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Performance Evaluation Of Bandwidth Scheduling Techniques In Passive Optical Networks

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***Abstract*— Passive Optical Networks are thought to be the next step in the development of Access Networks and providing broadband access in the ”last mile” area. Ethernet PONs (EPON) gain the most attention from the industry as they offer highly flexible, cost effective solution. In this paper we propose algorithms that provide Dynamic Bandwidth Allocation and shift the burden of queue management from the customer to the network, this results in less complicated and more generic equipment used on the customer's premises. We show the results of simulations to validate the effectiveness of algorithms presented.**

I. Introduction

With the increasing popularity of the Internet the traffic generated by domestic and small business users has been growing constantly over the last couple of years. Various technologies have been deployed to provide broadband access to the network in the area known as the ”last mile”. As network operators strive for cost efficiencies, Passive Optical Network (PON) seem to be the next step in the development of Access Networks (AN).

A PON is a point-to-multipoint all optical network with no active elements in the path between the signal source and the destination. On the network side there is an Optical Line Terminator (OLT) unit. The OLT is usually placed in the local exchange and it acts as a point of access to the Wide or Metropolitan Area Network. On the customer's side there is an Optical Network Unit (ONU). An ONU can be placed either in the curb, building or home and its primary task is to convert data between optical and electrical domains.

Two protocols, Asynchronous Transfer Mode (ATM) and Ethernet, have been proposed as the trans- mission protocol in PONs. In recent years EPONs have gained more attention from the industry. The architecture of an Ethernet network is simple yet extremely efficient. Interoperability between old and new networks can easily be maintained and legacy solutions can be used as EPON data is carried in standard Ethernet frames.

Typically EPON networks are connected in a tree topology with multiple ONUs attached to a single OLT by means of optical splitters as shown in Figs. 1 and 2. In a downstream (network→user) transmission the OLT uses all the available bandwidth to broadcast packets through the splitter/coupler to every ONU. Each ONU extracts packets from the stream based on the Medium Access Control (MAC) address.

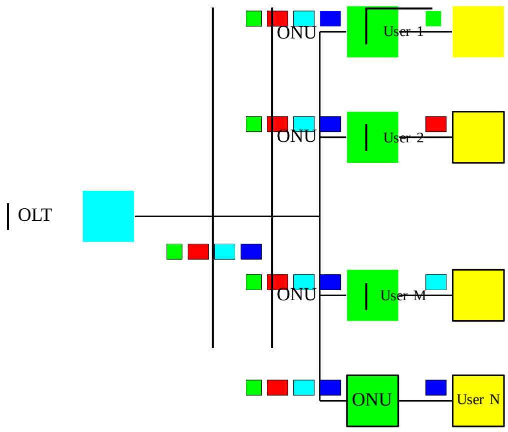

Fig. 1. Downstream transmission in EPON.

In the upstream direction packets sent by an ONU can only reach the OLT as optical splitter prevents an ONU from receiving packets from other ONUs. In order to avoid collisions between frames from different ONUs at the optical splitter available bandwidth must be shared among all ONUs. The OLT is responsible for assigning a non-overlapping time-slot to each ONU, and ONUs can only transmit during that time-slot. During an off period packets are buffered and when the time arrives send in a burst using all the available bandwidth.

One of the key features of EPON networks is their ability to support Differentiated Services (DiffServ) [1] architecture and offer various levels of quality of service (QoS). Generally three classes of traffic can be distinguished: Expedited Forwarding (EF), Assured Forwarding (AF), and Best Effort (BE). EF services (primarily voice and video) have very strict requirements and demand a constant, low end-to-end delay and jitter. AF services tend to be less sensitive to packet delay but require a guaranteed amount of band- width. BE traffic is generated by applications that have no strong requirements regarding traffic properties.

In this paper we analyze various Dynamic Band- width Allocation (DBA) algorithms that support

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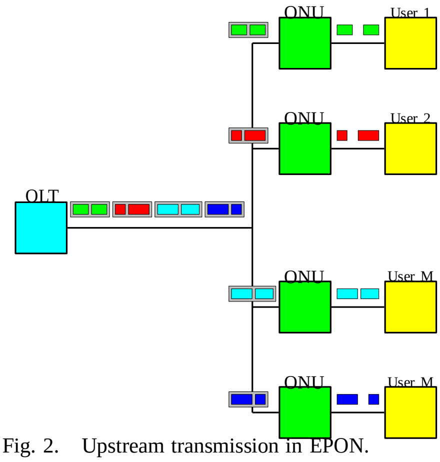

Fig. 2. Upstream transmission in EPON.

