Simulation and Performance Evaluation of Bandwidth Allocation Algorithms for Ethernet Passive Optical Networks (EPONs)

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Abstract

Ethernet Passive Optical Network (EPON) has been considered for access networks for quite some time to provide high-speed and high-capacity services. As a novel type of network, EPON presents many challenges so one main aim of this paper is to provide a test-bed based on IEEE 802.3ah standards using OPNET Modeler to enable smooth implementation of the wide range of bandwidth allocation algorithms.

This paper includes a full implementation of a sample EPON environment considering the standard messages, protocols and structures as well as the modeling, simulation and performance analysis of the selected bandwidth allocation algorithms. To the best of our knowledge, this work presents a detailed network architecture for the EPON environment and its most challenging issues for the first time. Simulation results demonstrate that the proposed test-bed provides smooth insertion of the different bandwidth allocation algorithms for EPON and can be considered as the standard model for further research and investigations.

Introduction

Digital Subscriber Line (DSL) and Cable Modem (CM) networks are the most deployed broadband solutions for telecommunication networks. Although they are improvements over 56 kb/s modems, they are unable to provide enough bandwidth for on-going services and bandwidth hungry applications such as online computer games, music and multimedia, video conferencing, social networking, online banking, etc. The Optical network is a solution for DSL and CM problem domains by offering services for users located beyond 20 km. The Passive Optical Network (PON) is the most promising candidate for an optical network. PON is a point-to-multipoint (P2MP) fiber to the premises network architecture includes Optical Line Terminal (OLT), 1: N passive splitter / combiner (in TDM scheme) or Array Waveguide Granting (in WDM scheme) and number of Optical Network Units (ONUs) which may serve one or more subscribers, Fig.1. In PON each splitter typically splits a fiber into 16, 32, or 64 fibers [2]. Ethernet Passive Optical Network (EPON) and Gigabit Passive Optical Network (GPON (ITU-T G.984 [5])) are the two major standards for PON's. EPON has three different technology generations: 1G EPON (2004), 2.5G EPON (2008) [4] and 10G EPON (2010). All three EPON's technology generations support QoS, traffic management and IPV6. They also can work with different EPON generations. EPON which is proposed in IEEE 802.3ah [6] is a solution for the main problem domain of DSL and CM services in terms of upgradability, higher bandwidth and physical distance. In EPONs, bandwidth allocation and arbitration are critical issues which require to be addressed efficiently in order to provide end-to-end QoS for different classes of service. The IEEE 802.3ah standard did not mention any specific algorithm for EPON's upstream shared bandwidth access and left it open for vendors, manufacturers and researchers [3]. Fig.2 depicts different bandwidth access methods in EPON.

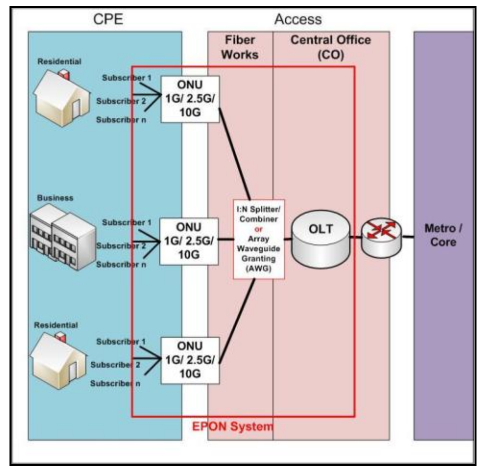

Fig.1 PON Market View Architecture

TDM-EPON and WDM-EPON are the two candidates for EPONs to allocate upstream shared bandwidth. For both transmission directions WDM supports much higher bandwidth by providing multiple wavelengths compare to standard TDM-EPON. Increasing number of ONUs linearly results in increasing average packet delay and queue length in TDM-EPON. However, WDM needs more expensive OLT than TDM.

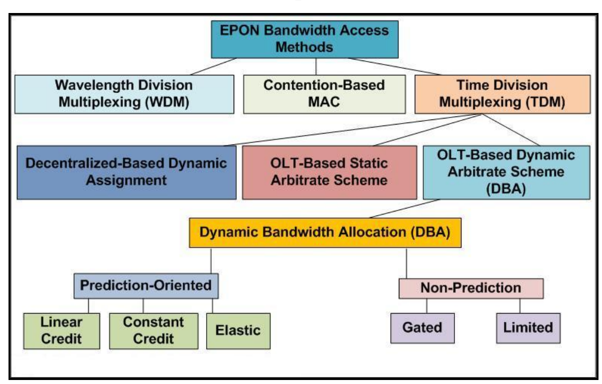

Fig.2 EPON Bandwidth Access Methods

In this paper we provide a test-bed for TDM-EPON based on IEEE 802.3ah standards by using OPNET Modeler. The simulation contains one node model for the Optical Line Terminal (OLT) which is placed in the central office (CO), and one node model for 1: N splitter/combiner which is located between OLT and ONU as well as one model for Optical Network Unit (ONU) which is placed near customer premises. We have used our model to simulate and evaluate two popular bandwidth allocation algorithms. The proposed test-bed provides standard environment for EPON which will help to accelerate future research in the EPON environment and its most challenging issues such as bandwidth allocation and arbitration.

