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MASTER THESIS

TITLE: Implementation of a simulation model in OPNET for the evaluation of heterogeneous OBS-EPON-WiMAX access networks.

MASTER DEGREE: Master in Science in Telecommunication Engineering & Management

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DATE: December 02 th 2009

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Overview

The Broadband Networks research group of the Telematic Department is studying the integration of heterogeneous technologies in metropolitan and access networks in the context of its participation in the Euro-NF Network of Excellence. One research line contemplates networks where WiMAX base stations are fed by Passive Optical Networks (PONs), and these are fed by Optical Burst Switching (OBS) systems.

In this context, the group has designed a novel MAC mechanism to improve the resource utilization. The present Master Thesis involves the implementation of the system model in the OPNET simulation platform, in order to confirm the interesting results obtained in preliminary experiments.

Resumen

El grupo de investigación de ancho de banda del departamento de Telemática está estudiando la integración de tecnologías heterogéneas en redes metropolitanas y redes de acceso en el contexto de su participación en la red de excelencia Euro-NF. Una línea de investigación contempla las redes donde las estaciones base de WiMAX son alimentadas por redes ópticas pasivas (PONs), y estas a su vez son alimentadas por sistemas de conmutación óptica a ráfagas (OBS).

En este contexto, el grupo tiene diseñado un nuevo mecanismo de acceso al medio para mejorar los recursos de utilización. La presente tesis de maestría se envuelve en la implementación de un modelo de sistema en la plataforma de simulación de Opnet, para poder confirmar los resultados interesantes obtenidos en experimentos preliminares.

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I. INTRODUCTION

1.1. Introduction

Due to the increment of the IP traffic over the past few years, specifically traffic generated by emerging applications such as e-science, e-learning, e-business, e-health, e-government, also peer to peer traffic, as well as business service and residential service such as triple play and IPTV is necessary to develop an access network technology with wide broadband.

All these services are expected to introduce a major leap in the networking infrastructure [1]. This mandates that the access, metro and core networks become progressively dynamic with respect to the transported traffic volume.

The recently technologies of broadband access network and metro network permit deliver a good quality of service end to end to the different applications. The access networks must permit mobility, broadband access to the users, and good Capital Expenditures (CapEx) y Operational Expenditure (OpEx) for the Internet Services Providers (ISPs).

For delivering mobility and broadband access, it is necessary that the broadband wireless access and the broadband optical access converge in an access network. To achieve convergence, it is necessary to develop a method for interconnect the different medium access control mechanism of the different technologies to ensure quality of service end to end from access network to core network.

1.2. Overview of Heterogeneous Access Networks

The access networks, which connect residential and small business users to the metropolitan network followed by the core network, have to scale up in bandwidth capacity to enable an end to end service guarantee for high speed data transmission and quality of service (QoS). Actually we should see a rapid development for broadband access technology in both fixed and mobile network infrastructure.

Emerging wired broadband access technology such as Passive Optical Networks (PONs) are able of provisionally or in the long term sustain the growth in traffic requirements in the access segment. However, there are specific deployment scenarios that render wireless broadband access solution more competitive in terms of capitalization and operational expenses compared to wired counterparts.

In particular, Ethernet PON (EPON), as the primary type of PON technologies, can reduce fiber deployment and maintain an inherently smooth connection with legacy Ethernet networking that is a mature local area network (LAN) technology ubiquitously deployed in our real life [2]. On the other hand, wireless access technologies such as WiMAX (IEEE 802.16) are also providing higher

bandwidth, larger coverage and better QoS support. These two technologies will be described in chapter II.

IEEE 802.16 and EPON act as promising broadband access technologies for high-capacity wireless access networks and wired access networks, respectively.

1.3. Integration of WiMAX, EPON and OBS Networks

Seeing the fast increment of the traffic by the end users and the quality of service that their application request, it is necessary that the networks involved in transporting the traffic ensure QoS end to end, reducing both CapEx and OpEx of these networks and give high bandwidth capacity. For all these, is necessary the integration of the better technology involved in each part of the total network.

WiMAX integrated with EPON as access networks connected to Optical Burst Switching (OBS) metropolitan network technology [23] is seen as the next step in future optical networking in the metro segment [4]. In this context, sample architecture is proposed that employs a composite network solution, involving various issues that need to be addressed for such an integrated approach to meet service-level requirements.

In chapter II we present the concept of the three technologies involved in this Master Thesis. Beyond architecture specification, we implemented a proof of concept simulation network model integrated that will be seen in chapter IV.

The integration of these three technologies makes that each edge node of interconnection of these technologies have to be adapted for give support to QoS end to end, from the Service Station (SS) of the user in WiMAX until the ingress edge switch in OBS network [23].

The integration of the Base Station (BS) in WiMAX with the Optical Network Unit (ONU) in EPON network is feasible as 802.16 BS's bandwidth capacity provides a perfect match to the ONU's. EPON supports a total of 1Gbps bandwidth in both downstream and upstream, which is shared by a group of (typically 16) remote ONUs. On the average, each ONU possesses about $1/16\text{Gbps} = 65\text{ Mbps}$ bandwidth. This value matches the total capacity offered by an 802.16 BS which is about 70 Mbps over a 20 MHz channel [5].

For the integration of the Optical Line Termination (OLT) in EPON with ingress edge switch in OBS network, OBS Edge switch aggregate traffic incoming from adjacent OLTs, create bursts comprising multiple IP packets and forward them through the OBS metro network towards the core following specific OBS routing mechanisms.

1.4. Proposed Algorithm

The integration enables the design of joint bandwidth allocation/reservation, connection admission control and transmission scheduling schemes, along all the networks. A better support of end-to-end QoS guarantees and improvement of the overall system performances such as throughput and delay can be expected. This integration can help enhance the rapid development of fixed mobile convergence (FMC) [6].

For this convergence is necessary to develop an optimal utility-based bandwidth allocation scheme for integrating the three network technologies. In chapter III we introduce the requirements that the proposed algorithm has to be met according to the standard specification of these technologies.

II. RELATED TECHNOLOGIES

2.1. WiMAX

The main features of IEEE 802.16/WiMAX technology are the following:

- (Carrier) frequency < 11GHz. For the moment, the frequency band considered are 2,5GHz, 3,5GHz and 5,7GHz.
- OFDM. The 802.16 is (mainly) built on the Orthogonal Frequency Division Multiplexing (OFDM) transmission technique known for its high radio resource use efficiency.
- Data Rates. A reasonable number is 10Mbps. Reports have given more ambitious figures going up to 70Mbps or even 100Mbps. These values would be for a very good state of the radio channel and for a very small cell size, making these values too optimistic for the moment.
- Distance. Up to 20Km, a little less for indoor equipment.

802.16-2004 was definitely very useful but other features were needed. This gave way to 802.16e amendment approved on December 7, 2005 and published in February 2006.

The main differences of 802.16e with regard to 802.16-2004 are the following [7]:

- Mobile stations (MS) appear. A station in a mobile telecommunication service is intended to be used while in motion or during halts at unspecified points. However, an 802.16e MS is also a subscriber station (SS).
- SOFDMA (Scalable OFDMA). More generally, the OFDMA PHY layer, i.e. Section 8.4 of the 802.16 standard, was completely rewritten

between 16-2004 and 16e. Although the word SOFDMA does not appear in the 802.16e document, it is the type of standardized OFDMA. For OFDMA and SOFDMA.

- Multiple-Input Multiple-Output (MIMO) and Adaptive Antenna System (AAS) techniques, both already introduced in 802.16-2004, have many enhancement and implementation details provided in 802.16e.
- Multicast and broadcast services (MBS) feature.
- A new (fifth) QoS class: ertPS [16]. (In addition to 802.16-2004 rtPS), ertPS Class supports real-time service flows that generate variable-size data packets on a periodic basis, e.g. VoIP with silence suppression.
- Other: the Low-Density Parity Check (LDPC) code is an optional channel coding, etc.

2.1.1. The protocol layers of WiMAX

The two lowest layers of the OSI model are then the Physical (PHY) Layer, or Layer 1, and the Data Link Layer, or Layer 2. IEEE 802 splits the OSI Data Link Layer into two sublayers named Logical Link Control (LLC) and Media Access Control (MAC). The PHY layer creates the physical connection between the two communicating entities (the peer entities), while the MAC layer is responsible for the establishment and maintenance of the connection (multiple access, scheduling, etc.).

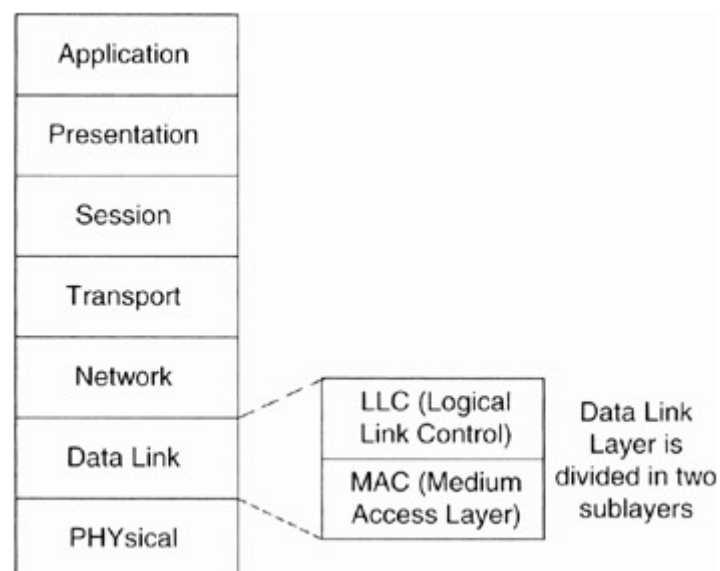


Fig. 2.1 The seven-layer OSI model for networks. In WiMAX/802.16, only the two first layers are defined

The IEEE 802.16 standard specifies the air interface of a fixed Broadband Wireless Access (BWA) system supporting multimedia services. The Medium Access Control (MAC) Layer supports a primarily point to-multipoint (PMP) architecture; with an optional mesh topology. The MAC Layer is structured to support many physical layers (PHY) specified in the same standard. In fact, only two of them are used in WiMAX.

The protocol layers architecture defined in WiMAX/802.16 is shown in Figure 2.2. It can be seen that the 802.16 standard defines only the two lowest layers, the PHYSical Layer and the MAC Layer, which is the main part of the Data Link Layer, with the LLC layer very often applying the IEEE 802.2 standard. The MAC layer is itself made of three sublayers, the CS (Convergence Sublayer), the CPS (Common Part Sublayer) and the Security Sublayer [8].

