Algorithm for Implementation of Wavelength Division Multiplexing in EPON

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Abstract — **Today, implementation of wavelength division multiplexing in the Ethernet passive optical network (EPON) is considered as one of the most perspective solutions for the bottleneck problem in the access network. With the development of new applications and services, multimedia applications above all, quality of service (QoS) support becomes a major concern in WDM EPON, as it was the case in EPON. In this paper, WDM EPON architecture is presented along with a novel algorithm for wavelength and bandwidth allocation with full QoS support. Besides theoretical analysis, simulation results are presented and they confirm a good performance of presented solution.**

Keywords — **DWBA algorithm, quality of service, WDM EPON.**

I. Introduction

IN recent years Ethernet passive optical network (EPON) has been considered as one of the most appropriate solutions to the problem of lack of bandwidth in the access network. However, EPON is a single-channel system in which the potential of optical fiber is not fully utilized. With the emergence of new services, the bandwidth that can be provided in EPON network is no longer sufficient to meet all the requirements of end users. The introduction of wavelength multiplexing i.e. wavelength division multiplexing (WDM) technology in EPON network is a logical step in the development of optical access networks. However, applications such as high definition television, video conferencing and many others require the implementation of the quality of services in WDM networks as was the case with conventional EPON systems [1].

In this paper we present and analyze the model for wavelength and bandwidth allocation in the WDM EPON network, namely FWPBA (Fixed Wavelength Priority Bandwidth Allocation) model. In addition to the model analysis, the simulation results will be presented and explained in order to confirm the effectiveness of the proposed model.

II. System Architecture And FWPBA Model

The proposed WDM EPON architecture is in fact a classical EPON architecture in which end-users are connected, through the optical network unit (ONU), to the central optical line terminal (OLT). Unlike conventional EPON systems that support only two wavelengths (one for downstream transmission from the OLT to ONUs and one for upstream transmission from ONUs to OLT), in FWPBA model we introduced support for the traffic transmission using four wavelengths: λ_0, λ_1, λ_2 and λ_3.

Support for the quality of service (QoS) implementation in the system is realized through support for the DiffServ architecture in which the traffic in the system is divided into three classes [2]: EF (Expedite Forwarding) - the highest priority for services that are sensitive to delay (voice) and that are typically characterized by a constant bit rate (CBR), AF (Assured Forwarding) – a medium level of priority for traffic that is not sensitive to delay (video applications), which has a variable bit rate (VBR) and BE (Best Effort) – the lowest priority for services that are not sensitive to delay, such as web browsing, file transfers and e-mail application. In the FWPBA model three wavelengths are reserved for data transmission as follows: λ_1 for EF, λ_2 for AF and λ_3 for BE traffic. The fourth wavelength (λ_0) is reserved for the transmission of control messages and synchronization, and may be the original wavelength used in the EPON network or some other wavelength [3]. We suggest that supported wavelengths should be selected from the C band, since the wide range of equipment from different vendors support this band. In addition, in order to realize the simultaneous transmission of traffic on different wavelengths in the OLT and ONU units it is necessary to use fixed-tuned transceivers.

In the proposed model communication between the OLT and ONUs is controlled through the implementation of the expanded multipoint control protocol (MPCP) [3]. MPCP GATE message is now extended with one byte field, in which the identifier of the wavelength assigned by the OLT to the defined ONU for data transmission is entered. Namely, the distribution of resources in the WDM EPON no longer consists of bandwidth allocation (grant sizing) only but also of the allocation of wavelengths (grant scheduling) [3]. In the downstream direction OLT, using the broadcasting mechanism, sends data to the ONUs simultaneously, in multiple wavelengths, which they receive based on the destination MAC address (as in a classical EPON [4]).

Since the FWPBA model makes a fixed link between the type of traffic and the wavelength used for its transmission, which is known by OLT, wavelength allocation is not required, making the algorithm more efficient. Now, each ONU generating REPORT MPCP

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control message that is sent to the OLT unit demands a certain amount of bandwidth, independently for each wavelength. After the arrival of REPORT messages from all ONUs, dynamic bandwidth allocation (DBA) module for the allocation of bandwidth in the OLT performs bandwidth allocation for each traffic class in all ONUs. In each cycle every ONU transmits traffic concurrently on three different wavelengths and retains all three wavelengths until transmission on each of them is over. When upstream transmission of all three traffic classes is finished ONU releases wavelengths and the next scheduled ONU can transmit traffic, Fig. 1.