EPON-Protocol Overview

Multi-Point Control Protocol (MPCP) was developed by the IEEE 802.03ah task force to support time slot allocation for multiple ONUs in EPONs. MPCP used two basic control messages: REPORT and GATE to accomplish the bandwidth allocation process. It also uses DISCOVERY messages which include three sub-messages namely: REGISTER_REQ, REGISTER and REGISTER_ACK which are used respectively to help a new ONU joins the EPON environment. REGISTER_REQ is the first message which is sent by ONU and provides communication features between newly joined ONU and OLT. ONU uses the REPORT message to request a time slot to transmit data with regard to its queue length. This request will be passed to the Dynamic Bandwidth Allocation (DBA) algorithm on the OLT side and replied back by a GATE message from OLT to issue a bandwidth grant to the ONU. REPORT and GATE messages include ONU's node identification and size of the requested / granted window. The MPCP extension [6] is a WDM Extension to MPCP which works based on wavelength division multiplexing scheme. It provides wavelength assignment features inside conventional MPCP. MPCP and MPCP extension are the two EPON's protocols which have been defined so far.

EPON-Upstream Bandwidth Negotiation and Access

MPCP supports bandwidth negotiation between the OLT and the ONUs by using REPORT and GATE messages. In EPONs as upstream bandwidth is shared between multiple ONUs, frames from different ONUs transmitted simultaneously may collide. Therefore, in order to provide end-to-end QoS and avoid bandwidth wastage as well as data collision defining efficient solutions for bandwidth allocation is required. Different ways for multiple accesses to the upstream shared bandwidth for EPONs are depicted in Fig.2 and specified as follows.

•Wavelength Division Multiplexing (WDM)
In this method each ONU operates at a different wavelength which avoids collision between frame transmissions. The following are challenges for this technique:
-In this method OLT has to have a transmitter array with one transmitter for each ONU to be able to receive traffic from multiple channels.
-WDM needs ONUs which can work on different wavelengths instead of only one type of ONU that we need in TDM access techniques.

•Contention-Based Media Access
This schema is difficult to implement because ONUs cannot detect the collision at the OLT. Although OLT is able to detect the collision and send jam signal to ONUs to inform collision, long distances between OLT and ONUs create a propagation delay which reduces the efficiency of such scheme.

•Time-Sharing Access
In this scheme each ONU is allocated a time slot which is capable of carrying several Ethernet frames. Each ONU buffers several Ethernet frames received from its assigned subscribers and waits for the allocated time slot to arrive. There are several ways to allocate time slots as follows:
-Fixed time-division multiple accesses
-Dynamic time-division multiple accesses
-Traffic priority / QoS, service level agreements (SLA)

•Decentralized-Based Dynamic Slot Assignment
In decentralized-based dynamic slot assignment ONUs decide when to send data and for how long. Although this method avoids bandwidth wastage and collision it has limitations:
-It requires connectivity and communicability between ONUs

•OLT-Based Static Allocation (SBA) Scheme
In this method OLT assigns fixed time slot for each ONU in the upstream channel. Although it can avoid collision between upstream frames, if a given ONU does not have any frame to transfer its allocated fixed time slot will be wasted which prevent the network from achieving efficiency.

•OLT-Based Dynamic Allocation (DBA) Scheme
This scheme is started by a REPORT message sent by a given ONU to report how many bytes of data it is about to send. The request is processed by OLT and will be replied back by a GATE message in the form of time slot assignment to the specific ONU. This scheme is the most attractive solution for allocating bandwidth in upstream channels between different numbers of ONUs with the following advantages:
-OLT knows the state of the entire network and can switch to another allocation schema based on the ONU's traffic state.
-This method requires simpler and cheaper ONUs as ONUs do not need to connect and communicate to each other.

•DBA, Non-Prediction Scheme
The DBA, Non-Prediction Scheme can be classified into Limited and Gated methods. In Limited methods OLT grants the requested bandwidth to ONU but no more than the maximum size of the transmission window. However, in the Gated method OLT grants as much of the bandwidth as it has requested but not more than Q bytes (OLT buffer size).

•DBA, Prediction-Oriented Scheme
DBA, Non-Prediction Scheme does not consider bytes that arrive after ONU sends its REPORT message to OLT. These bytes should wait in ONU buffer memory for the next transmission cycle which adds considerable delay to the transmission process. DBA, Prediction- Oriented Schemes avoid this delay by granting more bandwidth than requested to accommodate early arriving bytes. In Constant Credit the size of extra granted bandwidth is constant while in Linear Credit this size is a proportional to the ONU requested window. In the Elastic method the maximum size of the transmission window has no limit.

OPNET Implementation

In this section we describe the environment which is implemented for EPON along with its identified components. Since there is no ready-made model for EPON in OPNET Modeler, we developed an EPON model from scratch including a set of modules which have been designed and implemented using the features provided in OPNET. We verify the performance of our model by employing and inserting several bandwidth allocation algorithms. The proposed model includes one module for OLT which is part of equipment for the service provider and located in central office, one module for 1: N splitter / combiner which is allocated between OLT and ONU in EPON's TDM access scheme as well as one module for ONU which is placed near or inside customer premises equipment and connects home and business subscribers to the OLT. We implemented our model based on PON physical characteristics and IEEE 802.3ah [6] standards. The implemented environment and its related components have been fully detailed in following sections.

Implemented Scenario for EPON Environment

In order to implement a typical scenario for the EPON environment, we considered a single OLT which connects the entire network to the Internet, a single 1:16 splitter/combiner which is placed between OLT and 16 ONUs and 16 ONUs which are located near customer premises whilst each of which is connected to a single subnet, Fig.3. The distance between OLT and 1:16 splitter/combiner as well as ONUs and 1:16 splitter/combiner are equal to 10 km. Therefore each ONU is located at the same horizontal distance of 20 km from the OLT whilst the vertical distances vary from ONU to ONU, Fig.3. The link speed between OLT and 1:16 splitter/combiner as well as 1:16 splitter/combiner and each ONU are considered as 1 GB/s and each subnet is connected to relevant ONU by the link speed of 100 Mb/s.

