Implementation of Intra-ONU Scheduling for Quality of Service Support in Ethernet Passive Optical Networks

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Abstract—The Ethernet passive optical network (EPON) is a reliable cost effective, high bit-rate point-to-multipoint optical access network. With new applications and services that emerged in last decade, the quality of service support in EPON has become a major concern. In our work, we analyze the performance of dynamic bandwidth allocation algorithms and intra-ONU scheduling algorithms, and further investigate how a combination these algorithms can be implemented in EPON in order to efficiently support the transmission of multimedia traffic and improve the performance of the low priority traffic at the same time. The system model separates the transmission of high priority traffic from the transmission of lower priority traffic and introduces the implementation of intra-ONU scheduling algorithms for lower traffic class transmission. Numerical results show a slight degradation of transmission characteristics for high priority traffic but on the other side, significant improvement of the lower priority traffic transmission parameters has been detected.

Index Terms—Dynamic bandwidth allocation (DBA), Ethernet passive optical network (EPON), intra-ONU scheduling, quality of service (QoS).

I. INTRODUCTION

For the last ten years, Internet access speeds have been rising. Today, bandwidth-intensive content and peer-to-peer applications consume the whole bandwidth in most broadband networks. Digital subscriber line (DSL) and cable modem (CM) connections cannot support new bandwidth-hungry applications so access network remains the bottleneck.

EPON has been considered as solution for the first or last mile problem [1]. An EPON is point-to-multipoint fiber optical network which employs only passive optical network components in the signal’s path and typically consists of one optical line terminal (OLT) and multiple optical network units (ONUs). ATM (Asynchronous Transfer Mode) has been considered as transmission protocol in EPON, but inefficient ATM cell tax, lack of multicast support per service, and complicated adaptation layer (implementing RFC 2483, [2]), have left the door open to Ethernet PON.

With dramatic increase in end users bandwidth requirements, EPON quality of service has become a major focus, and various scheduling schemes with QoS support have been proposed [3]–[10]. Jitter performance in EPON networks is studied in [10]. In presented solution a transmission cycle is divided into two subcycles, i.e., EF subcycle and AF/BE subcycle. With separate subcycle EF service has been protected and its jitter performance is considerably improved. Transmission of lower priority traffic is based on scheme introduced in [4]. However, presented solution does not involve any intra-ONU scheduling mechanisms for lower priority traffic and does not address the issue of quality of service requirements for them.

In our work, we suggest and analyze the system model with full QoS support for lower priority traffic. In the proposed model we analyze the implementation of both inter-ONU and intra-ONU scheduling algorithms in order to improve the performance of the best-effort traffic class in QoS-aware EPON. We discuss how algorithms for dynamic bandwidth allocation, like HG protocol, based on prediction of high-priority traffic [10] can be combined with different intra-ONU schemes. Unlike [3] proposed solution is consistent with MPCP protocol and does not involve new system architecture as [5] and [9]. We conduct the detailed simulation results in order to confirm the effectiveness of the proposed solution. The rest of this paper is organized as follows. Section II provides an overview of network architecture and basic principles of MPCP and further presents a background motivation for our work. Section III presents inter-ONU scheduling and Section IV presents intra-ONU scheduling and discusses implementation of both scheduling mechanisms. Section V presents our simulation results and comparison with results published in literature and Section VI concludes the work.

II. NETWORK ARCHITECTURE AND QoS SUPPORT

Ethernet PON is a PON-based network that carries data traffic encapsulated in Ethernet frames as defined in the IEEE 802.3 standard [11]. In the downstream direction, the OLT broadcasts frames to all ONUs and only the ONU that has the right MAC address of the frames will receive them. In the upstream direction, each ONU could transmit its data to the OLT only in its time slots allocated by the bandwidth allocation algorithm (inter-ONU scheduler) at the OLT.

