A New QoS Aware Predictive Scheduling in EPONs

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***Abstract*—A new dynamic bandwidth allocation algorithm for the upstream channel of EPONs is proposed. In contrast to the existing competitive approaches, a standard prediction mechanism along with a judicious mix of QoS awareness and fairness in resource allocation is adopted in our approach. Via simulations we show that the proposed scheme offers an increase in overall system throughput while maintaining the mean packet delay and loss rate below the maximum permitted upper bounds.**

I. INTRODUCTION AND MOTIVATION

Among several broadband access technologies passive optical network (PON) is a popular one due to reliability and bandwidth guarantee of optical fiber links. Ethernet being a widely used protocol for IP data optimized access networks, Ethernet PONs (EPONs) are being considered as a promising solution for the broadband access bottleneck problem.

In PONs, local traffic from different end users are aggregated at the optical network unit (ONU), which is co-located at the customer sites and capable of buffering the aggregated data. The optical line terminal (OLT) is connected by a single fiber to a passive optical power splitter which supplies the optical signal to multiple ONUs.

An efficient scheduling should maximize the user satisfaction while maximizing the network revenue. To this end, EPON uses TDMA (time division multiple-access) access protocol, which can offer fine granularity and easy scalability, and requires low cost hardware. In addition, to address the cost sensitive nature of access networks, over-provisioning as in backbone networks is not allowed. Therefore, differentiated service provisioning and efficient bandwidth are essential for a competitive edge to EPON based access network technology.

Over-provisioning in EPONs has been addressed by several authors in research literature. In interleaved polling with adaptive cycle time (IPACT) [1], the polling sequence to the ONUs is varied by OLT depending on the prior information on their respective queue length. Priority scheduling was combined with IPACT in [2] to provide delay and jitter guarantee. In bandwidth guaranteed polling approach [3], the ONUs are assumed of two priority classes, and upstream polling sequence is adjusted by the OLT depending on the ratio of active ONUs of two type. To achieve low delay, queue length estimation based bandwidth allocation was proposed in [4]. The common feature in [2] and [4] is limited bandwidth allocation (LBA) based on service level agreement (SLA), where the OLT assigns the requested bandwidth to ONU$_i$ in the current frame if the request is less than the SLA$_i$, or else it grants only SLA$_i$. An enhanced dynamic bandwidth allocation (DBA) scheme [5] was proposed to assign the excess bandwidth proportionally to the heavily loaded ONUs. Further improved loss and delay performance in DBA was achieved in [6] by applying linear prediction [7] to calculate the required bandwidth at an ONU. For explicit QoS support as specified in DiffServ model, the DBA strategy in [8] assigns a fixed bandwidth to the EF (expedited forwarding, e.g., voice packet) traffic, irrespective of the immediate requirements, which, while maintaining the delay and bounds may invite resource waste. The leftover bandwidth is allocated to the AF (assured forwarding, e.g., video) traffic first and then to the BE (best effort, e.g., data) traffic. The strategy proposed in [6] limits the allocation to EF and AF traffic to their respective SLAs, while assigning the remaining bandwidth to BE traffic. In this approach the AF performance may suffer, even if the assigned bandwidth to the BE traffic remains unused. To achieve fairness among all classes, the bandwidth allocation in [9] is done in three stages: first allocate proportional to the queue length, then prune the allocated resource if it exceeds the respective SLA-high or SLA-low, and finally allocate the excess bandwidth proportionally to all queues. This approach however does not guarantee strict priority to different classes.

We observe that, while ONU based classification does not allow service differentiation within an ONU, service type based classification allows diverse QoS support. Moreover, strict QoS guarantee along with the over-provisioning issue in a multi-service EPON has not been well-studied in the literature, which is the main focus of this work.

II. OUR APPROACH

To address strict priority QoS with minimum possible channel resource, We propose an *SLA aware predictive scheduling*, in short PS. Following the DiffServ model, user traffic at the ONUs are classified into three: priority-0 (P0), priority-1 (P1), and priority-2 (P2). P0 is delay constrained, e.g., packetized voice, P1 is more delay tolerant but less loss tolerant, e.g., video stream, and P2 is delay tolerant but loss sensitive, e.g., data traffic. Instead of per ONU allocation, here the OLT assigns bandwidth with inputs from individual priority queues.

