Partially Online Dynamic Bandwidth Allocation Algorithm for Hybrid TDM/WDM EPON

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Abstract—**Dynamic Bandwidth Allocation (DBA) is a fundamental task in Ethernet Passive Optical Networks (EPONs). An EPON must use an efficient DBA to achieve good network performance. A variety of DBA algorithms have been proposed towards this end. Most of these algorithms use average packet delay as an important metric for measuring the performance of the algorithm. In this paper, algorithms for Time Division Multiplexed (TDM) EPON and Hybrid TDM/WDM (wavelength division multiplexed) EPON are briefly reviewed. A Partially Online DBA (ParOnD) for Hybrid TDM/WDM EPON is proposed to improve bandwidth utilization in Hybrid EPONs. After evaluation of ParOnD against a comparable algorithm for Dynamic Wavelength and Bandwidth Allocation (DWBA-2), it is analyzed that ParOnD reduces both packet delay and the average queue depth of an Optical Network Unit (ONU) over low to medium loads. Thus, ParOnD improves bandwidth utilization considerably. In the paper, analysis of the algorithm, its shortcomings and possible future improvements are discussed.**

Keywords: Hybrid Ethernet Passive Optical Network; dynamic bandwidth allocation (DBA); bandwidth utilization;

I. INTRODUCTION

The growth in Internet traffic and the emergence of high bandwidth-demanding applications have made the current copper based access infrastructure obsolete. Access networks are moving towards the adaptation of Ethernet Passive Optical Networks (EPONs). EPONs have proved to be the most promising and cost-effective solution, as described in [6]. Interoperability with existing Ethernet LANs also makes EPONs the preferred choice. The Ethernet in the First Mile (EFM) working group, which is the standardization body of EPONs, defines standards of IEEE 802.3ah [2]. The EFM has developed a polling mechanism based on Multipoint Control Protocol (MPCP). MPCP provides a control mechanism to implement a bandwidth allocation algorithm that dynamically allocates channel access to the central office and subscribers. Early EPON is a multipoint TDM based architecture. The architecture consists of a wavelength for downstream broadcast transmission and a wavelength for shared/time slotted upstream transmission. As the number of users increases, bandwidth demand is intensified, while the current TDM EPON networks provide limited bandwidth which would become insufficient for the number of users. Therefore, the need to migrate from TDM PONs to hybrid TDM/WDM and in future to WDM PON is imminent. WDM PON could be an ideal solution but has a huge deployment cost. A possible way to upgrade is to increase the line rate as mentioned in [7] but this would require up-gradation of the transceivers to support higher data rates. Another possible migration path from TDM to WDM PON is based on collector ring [3]. Ultimately, the improvement in bandwidth utilization is one of the foremost goals. In this paper, a novel dynamic bandwidth allocation algorithm for hybrid TDM/WDM EPONs is proposed in section IV. Its performance is then evaluated against the best performing variant of scheme discussed in [4]. In Section II related work is discussed, Section III presents the network architecture for our proposed bandwidth allocation algorithm whereas our algorithm is presented in Section IV. Evaluation of our algorithm is discussed in Section V where our simulation parameters are also described. Our conclusion is discussed in Section VI.

II. RELATED WORK

In section I, it is discussed that the deployment of WDM EPONs is expensive, therefore researchers are working on problems associated with up-gradation from TDM to WDM EPONs and hybrid TDM/WDM EPONs. The authors in [3] have presented the architecture called SUCCESS-HPON, which uses a combination of a collector ring ending in star topology. The authors in [4] have presented three variants, named DWBA-1, DWBA-2 and DWBA-3, of a Dynamic Wavelength and Bandwidth Allocation (DWBA) algorithm for WDM based EPON. The DWBAs use the MPCP extension for WDM PONs through which an Optical Line Terminal (OLT) can dynamically allocate wavelengths and time slots to the Optical Network Units (ONUs) [8]. Their architectural model uses tunable components both at the OLT and the ONU. In variant DWBA-1, OLT first collects REPORT messages from all ONUs to find out the bandwidth requirements of the ONUs and then sends GATE message (allocating bandwidth) to the requesting ONUs if the Requested Bandwidth (B_{req}) is within the Minimum Guaranteed Bandwidth (B_{min}). B_{min} is

