INFOTEH-JAHORINA Vol. 16, March 2017.

How long can ONU be inactive in four-wavelengths model of WDM Ethernet Passive Optical Network

Bojan Pajčin
School of Electrical Engineering, University of Belgrade
IRITEL A.D., Optical Transmission System Department
Belgrade, Serbia
bojan@iritel.com

Petar Matavulj
School of Electrical Engineering
University of Belgrade
Belgrade, Serbia
matavulj@etf.bg.ac.rs

Mirjana Radivojević
School of Computing Science
University Union
Belgrade, Serbia
mradivojevic@raf.edu.rs

Abstract— **In order to obtain energy-efficient Passive Optical Networks (PON), we are putting Optical Network Unit (ONU) to inactive state (i.e. sleep mode) before and after the allocated time slot in four-channel Fixed Wavelength Priority Bandwidth Allocation (FWPBA) model of Wavelength Division Multiplexing Ethernet PON (WDM EPON). We obtained that the ONU can be inactive for more than 70% of the time (up to 94%). However, in FWPBA energy-efficient WDM EPON a same time slot is assigned to ONU for packet transmission of all three traffic classes, hence the fiber bandwidth isn't fully utilized. The main objective of this paper is to examine how long ONU can sleep if mechanisms allocates unique time slot for each traffic class i.e. each wavelength and how much additional bandwidth at each wavelength is then available.**

Keywords – energy efficiency; sleep mode; WDM EPON.

I. INTRODUCTION

Today, energy saving have become one of the most important requirements for the next generation telecommunication networks. Having in mind that access networks consume about 80–90% of the total Internet power consumption, energy saving becomes even more important as the access network technologies evolve into the next generation with higher data rates and larger amount of users. Passive Optical Networks (PONs) are currently considered as a promising technology to deliver high data rates to users, and in the same time more energy efficient than their previous counterparts (e.g., ADSL and VDSL) [1].

In broadband access network, Ethernet PON (EPON) is currently considered as an optimal candidate for green network deployment since it has minimum power consumption compared to the other technologies. We presented in [2] implementation of saving mechanisms in Fixed Wavelength Priority Bandwidth Allocation (FWPBA) model of WDM EPON [3]. FWPBA model of EPON is four-channel WDM EPON that uses four wavelengths for downstream transmission and four wavelengths for upstream transmission in order to reduce the number of transmitters in Optical Line Terminal (OLT) and further reduce the cost and complexity of the equipment. In difference to various solutions presented up-to-date, in the FWPBA model wavelengths assignment take place per service class and not per ONU [3]. In [4] is showed that Quality of Service (QoS) is still fulfilled in presented energy-efficient model of WDM EPON, and reported results [2] show that ONU inactive time rise over 90%, which is better than the listed related works [5][6][7], where the savings were under 90%.

The principle applied in the FWPBA model of WDM EPON [2][3], in which an ONU retains all three wavelengths until the transmission on all three wavelengths was finished, does not use total bandwidth efficiently. In order to improve bandwidth utilization, we use described energy saving mechanisms [2] in Dynamic Wavelength Priority Bandwidth Allocation (DWPBA) model [3]. In the presented energy-efficient DWPBA model, the wavelength on which an ONU has finished traffic exchange with OLT of the defined traffic class is immediately released and allocated to the next ONU for the transmission of the same traffic class in accordance with the OLT polling table. One wavelength could be used only for the transmission of the defined class, just as it was case in the FWPBA model. We expect shorted inactive times of ONUs in comparison with FWPBA model, but still with significant savings when is compared with results from related work [5][6][7].

This paper is structured as follows. Next section presents the changes in DWPBA model of WDM EPON in order to obtain energy-efficient four-channel WDM EPON, and Dynamic Bandwidth Allocation (DBA) algorithm. Section III presents the simulation setup, while Section IV presents the simulation results. In Section V we discuss obtained results, conclude our work and present next steps for our future

This work was supported by the Serbian Ministry of Education, Science and Technological Development under Contracts Nos. TR32007 and 171011.