The IEEE 802.3ah task force has standardized MPCP protocol to control the data exchange in EPON [11]. MPCP
Fig. 1. Inter-ONU and intra-ONU scheduling.

protocol allows sharing of the upstream bandwidth among the various ONUs and prevents collisions of packets originating from different ONUs. MPCP is based upon time-division multiplexing and allows OLT to arbitrate between various ONUs requesting upstream transmission over the shared medium by assigning exclusive timeslots to individual ONUs. Each ONU can transmit packets upstream only during its assigned timeslot(s). MPCP uses two Ethernet control messages namely, a GATE message and a REPORT message. The GATE message, sent by an OLT to an ONU, assigns a transmission timeslot window to the ONU. The GATE message specifies transmission start and end time during which the ONU can transmit queued, customer traffic upstream to the OLT. Within allocated window ONU sends REPORT message along with data to report bandwidth requirements for upstream transmission of its traffic. Based on REPORT message that contains queue occupancy information DBA module (inter-ONU scheduler) in OLT allocates appropriate bandwidth to the ONU. In every ONU the intra-ONU scheduler schedules the packet transmission for various traffic queues from local users and the transmission window may comprise multiple Ethernet frames. An ONU can support up to 8 priority queues as defined in 802.1Q [12].

With new application and services including video-on-demand, voice over IP, two-way video conferencing and many others, QoS support has become the key concern. For multiservice provisioning we categorize the traffic into three different classes consistent with DiffServ (Differentiated Services) framework [13]: EF (Expedited Forwarding) – highest priority, delay sensitive traffic with constant bit rate such as voice transmission; AF (Assured Forwarding) – medium priority traffic, no delay sensitive traffic with variable bit rate such as video transmission; BE (Best Effort) – low priority traffic such as file transfer and e-mail applications. In order to support different services, it is necessary to implement two independent scheduling mechanisms in EPON, one in OLT (inter-ONU scheduling or DBA algorithm) for bandwidth allocation among ONUs and one in ONU (intra-ONU scheduling) for scheduling packets that belong to different traffic classes, Fig. 1, [1]. Three queues who share the same buffer space are defined in every ONU. Packets classification is based on ToS (Type of Service) field of every IP packet encapsulated in Ethernet frame.

In order to successfully implement QoS support, different priority have to be give to voice support. Voice transmission has to be separated from transmission of lower priority traffic. In our work, we discuss how algorithms for dynamic bandwidth allocation can be combined with different intra-ONU schemes in ONU in order to achieve more efficient support QoS, especially for best effort traffic class.

III. INTER-ONU SCHEDULING

To date, various DBA schemes with QoS support in EPON have been proposed. For transmission of lower priority traffic we implement dynamic bandwidth allocation algorithm with QoS support presented in [4]. Transmission of high priority traffic is based on HG protocol presented in [10].

A. DBA for QoS Over EPONs

Limited scheme presented in [14] grants the requested number of bytes to ONU but not more than predefined value and it was shown that this scheme have the best performance in terms of the packet delay and throughput comparing to other presented schemes in [14]. Minimum guaranteed bandwidth to ONU \( i \) can be calculated as follows:

\[
B_{i}^{\text{MIN}} = \frac{(T_{\text{cyk}} - NT_{g})R}{8}w_{i}
\]

where \( N \) represents the number of ONUs, \( T_{g} \) represents value of guard interval, \( R \) represents the OLT link capacity, and \( w_{i} \) represents the weight assigned to each ONU. In simulation we assumed that all ONUs are equale weighted so

\[
w_{i} = w = \frac{1}{N}, \forall i
\]
Under this condition, guaranteed bandwidth to ONU\textsubscript{i} can be calculated as

\[
B_i^R = \begin{cases} 
B_i^R, & \text{if } B_i^R < B_i^{MIN} \\
B_i^{MIN}, & \text{if } B_i^R \geq B_i^{MIN}
\end{cases} \tag{3}
\]

where \(B_i^G\) is guaranteed bandwidth to ONU\textsubscript{i} and \(B_i^R\) is requested bandwidth to ONU\textsubscript{i}. In EPON, some ONU might request less or more bandwidth then their minimum guaranteed bandwidth \(B_i^{MIN}\) (bursty nature of Ethernet traffic). From that reason, a weighted inter-ONU DBA scheme has been introduced in [4].