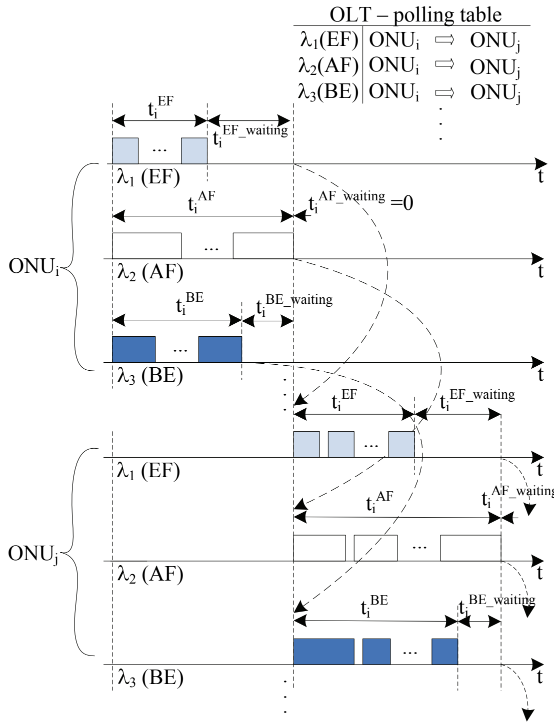

Fig. 1. Upstream ONU transmission.

In this algorithm the wavelengths that transmitted a smaller amount of traffic have to wait until the transmission on the most loaded wavelength is completed, which introduces a new waiting time in the system, namely $t^{waiting}$. For purposes of the present analysis, we assume that AF traffic class is the most common in the system due to the rapid development of multimedia applications [5]. It is obvious that AF class will not have a waiting time because it is the most represented and will define the transmission cycle. According to the fact that one ONU unit retains all wavelengths until the transfer on the most loaded wavelength is completed, the module for bandwidth allocation allocates the same amount of available upstream bandwidth to each ONU–based on a maximum requested bandwidth i.e. generates a single GRANT MPCP message with the approved amount of bandwidth for all three traffic classes, Fig. 2. This algorithm simplifies and reduces the processing time of OLT, but introduces a new inefficiency in the system - unused bandwidth at the two less loaded wavelengths.

Bandwidth allocation algorithm used in the model is based on a modified gated IPACT algorithm [6]. This algorithm will grant the requested amount of bandwidth to every ONU that cannot be larger than the size of the queue. Hence, we do not assume that the total network load is evenly distributed amongst all ONUs and that ONUs are equally weighted and we extend the algorithm with weight factors associated with every ONU.

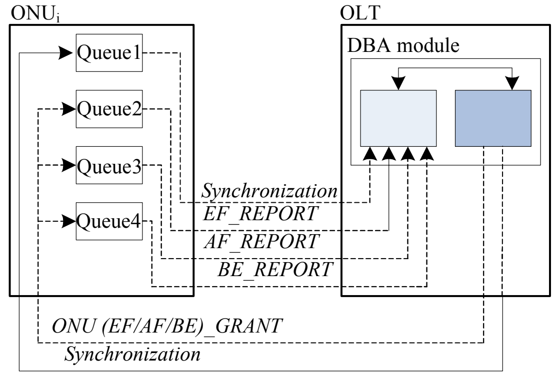

Fig. 2. OLT – ONU communication.

The total available upstream bandwidth of each wavelength in one cycle should be determined as:

$$W^{total} = R*\left(T_{cycle}^{max} - T_g\right) \tag{1}$$

where R is the line rate of each wavelength channel operating in the section between OLT and ONUs, T_g is a guard interval, and T_{cycle}^{max} is a maximum transmission cycle time (MTCT). Allocated bandwidth for all three traffic classes for ONU$_i$ can be expressed as:

$$W_i^{ONU\_requested} = \max\left\{W_i^{EF\_requested}, W_i^{AF\_requested}, W_i^{BF\_requested}\right\} \tag{2}$$

$$W_{total}^{ONU\_requested} = \sum_{i\in N} W_i^{ONU\_requested} \tag{3}$$

$$w_i = \frac{W_i^{ONU\_requested}}{W_{total}^{ONU\_requested}} \tag{4}$$

$$W_i^{ONU\_allocated} = \begin{cases} w_i * W^{total}, & W_i^{ONU\_requested} < W^{queue} \\ W^{queue}, & W_i^{ONU\_requested} \geq W^{queue} \end{cases} \tag{5}$$

$$W_i^{ONU\_allocated} = W_i^{EF\_allocated} = W_i^{AF\_allocated} = W_i^{BE\_allocated} \tag{6}$$

where:

N – Total number of ONU nodes,

w_i – The weight assigned to ONU$_i$, where $\sum_{i=1}^{N} w_i = 1$;

$W_i^{ONU\_requested}$ – Requested bandwidth of ONU$_i$;

$W_{total}^{ONU\_requested}$ – Requested bandwidth of all ONUs in the system;

$W_i^{EF\_requested}$ – Requested bandwidth for EF traffic class transmission in ONU$_i$;

$W_i^{AF\_requested}$ – Requested bandwidth for AF traffic class transmission in ONU$_i$;

$W_i^{BE\_requested}$ – Requested bandwidth for BE traffic class transmission in ONU$_i$;

$W_i^{ONU\_allocated}$ – Bandwidth allocated for ONU$_i$;

$W_i^{EF\_allocated}$ – Bandwidth allocated for EF traffic class in ONU_i;

$W_i^{AF\_allocated}$ – Bandwidth allocated for AF traffic class in ONU_i;

$W_i^{BE\_allocated}$ – Bandwidth allocated for BE traffic class in ONU_i;

W^{queue} – Maximum defined length of ONU's queue.

III. FWPBA Model Analysis

As explained previously, in the FWPBA model one wavelength is always used for transmission of the same type of traffic and cannot be assigned to another ONU until the transmission on all wavelengths in the observed ONU is completed. In this way, the system introduces a new delay component, namely $t^{waiting}$, Fig. 1. The delay in the ONU_i can be expressed as:

$$t_i^{ONU} = \max\left\{t_i^{EF}, t_i^{AF}, t_i^{BE}\right\} \quad (7)$$

$$t_i^{EF\_waiting} = t_i^{ONU} - t_i^{EF} \quad (8)$$

$$t_i^{AF\_waiting} = t_i^{ONU} - t_i^{AF} \quad (9)$$

$$t_i^{BE\_waiting} = t_i^{ONU} - t_i^{BE} \quad (10)$$

where:

t_i^{ONU} – Processing time in ONU_i;

t_i^{EF} – Transmission time of EF traffic in ONU_i;

t_i^{AF} – Transmission time of AF traffic in ONU_i;

t_i^{BE} – Transmission time of BE traffic in ONU_i.

Based on (7) - (10) it can be concluded that the most loaded wavelength, i.e. the most represented traffic class, will not have a waiting time. As we previously assumed, in accordance with the development of services and applications, AF class traffic is now most common in the access networks, while the amount of BE traffic is reduced [5]. From this we conclude that the waiting time will be dominant for EF class traffic, and to a lesser extent for the BE class.

Since the bandwidth allocation algorithm allocates the same bandwidth to all traffic classes based on the maximum requested bandwidth, the allocated bandwidth will not be fully utilized. On the other hand OLT is less occupied and processing is faster, but the bandwidth will be fully exploited only on the maximum loaded wavelength. Unused bandwidth for each class of traffic is calculated as:

$$W_i^{EF\_unused} = W_i^{ONU\_allocated} - W_i^{EF\_requested} \quad (11)$$

$$W_i^{AF\_unused} = W_i^{ONU\_allocated} - W_i^{AF\_requested} \quad (12)$$

$$W_i^{BE\_unused} = W_i^{ONU\_allocated} - W_i^{BE\_requested} \quad (13)$$

$$W_i^{ONU\_unused} = W_i^{EF\_unused} + W_i^{AF\_unused} + W_i^{BE\_unused} \quad (14)$$

where:

$W_i^{EF\_unused}$ – Unused portion of bandwidth allocated for EF traffic class in ONU_i;

$W_i^{AF\_unused}$ – Unused portion of bandwidth allocated for AF traffic class in ONU_i;

$W_i^{BE\_unused}$ – Unused portion of bandwidth allocated for BE traffic class in ONU_i;

$W_i^{ONU\_unused}$ – Unused bandwidth allocated for ONU_i.

Given that AF traffic class is most common in the system, this class fully utilized the allocated bandwidth, i.e. for this class there is no unused bandwidth.