based on the Service Level Agreement (SLA) and the weight assigned to that ONU. The excess bandwidth of lightly loaded ONUs is computed and is assigned to the requesting highly loaded ONUs in a round robin fashion along with B_{min}. The extension of a Fair-Excess (FE) allocation scheme is proposed in [8]. The proposed FE assigns excess bandwidth to high loaded ONUs according to the bandwidth demand. The variant DWBA-2 is the best performing among the three proposed DBA variants: the OLT does not wait to receive all report messages before sending a GATE message but sends a GATE message immediately only if the requested bandwidth is $B_{req} \leq B_{min}$. Otherwise the OLT waits for all the remaining ONUs (that are highly loaded) to send REPORT messages. Once the last REPORT message is received, it computes excess bandwidth and then sends GATE messages to all the highly loaded ONUs. The only difference here is that the lightly loaded ONUs are scheduled immediately resulting in improved delay performance. In DWBA-3, the OLT sends GATE messages on fly to the requesting ONUs as soon as their REPORT message is received, no matter if $B_{req} \leq B_{min}$ or $B_{req} > B_{min}$. Therefore, after all ONUs have sent REPORT messages and the OLT has sent them a GATE message allocating bandwidth equal to their demand i.e. B_{req} in the case of lightly loaded ONUs and equal to B_{min} in case of highly loaded ONUs, the OLT performs its excess bandwidth computation and then assigns another window to the overloaded ONUs. So, the lightly loaded ONUs are assigned one transmission window whereas the highly loaded ONUs are assigned two transmission windows within a cycle. This leads to more overhead and therefore to bandwidth wastage. Out of the three variants presented in [4], DWBA-2 performs best as it allocates B_{min} on the fly to lightly loaded ONUs and consolidates grants to highly loaded ONUs. The authors in [1] present two algorithms called DBA-1 and DBA-2. In DBA-2 the OLT performs on the fly allocation for lightly loaded ONUs but waits until all REPORT messages are received before computing excess bandwidth and allocating bandwidth to the highly-loaded ONUs. This leads to an idle time between the time the last REPORT message is sent by an ONU and the time the first grant for a highly loaded ONU begins. In [5], the authors proposed an algorithm called n-DBA for reduction of the idle time, as mentioned in [1]. In the algorithm, the OLT maintains a tracker that records the end time for the last scheduled ONU. In [5], the authors have compared n-DBA against the well-know algorithm (called DBA-2 in [1] or e-DBA in [5]) proposed in [1]. Both algorithms perform on the fly allocation for lightly loaded ONUs and compute the accumulated excess bandwidth by keeping track of the excess bandwidth. In n-DBA, if the requested bandwidth of the ONU is larger than the minimum guaranteed bandwidth, the OLT reduces idle time by making use of its knowledge of the starting time and ending time of each timeslot in the current cycle and the RTT for different ONUs. OLT checks if the tracker value is smaller than the end time of idle period (t_{eidle}) and the time the next REPORT message arrives is earlier than ($t_{tracker} RTT/2$). If the tracker

value is smaller than t_{eidle} but the time the next REPORT message arrives is later than ($t_{tracker} - RTT/2$), it schedules the ONU instantaneously. This makes better use of the idle time. To summarize, DBA2 (e-DBA) and DWBA-2 perform on the fly bandwidth allocation for lightly loaded ONUs but wait until all REPORT messages in a cycle are received before computing excess bandwidth and then allocating bandwidth for highly loaded ONUs. The algorithm we have presented also uses the mechanism of on the fly allocation for lightly loaded ONUs. The algorithm n-DBA allocates bandwidth to some of the highly-loaded ONUs on the fly to make better use of idle time. Our algorithm (ParOnD) makes use of this idea but with different criteria which are explained in Section III.