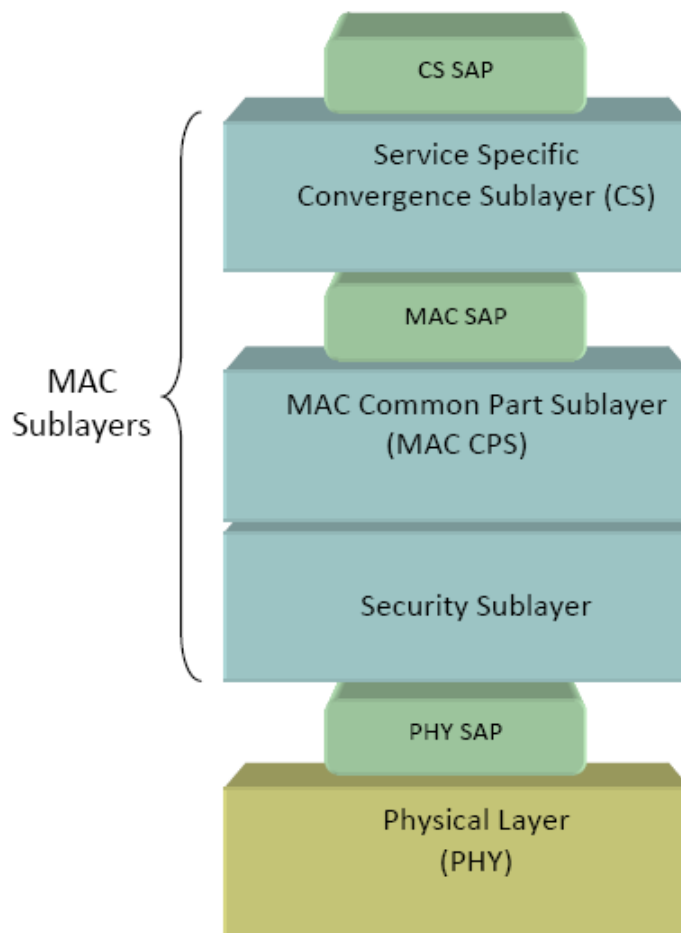


Fig. 2.2 Protocol layers of the 802.16 BWA standards

2.2. EPON

Ethernet over point to multipoint (P2MP) fiber is also known as EPON (IEEE 802.3ah). The scope of IEEE 802.3 work is confined to two lower layers of the

Open Systems Interconnection (OSI): physical layer and data link layer. Each of these layers is further divided into sublayers and interfaces. Figure 2.3 shows the sub-layers and interfaces defined for Ethernet devices operating at 1Gbps data rates.

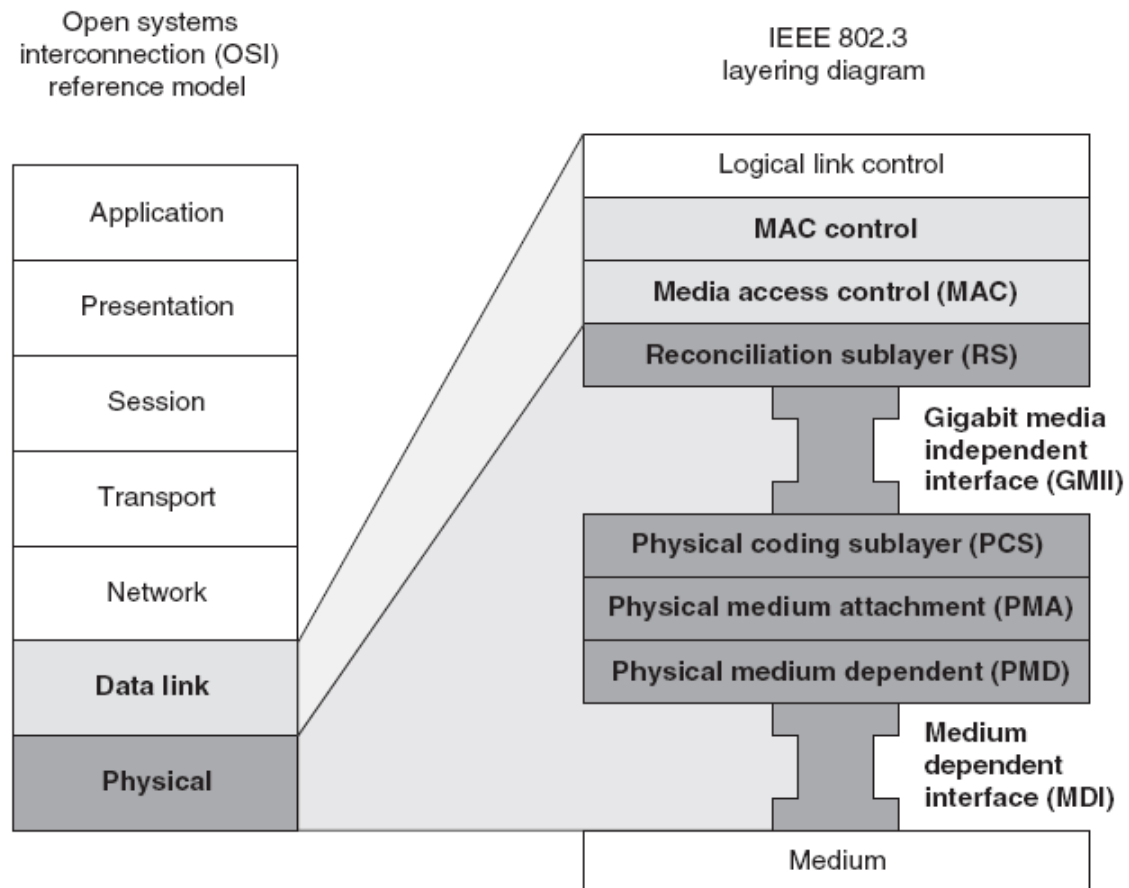


Fig. 2.3 Relationship of IEEE 802.3 layering model to Open Systems Interconnection reference model

IEEE 802.3 uses the subdivision of the physical layer (from lower sublayer to higher) and the data link layer from lower to higher) how was showed in the Figure 2.3. [9].

The EPON network is composed by the OLT that is connected to a passive optical splitter using an optical fiber, which fans out at the splitter to multiple optical drop fibers to which ONUs are connected. According to the standard IEEE 802.3ah, an EPON supports a nominal bit rate of 1Gbit/s, shared amongst the ONUs, which can be at a maximum distance of 20Km. In the downstream direction, the OLT transmits Ethernet frames that reach all the ONUs. In the upstream direction, the Ethernet frames transmitted by the ONUs are received only by the OLT and the medium access is arranged in a time-division (TDM) fashion. There are two wavelengths - one for the downstream and one for the upstream direction.

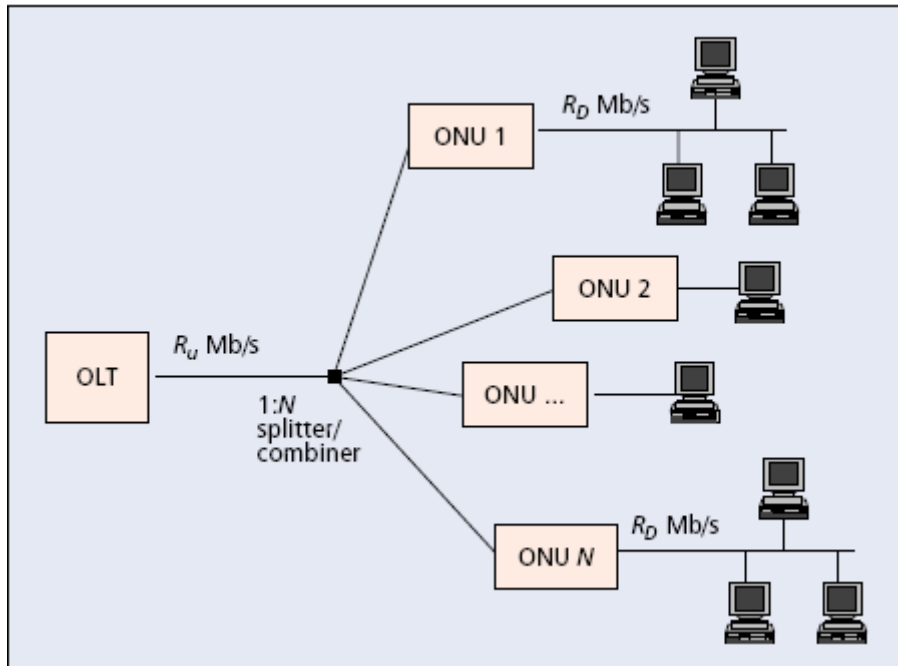


Fig. 2.4 typical access network based on tree PON topology

2.2.1. Logical Topology Emulation

The IEEE 802 architecture, assumes all communicating stations in a LAN segment to be connected to a shared medium. In a shared medium, all stations are considered as belonging to a single access domain, where at most one station can transmit at a time and all stations can receive all the time.

In other case, an access domain may consist of just one station. Typically, many such single-station domains are connected by point-to-point (P2P) links to a bridge, forming a switched LAN.

Devices attached to the PON medium implement a Logical Topology Emulation (LTE) function that, based on its configuration, may emulate either a shared medium or a point-to-point medium.