DiffServ architecture. In comparison to algorithms already presented in literature, the OLT should be responsible for granting time on a per class rather than per ONU basis, so no intra-ONU scheduling exists. This ensures that the equipment on the customer's side is kept as simple and inexpensive as possible.

II. Background

In EPON networks ONUs cannot transmit at the same time. It is the OLT's responsibility to divide the available bandwidth between ONUs. To achieve that the OLT assigns a non overlapping time-slot to every ONU. In a static bandwidth allocation (SBA) a fixed amount of time is assigned to every ONU. Algorithms with and without support for differentiated services based on a static bandwidth allocation were studied in [2], [3]. The obvious disadvantage of SBA is that bandwidth cannot be utilized efficiently. This is es- pecially true in the case where the difference between bandwidth requested by and bandwidth assigned to the source is large.

In [4], a DBA algorithm called "Interleaved Polling with Adaptive Cycle Time (IPACT)" was presented. This algorithm allocates time slots based on infor- mation received from ONUs during a polling cycle. IPACT provides statistical multiplexing and gives good bandwidth utilization but due to a variable polling cycle, delay sensitive services are hampered.

Dynamic bandwidth allocation combined with priority scheduling algorithms were studied in [4], [5]. In both papers OLT is responsible for granting time slots to ONUs. Every ONU assigns packets to different queues based on their QoS demands. The main disadvantage of this approach is that to fully support DiffServ, an ONU has to have knowledge about the SLA between a customer and the network provider. Here, we propose a different approach where all packet scheduling is done at the OLT and the ONU's functionality is limited to the minimum. The bandwidth is allocated per class of traffic rather than per ONU. For every class the OLT informs an ONU about the allocated transmission window with a Multi-Point Control Protocol (MPCP) [6] GATE message.

Removing the scheduling mechanism from an ONU has two benefits. Firstly the ONU becomes a very sim- ple unit that is easy to manufacture and is inexpensive to maintain. Secondly greater flexibility is achieved as the ONU becomes independent from the OLT. Various scheduling algorithms can be deployed on the OLT without any modifications at the client side. Hence Service Level Agreements (SLA) can be introduced, changed and modified at any time.

III. Dynamic Bandwidth Allocation with DiffServ Support

An efficient bandwidth allocation algorithm is the key to enabling PONs that support DiffServ. Before transmission windows are assigned, various parameters must be taken into account. As for the EF class, delay and jitter are the priority. AF class usually demands various levels of certainty that packets reach the destination and BE class has no strong requirements regarding QoS. The algorithm must balance these factors to achieve the optimal utilization of available bandwidth.

Two MPCP messages are involved in the exchange of control information. The REPORT message is used by an ONU to periodically inform the OLT about the length of its queues. On the other side the OLT issues GATE messages to notify each ONU about transmission times assigned to every class.

A granting cycle is a time in which all active ONUs should have a chance to transmit their data. An increase in the duration of a granting cycle leads to larger delays experienced by packets, as ONU must wait for a longer period of time for its opportunity to send its data. Conversely making a granting cycle too short leads to more bandwidth being wasted to guard intervals that are necessary to separate transmission from two ONUs.

There are two categories of bandwidth allocation algorithms. In static allocation every ONU/class is assigned its fixed share of bandwidth. In dynamic allocation bandwidth is assigned proportionally to the reported queue length. Data that can't be sent during a granting cycle has to wait for the next opportunity.

Here, we want to present new algorithms that could be used with EPONs supporting different classes of service. Let the system have N ONUs with q queues at each ONU. Also, let $B_{n,q}$ be a percent of the total bandwidth requested/assigned to a queue q at ONU n.

A. DBA with Priority Transmission Order - DBA-P

In this algorithm at the first stage every class is as- signed bandwidth that is proportional to the bandwidth requested.

$$B_{n,q}^{assigned} = \frac{B_{n,q}^{request}}{\sum_{n,q} B_{n,q}^{request}} \tag{1}$$

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To improve the performance of this algorithm for high priority traffic every ONU has a chance to transmit its EF packets at the beginning of the granting cycle.