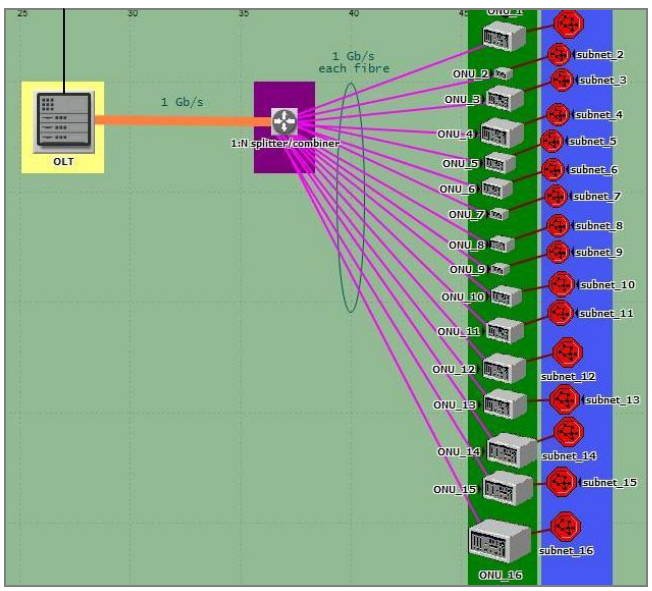

Fig.3 Implemented scenario for EPON

Modeling IEEE 802.3ah Standards

As we discussed before, IEEE 802.3ah standard defined Multipoint Control Protocol (MPCP) for the EPON environment includes three types of messaging format namely: Auto-discovery messages which consist of (REGISTER messages, REGISTER_REQ messages and REGISTER_ACK messages), REPORT messages as well as GATE messages. We used the Packet Format Editor in EPON for modeling all these messaging formats for our simulation scenario. To identify different types of messages in the implemented EPON scenario we defined a common packet field named as Opcode field which can be found in each and every single message either generated or received along the network. For each type of message we introduce a unique value as it is shown in Table.1. With regards to the nature of the generated packet the Opcode field gets a value from the source node then the middle nodes and destination node will take proper action based on these values.

Table.1 Opcode Values for EPON's Messaging Format

Message type	Opcode value	Source Node
REGISTER_REQ	1	ONUs
REGISTER	2	OLT
REGISTER_ACK	3	ONUs
REPORT	4	ONUs
GATE	5	OLT
Data Traffic	10	Subnets

Network Model Assumption

In order to simplify the simulation environment and to allow better focus on bandwidth allocation problem several assumptions have been considered as follows.

a. Static Network Configuration

We assume constant number of 16 ONUs in our implementation. According to the standards defined in 802.3ah for the EPON environment we implemented the registration procedure for constant number of ONUs (16 ONUs) during which each ONU joins the network before sending any data traffic towards OLT.

b. Avoid congestion in auto-discovery process

When the simulation starts working the ONUs begin joining the network one by one by sending the first auto-discovery message namely: REGISTER_REQ message towards OLT. In order to avoid congestion towards the upstream shared channel during the auto-discovery stage we configure each ONU to start working at the different time. Therefore, there is no common starting time between 16 ONUs which helps avoiding congestion on the first step.

c. Global Clock

In our simulation model all the network components use a single global clock which eliminates the synchronization requirement between simulation components such as OLT and ONU.

d. Bandwidth Allocation per ONU

In our implemented test-bed all bandwidth allocations are done per ONU which means OLT does not interfere in the bandwidth granting procedure to the subnet connected to different ONUs.

e. Static Number of Subnet per ONU

Based on the ONU node model each ONU is able to serve three types of traffic namely: Expedited Forwarding (EF), Assured Forwarding (AF) or Best Effort (BE) traffic which are define for EPON environment so far. In this paper we consider a single subnet for each ONU, Fig.3 which can generate any type of these three types of traffic.

OLT Node Model

The OLT device is composed of two main data paths: upstream and downstream, Fig.4. OLT's upstream data path is connected to the uplink fiber of the EPON through a receiver (number 2) module and receives all type of traffic includes real data traffic and control messages from ONUs. OLT's downstream data path connects to the downlink fiber of the EPON through a transmitter (number 1) and transmits traffic towards ONUs. The following are the specifications for the OLT node model.

1&2: ptp_tx and **ptp_rx:** a transmitter and a receiver which transmits and receives traffic between ONU and OLT, respectively.

