum choice. In the case of the proposed decentralized architecture aforementioned which take place at the ONUs without the participation of the OLT, it is observed that such decentralized EPON and DBA algorithm are able to provide high bandwidth utilization but is considered costly [1], [5].

This paper proposed a decentralized direct communicability scheme between the ONUs based on PON original structure as shown in Fig. 1. Supported by an instance of the same DBA algorithm executed simultaneously at each ONU, in which the OLT is excluded from the implementation of the bandwidth assignment. The proposed distributed EPON scheme supports differentiated services and ensures QoS for both inter and intra ONU allocation performed at the ONU leading to the notion of integrating both mechanisms at the ONU.

II. PREVIOUS WORK

Sherif*et. al*, [7], proposed a novel Ethernet over a star coupler-based PON architecture that uses a fully distributed TDMA arbitration scheme. Supported by the decentralized scheme, the paper proposes several QoS-based DBA algorithms in which the OLT is excluded from the implementation of the time slot assignment.

In E. Wong's article [8], the network frame is simulated in a Local Area Network (LAN) and all ONUs are connected with one star coupler by two fibers, and ONUs could accept the frames transmitted by other ONUs.

A.S.M. Delowar, *et.al*,[9],introduced two works: a simulation study of a distributed Dynamic Bandwidth Allocation (DBA) scheme over a decentralized architecture and an experimental study to explore the control plane feasibility of such architecture. However, the proposed decentralized architecture increased the complexity and cost of the ONUs.

Feng*et al*,[10] published an article analyzing a new distributed dynamic bandwidth allocation using simulation. The proposed algorithm need not modify the existing EPON architecture, but only transfers the requested bandwidth information transmitted to all ONUs by using the broadcasting agency of OLT. It is completely in accordance with the Multi Point Control Protocol (MPCP) protocol regulated by the IEEE 802.3ah standard and only needs to add some new fields in the REPORT frame and GATE frame. However, this algorithm doesn't support Diffserv and leads to an inefficient QoS.

However, when the network span is extended to 100 km and beyond, as suggested by next generation long-reach PONs (LR-PONs), the increased propagation delays severely degrade the performance of these algorithms since they are based on bandwidth negotiation messages frequently exchanged between the ONUs and the OLT. Helmy *et al*.[11], proposed a decentralized media access scheme for the emerging LR-PON that would enable faster transmission of upstream packets. They accompanied this scheme with centralized control over the network by proposing communication between ONUs over a control wavelength to manage media access. This wavelength is reflected back, creating a multipoint- to-multi point network among ONUs by attaching a Fiber Bragg Granting (FBG) to the splitter. However, his technique required additional ONU transceivers even though they operate at rates less than 100M Bps.

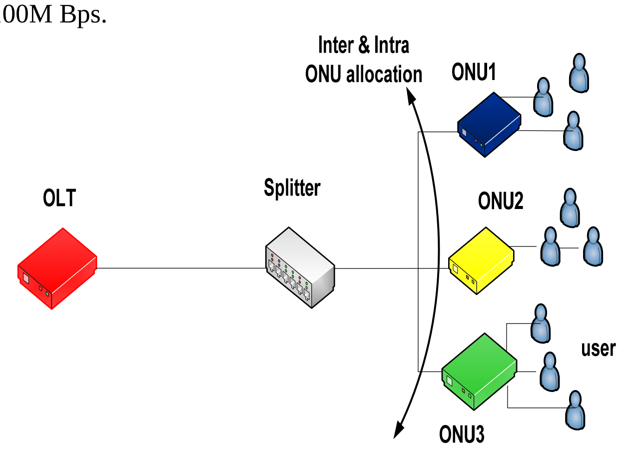

Fig.1 Decentralized Inter & Intra allocation

III. DECENTRALIZED EDDBA'S OPERATION

The flow chart of the proposed Efficient Distributed DBA (EDDBA) is depicted on Fig.2. EDDBA is using the existing PON structure with no modification [12], [13] and only transfer the information window transmitted by one ONU to the other ONUs by broadcasting, similar to the OLT functionality. In the downstream direction, the OLT will insert a "broadcast" link ID which will be accepted by every ONU which complies with the MPCP requirements as outlined in the IEEE 802.3ah standard,/ The OLT will then add some fields in the REPORT frame and the GATE frame. To avoid frame duplication when an ONU receives its own frame, the ONU accepts a frame only if the frame's link ID is different from the link ID assigned to that ONU. All information will be kept in a look- up table to be used later in bandwidth allocation decision making.

In the proposed algorithm, the ONU decides the size of time slot, and transmits the REPORT frame to OLT, and after OLT receives the REPORT frame, it broadcasts the GATE frames at once to all ONUs, and the authorization length is the time slot requested by ONU. OLT adds some extra information in the GATE frame, so ONU could compute the size of the uplink transmission window. Extra information includes the proportion bandwidth requested for each ONU from the total offered bandwidth in one polling cycle. ONU could identify the size of other ONUs' transmission windows in last polling cycle by this information.

