Zoltán BOSTERNÁK[1], Rastislav RÓKA[1]

Institute of Multimedia Information and Communication Technologies, Slovak University of Technology (1)

Bandwidth Scheduling Methods for the Upstream Traffic in Passive Optical Networks

Abstract. This paper deals with the bandwidth calculation, time slot assignment and average delay analysis in passive optical networks. The basic principle used throughout the time slot allocation for the upstream traffic is provided by the MPCP protocol control messages. The recommendation of this protocol contains both messages used in the upstream and downstream directions. Certainly, various results can be accomplished by different number of users in the network topology. To highlight the discrepancies and possibilities with increased number of optical units, several simulations have been made. During the workflow, we introduce the main topology used for the simulation, how the data transmission is handled in the network and the way the upstream traffic scheduling is completed in. At the end, the traffic utilization is smoothly increased several times to see the differences among various amount of traffic in the system. This work is mainly focusing on the system utilization, delay calculation and the eventual system delay overall.

Streszczenie. W artykule analizowane są: pasmo przenoszenia, szczelina czasowa i opóźnienie w pasywnej optycznej sieci. Do alokacji szczeliny czasowej użyto protokołu MPCP. Przeprowadzono symulację zwiększonej liczby użytkowników sieci. Obserwowano sposób przpływu danych w sieci przy wysyłaniu I odbiorze. Metoda planowania harmonogramu pasma przy wysyłaniu danych w pasywnej optycznej sieci

Keywords: delay calculation, TDM-PON, time slot allocation, bandwidth assignment
Słowa kluczowe: póżnienie, szczelina czasowa, pasmo, optyczna sieć przesyłowa

Introduction

During the last couple of years, passive optical networks PON has been identified as one of the most important mile technologies. As a consequence of the solution of passive optical networks, a huge amount of users can benefit from the use of broadband services worldwide. Particular subscribers have an increased demand with regards to the allocated bandwidth in passive optical networks as well. The main reason for that we can see is that there are various services introduced year by year like IPTV, HQ Video Services, etc. In a common structure of a passive optical network, the source traffic is initiated from a unit called as optical line termination OLT. That unit is located mainly in the central office CO and passing thru the data into the optical fiber for a distance of decades in kilometers. The next unit handling this incoming traffic is an optical splitter which is distributing the signal into several optical fibers. The traffic from here is handled towards by a network unit ONT, which is usually deployed next to the customer premises. [1] The optical signal is terminated here before it will pass over to the users and subscribers. Certainly there are different subscribers with different nature of requirements, therefore the requested time slots as well as the transmission delays within the network topologies are various.

To satisfy these needs, the developers have to constantly find new solutions on how to allocate bandwidth. So far, one of the most effective option seems to be to assign the time containers T-CONTs in many various ways. If this is accomplished, the architecture FTTX can still remain attractive to the subscribers. To make this solution competitive with regards to the other available network solutions, the initial cost of this system also has to be kept as low as possible. Passive optical networks PON are now available for many years. There are several standards out there for passive optical networks as APON, BPON, EPON, 10G_EPON, GPON and NG-PON. A well observed passive optical network can be utilized efficiently with the use of dynamic bandwidth allocation mechanism only if it's well designed. The aim of this paper is to analyze the traffic in passive optical network and to observe the possible output with increasing the utilization of the bandwidth up to the fully utilized links. In the upcoming sections, we will introduce some basics about the passive optical networks and do a general comparison of them. Then we can highlight the benefits of bandwidth allocation mechanisms used widely in the passive optical networks. In the last part of the paper, we will introduce our simulation and do a graphical interpretation of the achieved results [1, 11, 13].

Passive Optical Networks

A typical passive optical network PON contains a set of optical network units ONT/ONU, a passive optical splitter and obviously an optical line terminal OLT which is broadcasting the traffic down to the subscribers. Each optical splitter has some information about its performance loss and signal capabilities. That means, that we can split out one broadcasted signal from the optical line termination a number of times with regards to this information. When the loss characteristics are not taken into consideration, it can lead us to performance degradation and poor signal quality on the subscribers end. An optical network unit ONT can be placed near to the customer premise, as FTTH/FTTB or one of the available options. Passive optical splitter used in the PON topology is a unit which is basically without active power. This component can accept an optical signal in one direction on the ingress port and can split the optical signal into several egress fibers. When we are coming to the upstream traffic direction, when a proper time window has been allocated for a specific user, the passive optical splitter has the role to combine various signals from multiple traffic sources into one specific fiber [2, 5]. Without WDM, a single optical network component can transmit the optical signal at once, otherwise it can happen that there will be an interference among multiple signals. This is the point when we are coming to the term of bandwidth allocation, or to be more specific, time slot allocation. One of the important mechanism to be used in passive optical networks is the one, which is responsible to schedule time slots, to allow each unit to transfer their data without interfering one with another. One of the initial architecture among passive optical networks was the ATM PON with a definition of 155 Mbit/s in both directions and 622/155 Mbit/s asymmetrical data transmission. The next introduced technology was named as Broadband BPON, where an additional wavelength has been used to transfer video data. More detailed information about both protocols can be found under recommendation ITU-T G.983 [10]. Ethernet