Previous calculations of waiting time and unused bandwidth are used to evaluate the efficiency and numerical representation of FWPBA model efficiency.

IV. Simulation

We simulate the WDM EPON system with Matlab Simulink model in which we implemented FWPBA model. The parameters used in the simulation are as follows: number of ONUs is N=16; data rate of each wavelength is 1 Gbps; maximum transmission cycle time is 2 ms; guard interval is set to 1 μs; the traffic loads of ONUs are varied between 0.1 and 1 (i.e., 10 and 100 Mbps); buffering queue size is 1 Mby. The round-trip time (RTT) was randomly generated according to a uniform distribution U[50 μs, 200 μs], which corresponds to ONUs distances of 15–30 km from OLT. Since EF service is narrowband, it is assumed that it can occupy up to 15%, AF traffic class up to 50% and BE traffic class up to 35% of the available bandwidth [5]. For the generation of AF and BE traffic the model presented in [7] is used, while EF traffic is modeled by using the Poisson's distribution with packet size fixed to 70 by [2].

Fig. 3 shows a comparison of average packet delay and waiting time for each supported traffic class. The results confirm the conclusions obtained by theoretical model analysis from the previous section. Since EF traffic is the least represented in the system, the waiting time component of this traffic class is dominant and will have the highest average delay in the system. BE traffic is represented by a slightly better delay characteristic, while AF traffic that is the most represented in the system has the best characteristic of average packet delay and there is no waiting time component. In the case of the maximum loaded system, the average packet delay of EF traffic is by 7.5% higher than the average packet delay of BE traffic, and by 19.9% larger than the average packet delay of AF traffic, Fig. 3. The characteristic of maximum packet delay further confirms this behavior, Fig. 4. As we expect, EF traffic experiences the largest maximum delay in the system since it is the least represented traffic class compared to BE and AF traffic class. Fig. 5 shows the probability density function (pdf) of EF service packet delay at full loading scenario. The jitter is represented by the packet delay variation of two consecutively departed EF packets from the same ONU in the same transmission window [1]. EF delay sequence presents a dispersion with a sufficient number of data points in a tail until 1.6 ms which confirms the ability of FWPBA model to provide an appropriate level of the quality of service for high priority traffic regardless of the existence of waiting time. Further analysis of the average queue occupancy reserved for each of the supported traffic classes, as expected, shows that the queue in which AF packets are placed is the most loaded, followed by the queues for BE and EF traffic, which fully corresponds to the distribution of traffic in the system, Fig. 6. In the same figure the amount of unused bandwidth which is assigned to each traffic class, in accordance with the mathematical model, is represented. As we concluded in the theoretical analysis the unused bandwidth component is dominant for the EF traffic that is the least represented in the system, while for the AF traffic it is practically annulled.

The percentage of lost packets in the system is very small, as shown in Fig. 7, which is explained by increased efficiency due to more efficient OLT, mathematical model and a fixed allocation of wavelengths. This is further confirmed by the throughput characteristic which in the case of most of the load reaches 87%, Fig. 8.

The results obtained by testing WDM EPON models show that the efficiency and performance of the system are significantly improved compared to conventional EPON systems and HG (PBS) algorithm [1], [4]. The presented results show that the implementation of FWPBA model enable achieving significant improvements in the average packet delay of AF traffic (14.5%), average packet delay of BE traffic (25%) and percentage of lost packets (27.8%) compared with the results presented in [1] and [4].

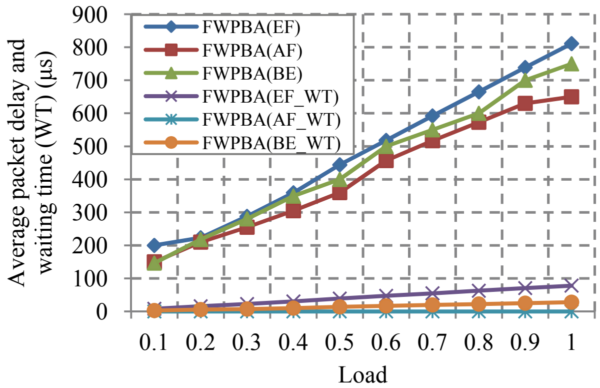

Fig. 3. Average packet delay and waiting time (WT).