B. DBA with a Guaranteed Minimum band- width - DBA-GM

This approach is a tradeoff between static and dynamic allocation schemes. Every class is assigned some minimal amount of bandwidth that was agreed in the SLA between the network provider and a customer. The amount of bandwidth assigned is dependent on the priority of the traffic.

$$B^{min} = \sum_{n,q} B^{min}{}_{n,q} \text{ and } B^{min} < 1 \qquad (2)$$

The remaining bandwidth is assigned to all classes proportionally to the bandwidth required.

$$B^{avail} = 1 - B^{min} \qquad (3)$$

$$B^{excess} = \sum B^{request}{}_{n,q} - B^{min}{}_{n,q} \qquad (4)$$

$$B^{assigned}{}_{n,q} = B^{min}{}_{n,q} + B^{avail} \div B^{access}(B^{request}{}_{n,q} - B^{min}{}_{n,q}) \qquad (5)$$

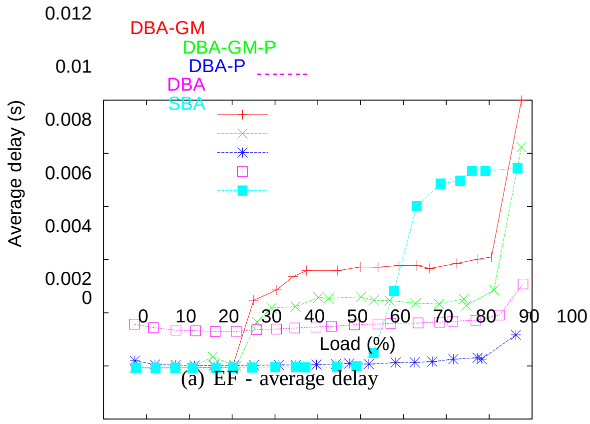
As in DBA-P in order to minimize the delay and jitter experienced by EF classes, these classes are assigned bandwidth at the beginning of the granting cycle. The modified version of DBA-GM scheme is shown as DBA-GM-P.

IV. Performance Evaluation

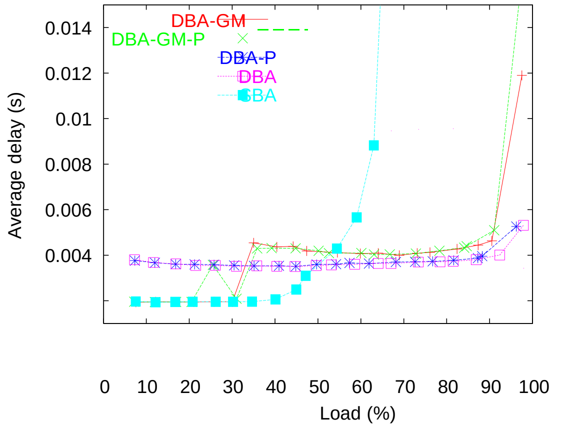
To measure the performance of each bandwidth allocation algorithm we designed an event-driven C++ based EPON simulator. In our research we used 16 ONUs connected in a tree topology to a single OLT operating at a speed of 1Gb/s. Each ONU has three queues with an independent buffering space. The guard time between transmissions from different ONUs is set to 1µs and the value of Inter-Frame Gap (IFG) between Ethernet packets is 96 bits. In our simulator the length of a granting cycle stays the same throughout the simulation.

It has been shown that most network traffic (i.e., http, ftp and VBR services) is best characterized by self-similarity and long-range dependence [7]. To model a high priority EF class of traffic (e.g., voice applications) a Poisson distribution is generally used. In our simulator we used a class of a high priority traffic with a fixed packet length of 70 bytes. A length of packets for AF and BE classes was uniformly distributed between 64 and 1518 bytes. We ran our simulations for various proportions in the volume of EF, AF and BE traffic. Average and maximum packet delay were measured during experiments.

We compared the performance of algorithms pro- posed in this paper with the performance of SBA and DBA algorithms. The results for 20% of EF, 40% of



(a) EF - average delay



(b) AF - average delay

Fig. 3. Algorithms performance comparison. EF - 20%, AF - 40% and BE- 40%.

AF and 40% of BE traffic are presented in Figs. 3 and 4, and for 30% of EF, 60% of AF and 10% of BE in Fig. 5.For light loads the SBA scheme showed better performance compared to other algorithms. On the other hand for heavy loads average and maximum delays are much longer than for other algorithms.DBA algorithm showed a steady performance under various conditions and the difference in the average delay for small and large loads was not larger 2ms.The DBA-P scheme gave good results for both EF and AF classes of traffic. The values of an average delay for light loads are similar to SBA. For heavy loads DBA-P outperforms all other algorithms. The DBA-GM algorithm showed properties of both static and dynamic allocation. Under low traffic conditions the average delay was as low as for the SBA. If traffic offered was average or heavy it behaved as DBA, although its performance was worse as some bandwidth was statically allocated.

The improved versions of those algorithms (DBA-GM-P) produced better results, due to the fact that high priority packets were sent at the beginning of every granting cycle in passive optical networks.