Passive Optical Networks (EPON) are functioning in a similar manner as other passive optical network technologies. A standardized 802.3ah protocol called as MPCP is responsible to provide specific time slots for each optical network component to avoid data transfer from various units at the same time. Each unit can request a bandwidth which is forwarded to the OLT. Then the optical line termination unit is responsible to grant transfer window to each of the subscriber units [1, 6, 15].
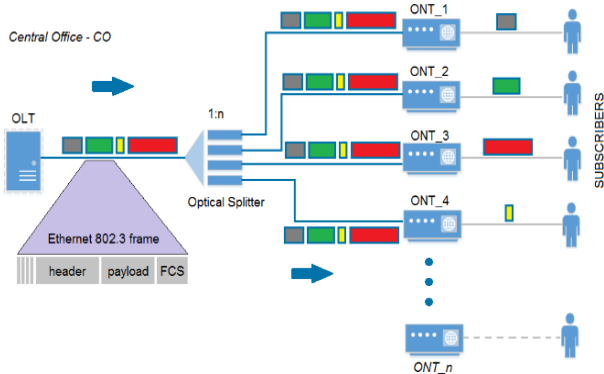

Fig.1. A typical Passive Optical Network topology

The dynamic bandwidth allocation mechanism DBA is responsible to provide appropriate and reliable queue sharing, across several ONU components. In the frame structure there is a field called as Logical Link Identifier LLID which is used to identify the proper ONU in the network topology. The initial discovery state is responsible to provide a unique LLID value to each ONT. In this way the standard preamble in EPON is modified by adding the LLID field and a CRC for error checking. A propagation delay in passive optical networks is defined to follow the timing standard. Both components, OLT and ONT have counters with 4 bytes that increment every 16 ns. The OLT unit sends out the first message with this counter information [9]. Then the ONT will receive this information and will synchronize this value with its own. The same process is done, when ONT will send a message back to the OLT. Once OLT gets that message, it will compare the value with its own value. The difference when the OLT sent and received the last frame is basically the propagation delay we need to consider when allocating time slots in passive optical networks. The discovery mechanism has the role of broadcasting GATE messages out to the ONTs in regular intervals. Once a GATE message is received by any of a newly added ONT into the topology, it will send back a message for registration. In case of more ONU have been added into the topology, a random interval has to be defined. This interval is responsible that not all ONUs will respond back to the discovery message in the same time. When the registration is done on the OLT side, the assignment of the unique LLID should be done to have the ability to distinguish among several components. There can be different network components attached to the ONTs at the customer premises, which will authenticate themselves once the registration has been successfully completed for the ONTs. Once the authentication is completed it includes the newly requested IP address with DHCP as well [2, 5, 6, 15].

Data Transmission in Ethernet PON
The way the downstream traffic is handled in passive optical networks is accomplished with broadcasting. When the optical network element OLT decides to send some traffic to a specific ONT, it will send out a broadcast message to all ONTs rather than only to that specific one. In this down-streamed traffic, the LLID prefix has to be included, so when all ONTs receive the message they can decide if the message was addressed to them or not. The particular ONT unit the traffic has been addressed for can then forward the traffic to its subscriber. That's the idea of the downstream message transfer in PON. As the downstream traffic can contain huge bandwidth consuming data (e.g. video transfer), the subscribers attached to the same PON topology are limited by one another [2].
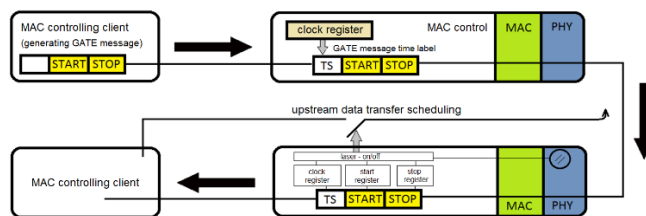