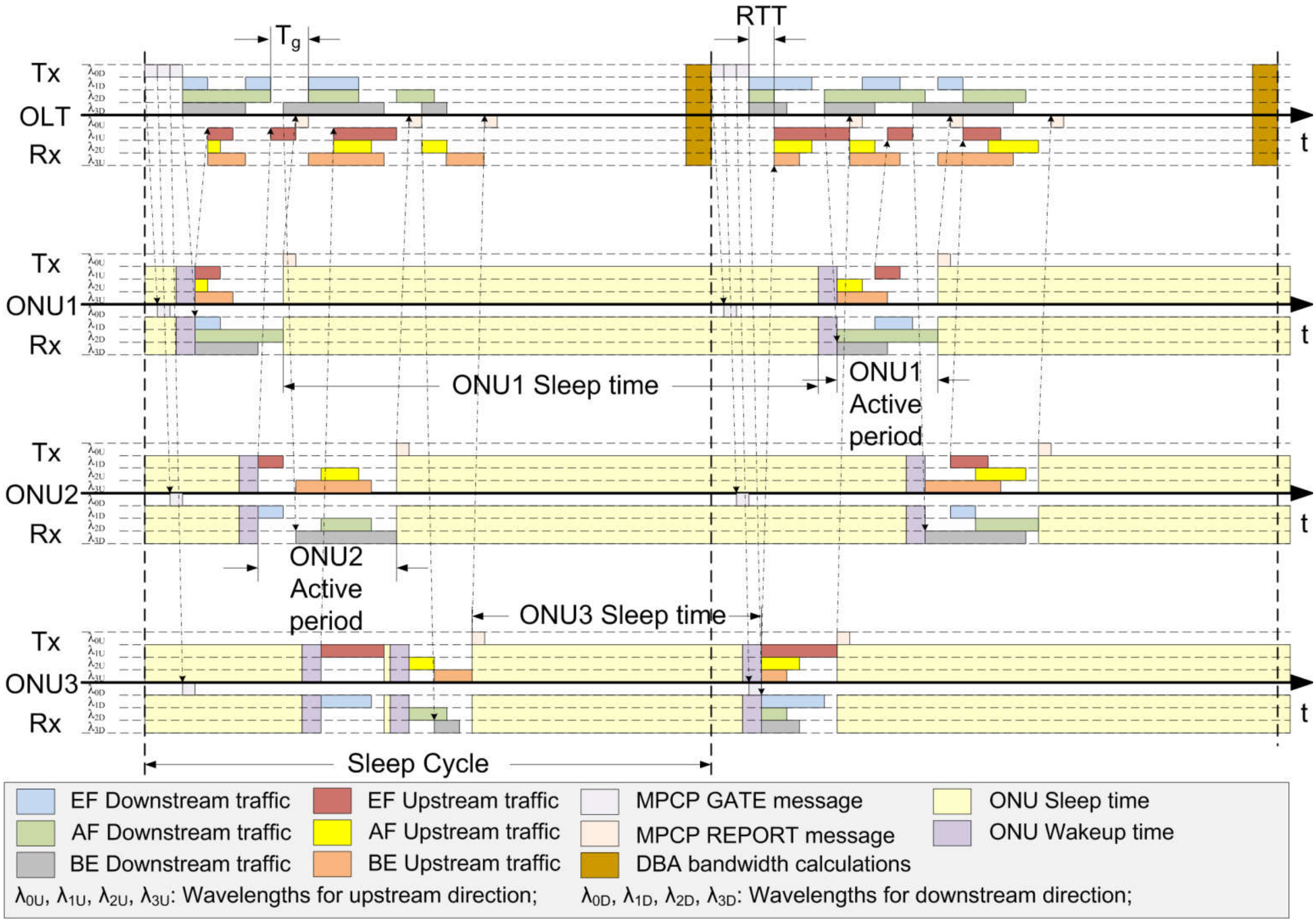

Figure 1: Packets, upstream and downstream scheduling, and sleep cycles flow in Energy-efficient DWPBA model of WDM EPON.

improving of bandwidth utilization in energy-efficient WDM EPON.