The ONU system model of our proposed priority scheduling is shown in Fig. 1. At the i-th ONU, as data packets arrive, the uplink frame n carries bandwidth request of each priority

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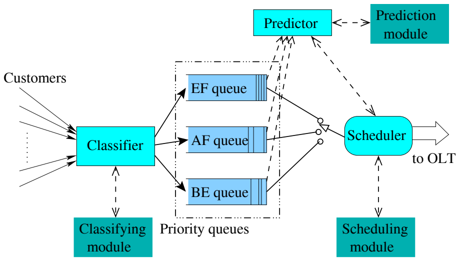

Fig. 1. ONU system model with service differentiation.

class for the next cycle (i.e., frame $n+1$). In doing so, the predictor of each class estimates the traffic arrival during the service interval of a frame. To predict the incoming traffic until the next cycle, a linear predictor is adopted [7], [10] as:

$$\tilde{b}^{w}_{P_{c,i}}(n+1) = \sum_{j=0}^{L-1} \alpha_{P_{c,i,j}}(n) b^{w}_{P_{c,i}}(n-j), \tag{1}$$

where $c \in \{0,1,2\}$, i is the ONU index, L is the prediction order, $\alpha_{P_{c,i,j}}$ is the weight factor indicating the effect of $b^{w}_{P_{c,i}}(n-j)$ on the prediction. The weight factor is updated by the standard LMS (least mean square) algorithm as: $\alpha_{P_{c,i,j}}(n+1) = \alpha_{P_{c,i,j}}(n) + \mu_{P_{c,i,j}}(n)\frac{e_{P_{c,i}}(n)}{b^{w}_{P_{c,i}}(n)}$, where $e_{P_{c,i}}(n)$ is the prediction error in the service cycle n, defined as: $e_{P_{c,i}}(n) = b^{w}_{P_{c,i}}(n) - \tilde{b}^{w}_{P_{c,i}}(n)$, and $\mu_{P_{c,i,j}}(n)$ is defined as $\mu_{P_{c,i,j}}(n) = \frac{L}{\sum_{j=0}^{L-1}\left[b^{w}_{P_{c,i}}(n-j)\right]^2}$.

With the predicted traffic, the requested bandwidth for class c traffic from the ONU$_i$ in the service interval $n+1$ is

$$b^{r}_{P_{c,i}}(n+1) = b^{q}_{P_{c,i}}(n) + \tilde{b}^{w}_{P_{c,i}}(n), \tag{2}$$

where $b^{q}_{P_{c,i}}(n)$ is the enqueued class c traffic at the ONU$_i$ in n^{th} service interval.

With the ONU requests the OLT processes class-based bandwidth assignments and informs the ONUs via the subsequent downlink frame. The OLT system model for priority scheduling is pictorially shown in Fig. 2. Assigned bandwidth to the ONUs is governed by the rules as defined below, where the SLA of class c traffic in ONU$_i$ is denoted by $B_{P_{c,i}}$ and the total bandwidth available for uplink user data traffic is B_{max}. It is assumed, the call admission control ensures that the sum of SLAs of accepted sessions do not exceed B_{max}.

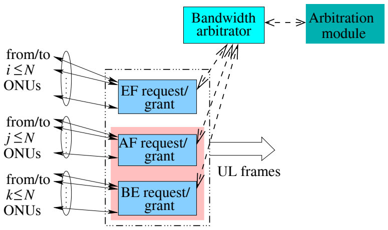

Fig. 2. OLT system model for priority scheduling.

Since the P0 traffic has strict delay constraint, the granted bandwidth is as given in (3):

$$b^{g}_{P_{0,i}}(n+1) = \min\left\{b^{r}_{P_{0,i}}(n+1),\ B_{P_{0,i}}\right\}. \tag{3}$$

Subsequently, the bandwidth to the P1 traffic is granted in two phases. In phase I,

$$b^{g}_{P_{1,i}}(n+1)\Big|_{I} = \begin{cases} b^{r}_{P_{1,i}} & \text{if } b^{r}_{P_{1,i}} \leq B_{P_{1,i}}, \\ B_{P_{1,i}} & \text{else,} \end{cases} \tag{4}$$

Next, the excess bandwidth $b_{ex}(n+1)$ is computed as:

$$b_{ex}(n) = B_{max} - \sum_{i=1}^{N}\left(b^{g}_{P_{0,i}}(n) + b^{g}_{P_{1,i}}(n)\Big|_{I}\right), \tag{5}$$

where N is the total number of ONUs assigned to the OLT. The granted bandwidth to P1 in phase II is:

$$b^{g}_{P_{1,i}}(n+1)\Big|_{II} = \begin{cases} b^{r}_{P_{1,i}} & \text{if } b^{r}_{P_{1,i}} \leq B_{P_{1,i}}, \\ B_{P_{1,i}} + \frac{b_{ex}\cdot b^{r}_{P_{1,i}}}{\sum_{i=1}^{N}\left(b^{r}_{P_{1,i}}+b^{r}_{P_{2,i}}\right)} & \text{else,} \end{cases} \tag{6}$$

and the granted bandwidth to P2 traffic is:

$$b^{g}_{P_{2,i}}(n+1) = \min\left\{b^{r}_{P_{2,i}},\ \frac{b_{ex}\cdot b^{r}_{P_{2,i}}}{\sum_{i=1}^{N}\left(b^{r}_{P_{1,i}} + b^{r}_{P_{2,i}}\right)}\right\}. \tag{7}$$