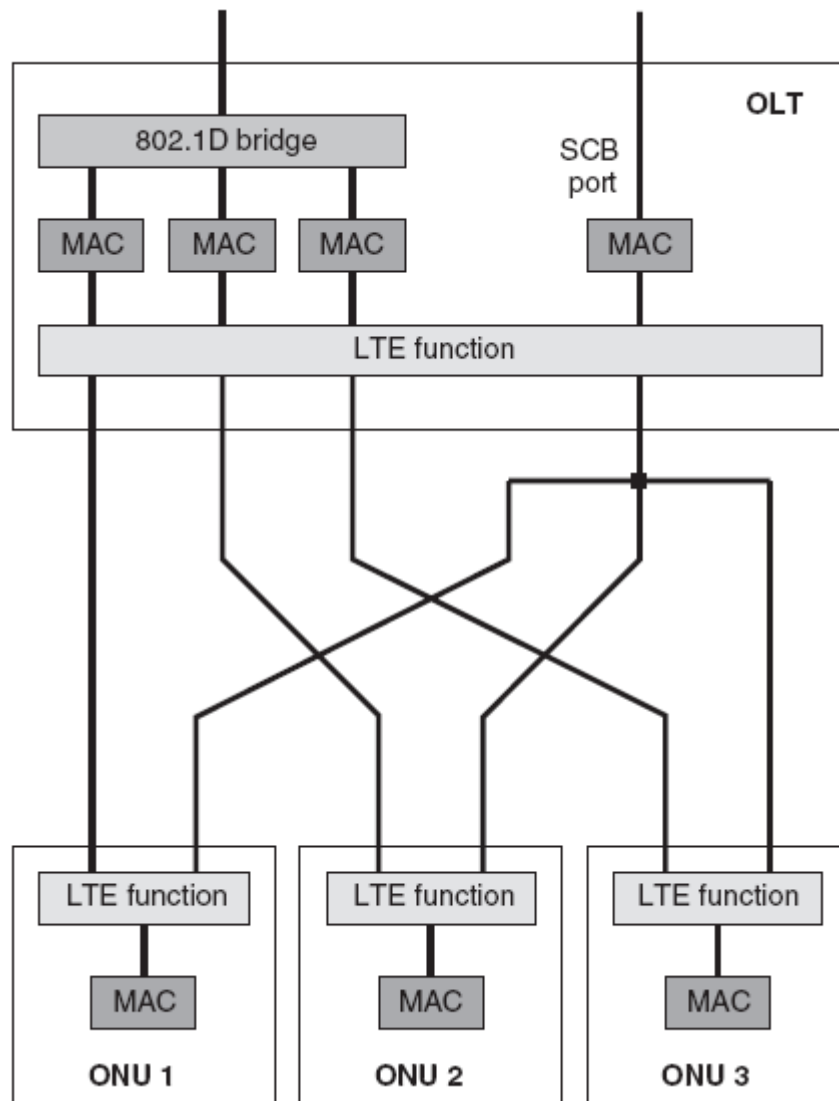


Fig. 2.5 Combined point-to-point and shared-medium emulation mode

To preserve the existing Ethernet MAC operation defined in the IEEE 802.3 standard, the LTE function should reside below the MAC sublayer. Operation of this function relies on tagging of Ethernet frames with tags unique for each ONU. These tags are called logical link identifiers (LLIDs) and are placed in the preamble at the beginning of each frame. To guarantee uniqueness of LLIDs, each ONU is assigned one or more tags by the OLT during the initial registration (auto discovery) phase [10].

2.2.2. Multi-Point Control Protocol: A Formal Specification

MPCP frames are commonly referred to as MPCP data units (MPCPDUs). MPCP defines five messages used to exchange information between the OLT and ONUs: GATE, REPORT, REGISTER_REQ, REGISTER, and REGISTER_ACK. All MPCPDUs are 64-byte MAC control frames consisting of the fields that can see in the next figure 2.6.

Fields	Octets
Destination address (DA)	6
Source address (SA)	6
Length/type = $88-08_{16}$	2
Opcode	2
Timestamp	4
Opcode-specific fields/pad	40
Frame check sequence (FCS)	4

Fig. 2.6 Format of generic MPCP frame

Each field of the MPCP frame is described in [11]. The OLT arbitrates the upstream transmissions from the ONUs by granting transmission windows, which can have variable lengths. An ONU is only allowed to transmit during the timeslot allocated to it. OLT informs the transmission window to the ONU by means of a Gate message. In order to inform the OLT about its bandwidth requirements, ONUs use Report messages that are also transmitted (along with the data) in the transmission window. MPCP is not concerned with any particular bandwidth allocation, it is meant to facilitate the implementation of various allocation algorithms in EPON [12].

2.3. OBS

The technology of SDH/SONET is still used in the metro networks of several carriers; these technologies are based in optical circuit switching and were used to development the Automatically Switched Optical Network (ASON) that has advantage in terms of QoS, management and security and is able to reduce the load taken from the IP/MPLS network. However, due to the domination of IP centric traffic, future solutions are focusing on bursty networking models able to handle dynamic segments instead of continuous data.

One idea is to set-up and tear down a path dynamically (similar to circuit switching) but for a much shorter duration, equal only to the duration required to transmit a complete set of data, a “data burst”. [14] This is the fundamental premise of OBS, which is based on the separation of the control and data planes, and the segregation of functionality within the appropriate domain (electronic or optical). Prior to data burst transmission, a burst control packet (BCP) is created and sent toward the destination by an OBS ingress node (edge router). The BCP is typically sent out-of-band over a separate signaling wavelength and processed at intermediate OBS routers. It informs each node of the impending data burst and sets up an optical path for its corresponding data

burst. Data bursts remain in the optical plane end-to-end and are typically not buffered as they transit the network core. The bursts' content, protocol, bit rate, modulation format, and encoding are completely transparent to the intermediate routers.

The main advantages of the OBS in comparison to the other optical networking schemes are that unlike optical wavelength switched networks, the optical bandwidth is reserved only for the duration of the burst, and that unlike the OPS network, it can be bufferless, but it also needs a switch reconfiguration speed in the order of microseconds. [4].

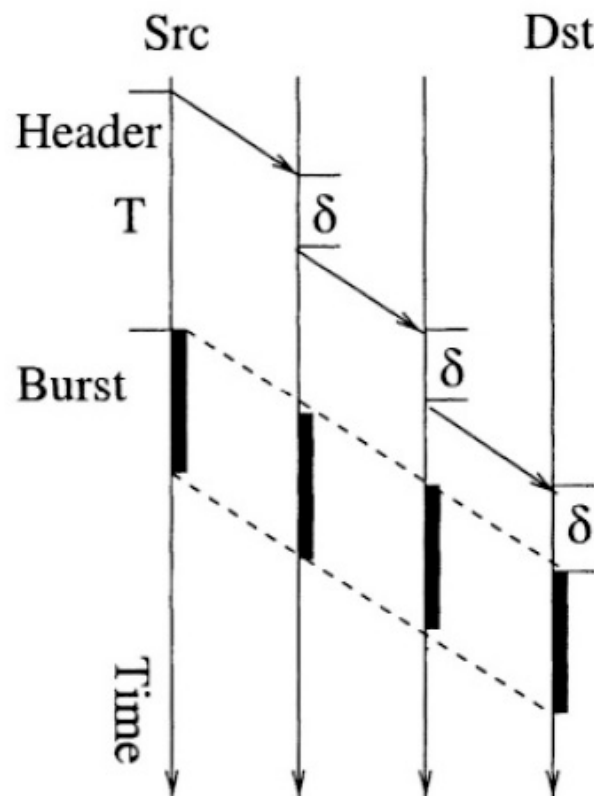


Fig. 2.7 The use of offset time in OBS

The offset time allows for the BCP to be processed and the switch to be set up before the burst arrives at the intermediate node.

2.3.1. OBS Network Architecture

An optical burst-switched network consists of optical burst switching nodes that are interconnected via fiber links. Each fiber link capable of supporting multiple wavelength channels using wavelength division multiplexing (WDM). Nodes in an OBS network can either be edge nodes or core nodes as shown in the Figure 2.8. Edge nodes are responsible for assembling packets into bursts, and

scheduling the bursts for transmission on outgoing wavelength channels. The core nodes are primarily responsible for switching bursts from input ports to output ports based on the burst header packets, and for handling burst contentions.

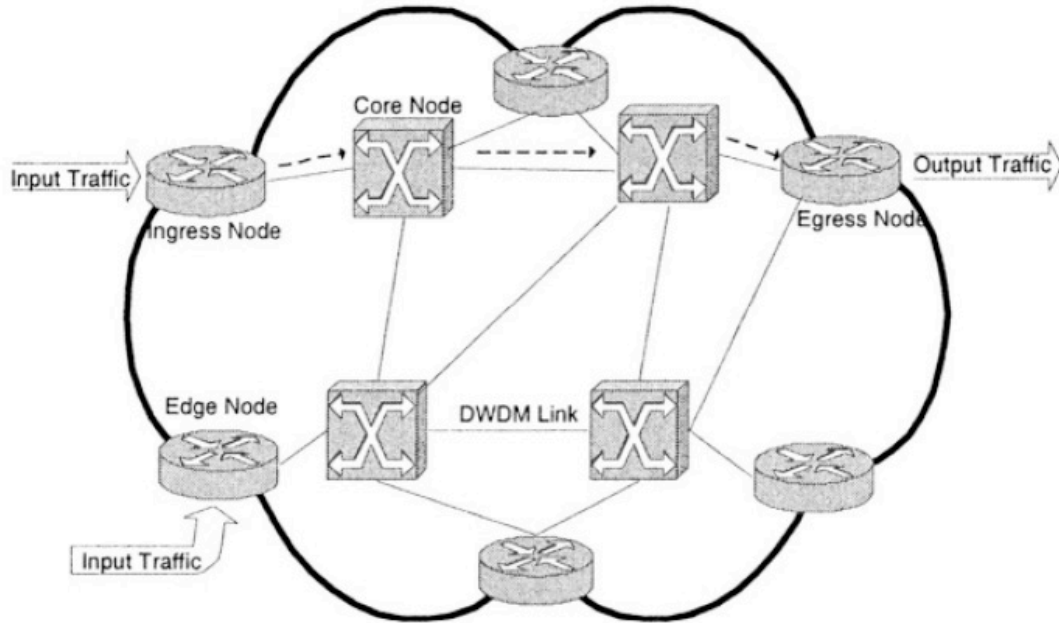


Fig. 2.8 OBS network architecture

The ingress edge node assembles incoming packets from the client terminals into bursts. The assembled bursts are transmitted all-optically over OBS core routers without any storage at intermediate nodes within the core. The egress edge node, upon receiving the burst, disassembles the bursts into packets and forwards the packets to the destination client terminals.