III. NETWORK ARCHITECTURE

The proposed algorithm is designed for hybrid TDM/WDM architecture shown in Figure 1. The designed architecture is according to the model presented in [2]. Here every ONU is equipped with tunable lasers, whereas the OLT has fixed transceivers for receiving data from connected ONUs. The OLT REPORT message allocates initially the available wavelength and then time slot to various ONUs. Therefore, the architecture enables the OLT to make use of dynamic wavelength and dynamic time slot allocation.
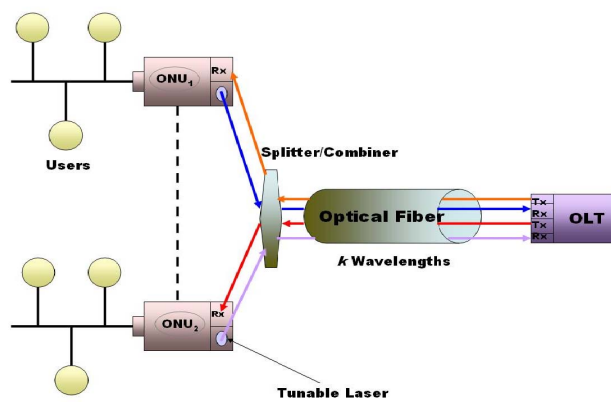

Fig. 1. Network Model

IV. PARTIALLY ONLINE DYNAMIC BANDWIDTH ALLOCATION ALGORITHM (PAROND)

Our algorithm, ParOnD, is under the category of DBAs developed by using a different Grant Sizing Policy, specifically Limited with Excess Distribution as described in [9]. To develop ParOnD, the algorithm proposed in [4] is modified by allocating bandwidth to highly loaded ONUs as soon as the Bandwidth Requested by a highly loaded ONU can be fulfilled using the sum of B_{min} and excess bandwidth accumulated from lightly loaded ONUs (B_{excess}) instead of waiting till the end of the cycle. This reduces the number of unserved highly loaded ONUs at the end of each cycle, reducing idle time and improving bandwidth utilization. An overview of the complete algorithm is given in Figure 2. An EPON of N ONUs

Input:ReportTable R
Output: R
    Initialisation :
 1: Get REPORTs from all ONUs (sorted w.r.t. arrival time)
 2: i=0
    LOOP Process
 3: **while** 1 **do**
 4:    Pick ith REPORT
 5:    **if** REPORT is from lightly loaded ONU **then**
 6:       ProcessLightlyLoadedONU(R)
 7:    **else**
 8:       ProcessHighlyLoadedONU(R)
 9:    **end if**
10: **end while**
11: **return** R

Fig. 2. Overview of ParOnD Algorithm

Input:ReportTable R
Output: R
 1: Grant requested Bandwidth (on next available)
 2: Update excess bandwidth available
 3: **if** all BW requests for current cycle already granted **then**
 4:    Update Report Table R
 5:    Reset excess bandwidth
 6: **else**
 7:    Find minimum BW Request from HL ONUs
 8:    **if** a request is found **then**
 9:       **if** request can be satisfied using available excess bandwidth **then**
10:          Grant requested Bandwidth (on next available)
11:       **else**
12:          **if** this is last REPORT of cycle **then**
13:             Grant bandwidth in proportion to requested bandwidth to all highly loaded ONUs not already served in current cycle (next available)
14:          **end if**
15:       **end if**
16:    **end if**
17: **end if**
18: **return** R