3: q_in: a queue to buffer all types of traffic generated by ONUs

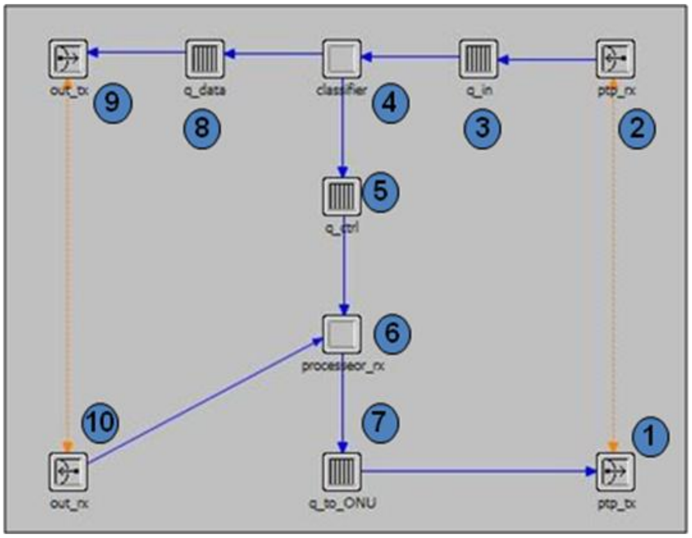

Fig.4 OLT Node Model

4: classifier: a classifier which receives, classifies and then directs different data traffic from ONUs into two queues: (number 8) and (number 5).
5: q_ctrl: a queue to buffer control messages such as REGISTER_REQ, REGISTER_ACK and REPORT messages received from ONUs.
6: processor_rx: OLT's single processor which processes control messages such as REGISTER_REQ, REGISTER_ACK and REPORT messages received from ONUs and sends back appropriate responds such as REGISTER and GATE messages to the ONUs (downlink fiber). It is also able to receive traffic from outside the EPON environment and makes proper decisions.
7: q_to_ONU: a queue to buffer traffic receives from the OLT's single processor and directs them towards ONUs (downlink fiber). It can also buffer traffic routed from the Internet to the EPON environment.
8: q_data: a queue to buffer data traffic received from the ONUs and directs them to the outside of the optical network.
9&10: out_tx and **out_rx:** a transmitter and a receiver which transmits and receives traffic between OLT and the outside of the optical network (Internet), respectively.

OLT Process Model

processor_rx (number 6, Fig.4) is the key process model inside the OLT node model. It is responsible for dealing with control messages coming from different ONUs which are received through q_ctrl (number 5, Fig.4). Based on IEEE 802.3ah, these control messages can be REGISTER_REQ, REGISTER_ACK or REPORT messages. We implemented TDM access scheme inside processor_rx process model. It generates time slots for ONUs during which each ONU can transmit the portion of its buffered traffic towards the OLT. Moreover, from the OLT's point of view, processor_rx is the only component that can define which ONU and how long it has access to the upstream shared fiber. processor_rx is composed of the following states, Fig.5.
1: init: this state initializes the process model for processor_rx and resets the variables which are used between states.
2: idle: this is the default state between process interrupts.
3: arrival: this state receives all the control messages that were routed from ONUs towards OLT and then distributes them to three different states to take the appropriate action: rg_rq_msg, rg_ack_msg and report_msg states.

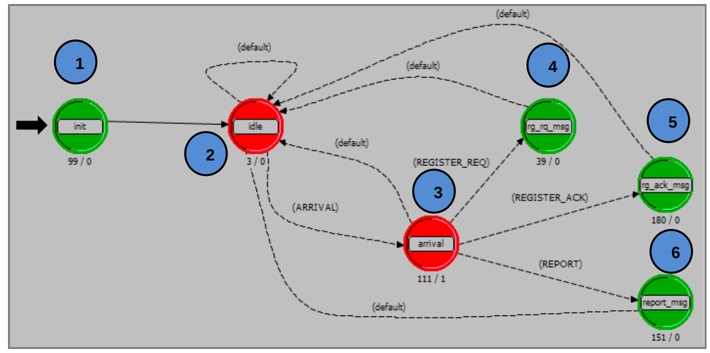

Fig.5 Process Model for processor inside OLT (number 6)

The Arrival state can handle three possible massaging formats which are defined in IEEE 802.3ah namely: REGISTER_REQ, REGISTER_ACK and REPORT messages.
4: rg_rq_msg: this state deals with the REGISTER_REQ massage which is the first message generates by the newly joined ONU. It is responsible for capturing the information such as ONU_id and calculating the Round Trip Time (RTT) for each and every single ONU. The output of the rg_rq_msg state is REGISTER message which is sent back to the correspondent ONU as an acknowledgement to accept ONU's request to join the EPON environment.
5: rg_ack_msg: arrival state is changed to rg_ack_msg state when the REGISTER_ACK messages arrive from ONUs which puts an end to the auto-discovery procedure for newly joined ONUs. After receiving REGISTER_ACK message new ONUs can start sending data traffic towards OLT.
6: report_msg: when the newly joined ONUs finish the registration procedures and identification, they should start sending REPORT messages to inform OLT about their queue length. Based on the received REPORT messages, OLT assigns specific time slots in the format of GATE messages during which correspondence ONU can transmit its data traffic. At the end of each time slot ONU generates another REPORT message for its remaining buffered data and waits until the next GATE message arrives before sending any more data traffic.

ONU Node Model

The ONU device is composed of upstream and downstream data paths, Fig.6. ONU's upstream data path is connected to the up link fiber of the EPON through a transmitter (number 12) and its downstream data path connects to the downlink fiber of the EPON through a receiver (number 13). The following are the ONU's node model specifications.

1&2: ptp_tx_sn1 and **ptp_rx_sn1:** a transmitter and a receiver for a subnet connected to the ONU. In Fig.6 three subnets are connected to each ONU each of which is assigned a single transmitter and a receiver and generate data traffic with different priorities. In our model each ONU can support up to three subnets therefore, three transmitters and three receivers are connected to each ONU in total.
3: rx_classifier: a classifier which receives, classifies and then directs data traffic from associated subnets into three queues. The classifier starts passing traffic from its related subnets only if the ONU's auto-discovery procedure is finished and its corresponding time slot has arrived through GATE message.