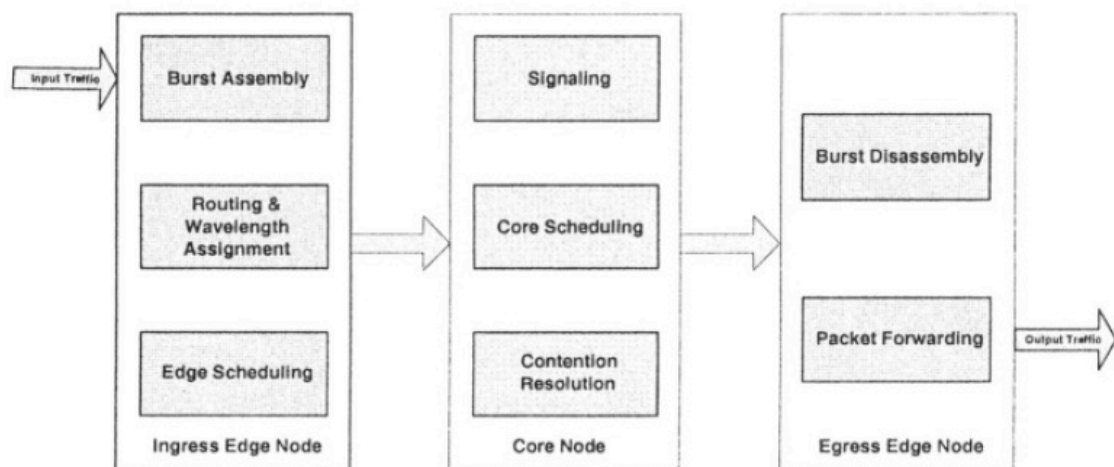


Fig. 2.9 OBS functional diagram

The nodes of OBS have various functionalities that are implemented. The ingress edge node is responsible for burst assembly, routing, wavelength assignment, and scheduling of bursts at the edge. The core node is responsible for signaling, scheduling bursts on core links, and resolving contention. The egress edge node is primarily responsible for disassembling the burst and sending the packets up to the higher network layer [13].

III. THE BANDWIDTH ALLOCATION OF WIMAX AND EPON

3.1. WiMAX Bandwidth Allocation

IEEE 802.16 standard provides a set of mechanisms to achieve reliable and link-adaptive transmission over wireless link. The MAC protocol is connection-oriented where all communications, either for data or control messages transmission, start with a connection set-up process.

In the downlink, all decisions related to the allocation of bandwidth to various SSs are made by the BS on a per Connection Identifier (CID) basis, which does not require the involvement of the SS. As MAC Packet Data Units (MAC PDUs) arrive for each CID, the BS schedules them for the PHY resources, based on their QoS requirements. Once dedicated PHY resources have been allocated for the transmission of the MAC PDU, the BS indicates this allocation to the MS, using the DL-MAP message.

In the uplink, the MS can request resources by either using a stand-alone bandwidth-request MAC PDU or piggybacking bandwidth requests on a generic MAC PDU, in which case it uses a grant-management sub header. Since the burst profile associated with a CID can change dynamically, all resource requests are made in terms of bytes of information, rather than PHY-layer resources, such as number of sub channels and/or number of OFDM symbols.

The bandwidth allocation is the key to the QoS provisioning process and it mainly depends on the type of the scheduling service used [15].

Basically the Bandwidth Request/Grant procedure is as follows:

1. The SS shall get a bandwidth request opportunity. This could be in two ways:
 - a. Either the BS sends a broadcast polling message to all the subscriber stations and listens to the subscribers who respond to the message. Or,
 - b. An SS can use the uplink contention period to contend for a bandwidth request opportunity. In case of contention the binary exponential back off algorithm is used.

2. BS replies to the bandwidth requesting subscriber stations with a bandwidth request response message.
3. The SS transmits its bandwidth request message, which contains the bandwidth request size.
4. On approval the BS allocates the required radio resources to the SS and sends the bandwidth grant message.

Upon being granted bandwidth, each SS makes local decisions to allocate the bandwidth and schedules packet transmission for each service connection. It supports two types of bandwidth allocation modes: unsolicited and upon request. WiMAX classifies the data traffic into five scheduling services [15]:

- Unsolicited Grant Service (UGS)
- Real Time Polling Service (rtPS)
- Enhanced Real Time Polling Service (ertPS)
- Non Real Time Polling Service (nrtPS)
- Best Effort (BE)

From the quality of service point of view, the scheduling algorithm is the most critical part of the procedure. This is so since the scheduler is the only entity to decide which packet is to be written into the UL-MAP. Therefore, designing a scheduling algorithm that takes care of all the queues' QoS constraints at the same time is of great importance. The IEEE 802.16e document clearly states that the definition of both the BS (uplink and downlink) and the SS scheduling algorithms is out of the scope of the standard, and is thus left up to the manufacturers [16].

3.2. EPON Bandwidth Allocation

In an EPON-based network, all ONUs share the same transmission channel while sending traffic in the upstream direction; thus, MAC arbitration mechanisms are required to avoid data collision and to fairly share the channel capacity. To achieve this, one needs to allocate a non overlapping transmission window (timeslot) to each ONU. The timeslot may be fixed (static) or variable (dynamic) based on the arbitration mechanism implemented at the OLT.

Using fixed timeslots, light-loaded ONUs will probably under-utilize their allocated slots, leading to increased delay in other ONUs and eventually deteriorate the throughput of the system. A dynamic scheme reduces the timeslot size when there is no data would allow the excess bandwidth to be used by other ONUs. A proposed algorithm uses an interleaved polling approach where the next ONU is polled before the transmission from the previous one has arrived. This scheme provides statistical multiplexing for ONUs and results in efficient upstream channel utilization [17].

3.2.1. IPACT

IPACT is a proposed algorithm for bandwidth allocation that is centralized and controlled by the OLT. Uses an interleaved polling approach, where the next ONU is polled before the transmission from the previous one has arrived. By the interchange of Report and Gate messages, the OLT fill a table with two parameters, the actual number of bits in the queue of each ONU and the RTT between the OLT with each ONU [18].

3.3. New Bandwidth Allocation Algorithm

The process of allocation bandwidth used by WiMAX and EPON is similar, the above similarity facilitates the integration of bandwidth allocation and QoS support in the integrated access architectures. However, there is a certain difference on technical details. EPON supports QoS in a DiffServ mode, under which packets are classified and stored in different priority queues. In contrast, although the services of WiMAX are classified to support different levels of QoS, WiMAX is a connection-oriented technology, which essentially follows an integrated service (IntServ) mode. Thus, for integration, an interesting problem is how to make efficient conversions between DiffServ and IntServ services. In addition, it is also interesting to see how the end-to-end QoS can be supported after these two systems are integrated.

The proposed algorithm must accomplish [14] [19]:

- A better support of end-to-end QoS guarantee and improvement of the overall system performances such as throughput and delay can be expected.
- Not require any amendment of the 802.16 standards and 802.3ah standard.
- The OLT can have frames of variable lengths in his buffer for transmit to the OBS metro network. The data burst of the OBS network is composed of several shorter packets that have the same destination node or the same QoS treatment. In order to allocate as much data as possible in each OBS burst, is necessary a mechanism to map IP addresses to the same possible destinations in the OBS-PON network [23].

There a proposed algorithm in [19] for integration WiMAX BS with EPON ONU, where them proposed a converging boundary device VOB (Virtual ONU BS), that is focused in how to map 802.16 differentiated traffic to the appropriate EPON queues and vice versa. For the map, classify EPON service into three priorities: Best Effort (BE), Assured Forwarding (AF) and Expedited Forwarding (EF). In a similar manner for IEEE 802.16 standards, both nrtPS and BE packets from BS are mapped to the BE queue at the ONU, rtPS/ertPS packets from BS are mapped to the AF queue at the ONU and UGS packets are mapped to the EF queue at the ONU. The DBA algorithm at VOBs operates on

these logical priority queues. For the bandwidth request and grant in the converging network proposed a work of cascading manner.

In the context of this Master Thesis, the proposed algorithm aims at clustering uplink packets according to the destination gateway before they arrive at the OLT-OBS interface.

IV. NETWORK ARCHITECTURE AND SIMULATION MODEL

4.1. Deployment Global Architecture of the Network

The global architecture of the network is formed by EPONs networks that feed IEEE 802.16 networks how see in the figure 4.1. Within a single EPON, some of the Optical Network Units (ONU), which is edge nodes of the EPON, may be connected to an IEEE 802.16 base station (BS). The Optical Line Terminals (OLTs), which are the head end nodes of the EPON, are connected to nodes in a metropolitan OBS network with a mesh topology.

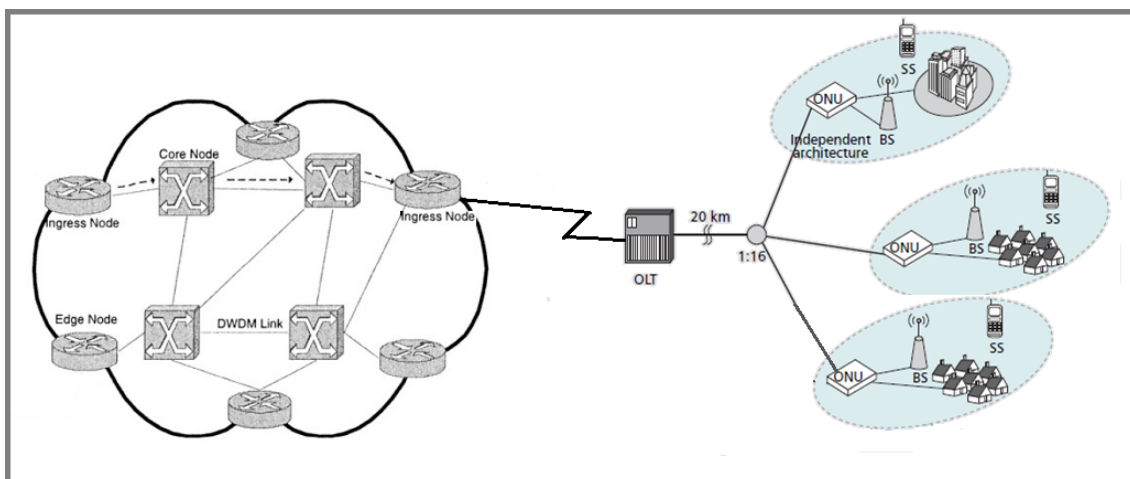


Fig. 4.1 OBS – EPON – WiMAX Network Topology

4.1.1. Implementation of ONU – BS device in OPNET

For the implementation of the convergence (BS – ONU) device for ensure QoS support, recent research work has been done to address the support of QoS in the specific scenario where IEEE 802.16 and EPON are integrated [20]. Where introduce three different architectures that can be used to support the integration of WiMAX and EPON, and focuses on the analysis of the integrated bandwidth allocation and QoS guarantee. These three architectures are:

- Independent Architecture
- Hybrid Architecture

- Unified Connection-oriented architecture

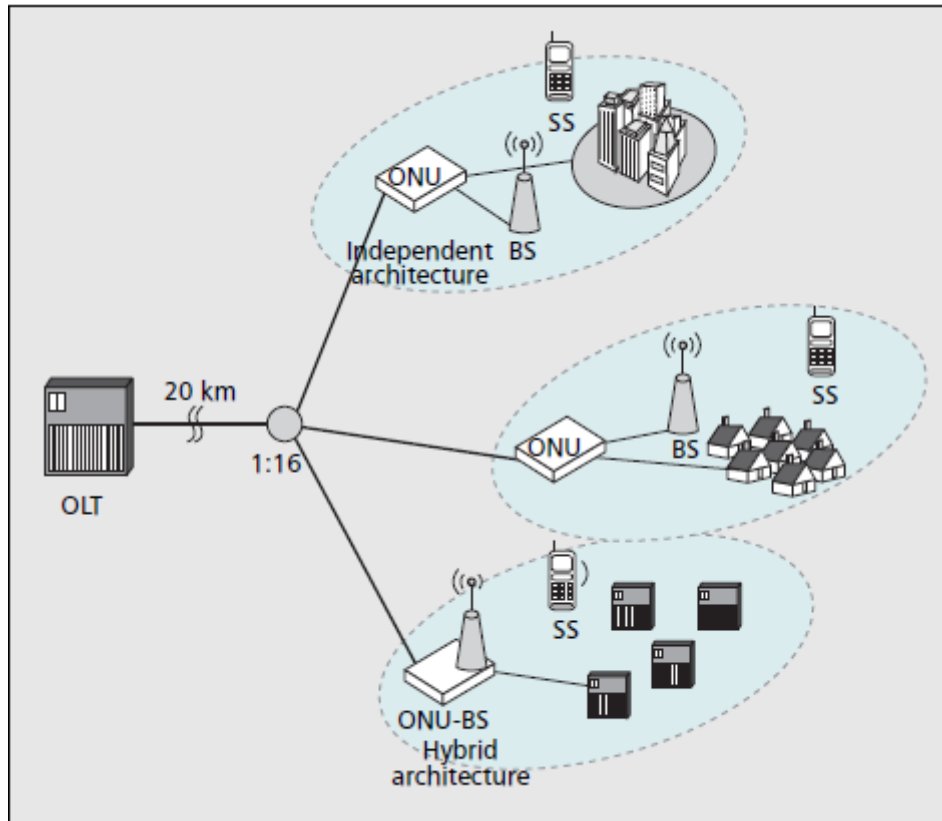


Fig. 4.2 Architecture for integration of EPON and WiMAX

In the case of this Master Thesis, the implemented architecture is an independent architecture, where WiMAX and EPON interactive with each other in a relatively independent manner. The WiMAX BS will be treated as an ordinary user to connect to the ONU. As long as they support the same standard interface (Ethernet at 1Gbps) they will be able to interconnect well. The direct benefit of the independent architecture is that the ONU and BS can be connected without any special requirements being met.

The BS will receive the traffic that is generated by all their SSs then the BS by his Ethernet interface sends all the frames to the ONU by his Ethernet Interface.

The ONU that was implemented in a pass in Opnet [22] [24], we modified for introduce an Ethernet interface and three queues one by each Type of Service (ToS) (EF, AF and BE). Each queue has subqueues where all the packets received from the BS are clustered by destination IP Address (figure 4.3).

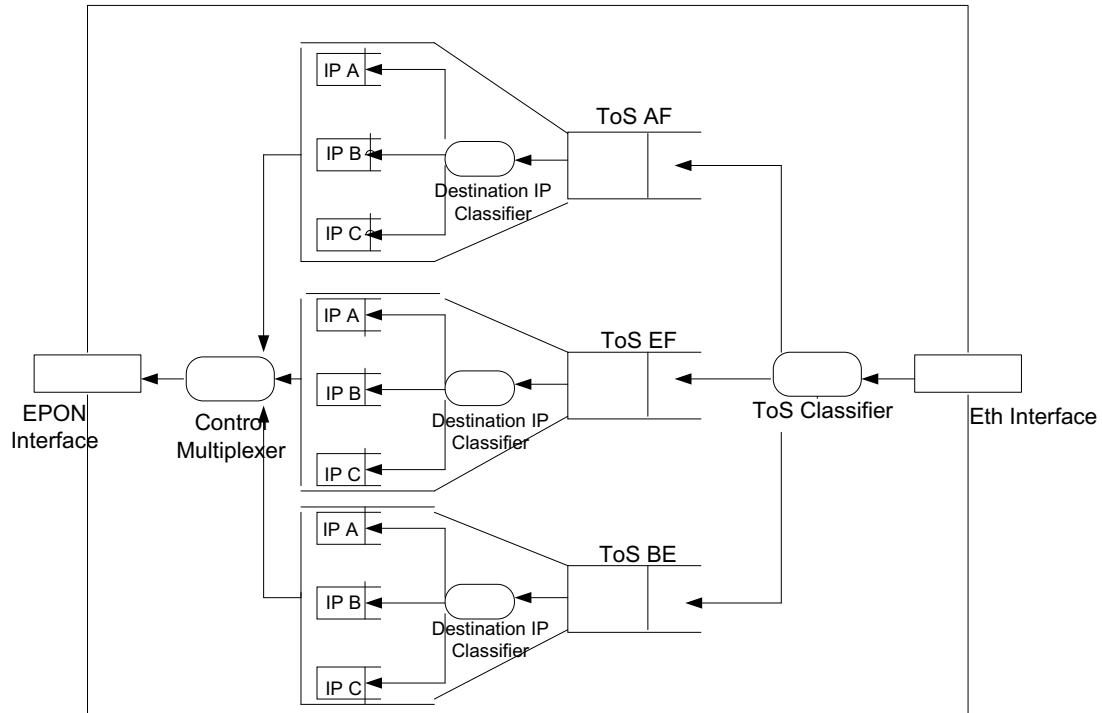


Fig. 4.3 Packets classification scheme within the ONU

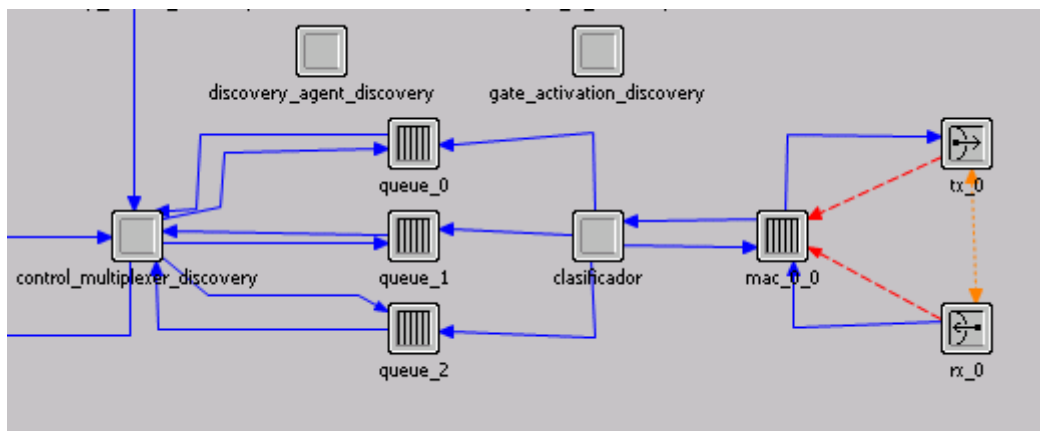


Fig. 4.4 Part of ONU architecture with three queues for each ToS

On the figure 4.4 the “tx_0” and “rx_0” is the Ethernet transceiver, “mac_0_0” module receive all the Ethernet frames and decapsulates the frames and after send the IP packets to the “clasificador” module for classification the IP packets by ToS and after send to the respective queue:

- Queue_0: queue for EF ToS.
- Queue_1: queue for AF ToS.
- Queue_2: queue for BE ToS.

When each queue has received the respective packet, this queue reads the destination IP address and puts the packet in the respective sub-queue.

4.1.2. Implementation of OLT – Edge Switch OBS in OPNET

As the OLT receives all the packets from all the ONUs, the OLT has to buffer all these packets in queues for sending to the edge switch of OBS. The OLT is composed by three queues where each queue stores all the packets by destination IP address (figure 4.5). Then the OLT will send the packets of its queues to the corresponding edge switch. Here we assume that packets with different IP destinations are to arrive to different edge switches.

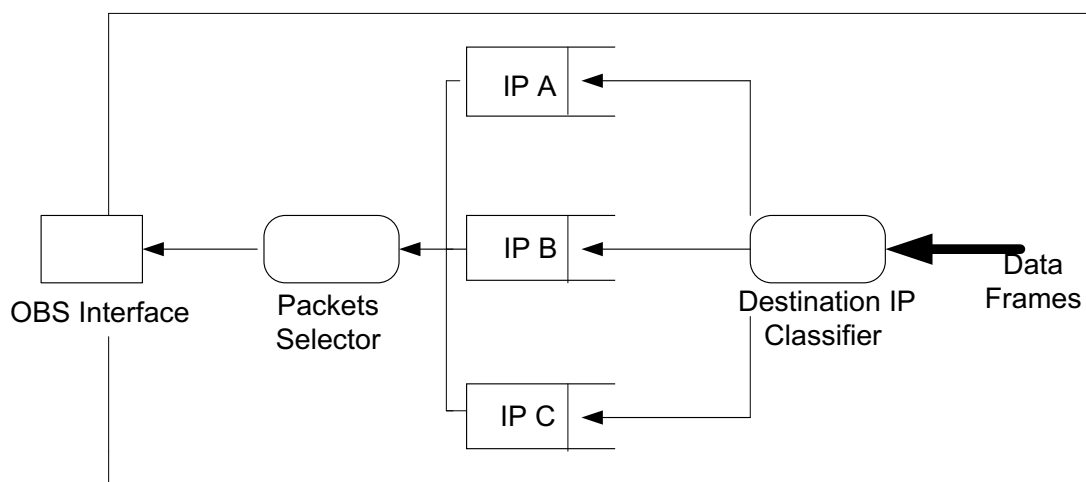


Fig. 4.5 Packets classification scheme within the OLT

Before the OLT begins to send packets to the edge switch OBS, it must meet any of these two conditions:

- When each queue has the number of packets needed to form a burst, the OLT will send the packets of this queue, or
- If all the queues does not contain enough packets for form a burst and has reached the limit time for sending the packets, the OLT must send the packets of the queue that has more packets than the other queues.