Fig. 3. ParOnD: ASAP Scheduling of Lightly Loaded ONUs

is simulated. The number of wavelengths available to the OLT is K with a line rate of R_N in Mbps each. Each cycle is of T_{cycle} duration (in milliseconds) while the guard time is T_g. Whenever the REPORT message is received the OLT checks if the $B_{req} \leq B_{min}$, then it sends a GATE message to transmit B_{req}. The B_{min} for each ONU depends on the weight w_i assigned to that ONU based on its SLA such that $\sum_{n=1}^{N} w_n = 1$. The B_{min} for each ONU can be calculated as:

$$B_{min}^i = \frac{(T_{cycle}T_g * N) * K * R_N * w_i}{8} \quad (1)$$

Assuming there is no SLA classification of ONU, then all $w_i = 1/N$ and Minimum Guaranteed Bandwidth of ONU_i is given by

$$B_{min}^i = \frac{(T_{cycle}T_g * N) * K * R_N}{8 * N} \quad (2)$$

If, however, $B_{req} > B_{min}$, then the OLT checks whether the excess bandwidth accumulated from lightly loaded ONUs together with B_{min} satisfies B_{req} . If the condition is satisfied then it sends the GATE message, otherwise it waits for more excess bandwidth to accumulate. Therefore, whenever the excess bandwidth increases, the OLT checks which high loaded ONU request can be completely satisfied using the minimum guaranteed bandwidth and excess bandwidth accumulated so far. If such ONUs are found, the OLT sends GATE messages to the ONUs and allocates their requested bandwidth on the next available wavelength as shown in Figure 3.

Once all the REPORT messages of a cycle are received by the OLT, the highly loaded ONUs which have not yet been sent a GATE message in the same cycle are allocated bandwidth from the accumulated excess bandwidth in proportion to the bandwidth requested by them as illustrated in Figure 4.

Input:ReportTable R
Output: R
 1: **if** all BW requests for current cycle already granted **then**
 2:    Update Report Table R
 3:    Reset excess bandwidth
 4: **else**
 5:    **if** this is last REPORT of cycle **then**
 6:       Grant bandwidth in proportion to requested bandwidth to all highly loaded ONUs not already served in current cycle (on next available)
 7:    **end if**
 8: **end if**
 9: **return** R

Fig. 4. ParOnD: Scheduling of Hightly Loaded ONUs

V. PERFORMANCE EVALUATION

We simulate an EPON of 64 ONUs at a distance of 20 km from the OLT. The number of wavelengths available to the OLT is two ($K = 2$) with a line rate of 1 Gbps each. Each cycle is of 2 milliseconds ($T_{cycle} = 2ms$) while the guard
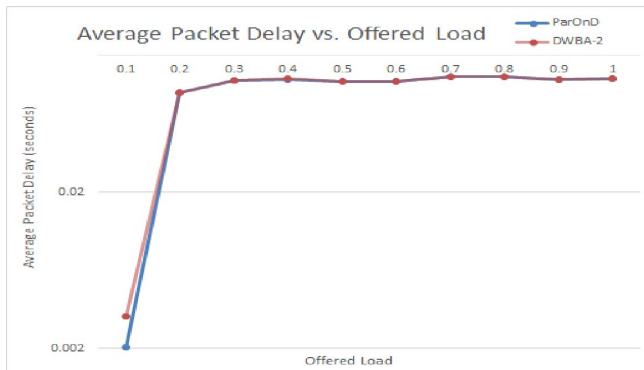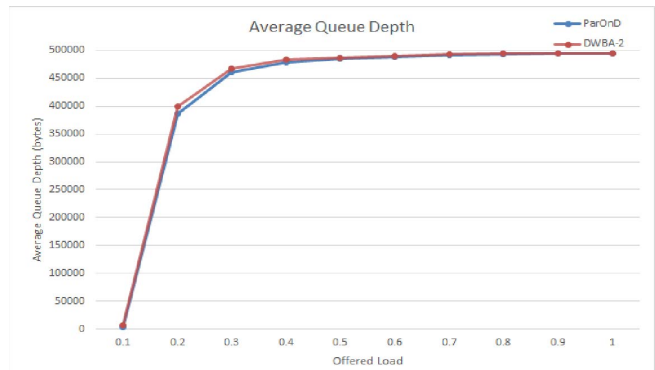
Fig. 5. Average Packet Delay
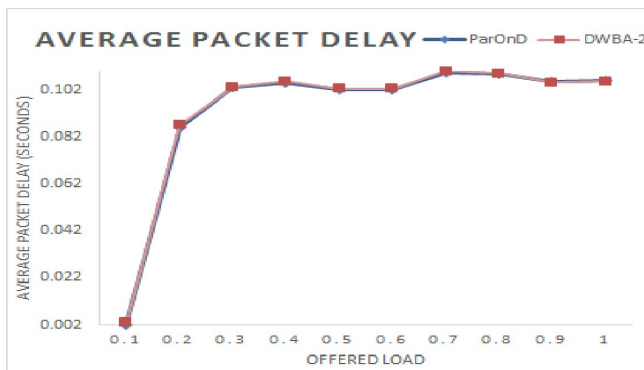