In this scheme, all ONUs could be partitioned in two groups, namely, underloaded and overloaded based on their requested bandwidth.

Total excessive bandwidth saved by underloaded ONUs can be expressed as

\[
B_{total}^{EXCESS} = \sum_{i \in M} (B_i^{MIN} - B_i^R), B_i^{MIN} > B_i^R \tag{4}
\]

where \(M\) represents the number of underloaded ONUs.

Now, bandwidth granted to overloaded ONU\textsubscript{i} could be calculated in the following way:

\[
B_i^G = B_i^{MIN} + B_i^{EXCESS} \tag{5}
\]

where \(B_i^{EXCESS}\) represented excessive bandwidth allocated to overloaded ONU\textsubscript{i} and can be calculated as

\[
B_i^{EXCESS} = \frac{B_{total}^{EXCESS}}{\sum_{p \in P} B_p^R} \tag{6}
\]

where \(P\) represents the number of overloaded ONUs.

This DBA scheduler (called DBA1 hereafter) can allocate bandwidth more efficiently than limited scheme but an overloaded ONU may get more bandwidth than requested so capacity may be wasted.

### B. HG Protocol

In standard EPON algorithms, MPCP protocol is implemented in GAR (Grant After Report) way. DBA module in OLT generate GATE message with allocated bandwidth for ONU after receiving REPORT message from that ONU with their requested bandwidth. With this kind of mechanism, we can define minimal queuing delay in every ONU but this is not optimal solution for transmission of traffic that is not delay sensitive.

HG protocol take into account the fact that amount of EF traffic in the system is fully deterministic and based on that suggest the use of GBR (Grant Before Report) mechanisms [10]. In GBR mechanisms, GATE message transmit information about expected EF traffic, e.g., about EF traffic that will arrive in the system before next transmission cycle in the given ONU. On such way, it is possible to define maximum queuing time for EF packets. AF and BE traffic behavior is nondeterministic so for they transmission we use standard GAR technique.

HG protocol defines two subcycles for data transmission, one for EF traffic using GBR mechanism and one for AF/BE traffic using GAR mechanism. Bandwidth allocation for EF traffic is not based on last received REPORT message so OLT have to allocate bandwidth for EF traffic in advanced before allocating bandwidth for the rest of the traffic in the system. In order to accomplish this, OLT have to precisely predict the beginning of the next cycle in every ONU. Bandwidth for EF traffic is always allocated before AF/BE subcycle. The remaining bandwidth is used for transmission of AF/BE traffic taking into account the maximal bandwidth defined with MTCT (Maximum Transmission Cycle Time). MTCT defines the maximum transmission interval in ONU that is called DBA cycle. Based on MTCT for every ONU minimal guaranteed bandwidth can be defined in one cycle, as sum of EF and AF/BE subcycles.

Besides GBR mechanisms, authors in [10] have introduced two new concepts, namely, DBA cycle (DBA-CL) and MPCP cycle (MPCP-CL). DBA-CL is computation based and MPCP-CL is operational based. DBA-CL is defined by MTCT parameter and determines the minimum guaranteed bandwidth for each ONU in one cycle. MPCP-CL defines exchange of MPCP messages between the OLT and every ONU. The main reason for introducing new concept is shifting these cycles in time because they do not have to be co-phased (in previous schemes they were completely overlapped), Fig. 2.