The decentralized algorithm will run simultaneously at each ONU, and the requested bandwidth for each ONU is then calculated using:

$$R_{onu} = R_{onu}^{data} + R_{onu}^{video} + R_{onu}^{voice} \qquad (1)$$

If the requested bandwidth is less than the allowed bandwidth then the bandwidth given is the requested bandwidth based on Differentiated Service (Diffserv) criteria where the voice will get up to 20% of the available bandwidth with the highest priority, the video's portion is 40% with medium priority and the data's share is 40% with lowest priority.

If the total demanded bandwidth is higher than the available bandwidth then excessive bandwidth from other ONUs will be considered as in equations below in the same manner as the algorithm in [14].

$$B_{total}^{demand} = \sum_{onu=1}^{N} R_{onu}^{k} - \sum_{onu=1}^{N} B_{onu,k}^{min}$$

$$B_{total}^{excess} = \sum_{i=1}^{N} B_{onu,l}^{min} - \sum_{onu=1}^{N} R_{onu}^{l} \qquad (2)$$

Then the extra bandwidth will be distributed between the ONUs using equation (3) below [14], where R_{onu}^{k} represents ONUs with heavy load, while R_{onu}^{l} represents ONUs with light load.

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$$B^{onu}_{excess} = \frac{R_{onu}}{\sum_{K \in i} R^{k}_{onu}} * B^{excess}_{total} \quad . \qquad (3)$$

To ensure the efficient utilization of excess bandwidth, the excessive bandwidth should be shared according to the requested bandwidth within the overloaded group.

B^{onu}_{excess} is compared with the requested bandwidth, if it is higher than R_{onu} , then the bandwidth given will be only as much as requested. Therefore, no extra unused bandwidth will be wasted.

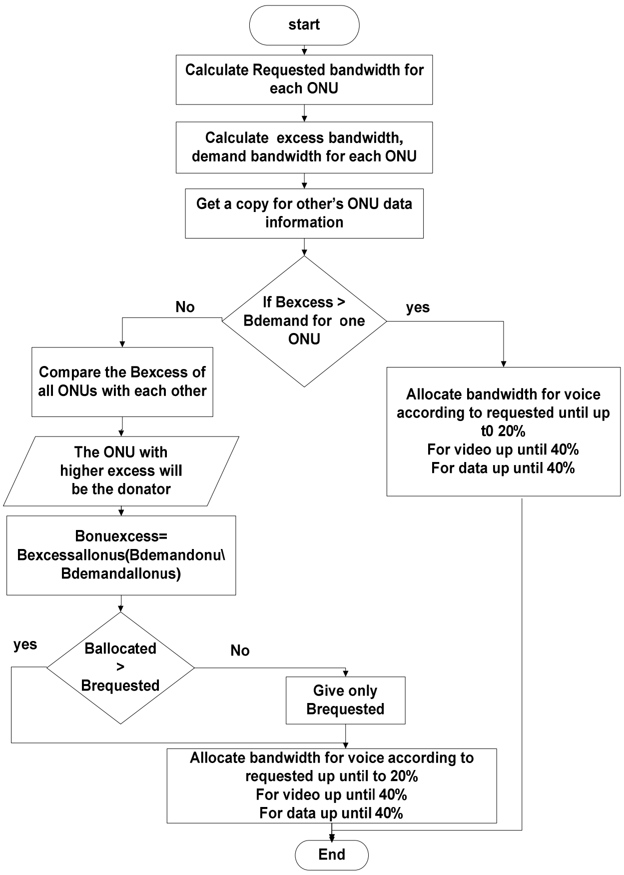

Fig.2 Flow chart of the Efficient Distributed DBA

IV. PERFORMANCE STUDY

The performance model comprise of ONUs that maintain three separate priority queues which share the same buffering space to allow straight forward mapping of DiffServ's expedited forwarding (EF), assured forwarding (AF), and best effort (BE) classes [7].

A simulation study was performed with the traffic profiles as shown in Table 1. Considering three priority classes P0, P1, and P2, with P0 being the highest priority constant-bit-rate (CBR) used for delivering voice, and P1 for variable-bit-rate or (VBR) traffic, which represents the video stream, and P2 the best-effort data. The simulation study was conducted using the PROLOG simulation interface window [15], as shown in Fig.3.