Fig.2. The GATE message transmitted from OLT to ONUs

The upstream traffic on the other hand is more challenging, as to avoid interference among the optical signals from various users, only one optical network unit ONT can transfer data in a specific time. When a component decides to transmit data, it will send and receive a pair of REPORT/GATE messages. As the ONT can have multiple queues in its buffer, the REPORT message will share this information to the OLT. In the received OLT GATE message the transfer information will be provided with a specific START/STOP value. The optical line terminal has to be capable to maintain all requests from all the optical units. Nevertheless, the grants have to be prioritized as well with the ability to load balance among various elements. This scheduling is supposed to be completed by the dynamic bandwidth allocation mechanism DBA. Therefore it's critical to develop an deploy a bandwidth allocation mechanism which can make the most important decision in the system, which would be the way how the time windows are allocated for each optical unit to minimize the gaps between particular transfers [2, 15, 16].
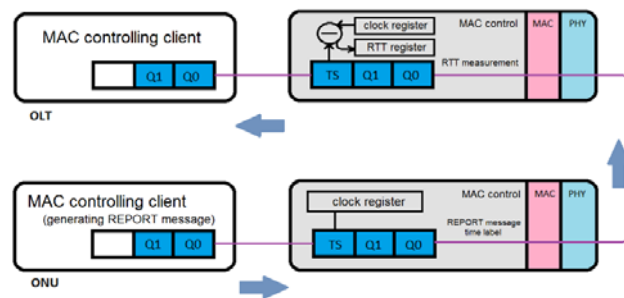

Fig.3. The REPORT message transmitted from ONU to OLT

Upstream Traffic Scheduling
Various application interfaces can be used to simulate the upstream traffic in passive optical networks. With regards to our previous simulations, also published in our article [17], we've decided to use the programming language developed by MathWorks. With Matlab we are allowed to do matrix handling, creating of plots for functions and data, to use different algorithms whenever needed. Matlab can work

simultaneously with other programming languages as well, e.g. Python, C/C++, etc. The first value we initiated our simulation with, was the Round Trip Time RTT. It's basically the delay calculated by the nature of the optical signal. This value is one of the most important details that we need to ascertain in order to make a data transfer without any collision. There are several messages exchanged between the optical line terminal OLT and optical units ONT.

Table 1. The configuration used for the simulated topology

NAME	VARIABLE	VALUE
Simulated ONUs	N	4 – 32
BW for upstream	$BWTH_{UP}$	1.25 Gb/s (aft. 8/10B LC is 1 Gb/s)
Allowed distance	L_{ALL}	20 km
Guard Time	t_{GUA}	75-150 µs
On/off time for laser	t_{LAS}	512 ns
Process time	t_{PROC}	30 µs

The REPORT and GATE messages are responsible to ensure data transfer as well without any collision. The synchronization has to happen between OLT and each ONT unit with the use of local clocks. Subsequently, the GATE message is the one which is passed over to each ONU. Couple of topologies are already defined which can be used for the simulation, like bus, star, ring. We have decided to deploy our simulation with the common topology in passive optical networks, called as tree topology. There always has to be some initial parameters defined in passive optical networks. In the presented simulation we will consider the transfer delay, as this is the one which has the highest impact on the bandwidth results. Certainly, as we can foresee, it's dependent on the physical distance of the optical fiber. Couple of optical network units can be used, each at different location placed differently from the main optical line termination. The unit, responsible to distribute the optical signal into several fibers is called optical splitter OSP. The decision making unit in this topology is called OLT. The MPCP protocol is very similar to TDM, whereas in our case the optical element responsible to provide the scheduling details is the mentioned optical line terminal. The SLA is one of the important values in PON – see below in Table 2. The SLA that can be defined by the service provider is responsible to specify the amount of traffic that can be used by the particular user. If the SLA would be exceeded for one specific unit, that would lead the other optical network units to be "handicapped".

In our simulation, the OLT will gather all the REPORT messages and once the time windows have been calculated for data transfer in the upstream direction, it will provide the scheduling details within one polling cycle to all ONTs. The message used in this polling cycle is called as GATE. This work is focusing on the transmission delay and the bandwidth utilization in passive optical networks.