Now, REPORT message is sent at the end of transmission window for each ONU. In such way OLT get information about buffer occupancy updated up to the moment who is one cycle (one EF and one AF/BE subcycle) ahead the starting time of the next AF/BE subcycle. Now, OLT can allocate more bandwidth to next AF/BE subcycle in a case that MTCT limitation is not exceeded.

The total available bandwidth in DBA-CL can be expressed as follows:

\[
B_{TL} = R(T_{cl}^{MAX} - 2T_g) \tag{7}
\]

where \(R\) is OLT link capacity, \(T_g\) is guard interval, and \(T_{cl}^{MAX}\) is maximum transmission cycle time. Granted EF subcycle window size for ONU\textsubscript{i} can be computed as follows:

\[
B_{i,k+1}^{EF} = R(t_{i,k+1}^{START} - t_{i,k}^{START}) + I_{report} \tag{8}
\]

where \(t_{i,k}^{START}\) is EF subcycle transmission start time of ONU\textsubscript{i} in \(k\)th DBA-CL, and \(I_{report}\) is bit length of REPORT message. Transmission of AF and BE traffic is based on weighted scheme. According to that amount of AF and BE traffic in \(k\)th DBA-CL
in ONU, granted subcycle window size can be calculated as
\(9\)–\(12\), shown at the bottom of the page, where

\[
\begin{align*}
\alpha_{i,k} & \quad \text{is requested AF subcycle window size by ONU}_i; \\
B_{i,k}^{AF} & \quad \text{is granted AF subcycle window size for ONU}_i, \\
\text{where } B_{i,k}^{AF} & \leq \alpha_{i,k}; \\
b_{i,k} & \quad \text{is requested BE subcycle window size by ONU}_i; \\
B_{i,k}^{BE} & \quad \text{is granted BE subcycle window size for ONU}_i, \\
\text{where } B_{i,k}^{BE} & \leq b_{i,k}; \\
M & \quad \text{is number of underloaded ONUs;} \\
P & \quad \text{is number of overloaded ONUs;} \\
B_k^{UNDER} & \quad \text{is total excessive bandwidth saved by } M \\
\text{underloaded ONUs;} \\
P_k^{OVER} & \quad \text{is total excessive bandwidth requested by } P \\
& \quad \text{overloaded ONUs.}
\end{align*}
\]

IV. INTRA-OUN SCHEDULING

For scheduling packets we need scheduler who takes into account different packets priorities. The basis scheduler defined in EPON is strict priority scheduler (SPS), Fig. 3. In this mechanism, highest priority traffic is always transmitted first. In such case, lower priority traffic can suffer from unlimited delay in system and its propagation can spread in several cycles for data transmission. As we early explained ONU send a REPORT message to inform OLT about current buffer occupancy and request some amount of bandwidth. DBA module in OLT processes this request and generates a GATE message with allocated bandwidth. Time interval between sending the REPORT message and receiving the GATE message is called waiting time (WT). During the waiting interval in ONU more packets arrive in buffer. Highest priority traffic that has arrived during this period is scheduled for transmission before lower priority traffic that has arrived before the ONU generated the REPORT message. In this way, lower priority traffic has to wait for transmission and its delay can be indefinitely spread on several cycles.

To overcome this problem, authors in [4] have suggested scheduling mechanism based on packet priorities – PBS (Priority Based Scheduling) mechanism. In this mechanism, packets that have arrived before waiting interval are scheduled for transmission first based on their priorities. If window size can accommodate more packets for transmission, algorithm will schedule packets arrived during the waiting time based on their priorities. In this way, scheduling mechanism does not allow highest priority traffic to monopolize the use of bandwidth.

In a case of implementation of HG scheduling mechanisms, highest priority traffic is always served first. HG protocol protects the transmission of highest priority traffic in terms of delay and jitter. The amount of bandwidth for EF traffic is determined one cycle ahead and MTCT does not allow high priority traffic to completely utilize the entire bandwidth. Nevertheless, transport of lower priority traffic have to be solved, because AF traffic in the basis algorithm is always transmitted before BE traffic class. In that way, AF traffic can occupied the whole remaining bandwidth and BE traffic transport will spread on several cycles. BE traffic is not delay sensitive but this unlimited delay could seriously degrade the performance of the entire network.