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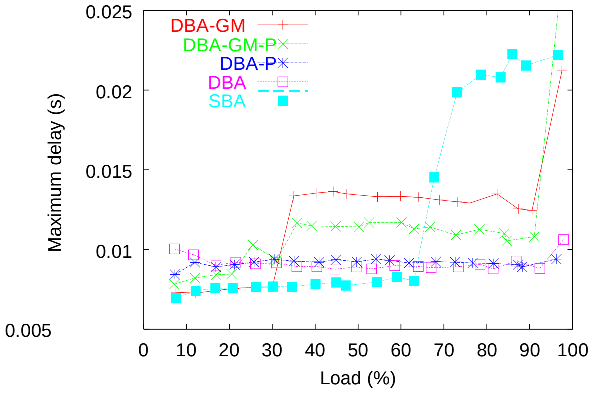
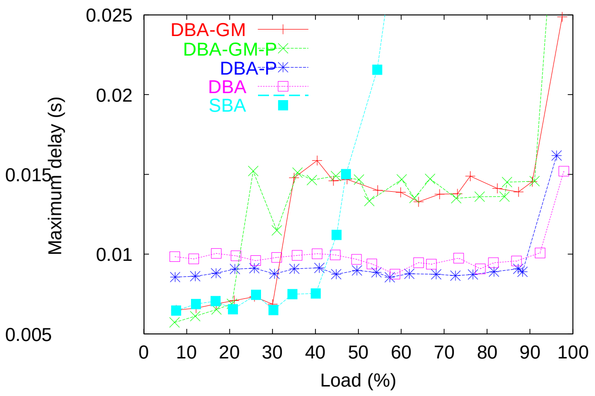
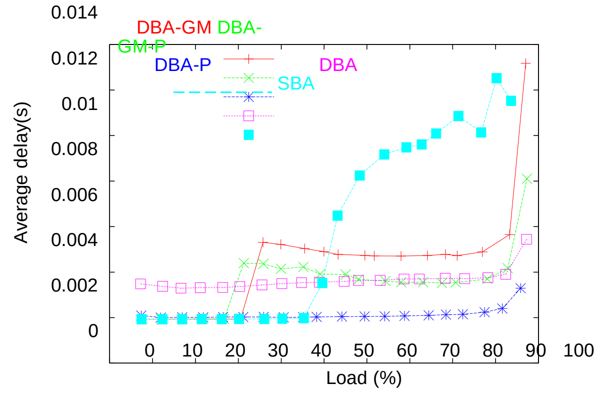


(a) EF - maximum delay

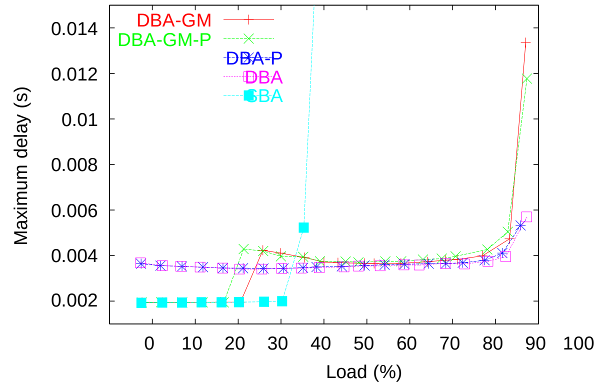


(b) AF - maximum delay

Fig. 4. Algorithms performance comparison. EF - 20%, AF - 40% and BE- 40%.



(a) EF



(b) AF

Fig. 5. Average delays comparison for EF - 20%, AF - 60% and BE- 10%.

V. Conclusion

In this paper we addressed the problem of the sup- port for DiffServ in EPON. We proposed algorithms that shifted the responsibility of Access Control and queue management from the ONU to the OLT, as this creates a possibility of developing more generic, less complicated hence cheaper equipment.

We introduced new algorithms that supported that scheme. We ran detailed simulation experiments to analyze their performance.

A novel DBA-P scheme showed the best performance for EF and AF class of traffic. The disadvantage of this approach was that as the bandwidth was as- signed proportionally to the reported length of queues there was no mechanism to guarantee that the user was allocated as much bandwidth as it was promised in the SLA.

We addressed that problem and proposed an DBA-GM algorithm, where a protection of parameters was achieved by static assignment of a certain amount of bandwidth agreed in the SLA. The results showed that DBA-GM performance was comparable but not as good as the DBA scheme. Considerable improvement in the values of average delay for EF classes was achieved when a mechanism of priority transmission was applied.

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