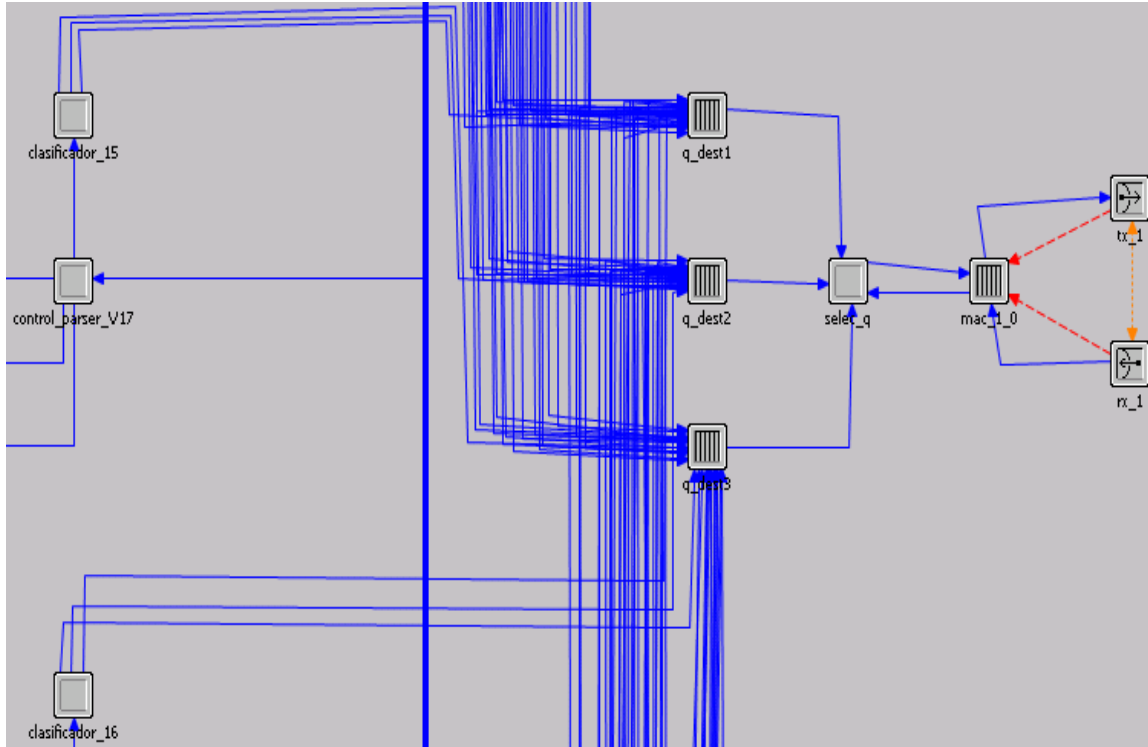


Fig. 4.6 Part of OLT architecture with three queues for destination IP address

On the figure 4.6 the “control_parser_vx” module receives all the frames from the all ONUs and analyzes each frame to obtain the type/length of the frame. If the value corresponds to the type/length of a control frame, the module sends the frame to the respective modules that will analyze the report frame. However, if the value corresponds to the type/length of a data frame, the module sends the frame to the “clasificador_vx” module. This module receives the data frames and decapsulates all of them to obtain the IP packet, then it reads the destination IP address and finally sends the packet to the respective queue.

The OLT is composed by three queues, where:

- Q_dest1: receive all the IP packets to destination 1.
- Q_dest2: receive all the IP packets to destination 2.
- Q_dest3: receive all the IP packets to destination 3.

Following figure 4.6, the “select_q” module sends an interruption to the respective queue to obtain the IP packets from the queue, then sends the IP packets to the “mac_1_0” module, where all the IP packets will be encapsulated in Ethernet frames, and then it sends these frames to the Ethernet transceivers “tx_1” and “rx_1” to be sent to the respective edge switch of the OBS network.

The interruption [24] that is sent by the “select_q” module to the respective queue, depends on either whether any of the three queues has the established quantity of frames for assembling an OBS burst, or whether the established time is reached for the OLT to send frames that are contained in any queue to form the respective OBS burst.

4.1.3. Implemented Algorithm for inter and intra ONU Bandwidth Allocation

The scenario implemented in a first work [22]. It only considered a queue by ONU and IPACT as algorithm inter ONU. In this Master Thesis we considered one queue by each ToS and three sub-queues in each queue by IP destination address (figure 4.3). Also consider the same IPACT implemented in [22] as dynamic bandwidth allocation algorithm for inter ONUs and as a bandwidth allocation for intra ONU we implementing a Round Robin algorithm.

4.2. Scenarios Implemented to Verify in OPNET

In Opnet modeler we build two networks topology:

- A network topology with thirty two fixed sources (Figure 4.7), where the half of the sources has the same traffic generation pattern (Figure 4.8), and the other half have other traffic generation pattern (Figure 4.9). These is could see in the next figures.

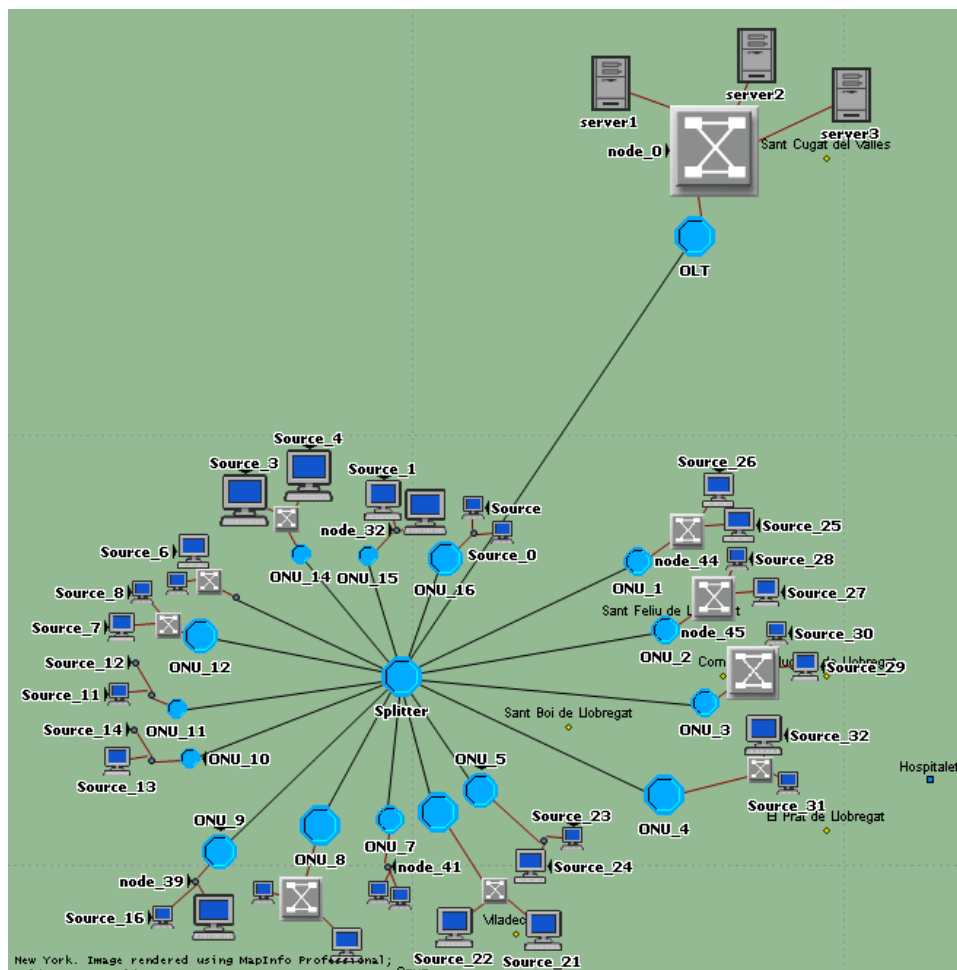


Fig.4.7 Network Topology with fixed sources

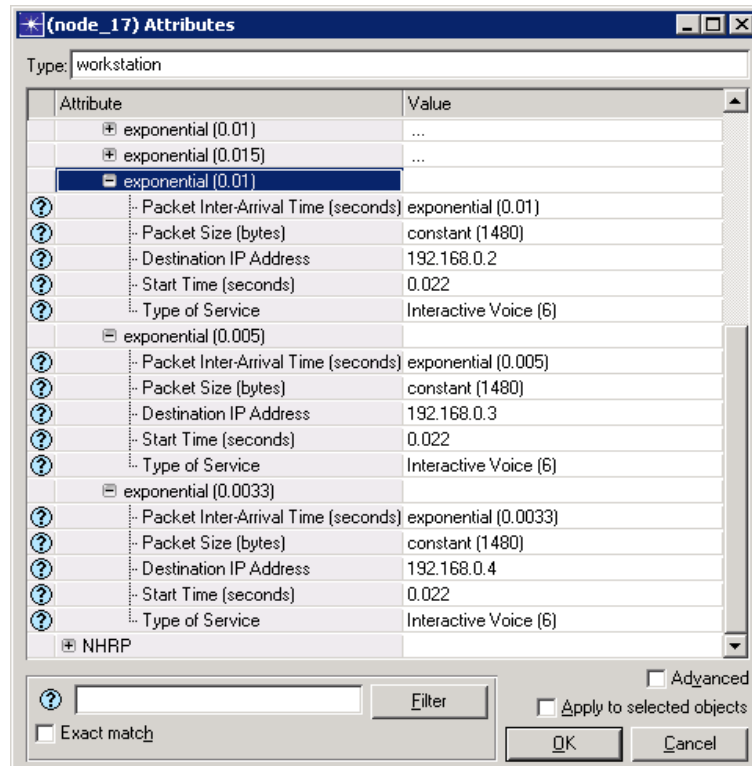


Fig. 4.8 A Traffic Generation Pattern of source.