If the PBS scheme is implemented along with DBA1 Inter-OUN scheduling mechanism, we do not have such problem, because all three traffic classes are served exclusively by their priority – we do not have a case of predicted bandwidth for highest priority class.

In order to overcome this problem in HG protocol that is initially concerned only with transmission of EF traffic, we analyze the situation in which we implement PBS scheme on transmission of both AF and BE traffic. Now, AF traffic is not absolutely prioritized and BE traffic has the opportunity to be transmitted without “unlimited” delay. We also analyze the situation in which SPS scheduler is implemented for the purpose of comparison of the key network parameters.

HG protocol presented in [10] involves only two separate subcycles, one for EF traffic and another for aggregated AF and BE traffic. That model does not fully address the QoS issue in EPON because it does not take into account QoS requirements.

\[
B_k^{AF} = \begin{cases} 
\alpha_{i,k}, & B_k^{OVER} \leq B_k^{UNDER} \quad \text{or} \quad \alpha_{i,k} \leq B_k^{MIN} - B_{i,k}^{AF} \\
B_k^{MIN} - B_{i,k}^{AF} + B_k^{UNDER}, & \text{otherwise}
\end{cases}
\]

\[
B_k^{BE} = \begin{cases} 
b_{i,k}, & B_k^{OVER} \leq B_k^{UNDER} \quad \text{or} \quad b_{i,k} \leq B_k^{MIN} - B_{i,k}^{BE} - B_{i,k}^{AF} \\
B_k^{MIN} - B_{i,k}^{BE} - B_{i,k}^{AF} + B_k^{UNDER}, & \text{otherwise}
\end{cases}
\]

\[
B_k^{UNDER} = \sum_{i \in M} \left( B_i^{MIN} - B_{i,k}^{AF} - \alpha_{i,k} - b_{i,k} \right)
\]

\[
P_k^{OVER} = \sum_{i \in P} \left( B_{i,k}^{AF} + \alpha_{i,k} + b_{i,k} - B_i^{MIN} \right)
\]
of lowest priority traffic. On that way transmission of AF traffic could utilize the entire bandwidth and delay of BE traffic could be practically infinite. In our simulation model we further develop the model suggested in [10] with the QoS support for lower priority traffic. We implement and analyze the Intra-ONU scheduling algorithms for AF and BE traffic in order to achieve fairness and bandwidth allocation based on packets priorities.

V. PERFORMANCE EVALUATION

We study the performance of different dynamic bandwidth algorithms and analyze the impact of queuing mechanisms on network performance. To verify proposed model that incorporates combination of intra-ONU and inter-ONU scheduling, and compare it with other systems we have used standardized parameters in system model in order to measure average and maximum delay, network throughput, packet loss rate and average queue delay. For the purpose of comparison we study the network performance in a case that DBA1 algorithm with PBS mechanism has been implemented. Model of analyzed network consists of one OLT and 32 ONUs. Maximum transmission cycle time $T_{\text{MAX}}$ is 2 ms and guard interval is set to 1 μs. The downstream and upstream channels are, both, 1 Gbps. The distance from an ONU to the OLT is assumed to be 20 km. Self-similar traffic is generated for all ONUs and outcomes of multiple repeated simulation are averaged for all results. The schemes are tested using network model developed in Matlab, using Simulink packet. In our simulation we take into account that most network traffic can be characterized by self-similarity and long-range dependence [15]. According to that, in our model AF and BE traffic is highly bursty and packet sizes are uniformly distributed between 64 and 1518 bytes. High priority traffic is modeled using Poisson distribution with packet size fixed to 70 By [13]. The total traffic load of the entire network is changing from 0.1 to 1.0. The traffic profile is as follows: 20% of the total generated traffic is allocated for narrowband EF service, and the remaining 80% is equally distributed between AF and BE services, [4], [10], [16]. When requesting next time slot ONU must take into account additional overhead. Overhead includes 8 By frame preamble and 12 By interframe gap (IFG) between consecutive frames. In addition, guard time interval between two different ONUs data have been taken into account, too. We assumed that all ONUs have the same weight and the network load is evenly distributed among ONUs. In our simulation, we take into account queuing delay, transmission delay and packet processing delay.