Fig. 7. Average Queue Depth Vs. Offered Load

Fig. 6. Average Packet Delay Vs. Offered Load
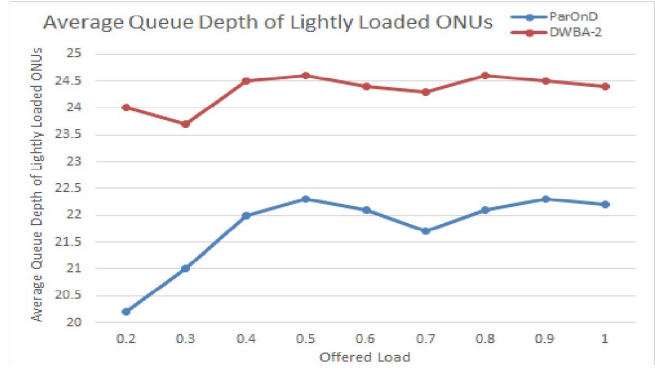

Fig. 8. Average Queue Depth of Lightly Loaded ONUs

Fig. 9. Average Queue depth of Highly Loaded ONUs

time is 1 microsecond ($T_g = 1\mu s$). Traffic is generated for the three different classes of service, i.e. EF, AF, and BE, in a 20: 40: 40 ratio using Pareto distribution. B_{min} for each ONU depends on the weight assigned to that ONU based on its Service-Level Agreement (SLA).

Strict priority scheduling is adopted in our proposed algorithm as our intra-ONU scheduling mechanism. Figure 5 shows the average packet delays for the two algorithms. ParOnD improves packet delay over DWBA-2. Our results show that by reducing the average queue sizes, and thus the bandwidth requirement (as reported to OLT) of each ONU, ParOnD decreased the average number of highly loaded ONUs by 2 in each cycle.

The graph in Figure 6 shows performance of ParOnD against DWBA-2 in terms of average packet delay. Our algorithm, ParOnD, reduces delay at low and medium loads. It performs significantly better than DWBA-2 at low loads (0.10-0.40) reducing the average packet delay in hundreds of microseconds. Figure 7 shows the average queue depth of an ONU in a cycle for both algorithms. As can be seen from Figure 7, ParOnD reduces the average queue depth of an ONU by thousands of bytes in a cycle at low to medium loads.

The effect of ParOnD and DWBA-2 can be observed on average queue depth of lightly loaded ONUs in Figure 8. ParOnD reduces the average queue depth by 2500 bytes to 6000 bytes per ONU in a cycle as compared to DWBA-2.
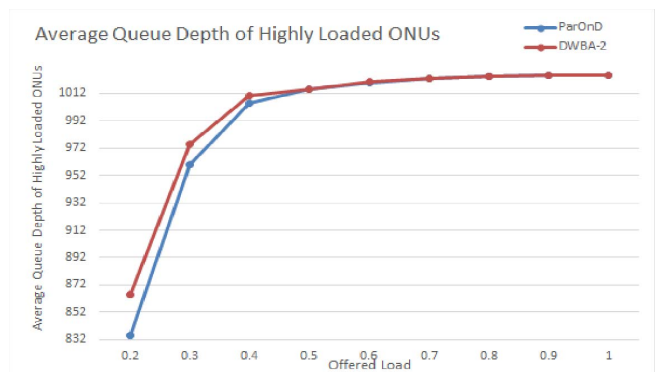
Similarly, Figure 9 shows that ParOnD reduces average queue depth of highly loaded ONUS as compared to DWBA-2. Here the minimum reduction in average queue depth by our algorithm is 6000 bytes while the maximum reduction is 25000 bytes as compared to DWBA-2.