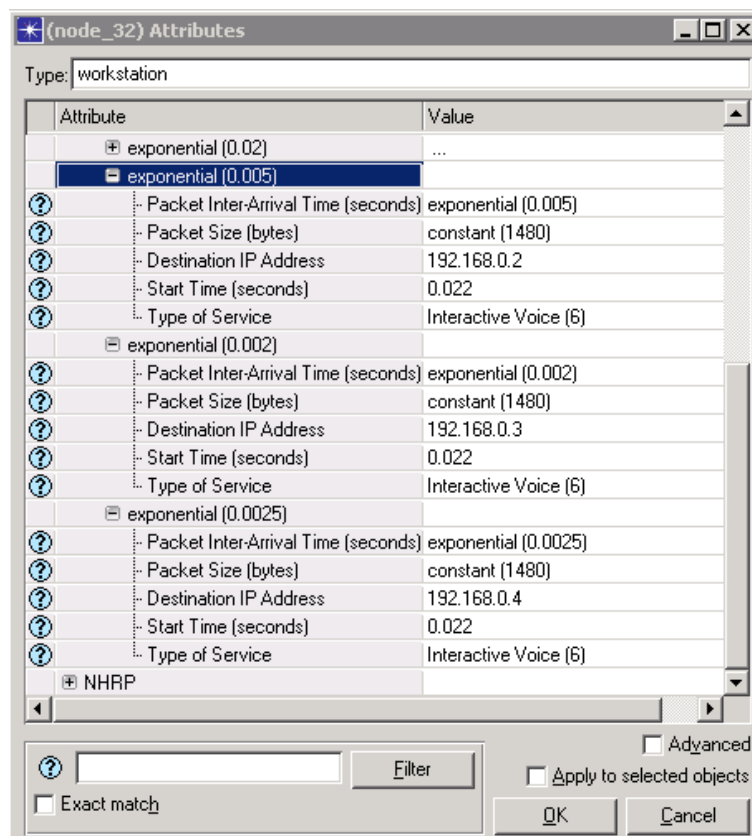


Fig. 4.9 Another Traffic Generation Pattern of a source

- Another network topology with fixed sources and WiMAX sub-networks (figure 4.10). WiMAX sub-networks are composed by five Service Stations and a Base Station (figure 4.12).

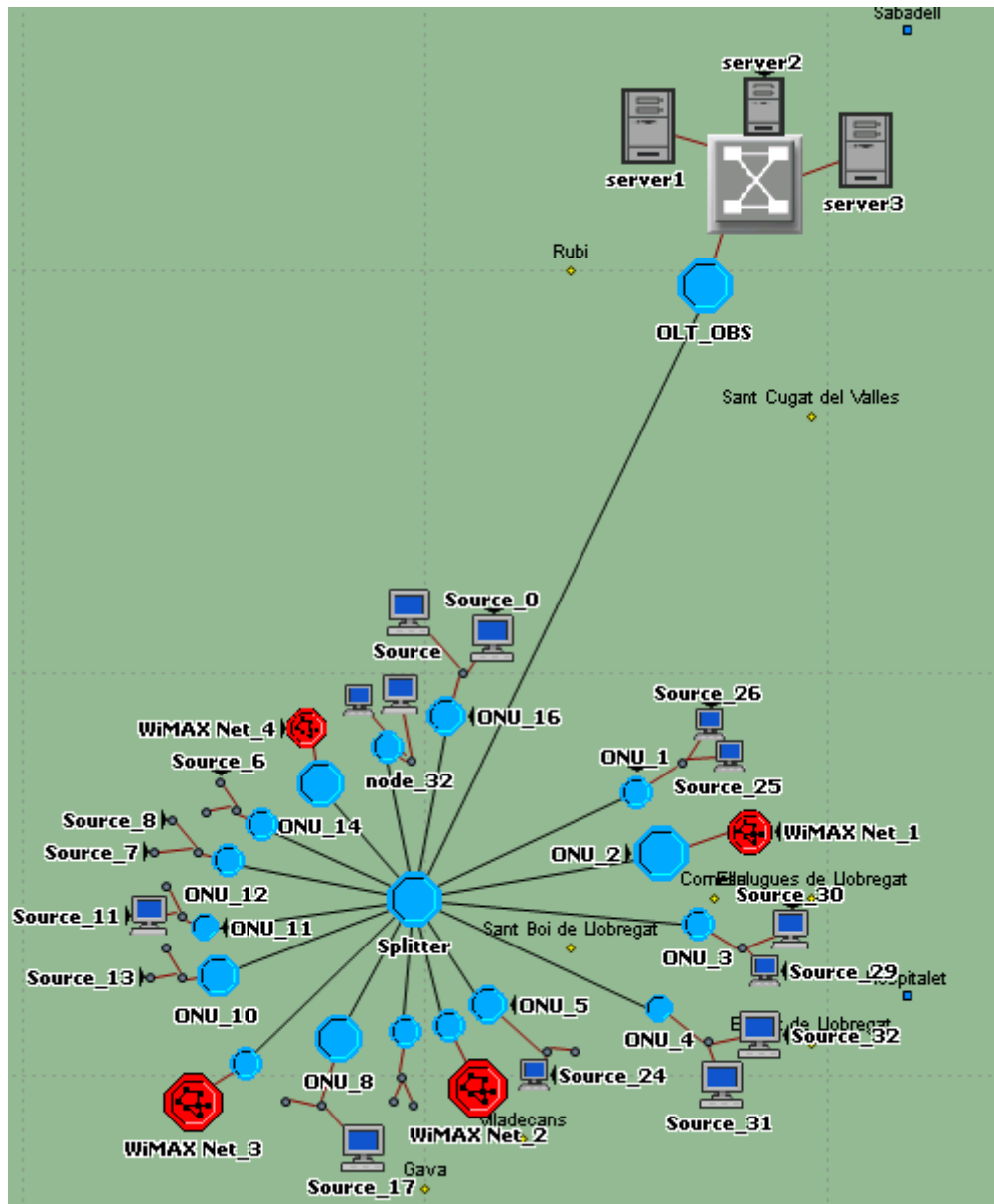


Fig. 4.10 Network topology with WiMAX Sub-networks

Some ONUs have connected an Ethernet workstation that generates traffic of the three ToS to the three different destinations.

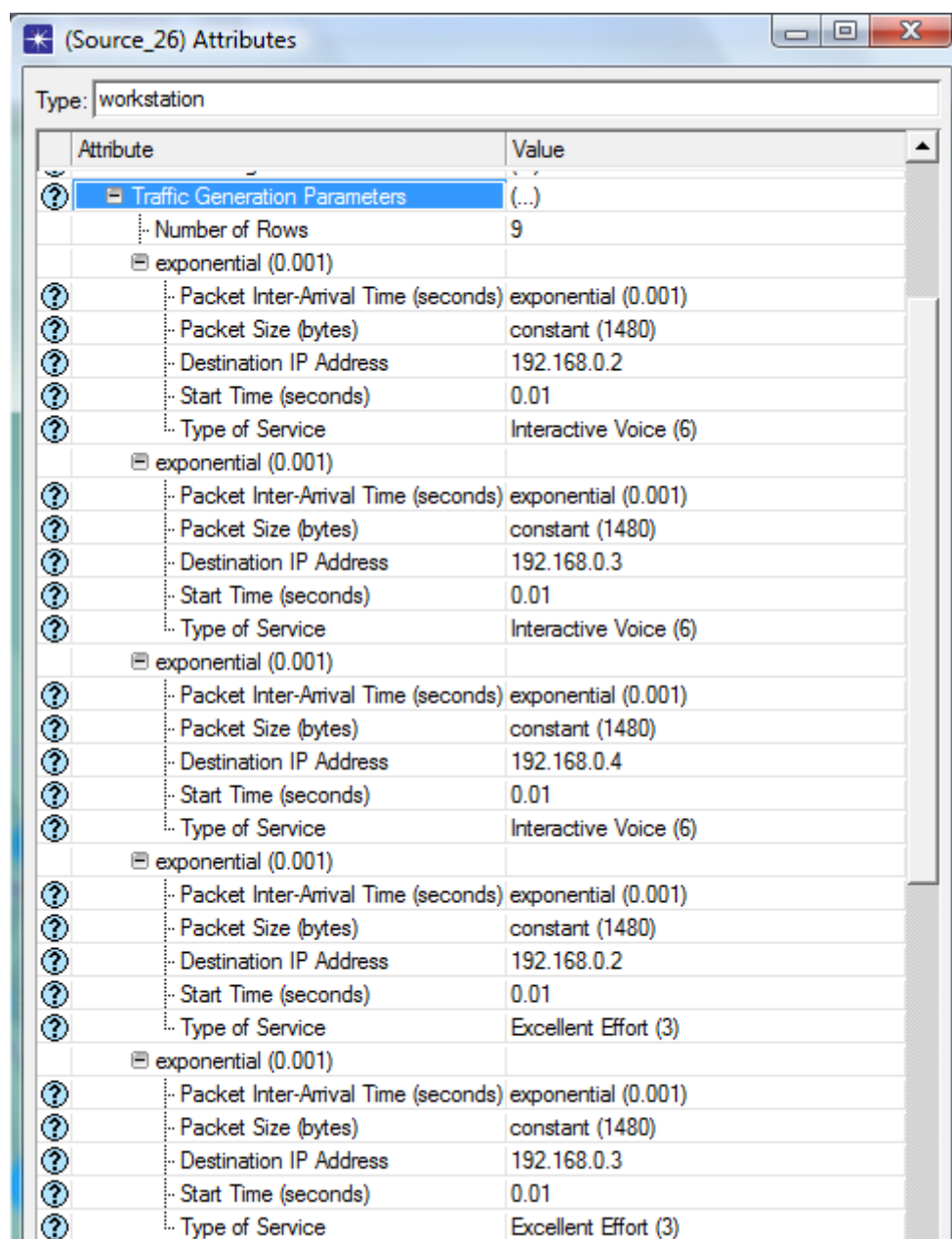


Fig. 4.11 Parameters of generation traffic of all the Ethernet workstations

The rest of the ONUs are connected to WiMAX Base Station, that is into of any WiMAX subnet.