We simulate EPON system with Matlab Simulink model in which we implemented different inter- and intra-ONU algorithms. First, we test the effectiveness of dynamic bandwidth allocation with differentiated service support (DBA1 algorithm) in order to compare our model and confirm the effectiveness of proposed solution. Further, we implement dynamic bandwidth allocation with traffic prediction of high priority class (HG protocol) and simulate the implementation of this protocol along with different intra-ONU scheduling mechanisms, namely HG(SPS) and HG(PBS). First, we analyze the average and maximum packet delays in EPON in case when we implement SPS mechanism, Figs. 4 and 5, and PBS mechanism, Figs. 6 and 7. Along with analyses of AF and BE traffic behavior we also analyze transmission characteristics of EF traffic in order to confirm that implementation of scheduling mechanisms for lower priority traffic does not affect in any way the transmission of highest priority jitter sensitive traffic. Simulation results shows that in a case we implement strict priority scheduling BE traffic suffer from increased average and maximum delay comparing to implementation of priority based scheduling (Figs. 4–7). In HG(SPS) mechanisms, transmission of AF traffic can easily occupied the entire bandwidth because AF traffic is always prioritized against BE traffic, so transmission of lowest priority traffic can be prolonged in several cycles. Implementation of PBS mechanisms improves the performance of BE traffic transmission in terms of average and maximum packet delay. Delays for AF traffic is now slightly increased for higher load (see Fig. 10) because AF traffic arrived during waiting interval have to wait for the next cycle to be transmitted. Transmission of AF traffic is not significantly degraded with implementation of PBS scheduling mechanisms. Moreover, simulation results confirm that transmission of EF traffic is not degraded with implementation of scheduling mechanisms for lower priority traffic (see Fig. 8). Actually, we notice the improvement in average and maximum packet delay of EF traffic that could be explained with separated cycles for transmission of EF (EF subcycle) and AF/BE (AF/BE subcycle) traffic. Besides decreased latency, amount of transmitted BE traffic is increased, and percent of dropped packet is now lower (Fig. 14).
In Figs. 9 and 11, we compare the average packet delay between HG(PBS) and DBA1 algorithm. As we expected, results confirm that with implementation of HG(PBS) mechanisms packet delays for all three classes decrease. Reduced latency of highest priority traffic is result of HG scheduler implementation comparing with classic EPON scheduler implemented in DBA1 [4]. Moreover, increased efficiency of suggested HG(PBS) solution results in decreased latency for lower priority traffic especially for BE traffic. PBS mechanism now protects the transmission of BE traffic and does not allow the situation in which transmission of BE traffic could be prolonged on several cycles.

This conclusion is further confirmed with the analysis of the AF and BE average queue occupancy (Figs. 12 and 13). Simulation results show that average occupancy of AF and BE queues is decreased in a case of the implementation of HG(PBS). In this way, BE traffic bandwidth starvation is eliminated and overall
Fig. 12. Comparison of AF queue occupancy between HG(PBS) and HG(SPS) algorithm.

Fig. 13. Comparison of BE queue occupancy between HG(PBS) and HG(SPS) algorithm.

Fig. 14. Packet loss rate.