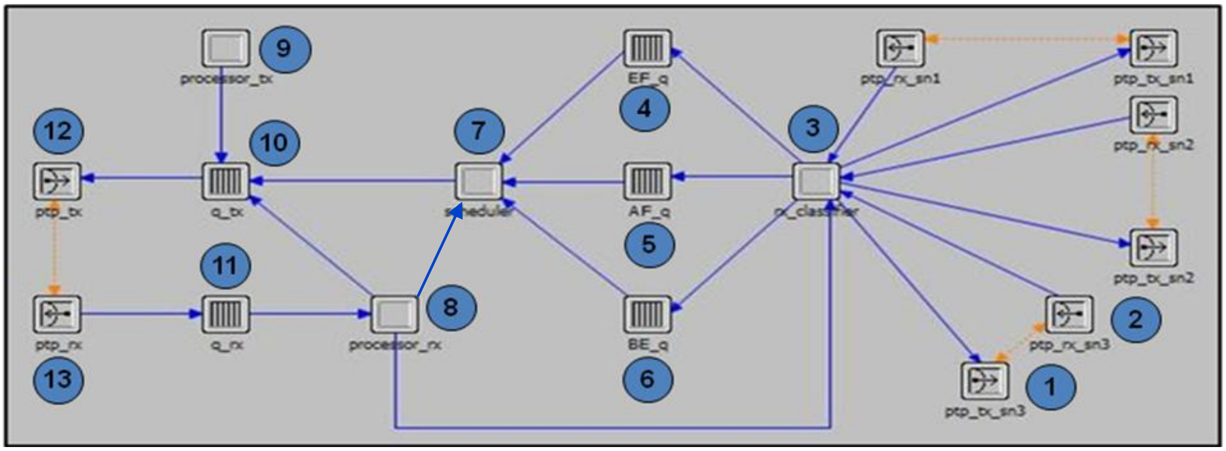

Fig.6 ONU Node Model

4&5&6: EF_q, AF_q and **BE_q:** queues for buffering three different type of data traffic: EF, AF and BE generated by ONU's connected subnets.

7: schedulers: a scheduler which plans and schedules transmission of data traffic buffered in EF, AF and BE queues towards OLT. It is also where the DBA algorithm is allocated. From ONU's point of view the scheduler is the only component which arbitrates access to the upstream shared bandwidth. It starts sending traffic only after receiving a GATE message from OLT which is directed towards the processor (number 8).

8: processor_rx: a processor which: generates REGISTER_ACK message and acknowledges the classifier to start data traffic transmission.

9: processor_tx: a processor which generates REGISTER_REQ message once when ONU joins the EPON which helps OLT identifying the newly joined ONU.

10& 11: q_tx and q_rx: a transmitter queue and a receiver queue which buffer traffic routed from inside/outside ONU.

12& 13: ptp_tx and **ptp_rx:** a transmitter and a receiver which transmits and receives traffic between ONU and OLT.

ONU Process Model

We implemented four process models inside the ONU node model. Among them, scheduler (number 7, Fig.6) is the key process model where different bandwidth allocation algorithm can be implemented. Scheduler is composed of the following states, Fig.7.

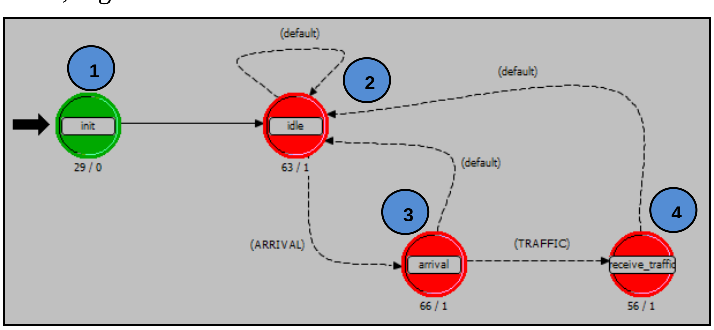

Fig.7 Process Model for scheduler inside ONU (number 7)

1: init: this state initializes the process model for the scheduler (number 7) inside the ONU node model and resets the variables which are going to use between states.

2: idle: this is the default state between process interrupts.

3: arrival: this state receives GATE messages which are allocated by the OLT to the correspondent ONU during which ONU has access to the upstream fiber link. GATE messages are identified and routed from another processor (number 8) towards scheduler (number7). When the GATE messages received by the scheduler, it acknowledges the three specified queues (EF, AF and BE) to start sending data traffic and changes to the arrive_traffic state immediately.

4: receive_traffic: this state is considered to spend the time slot which is assigned by OLT to the correspondent ONU and received through the GATE message. When the assigned time slot is finished, receive_traffic state acknowledges the three specified queues (EF, AF and BE) to stop sending data traffic and start buffering the data until the next time slot arrives. Eventually receive_traffic changes to the idle state and waits for the next time slot to arrive.

1: 16 Passive Splitter/Combiner Node Model

1:16 Splitter / Combiner device is composed of upstream and downstream data paths, Fig.8. The upstream data path connects to the uplink fiber of the EPON through a transmitter (number 6) and transmits traffic from the ONUs towards the OLT whilst downstream data path connects to the downlink fiber of the EPON through a receiver (number 5) and receives traffic from the OLT towards ONUs. The following are the specifications for the 1:16 Splitter/Combiner node model.

1: ptp_tx (1 to 16): 16 point to point transmitters each of them related to a single ONU which helps transmitting traffic from OLT routed to relevant ONU.