II. ENERGY-EFFICIENT DWPBA MODEL OF WDM EPON

In classic single-channel TDM EPONs, the allocation of resources is primarily related to the problem of dynamic bandwidth allocation, i.e. to scheduling upstream transmission on a single wavelength channel. The implementation of WDM technology introduces a new scheduling dimension because upstream transmissions have to be scheduled on different upstream wavelengths supported by the ONUs. New approach to QoS implementation in WDM EPON in which we use wavelength assignment per service class to improve service sensitivity and customer subjective impression is presented in [3]. Similar to the FWPBA model, in the DWPBA model we have defined the same static mapping between traffic classes and data wavelength in order to avoid the implementation of an additional algorithm for wavelength allocation. However, the exchange of control messages in downstream direction is the similar as the exchange defined for FWPBA model which was presented in [4]. Now, OLT informs ONUs about bandwidth allocation for each wavelength, instead unique bandwidth allocation in FWPBA [3]. In the upstream direction, all ONUs use REPORT MPCP messages to request bandwidth for each traffic class independently. Having received REPORT messages from all ONUs, the DBA module in the OLT allocates bandwidth to each ONU and to each traffic class and notifies ONUs by using a GRANT MPCP message. Dynamic bandwidth allocation is more complex in the DWPBA model in comparison with the FWPBA model because every wavelength is processed independently. Moreover, once again in contrast with FWPBA model, the OLT now allocates a certain amount of available bandwidth to each traffic class. When the transmission on one wavelength in the selected ONU is over, that wavelength is scheduled to the next ONU for the transmission of the same (defined) traffic class. The allocation of wavelengths is completely asynchronous. When the data transfer is complete, ONUs immediately release the appropriate wavelength for the given traffic class and the OLT assign it to the next ONU.

In order to support differentiated services over WDM EPON, OLT is installed with an array of physical queues where each queue is used to store a defined class of traffic for each ONU. When a packet arrived to OLT, it will be first categorized by destination ONU, and next into one of the priority groups according to its type and content and then it will be placed into corresponding queues. So, the changes in the OLT are new buffers for making TDM downstream traffic [2].

Regardless of the installation of new buffers and additional TDM traffic, QoS requirements must be fulfilled as in the 'ordinary' DWPBA model. The ONU architecture is unchanged in comparison with energy–efficient FWPBA model. Fig. 1 shows traffic and control messages flow in the energy-efficient DWPBA model of WDM EPON. As showed, while one ONU exchanges traffic with OLT at one wavelength other ONUs don't use that wavelength for traffic exchange. If ONU don't use any wavelength it can go to inactive state, i.e. into sleep mode. The both models, FWPBA and DWPBA, incorporate the offline scheduling mechanism. At the end of each sleep cycle OLT forms load state of its buffer and calculates how much bandwidth will be allocated for each ONU using the requested bandwidth information previously sent by each ONU for all three wavelengths in REPORT messages.

III. SIMULATIONS

For simulating energy efficient DWPBA model of WDM EPON we use the programming language C. All network elements and their functions (OLT, ONU units, OLT and ONU buffers, traffic generators, packages, MPCP messages, etc.) are implemented in this programming language. The simulation setups are identical like setups in [4], in order to compare obtained results with the results from [4]. For that purpose, the number of users (32 ONU units), the number and speed of uplinks from OLT to core network (two 1Gbps uplinks), transmission speed per lambda in WDM EPON (1Gbps), maximum OLT and ONU buffers size (1MB), the durations of the sleep cycle (5ms, 10ms, 20ms and 50ms), services and the number of services per user, package size and required bandwidth for each service, among others are identical to values in [4]. Also, the same services in packages of services provided to end users by provider are used. Services used in simulations are Standard Definition Television (SDTV), High Definition Television (HDTV), Voice over IP (VoIP), Video on Demand (VoD), Video Streaming, Live streaming/Gaming and Broadband Internet access. Packages of services were created to represent typical demands of today's end-user and service providers offer, so we have the largest number of end-users subscribed to a one SDTV channel, one telephone line and broadband Internet access (5Mbps downstream and 1Mbps upstream), while a small number of end-users is subscribed to the packages with more HDTV and SDTV channels, two telephone lines and additional services such as VoD and 25 Mbps downstream and 5 Mbps upstream Internet access. The results are presented in the following section, and were obtained by running the simulation for different values of the sleep cycle: 5ms, 10ms, 20ms and 50ms. It's important to mention that all setups simulate events in 100% loaded network for 3 minutes, where all simulated users use all their services during the entire duration of the simulation. This presents the "worst case" scenario and any other setup will have better results.