We also evaluated ParOnD for bandwidth wastage (bandwidth allocated but not used). We ran our simulation at load 0.5 and measured the bandwidth wasted in each cycle by our average highly loaded ONU. As shown in Figure 10, we found that bandwidth wastage for an average highly loaded ONU is reduced from an average of 781 bytes per cycle using DWBA-2 to 412 bytes per cycle using ParOnD. This shows
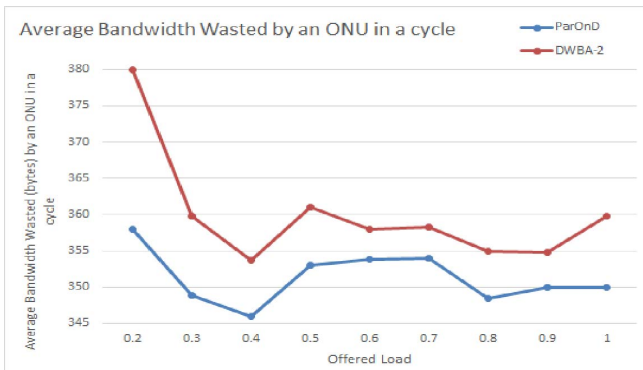
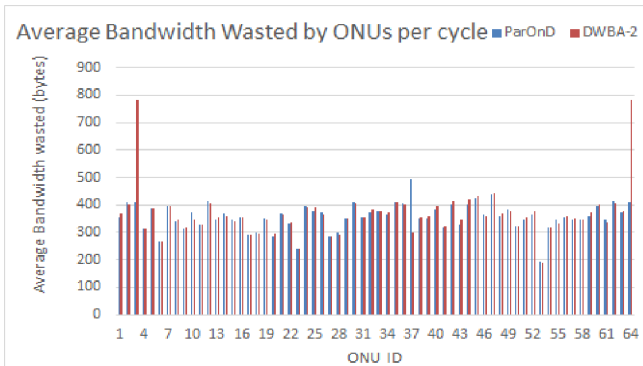Fig. 10. Average Bandwidth Wasted by an ONU in a cycle

Fig. 11. Average Bandwidth Wasted by ONUs at load 0.5

considerable improvement over DWBA-2.

Figure 11 shows the performance of ParOnD and DWBA-2 in terms of bandwidth wastage by all ONUs per cycle at load 0.5. An overall picture of average bandwidth wasted in a cycle by any ONU is shown in Figure 10. ParOnD reduces bandwidth wastage at all loads, thus improving bandwidth utilization.

VI. CONCLUSION

We have presented an algorithm for dynamic bandwidth allocation in Hybrid TDM/WDM EPONs that reduces average packet delay over low to medium loads. It also reduces the average number of highly loaded ONUs in each cycle. ParOnD improves bandwidth utilization by reducing the average bandwidth wasted by an ONU in a cycle by a minimum of 10 bytes per ONU per cycle at the highest load to a maximum of 345 bytes per ONU per cycle at the lowest load when compared with DWBA-2. Also, when we run our simulation at a load of 0.5 ParOnD reduces the bandwidth wasted by a highly loaded ONU from 781 bytes per cycle for DWBA-2 to 412 bytes per cycle. This leads to better bandwidth utilization. As discussed in section V, its performance is degraded at higher loads (0.9-1.00). A possible remedy can be to monitor the offered load and employ a modified version of this algorithm to overcome the packet delay at higher loads. Other possible future directions include investigating the criteria for allocating bandwidth to highly loaded ONUs online, incorporating wavelength assignment with restrictions

on wavelengths supported by different ONUs, and modifying the algorithm to accommodate different SLAs for each ONU.

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