2: ptp_rx (1 to 16): 16 point to point receivers each of them related to a single ONU which helps receiving traffic routed to the OLT from the correspondent ONU.

3: q_OLT: a queue to buffer traffic received from the OLT and then passes it to the appropriate transmitter among 1 to 16 transmitters towards the correspondent ONU.

4: q_ONU: a queue to buffer traffic received from 16 ONUs through 16 point to point receivers and pass it towards OLT.

5& 6: ptp_rx_OLT and ptp_tx_OLT: a receiver and a transmitter which receives and transmits traffic between the ONU and the OLT, respectively.

We used acb_fifo for both queues inside the 1:16 Splitter / Combiner. acb_fifo process model is defined as the standard process model inside the OPNET environment. The structure of the q_ONU process model (number 4) is as same as acb_fifo process model, however we modified it for the q_OLT (number 3) to identify an appropriate output stream to send the OLT traffic towards correspondent ONU among 16 different ONUs.

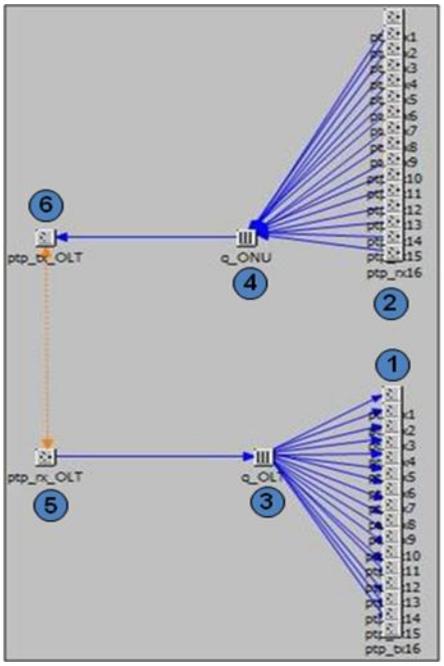

Fig.8 1: 16 Splitter/Combiner Node Model

Implementation and Comparison of the BA Algorithms

Bandwidth allocation and arbitration is the critical issue in EPON which needs to be addressed efficiently in order to guarantee end-to-end QoS for different classes of service. IEEE 802.3ah did not mention any bandwidth allocation algorithm for the EPON environment and left it open for researchers, manufacturers and vendors. A wide range of bandwidth allocation algorithms has been proposed for EPON environment which we grouped in Fig.2, for more studies please refer to [7-20]. To evaluate our proposed EPON test-bed we implemented two known bandwidth allocation algorithms namely: OLT-based static bandwidth allocation (SBA) algorithm and OLT-based dynamic bandwidth allocation (DBA) algorithm, Fig.2, with detailed configurations in the next sections. Based on IEEE 802.3ah standards each GATE message can accommodate up to four different grant messages each of which is specified by grant start time, grant length as well as the ONU's id to which the grant message belongs. Therefore, we considered four grant messages for four different ONUs on each cycle. The length of the cycle is assumed static which contains four grant windows each of which can have a different length. At the end of the time slot, ONU sends the next REPORT message to the OLT asking for the next time slot and stops sending messages till the next time slot is arrived. For 16 ONUs and four grants in each cycle, each ONU should wait for four cycle lengths to get the next grant window and transmit its buffered data. In our simulation scenario we used a global clock to eliminate the need for exchanging the synchronization information, therefore all the network components such as OLT and ONU are assumed to use the same global clock. One factor which affects the time slot allocation is the Round Trip Time (RTT) value or the delay time value which is the time required to send the time slot to the correspondent ONU. As time is passing during the simulation, OLT needs to consider the RTT value for every ONU in any time slot allocation. In our scenario ONUs are located beyond 20 km from the OLT in CO each of which has different RTT. processor_tx (number 6, Fig.5) cooperates with OLT in calculating the RTT for each ONU by capturing the simulation time by the time the REGISTER_REQ message is generated. Later on when the REGISTER_REQ message is received by OLT, OLT again captures the simulation time and calculates the RTT and saves it for the correspondent ONU. This value will be used when OLT allocates time slot to the correspondent ONU in future allocations. The third factor which we considered in time slot allocation is the gap value which is the time between each granted time slot assumed to be 1 millisecond, which avoids data overlapping between ONUs. Grant start time ($grant_{stime}{}_n^i$) for the ith ONU in the nth cycle is the time when the allocated time to the (i-1) th ONU in the same cycle is finished ($grant_{ftime}{}_n^i$) in addition to 1 millisecond gap plus the Round Trip Time for the ith ONU, (1) and (2).

$$grant_{stime}{}_n^i = grant_{ftime}{}_n^{i-1} + Gap + RTT_i \quad (1)$$

$$grant_{ftime}{}_n^i = grant_{stime}{}_n^i + grant_{length} \quad (2)$$

a. OLT-based static bandwidth allocation (SBA)

In the OLT-based static bandwidth allocation (SBA) algorithm, Fig.9, OLT allocates the same time slot length to each and every single REPORT message received from ONUs during which the ONU can transfer its buffered data traffic.