IV. RESULTS

The simulated C code and functions are unique for energy-efficient FWPBA and DWPBA models of WDM EPON, except DBA algorithm block in OLT. There is one different C function for each model, and in those functions specific, early described DBA algorithms are implemented. Choice of DBA algorithm and simulated model is simply realized by setting one flag in simulation configuration before its running. All that code integration enables the same simulation environment and conditions for both models and as a consequence real result comparison. Simulation functions periodically verify the status of all traffic generators, count generated packets, write and read packets from buffers, monitor loads of the all buffers, check start and finish of the packet transmission, measure the ONU sleep times and active periods, etc. After the end of simulation all obtained data for each service and each wavelength of each ONU are recorded to the output file in the form of tables. All results plotted at Fig. 2, Fig. 3 and Fig. 4 are obtained for most demanding users. These usere are subscribed in simulations for package of services which contains one HDTV, one SDTV, two VoIP lines, VoD service, Video Streaming, Gaming service and 25/5 Mbps Internet access. Results from all other users are slightly better, and that is reason why we present result only for most demanding user. Fig. 2 shows percentage of ONU inactive time in FWPBA and DWPBA simulations in function of sleep cycle duration, while the maximum additional delays induced by OLT buffers for sleep cycle duration of 5ms are presented at Fig. 3.

Total available bandwidth per wavelength can be calculated as:

$$W^{total} = R * (T^{cycle} - (N-1)T_g - T_{RTT} - T_{MPCP} - T_{PROC})$$

where R is the line rate of each wavelength channel, T^{cycle} is maximum duration of sleep cycle, N is number of ONU units, T_g is the guard interval, T_{RTT} is road-trip time, T_{MPCP} is time

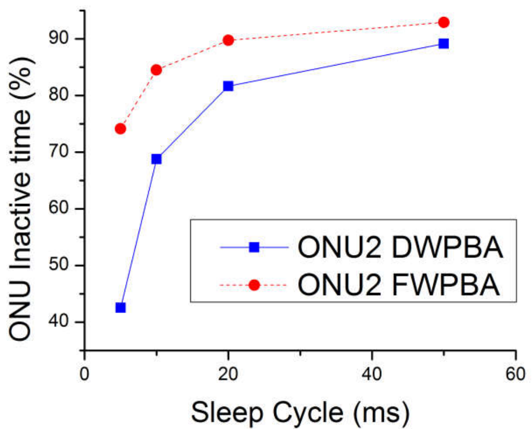

Figure 2: ONU inactive time in function of the sleep cycle duration.

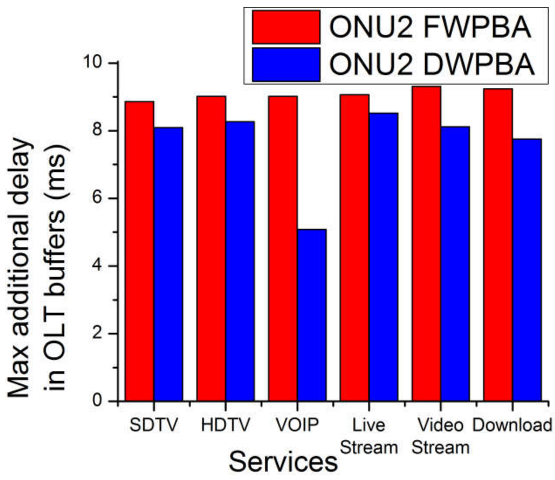

Figure 3: Maximum additional delays for 5ms sleep cycle duration.

period in one sleep cycle for sending all GATE MPCP messages, and $T_{PROCESSING}$ is time period in one sleep cycle for processing all received REPORT MPCP messages. Average unused bandwidth per wavelength can be calculated as:

$$W_{average}^{tc\_free} = \frac{\sum_{N^{cycle}}\left(W^{total} - \sum_{j=1}^{N}\left(W_i^{tc\_allocated}\right)\right)}{N^{cycle}W^{total}}, tc \in EF, AF, BE$$

where N^{cycle} is number of sleep cycles, *tc* represent class of traffic (wavelength assigned to class of traffic) - EF, AF and BE are Expedited Forwarding, Assured Forwarding and Best Effort traffic classes.

At Fig. 4 average unused bandwidths per wavelength in function of sleep cycle duration are plotted.