Simulation results

Referring to our previous article [17], the following methods have been used in this simulation:

- Static allocation mechanism (allocating the bandwidth request regardless the needs)
- Bandwidth assignment dependent on the network unit identifier NUI resp. NTI (this mechanism is inferior to the initial process of the system)
- Bandwidth allocation based on the transmission delay (highly dependent on the physical length of the cable)
- Bandwidth allocation method responsible to provide time slots per the requested amount of traffic

In this simulation, we initially used four optical network terminals with a particular network utilization scheme that

we deployed for. The value of RTT, which is quite subordinated to the physical distance in the system, was designed to use in this simulation as a value between 25 and 125 µs. Each value is generated randomly by the simulation and was used to show us the differences among various results. The bandwidth requests in the topology have been raised indiscriminately, so the different nature of the network can be observed. Upon the results from the first phase of testing, an increased number of users have been added into the topology.

Table 2. The script to keep the pre-defined SLA for the topology

```
while j<(K+1)
  ont-id_unique=j;
  str_show_a = sprintf('The ONT ID is %d.', ont-id_unique);
  disp(str_show_a);
  bandwidth1_ont_units(j)=input('Enter the value for this ONT: ');
  while bandwidth1_ont_units(j)>bandwidth_opt_unit
  str_show_b = sprintf('The max value is %d Mbit/s', bandwidth_opt_unit);
  disp(str_show_b);
  bandwidth1_ont_units(j)=input(Please try again: ');
end
  j=j+1;
end
```

Table 3. The results of the basic simulation

Network utilization: 230 000 Kbit/s				
Allocation	M1	M2	M3	M4
AD(K=4)	375.073 µs	70.801 µs	85.300 µs	54.311 µs
AD(K=8)	437.635 µs	111.447 µs	116.633 µs	53.112 µs
AD(K=16)	469.136 µs	124.944 µs	106.712 µs	60.189 µs

Four different bandwidth allocation methods M1 - M4 have been used in this simulation, starting with the most common (and less effective) static bandwidth assignment ending up with various ways of bandwidth assignments. The criterias that have been used to allocate the time slots are the bandwidth requests from various end users, the delay and the ID assigned to the optical network terminals. Our simulation test has been executed with doubling the number of users "K", therefore the following equation has been concluded:

(1) $$K = 2^n$$

where: k – number of users, n – 1,2,3,…

Certainly, the number of users can be various in each passive optical network, however the most common topologies have the connections with a number of 4, 8, 16, 32, 64 up to 128 network units. To substantiate a good overview of the network, several simulations have been made to see the results on the Average Delay AD in the system.

Table 4. The results of the simulation with increased throughput

Network utilization: 380 000 Kbit/s				
Allocation	M1	M2	M3	M4
AD(K=4)	375.082 µs	110.598 µs	122.620 µs	108.543 µs
AD(K=8)	437.564 µs	116.893 µs	217.606 µs	84.831 µs
AD(K=16)	469.070 µs	194.482 µs	182.221 µs	128.501 µs

With increasing the number of users in passive optical networks, we developed to be interested in the results with increasing the amount of data flown thru the system as well. Therefore, the network utilization has been progressively increased as well. In our simulation, we've used various bandwidth requests from each particular user and we used the same value at the specific network utilization for all methods. In this way we could make a fair method comparison for the whole system. The only thing we had to consider was to deliver the pre-defined SLA for each user based on the actual network utilization.

Table 5. The results of the simulation with the highest utilization

Network utilization: 590 000 Kbit/s			
Allocation	M1	M2	M3	M4
AD(K=4)	375.119 µs	216.273 µs	263.029 µs	145.064 µs
AD(K=8)	437.626 µs	255.528 µs	294.656 µs	185.041 µs
AD(K=16)	469.085 µs	259.093 µs	256.765 µs	198.152 µs

Conclusions

This paper is analyzing the idea of bandwidth allocation, time window allocation and average delay analysis in passive optical networks. In our simulation, several calculations have been made to see what happens in the network in case of increased bandwidth utilization. The number of users has been initially taken from 4 and has slightly been increased in the network as well. Various results have been achieved with different methods of bandwidth allocation. We have conducted to increase the number of optical networks units in our case study, whereas it can be easily concluded that with placing some extra optical network units into the network topology, some additional average delay will be created in the system. Subsequently, to see what is happening with the values of delay in the system with adjusting the throughput, additional simulations have been created. With increasing the utilization in the system, the results are proving, that in case of static allocation the slots are allocated constantly and the number of users along with the network utilization don't really affecting the value of system delay. The most effective way of bandwidth allocation seems to be the allocation based on the transmission delay and the amount of traffic requested by the users distributed within the network topology. For future research, additional simulations can be performed - e.g. with adjusting the guard time, to fully utilize the network, etc. - to see a more detailed reflection of the model and to ascertain about the complementary benefits of the time slot assignments in the adequate way. With using the WDM-PON, some additional wavelengths can be added to the system, which will adequately increase the bandwidth and show us the cross-functionality of the various platforms.