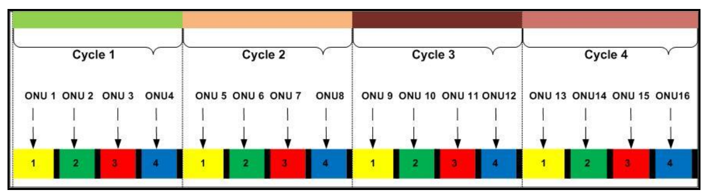

Fig.9 SBA Timing Regime

The next REPORT message will be generated at the end of the previous allocated window by ONU and will be captured and then considered by OLT for the next GRANT cycle. The lengths of the granted time slots are all same regardless of the actual need of ONU. It also regardless of Service Level Agreement (SLA) configuration which is different for network services and defined with three priorities for EPON: Expedited Forwarding (EF) services such as voice, Assured Forwarding (AF) services like video and Best Effort (BE) services such as email and ftp. Although this allocation technique provides fairness among ONUs by allocating same time slot length for each GRANT, it does not consider QoS for differentiated classes of service as the granted time slot is regardless of ONU's QoS requirement. SBA also does not provide efficiency as the granted time slot can be more or less than the actual requirement of each ONU.

b. OLT-based dynamic bandwidth allocation (DBA)

In the OLT-based dynamic bandwidth allocation (DBA) algorithm, Fig.10, the length of the time slot which is allocated by OLT to each ONU varies from cycle to cycle. Parameters such as actual need of ONU which is captured from REPORT messages and QoS requirement based on SLA configuration will affect the time slot allocation length over different cycle. To avoid services with higher priority dominating the network when they are highly loaded, DBA should also consider fairness among EF, AF and BE. Fairness avoids lower priority services from resource starvation when the network is fully loaded by higher priority class of service.

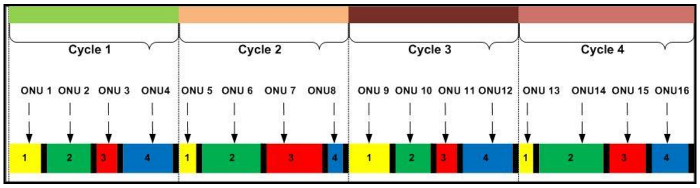

Fig.10 DBA Timing Regime

Initial Testing and Simulation Results

In order to give a general performance of the proposed test-bed and show how it acts in different conditions, we have done some initial testing based on the characteristic of the EPON environment as well as the properties of the implemented SBA and DBA algorithms. We picked up random ONUs and focus on their behavior during 7 hours simulation time by the seed of 195. We selected ONUs generating three traffic types defined for EPON: Expedited Forwarding (EF), Assured Forwarding (AF) and Best Effort (BE) by the various traffic patterns. The packet length is drawn by the constant distribution of 8000 bits for the highest traffic type (EF), exponential distribution of 6000 bits and 4000 bits for AF and BE traffic types, respectively. The packet-interarrival time is exponentially distributed. Traffic sources are awakened at different times to avoid congestion in the auto-discovery step but they only start sending traffic after the correspondent ONU is identified by OLT through the registration procedure (IEEE 802.3ah).

ONU queue size vs. grant size in SBA

We focused on the behavior of the ONUs queue size by considering three random static time slot (TS) with sizes of 35ms, 55ms and 75ms which form the cycle size of 144ms, 224ms and 304ms, respectively in three duplicated scenarios. Fig.11 reveals the average queue size for two random ONUs which generate AF and BE traffic by two time slot lengths (35ms and 55ms). As was expected the SBA algorithm treated both traffic types in the same manner without considering QoS requirement, therefore there is not many differences between their queue sizes. It also indicates that when we increase the time slot length from 35ms to 55ms the queue sizes will be increased by the ratio of 1.54 and 1.44 for AF and BE traffic, respectively. The same result which is not depicted here is captured for EF traffic types which reveals that there is no consideration for QoS requirements in the SBA algorithm therefore all three types of EF, AF and BE traffics will be treated almost in the same way when the grant size is either increased or decreased. Generally speaking SBA provides fairness by considering the same length of time slot in each cycle for various traffic types but it is unable to provide QoS requirement for differentiated classes of service.

Number of REPORT messages vs. grant size in SBA

We also captured the number of the REPORT messages received from four random ONUs by OLT with five different time slot values: 15ms, 35 ms, 55 ms, 75 ms and 95ms, Fig.12. As was expected this number is decreased significantly in the ratio of 2.28, 1.55, 1.35 and 1.13 when the grant size is increased gradually from 15ms to 95ms. Almost the same result which is not depicted here is captured for the number of the GATE messages generated by OLT for the same four random ONUs. Generally speaking we can say that there is a converse relation between the size of the granted time slot and the number of the generated REPORT messages by ONU and GATE messages by OLT.