V. DISCUSSION, CONCLUSION AND FUTURE WORK

Making independent bandwidth allocation for each wavelength (class of traffic) decreases ONU inactive period in sleep cycle. This is expected, because time slots for different wavelengths aren’t synchronous any more, and transmitters don't work at same time. For smaller duration of sleep cycle there is possibility for smaller ONU inactive intervals. If we observe standard WDM EPON ONU which consume 10W in active time and 1W in idle time [8] we notice that is possible to save more than 1.8MWh (up to 3.7MWh) per year in one WDM EPON with 64 ONUs (users). This is still great potential for energy saving in WDM EPON.

The most interesting results are obtained for unused bandwidth per wavelength. As we can see from Fig. 4, in FWPBA model all wavelengths have the same part of unused bandwidth. This is consequence of unique time slot allocated for all three wavelengths. With implementing energy saving mechanisms in DWPBA model of WDM EPON we decreased ONU inactive time, but we increased additional bandwidth for 10% to 75% in comparison to FWPBA model results. And in DWPBA model there is very weak unused bandwidth dependence from sleep cycle. Also, in DWPBA model maximum additional packet delays induced by OLT buffers are decreased in comparison with FWPBA model.

The future work will be based on reusing unused bandwidths of all wavelengths to increase total optical fiber capacity utilization and improve QoS parameters. It means that we need to implement online DBA algorithm [3] in presented energy-efficient DWPBA model of WDM EPON in purpose to allocate unused bandwidth and frequently read-out packets from buffers for minimizing additional packet delay.

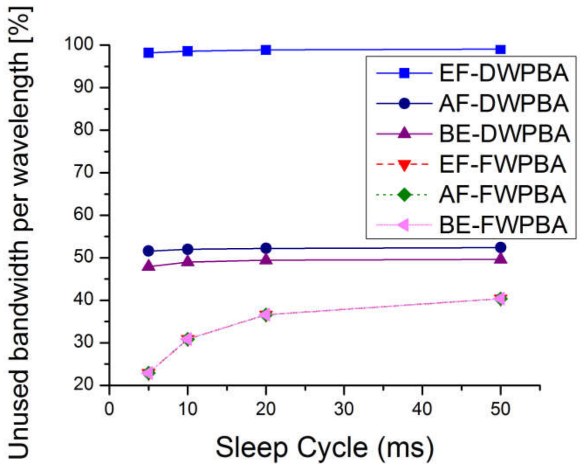

Figure 4: Unused bandwidth per wavelength in function of the sleep cycle. duration

ACKNOWLEDGMENT

This work was supported by the Serbian Ministry of Education, Science and Technological Development under Contracts Nos. TR32007 and 171011.

REFERENCES

[1] J. Baliga et al., “Power Consumption in Access Networks”, OFC 2008, paper OThT6 (2008)

[2] B. Pajcin, P. Matavulj, M. Radivojevic: Simulation analysis of energy efficient WDM ethernet passive optical network, Optical and Quantum Electronics 48:313 (2016)

[3] M. Radivojevic, P. Matavulj: The Emerging WDM EPON, 978–86-7466-449-0. Academic Mind, Belgrade, SRB (2012)

[4] B. Pajcin, P. Matavulj, M. Radivojevic - MPCP adjusting for improving QoS in Green WDM EPON, 6th International Workshop on Fiber Optics in Access Networks – FOAN 2016, Lisbon – Portugal, pp. 29-34, October 2016.

[5] A. Dixit, B. Lannoo, D. Colle, M. Pickavet, P. Demeester: Energy efficient dynamic bandwidth allocation for Ethernet passive optical networks: overview, challenges, and solutions, Opt. Switch. Netw. 18(2), 169–179 (2015)

[6] D. P. Van, L. Valcarenghi, M. Chincoli, P. Castoldi: Experimental evaluation of a sleep-aware dynamic bandwidth allocation in multi-ONU 10G-EPON testbed, Opt. Switch. Netw. 14(1), 11–24 (2014)

[7] S. Chen, A. R. Dhaini, P.-H. Ho, B. Shihada, G. Shen, C.-H. Lin: Downstream-based Scheduling for Energy Conservation in Green EPONs, J. Commun. 7(5), 400–408 (2012)

[8] Advanced Media Technologies, Inc. (AMT), PBN EPON-ONU - current product specification, http://www.goamt.com/wp-content/uploads/2015/08/EPON-ONU.pdf