Note that, (3) minimizes resource waste in case some ONUs require less bandwidth than their respective SLAs for P0 traffic in a cycle. Because P0 is loss tolerant, our proportional bandwidth allocation does not account for the P0 traffic, and thus P0 queue is served independent of P1 and P2 queues. (4) first ensures the minimum resource guarantee to the P1 traffic. Since P1 is also expected to be more bursty, remaining bandwidth allocation is done in (6) to the ones those require higher than the P1 SLA. Our excess bandwidth allocation approach, after ensuring the minimum QoS guarantee to P1, also ensures some resource sharing fairness to the P2 traffic.

III. RESULTS AND DISCUSSION

Via MATLAB simulations we tested our proposed strategy for P0, P1, and P2 service classes, where P0 traffic constituted 20% of the load and the remaining load was divided equally between P1 and P2. As per G.723.1 voice coder spec, P0 packet size was fixed at 70 Bytes. Since P1 traffic is highly bursty, the considered packet size of P1 streams ranges from 64 to 1518 Bytes. P2 packet size was also considered variable between 64 to 1518 Bytes. The packet arrival process for all classes was considered Poisson. P1 and P2 class packet sizes were generated as truncated exponentially distributed.

TDMA cycle time was 2 ms. For P0 class, ITU-T G.1010 suggested end-to-end delay is 150 ms and packet loss rate is 1%, and ITU-T G.114 specified multiplexing delay limit is 1.5 ms. Hence we considered that a voice packet scheduling cannot be delayed to the next cycle. For P1 class, ITU-T G.1010 specified end-to-end delay is 2 s and loss rate is 3%. In this study, an estimated access delay taken was 5 ms. Accordingly, in our simulation the waiting video packets were allowed to enqueue beyond the current frame. Number of ONUs considered was 16, and the line rate was taken 1

Gbps. Maximum distance between an ONU and the OLT is 20 km. So, as per the IEEE 802.3ah standard's target, guard time between adjacent slots was taken 1 μs.

We compared our proposed PS strategy with the two closest strategies, namely, DBA and SLA-DBA approaches; their respective properties are outlined in Section I. Due to space limit only the pertinent results are shown here.

Figs. 3-4 show the access delay of P1 and P2 traffic, where the access delay is defined as the average time between enqueueing a packet in the buffer and sending out the last bit of the packet. The X-axis represents the load of an ONU, which is uniform across all ONUs. At low load, the access delays in all methods are comparable, which is intuitive. The combined effect of strict priority awareness and predictive bandwidth request is that, for P1 traffic PS clearly has a lesser delay than SLA-DBA and it is nearly comparable to that of DBA. However, because of proportional bandwidth assignment in SLA-DBA, the delay of P2 traffic is the least with SLA-DBA.

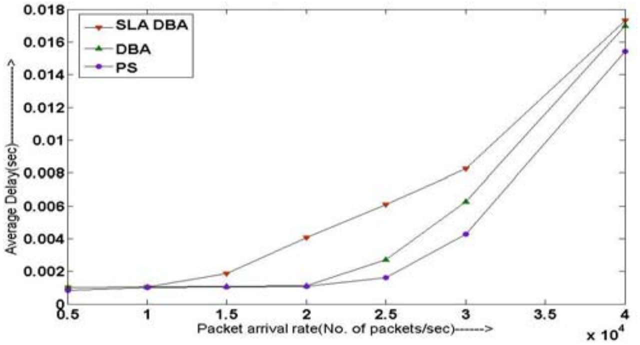

Fig. 3. Access delay performance of video (P1) traffic.

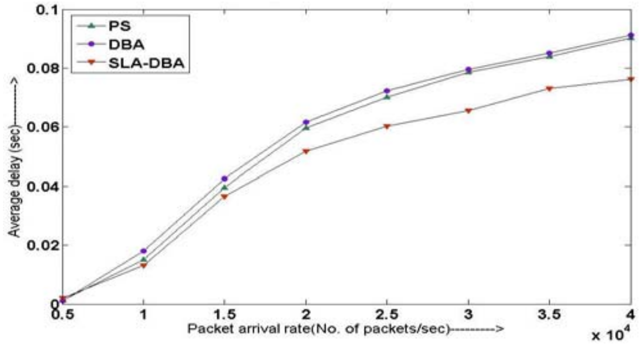

Fig. 4. Access delay performance of data (P2) traffic.