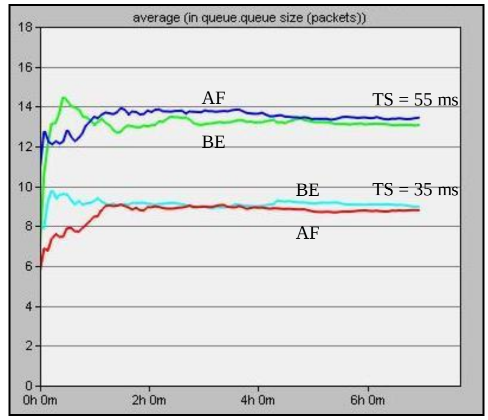

Fig.11 Average queue size vs. grant size for AF&BE in SBA

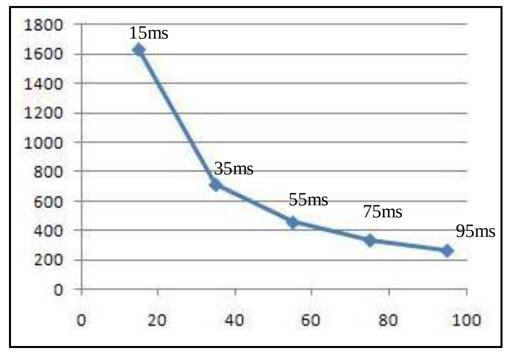

Fig.12 Max received REPORT messages vs. grant size on OLT

ONU queue size vs. grant size in DBA

In the Dynamic Bandwidth Allocation (DBA) algorithm the size of the allocated time slot to each ONU differs from cycle to cycle and will be affected by factors such as QoS requirement, ONU's actual need, fairness, available bandwidth, network current requirements, etc. We have implemented the DBA algorithm in which various traffic types are treated in different ways. As we assumed in our scenario OLT can allocate up to four grants (IEEE 802.3ah standards) in each cycle. Our implemented DBA algorithm changes the length of the allocated time slot based on factors such as class of service and network traffic load e.g. when the network is loaded by all three types of EPON traffic (EF, AF and BE) DBA allocates a longer time slot to highest priority traffic (EF), less long to second priority (AF) and the shortest to the lowest priority (BE) in each cycle. Therefore all three types of traffic will be served in each cycle but with different granted time slot length which provides fairness for all traffic priorities and avoids bandwidth starvation for lower traffic types. As for the SBA algorithm we have monitored the average queue size inside ONU's main queue for the DBA algorithm which considers the QoS requirement and fairness in each time slot allocation. As Fig.13.reveals against SBA algorithm, DBA allocates various time slot lengths to different traffic types which decreases the queue size for EF traffic by the ratio of 4.10 and 10.21 in comparison with AF and BE, respectively.

ONU queuing delay: SBA algorithm vs.DBA algorithm

We have also compared queuing delay for two implemented algorithms: SBA and DBA to reveal how changing the time slot

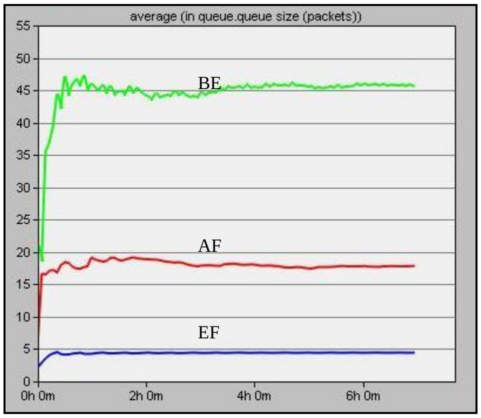

Fig.13 Average queuing size for AF, EF and BE in DBA

length in a dynamic manner can improve the network performance. As it is depicted in Fig.14 DBA decreases the queuing delay by the ratio of 1.20 for the highest class of service (EF) as compared to SBA algorithm.

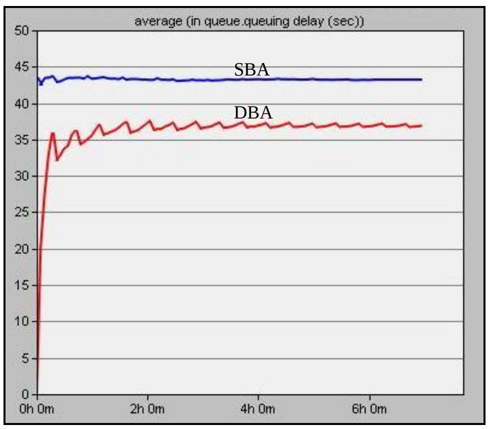

Fig.14 Average queuing delay SBA vs. DBA for EF

Conclusion and Future work

Ethernet Passive Optical Network (EPON) which is identified as one of the best candidates for the next generation wired access network has attracted much attention in recent decade. EPON which is based on legacy Ethernet and standardized by IEEE 802.3ah can provide low expenses, high-speed and high-capacity services for the next generation wired broadband access network. As there is no ready-made standard model in OPNET modeler for EPON environment, in this paper we implemented a sample EPON scenario based on the features which are already provided by OPNET as well as the IEEE 802.3ah standard definitions. Our implementation includes all the steps which an Optical Network Unite (ONU) should take to be able to send traffic towards Optical Line Terminal (OLT) through high-speed upstream optical link. We considered bandwidth allocation issue which is the major challenging topic in OPNET and implemented OLT-based static bandwidth allocation (SBA) algorithm and OLT-based dynamic bandwidth allocation (DBA) algorithm on top of our implemented scenario. We revealed how DBA in comparison with SBA considers a QoS requirement for time slot allocation between EF, AF and BE traffic types. We considered the Time Division Access technique (TDM) in our developed scenario which grants fixed size of time slots in the SBA and dynamic size of time slots in DBA for different REPORT messages received by OLT. Simulation results reveal that there is a strong relation between the assigned time slot length, simulation performance and QoS provision scheme in the SBA and DBA algorithm. To better evaluate the performance of the proposed test-bed we aim to implement the most of the EPON's bandwidth allocation techniques which are depicted in Fig.2. This implementation can provide a wide comparison between various bandwidth allocation methods as the most critical issue in EPON. We also target to integrate the implemented EPON scenario (best solution for wired broadband access network) with a typical WiMAX scenario (best candidate for wireless broadband access network) which can form the best candidate for next generation broadband access network. To our best of knowledge this work presents the full and detailed implementation for the EPON environment and its most challenging issues using OPNET modeler for the first time and can be considered as the standard model for future research.

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