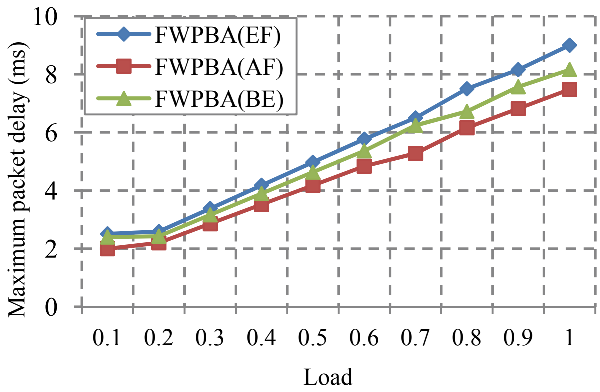

Fig. 4. Maximum packet delay.

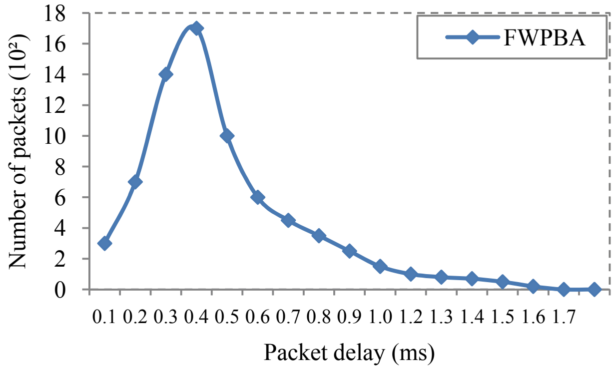

Fig.5. Jitter.

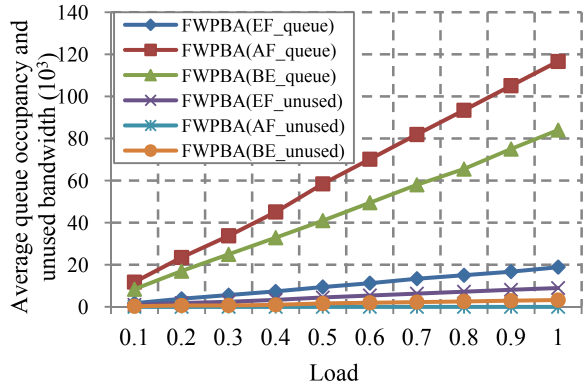

Fig. 6. Average queue occupancy and unused bandwidth.

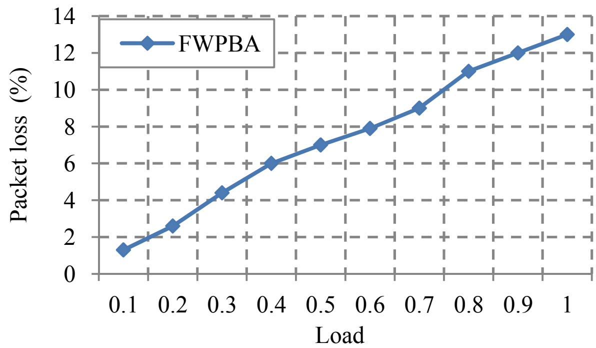

Fig. 7. Packet loss.

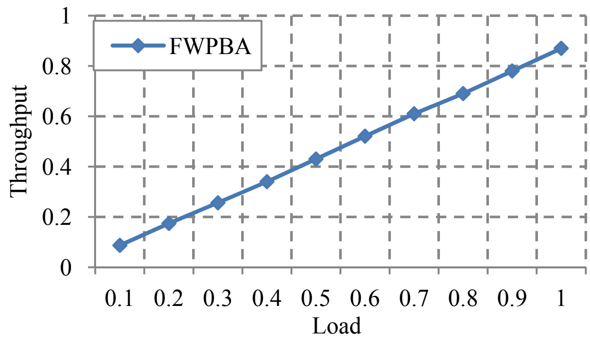

Fig. 8. Throughput.

The proposed FWPBA model optimizes packet loss and throughput of WDM EPON systems, as well as the delay of AF traffic that is currently a dominant traffic class in the access network. The results of theoretical analysis and simulations show that the EF traffic experiences the largest average delay due to waiting time. However, this delay is shorter than 1ms, which enables the provision of quality service for this class, also.

V. CONCLUSION

The FWPBA model proposed in this paper allows the dynamic allocation of bandwidth for different traffic classes at different wavelengths in a WDM EPON network. Bandwidth allocation is based on the algorithm which allows efficient operation and improves overall system performance by all measured parameters.

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