Authors: Ing. Zoltán Bosternák, Slovak University of Technology in Bratislava, Faculty of Electrical Engineering and Information Technologies, Institute of Multimedia Information and Communication Technologies, Ilkovičova 3, 812 19, Bratislava, SK, E-mail: zoltan.bosternak@stuba.sk; doc. Ing. Rastislav Róka, PhD., Slovak University of Technology in Bratislava, Faculty of Electrical Engineering and Information Technologies, Institute of Multimedia Information and Communication Technologies, Ilkovičova 3, 812 19, Bratislava, SK, E-mail: rastislav.roka@stuba.sk

REFERENCES
[1] C. F. Lam - Passive Optical Networks - Principles and Practice. Academic Press Elsevier, 2007, San Diego, USA, ISBN 978-0-12-373853-0
[2] Agilent Technologies: Testing Ethernet Passive Optical Networks (White Paper)
[3] R. Róka, F. Certik - Simulation Technologies in Networking and Communications: Selecting the Best Tool for the Test. A. Pathan, M. Monowar and S. Khan (eds.). CRC Press, 2014, p. 337-364, ISBN 978-1-4822-2550-1. DOI: 10.1201/b17650-16
[4] R. Róka – Hybrid PON Networks - Features, Architectures and Configuration. LAP Lambert Academic Publishing, Saarbrücken, 2015, Germany, ISBN 978-3-659-43686-4
[5] M. P. MCGarry, M. Maier, M. Reisslein - Ethernet PONs: A Survey of Dynamic Bandwidth Allocation (DBA) Algorithms. IEEE Communications Magazine, 2004, vol. 42, no. 8, p. 9-14
[6] D. Hood, E. Trojer - Gigabit-capable Passive Optical Networks. Wiley, 2012, ISBN 978-0-470-93687-0
[7] G. Kramer, B. Mukherjee, D. G. Pesavento - IPACT: A Dynamic Protocol for an Ethernet PON (EPON). IEEE Communications Magazine, 2002, vol. 40, no. 2, p. 74-78
[8] CommScope Solutions Marketing (White Paper). GPON & EPON Comparison, 8 pages, 2013, Available at: http://www.commscope.com/Docs/GPON_EPON_Comparison_WP-107286.pdf
[9] H. J. Byun, J. M. Nho, J. T. Lim - Dynamic bandwidth allocation algorithm in Ethernet passive optical networks. Electronics Letters, 2003, vol. 39, no. 13, p. 1001-2
[10] ITU-T G.983.4: A broadband optical access system with increased service capability using dynamic bandwidth assignment. Available at: http://www.itu.int/rec/T-REC-G.983.4/en
[11] J. Ozimkiewicz, S. Ruepp, L. Dittmann, et al. - Dynamic Bandwidth Allocation in GPON Networks. Recent advances in circuits, systems, signal and telecommunications, p. 182-187, ISBN: 978-960-474-152-6, ISSN: 1790-5117
[12] S. I. Choi, J. D. Huh - Dynamic bandwidth allocation algorithm for multimedia services over Ethernet PONs. ETRI Journal, 2002, vol. 24, no. 6, p. 465-468
[13] I. Cale, A. Salihovic, M. Ivekovic - Gigabit Passive Optical Network – GPON. Information Technology Interfaces, 2007. ITI 2007. 29th International Conference; IEEE Xplore, ISSN: 1330-1012
[14] S. K. Yakhlef, O. Abusaeeda, I. Sherina - A Comparison of Dynamic Bandwidth Allocation and Costs for EPON and GPON Technologies. 2015, vol. 4, no. 7, ISSN: 2277-3754
[15] N. A. M Radzi, N. M. Din, S. K. Sadon, et al. - Dynamic bandwidth allocation EPON survey. IEEE Xplore, 2015, ISBN: 978-1-4799-2656-5
[16] I. Qui - A dynamic bandwidth allocation algorithm in EPON networks. JATIT, 2012, vol. 44, no. 2, ISSN: 1992-8645
[17] Z. Bosternák, R. Róka - Approach of the T-CONT Allocation to Increase the Bandwidth in Passive Optical Networks; In: Radioengineering, 2017, vol. 27, no.4, p. 954-960, ISSN 1805-9600, DOI: 10.13164/re.2017-4