Fig. 15. Comparison of network throughput.

system efficiency is increased. Simulation results show the significant improvement in the packet loss rate, too (Fig. 14). Consequently, minimized packet loss rate led to the maximized network throughput. In HG algorithm duration of DBA cycle is somewhat longer because it uses two sets of guard times in order to separate the transmission of different traffic classes. According to that in case of heavy load HG algorithm has a slight degradation of performances comparing with DBA1 algorithm. Throughput analysis shows improvement in a case we use priority based queuing (89%) comparing with HG(SPS) (86%), and confirms that DBA1 algorithm has better performance from them both (91%) (see Fig. 15).

Simulation results show the improvement in overall system efficiency if we compare the suggested algorithms HG(SPS) and HG(PBS) with DBA1 algorithm. There are several reasons for this, but the dominant one is the fact that HG protocol separates the transmission of EF traffic from the transmission of lower priority traffic. Both suggested solutions introduce the degradation of delay performance for EF traffic at lighter load (see Figs. 8 and 9) where some ONUs cannot buffer EF packets for transmission in the next subcycle. REPORT message along with two guard intervals is generated and because of that delay is slightly increased. However, average packet delays are significantly decreased (22% for AF traffic, and 53% for BE traffic), so this discrepancy could be tolerated. Implementation of intra-ONU scheduling mechanisms further improves the solution suggested in [10]. Now, AF traffic is controlled and BE traffic bandwidth starvation is not an issue any more. Average and maximum packet delays are decreased, and simulation results show that implementation of PBS mechanism further improves the system characteristics comparing to the SPS mechanism. Average packet delay is decreased for the 25% in a case of PBS implementation, and 5% in a case of SPS implementation for BE traffic comparing to the results presented in [10]. Besides that, delay performances for both AF and BE are also improved due to the fact that intra-ONU scheduling has been implemented. Simulation results show improvement in AF packet delay (35%) and in EF average packet delay (3%), too. Network throughput is increased (direct consequence of decreased packet loss and decreased average queue length) for the 5.5% and 2.5% in a case we implement HG(PBS) and HG(SPS) respectively, comparing to the results given in [10].

In our work, the detailed analysis of scheduling algorithms have been conducted in order to investigate how scheduling algorithms implemented for lower priority traffic could be used to achieve better QoS performance in EPON. Simulation result shows that implementation of HG protocol that is based on deterministic nature of high priority traffic improves the
transmission parameters of EF traffic which is delay and jitter sensitive. On the other hand, intra-ONU scheduling for the lower priority traffic must be implemented in order to restrain AF traffic to completely utilize entire bandwidth. Simulation results confirm our analyses that implementation of intra-ONU scheduling mechanisms for AF and BE traffic considerably improves the system performance. HG(PBS) shows better performance compared with HG(SPS) in terms of network throughput, average and maximum packet delay. Besides that, queue occupancy in HG(PBS) have been decreased because amount of transmitted BE packet have been increased. System modeling with Matlab and Simulink packet allowed us to implement and test the presented algorithms in real network environment in cable service provider network (SBB – Serbia BroadBand). System is tested in multimedia ISP network and its efficiency, in terms of delay, throughput and buffer occupancy has been further confirmed. Therefore, we are convinced that hardware implementation of suggested solution would operate on foreseen manner and would not involve any additional implementation complexity.

VI. CONCLUSION

Simulation results show that solutions with involved both inter-ONU and intra-ONU scheduling has better performance in terms of delay, throughput and overall system efficiency comparing with standard solution that includes only dynamic bandwidth allocation. With implementation of HG(PBS) protocol average packet delay is decreased about 20% for AF and 50% for BE traffic. HG scheduler ensures that higher priority traffic is served with less average delay and jitter and does not allow EF traffic to occupy the entire bandwidth. Intra-ONU scheduler at each ONU guarantees the minimal bandwidth allocation to each service class with different priorities for each user. It can also guarantee the minimal bandwidth allocation to each traffic queue. The analyzed solution can fulfill QoS requirements in EPON and improve the transmission efficiency of multimedia traffic.

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