Imposing 1.5 ms access delay limit for P0 traffic, we have studied its packet loss rate. As shown in Fig. 5, the loss rate of PS is fairly low compared to SLA-DBA, which is because PS strictly adheres to QoS priority. It is comparable with DBA, as in both cases the SLA bound for P0 is strictly enforced.

Fig. 6 shows that the overall throughput with PS is higher than that of DBA as well as SLA-DBA. Thus, it might be worthwhile taking the delay tradeoff of P2 traffic.

IV. CONCLUSION

We have proposed a strict QoS aware predictive dynamic scheduling for the uplink access in EPONs that achieves a lesser loss rate and delay of higher priority traffic and a higher network throughput while incurring only marginally higher delay for the best effort traffic. The effects of traffic burstiness will have to be more extensively studied to show the benefits of the proposed approach in a more realistic setting.

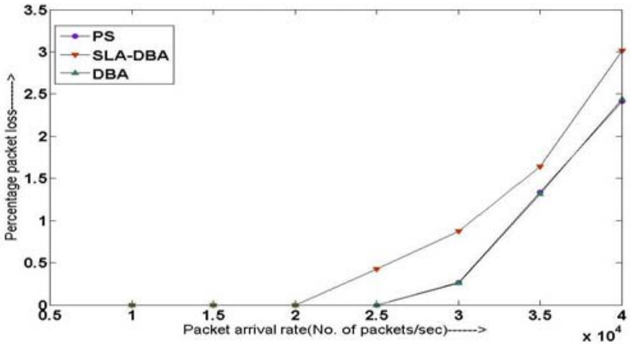

Fig. 5. Frame loss performance of voice (P0) traffic.

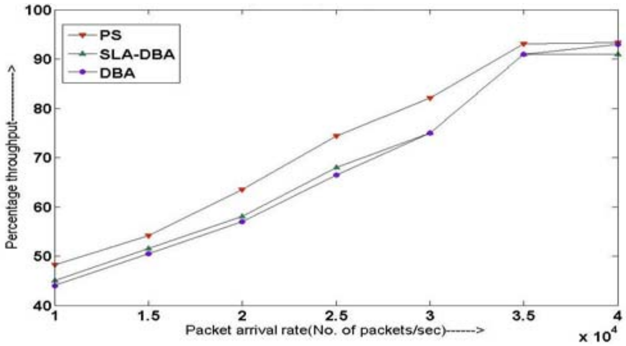

Fig. 6. Overall network access throughput performance.

REFERENCES

[1] G. Kramer, B. Mukherjee, and G. Pesavento, "IPACT: a dynamic protocol for Ethernet PON (EPON)," *IEEE Commun. Mag.*, vol. 40, no. 2, pp. 74–80, Feb. 2002.

[2] G. Kramer, B. Mukherjee, S. Dixit, Y. Ye, and R. Hirth, "On supporting differentiated classes of service in EPON-based access network," *J. Opt. Networks*, vol. 1, no. 8-9, pp. 280–298, Aug. 2002.

[3] M. Ma, Y. Zhu, and T. H. Cheng, "A bandwidth polling MAC protocol for ethernet passive optical networks," in *Proc. IEEE INFOCOM*, San Francisco, CA, USA, Mar.-Apr. 2003, pp. 22–31.

[4] H.-J. Byun, J.-M. Nho, and J.-T. Lim, "Dynamic bandwidth allocation algorithm in ethernet passiv optical networks," *IEE Electronic Letters*, vol. 39, no. 13, pp. 1001–1002, June 2003.

[5] C. M. Assi, Y. Ye, S. Dixit, and M. A. Ali, "Dynamic bandwidth allocation for quality-of-service over ethernet PONs," *IEEE J. Sel. Areas in Commun.*, vol. 21, no. 9, pp. 1467–1477, Nov. 2003.

[6] Y. Luo and N. Ansari, "Bandwidth allocation for multiervice access on EPONs," *IEEE Commun. Mag.*, vol. 43, no. 2, pp. s16–s21, Feb. 2005.

[7] S. Haykin, *Adaptive Filter Theory*. Prentice Hall, 4th Ed., 2001.

[8] S.-I. Choi and J.-D. Huh, "Dynamic bandwidth allocation algorithm for multimedia services over Ethernet PONs," *ETRI Journal*, vol. 24, no. 6, pp. 465–468, Dec. 2002.

[9] D. Nowak, J. Murphy, and P. Perry, "Bandwidth allocation in DiffServ-enabled ethernet passive optical networks," *IET Commun.*, vol. 3, no. 3, pp. 391–401, Mar. 2009.

[10] Y. Luo and N. Ansari, "Limited sharing with traffic prediction for dynamic bandwidth allocation and qos provisioning over EPONs," *OSA J. Optical Networking*, vol. 4, no. 9, pp. 561–572, Sept. 2005.