TABLE I
SIMULATION PARAMETERS

Symbol	Amount	Description
ONU	3-16	Total numbers of Optical Network Units
G	1G	Total bandwidth
D	10Km-100km	OLT - ONU distance
T	2ms	Cycle time
T_g	1 µs	Guard time
B_{min}	1G/ONUs	Minimum bandwidth can be allocated to each ONU
B_i^{voice}	20% Balloc.	bandwidth percentage for voice of total allocated bandwidth
B_i^{video}	40% Balloc.	bandwidth percentage for video of allocated bandwidth
B_i^{data}	40% Balloc.	bandwidth percentage for data off allocated bandwidth

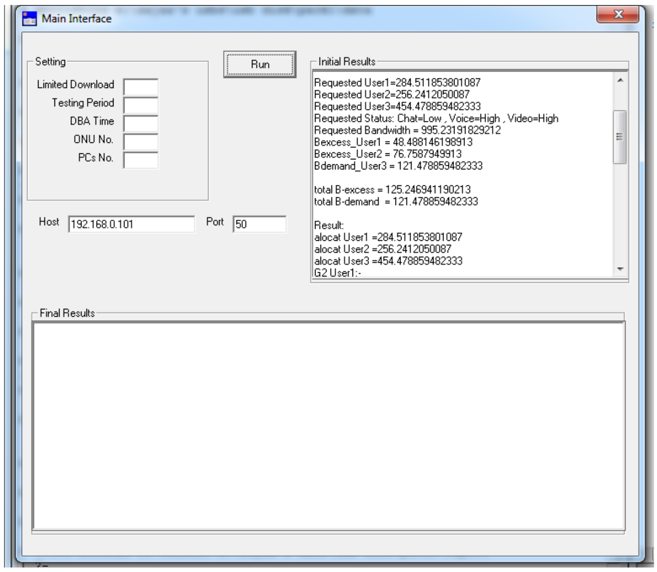

Fig.3 PROLOG simulation interface window

The starting point for our comparative study is to look at how the offered load affects the bandwidth utilization of the IPACT [16] and EDDBA. An efficient decentralized DBA algorithm strives to achieve as high bandwidth utilization as possible. The bandwidth utilization is calculated as follows:

$$B.U = \frac{B^{actual}_{used}}{B^{offered}_{total}} * 100\ \% \qquad (4)$$

The simulation can be done with any number of ONUs. However, 3 ONUs considered in simulation for cooler data collection.

The simulation was conducted for seven various traffic conditions ranging from low voice, low video, low data requested bandwidth to high voice, high video, high data requested bandwidth using PROLOG. The improvement of the bandwidth utilization for EDDBA shows a useful performance in Fig. 4, 5, and 6 for voice, video, and data respectively in comparison to the IPACT algorithm due to the efficient reuse of unclaimed access bandwidth.

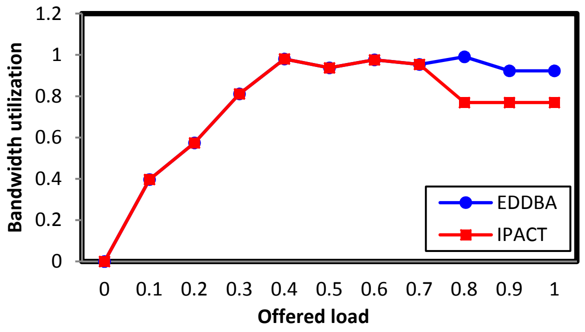

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Fig.4 bandwidth utilization versus offered load for voice

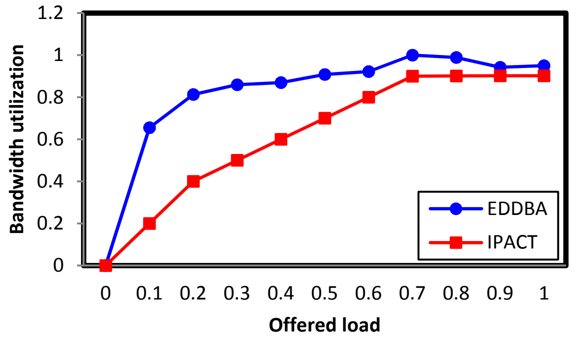

Fig.5 bandwidth utilization versus offered load for video

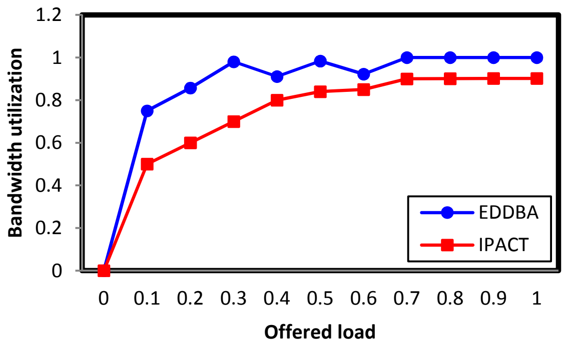

Fig.6 bandwidth utilization versus offered load for data

V. Conclusion

The proposed EDDBA ensures inter and intra–ONU allocation algorithm independently at the ONU's side, supports triple play classes and improve bandwidth efficiency by allowing the ONUs to share the uplink bandwidth according to their bandwidth demands for different traffic priority classes autonomously. The performance of the decentralized EDDBA is analyzed to prove the bandwidth utilization based on DiffServ functionalities with around 20% in contrasted to IPACT.

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