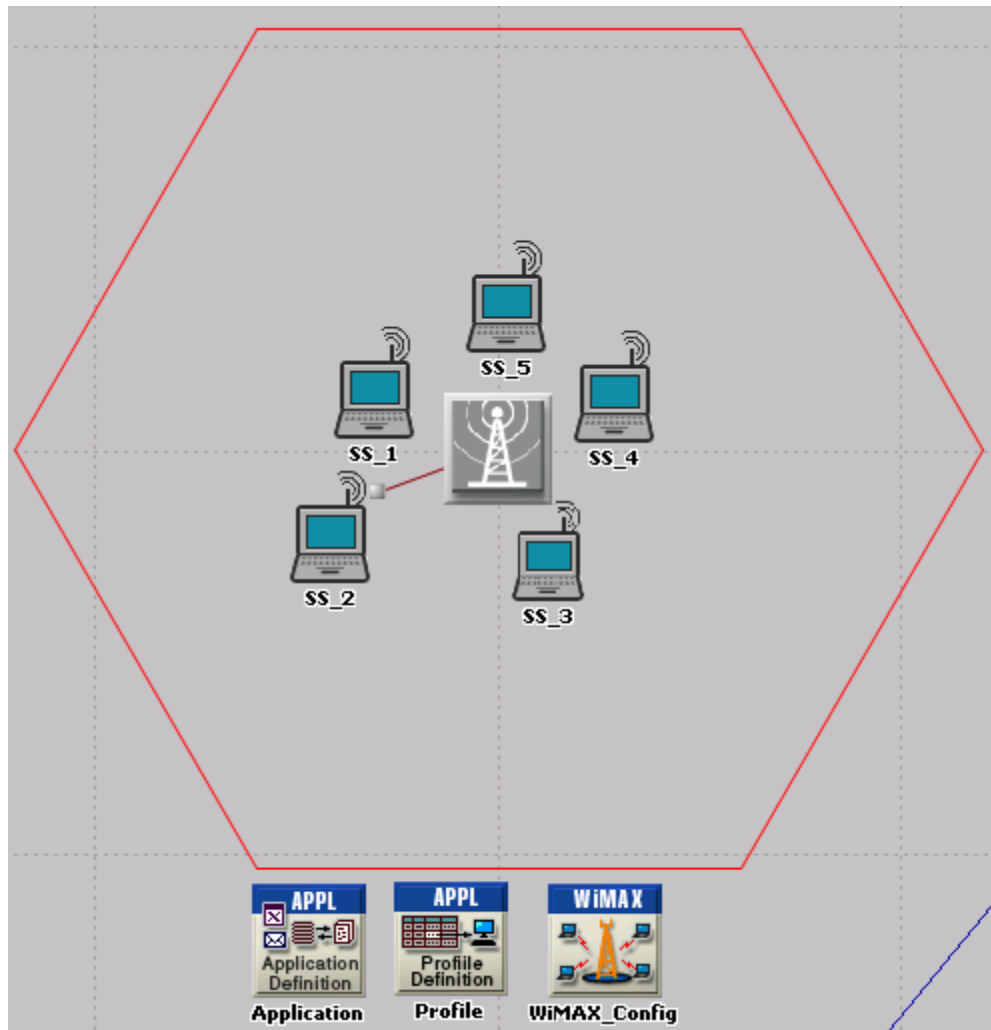


Fig. 4.12 WiMAX Subnet with five fixed workstation

On the WiMAX subnet is defined the next applications:

Table 4.1 Services defined in all the WiMAX subnets

Profile Definition	Application Definition	Type of Service	WiMAX QoS
FTP_User	Service_FTP	BE	BE
Http_User	Service_Http	BE	BE
Voice_User	Service_Voice	EF	UGS
Video_User	Service_Video	EF	UGS
Email_User	Service_Email	BE	BE
MPEG_Frames	MPEG_Service	EF	rtPS

Each Workstation on the WiMAX subnet has defined different applications for different destinations.

On WiMAX sub-network we defined the MAC Service Class Definitions for the five scheduling services as see in the table 4.2.

Table 4.2 MAC Service Definitions

Service Class Name	Scheduling Type	Maximum Sustained Traffic Rate (bps)	Minimum Reserved Traffic Rate (bps)	Maximum Latency (milliseconds)
Gold	UGS	5 Mbps	3 Mbps	5
Silver (rtPS)	rtPS	1Mbps	0,5 Mbps	30
Gold (ertPS)	ertPS	96 Kbps	96 Kbps	10
Basic Control	nrtPS	32 Kbps	32 Kbps	30
Bronze	BE	3 Mbps	2,7 Mbps	30

4.2.1. Results

The first scenario (network topology with all fixed sources), has two traffic generation patterns. A source that generate traffic with a traffic pattern of the figure 4.8, it create the number of packets that is show in the table 4.3.

Table 4.3 Packets generated and received by each ONU

ONUs	Fixed Source	Packets generated by Source	Total packets received by ONU
ONU_1	Nodo 1	927	1910
	Nodo 2	983	
ONU_2	Nodo 3	978	1921
	Nodo 4	943	
ONU_3	Nodo 5	974	1960
	Nodo 6	986	
ONU_4	Nodo 7	977	1969
	Nodo 8	992	
ONU_5	Nodo 9	982	1925
	Nodo 10	943	
ONU_6	Nodo 11	956	1958
	Nodo 12	1002	
ONU_7	Nodo 13	981	2013
	Nodo 14	1032	
ONU_8	Nodo 15	984	1993
	Nodo 16	1009	

We can see that the sum of traffic generated by the sources nodes is equals the traffic received at each ONU.

Now is showing in the table 4.4 the number of packets received by Type of Service on each ONU.

Table 4.4 Number of packets by Type of Service in each ONU

ONUs	Type of Service	Number of packets by queue
ONU_1	AF	782
	EF	317
	BE	811
ONU_2	AF	799
	EF	305
	BE	817
ONU_3	AF	819
	EF	300
	BE	841
ONU_4	AF	799
	EF	338
	BE	832
ONU_5	AF	832
	EF	302
	BE	791
ONU_6	AF	842
	EF	285
	BE	831
ONU_7	AF	862
	EF	317
	BE	834
ONU_8	AF	827
	EF	316
	BE	850

The ONUs that receives this traffic pattern that were generated by the sources of the table 4.3, is showing their average traffic receive by its Ethernet interface in the figure 4.13.

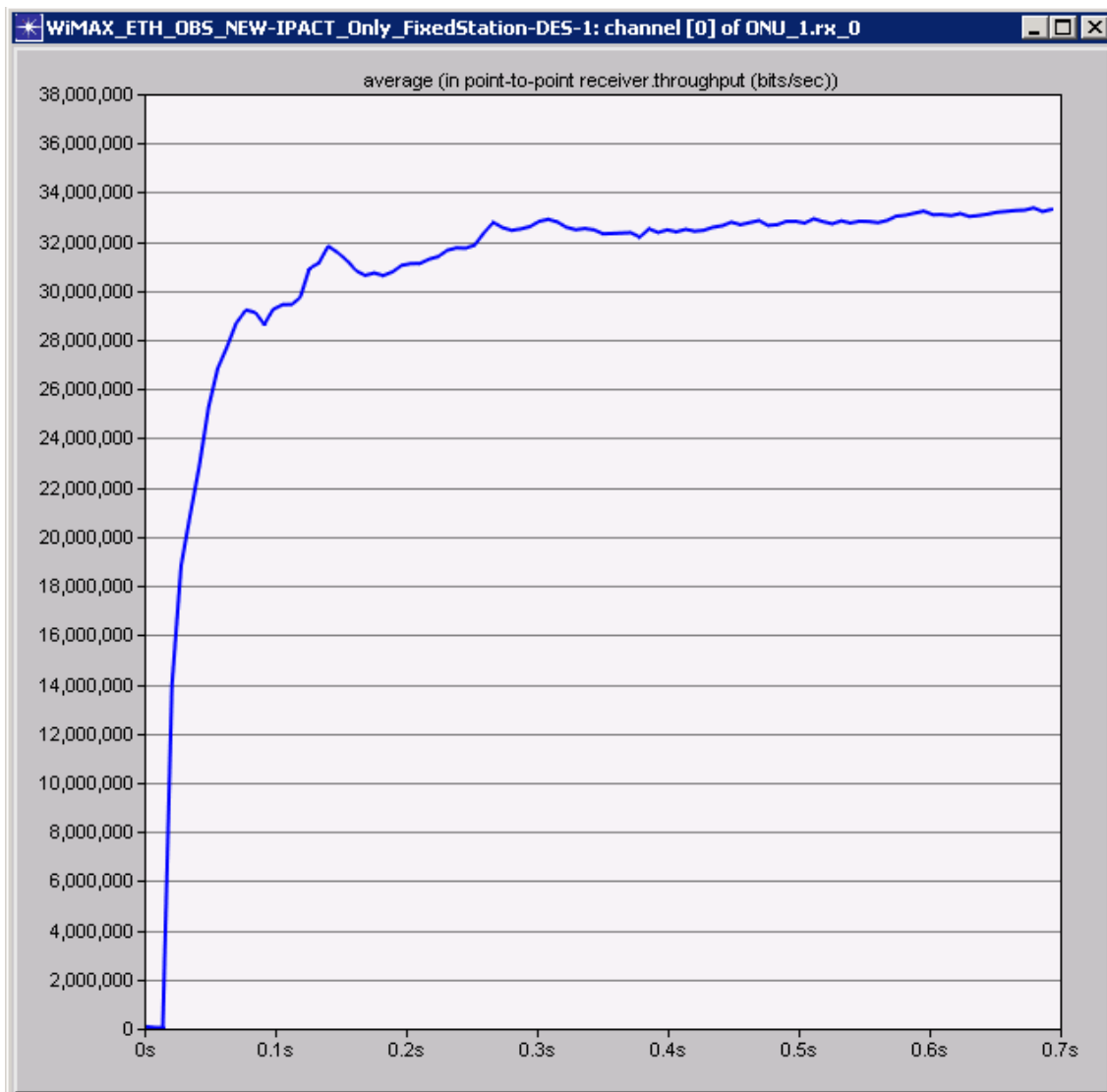


Fig. 4.13 Traffic receive average in an ONU

Now the next table 4.5 show the number of packets created by each source with the other traffic pattern showed in the figure 4.9.

Table 4.5 Packets created and received by each ONU

ONUs	Fixed Node	Packets created	Total packets received by ONU
ONU_9	Nodo 17	1334	2734
	Nodo 18	1402	
ONU_10	Nodo 19	1340	2685
	Nodo 20	1345	
ONU_11	Nodo 21	1344	2645
	Nodo 22	1301	

ONU_12	Nodo 23	1427	2774
	Nodo 24	1347	
ONU_13	Nodo 25	1320	2654
	Nodo 26	1335	
ONU_14	Nodo 27	1386	2708
	Nodo 28	1322	
ONU_15	Nodo 29	1361	2708
	Nodo 30	1347	
ONU_16	Nodo 31	1349	2747
	Nodo 32	1398	

We can see that the sum of traffic generated by the sources nodes is equals the traffic received at each ONU.

By the other traffic pattern defined in the sources, on the table 4.6 is showing the number of packets received on each ONU by type of service.

Table 4.6 Number of packets by Type of Service in each ONU

ONUs	Type of Service	Number of packets by queue
ONU_9	AF	1565
	EF	246
	BE	923
ONU_10	AF	1467
	EF	251
	BE	967
ONU_11	AF	1507
	EF	277
	BE	861
ONU_12	AF	1559
	EF	282
	BE	933
ONU_13	AF	1466
	EF	250
	BE	938
ONU_14	AF	1550
	EF	251
	BE	907
ONU_15	AF	1501
	EF	263
	BE	944
ONU_16	AF	1541

	EF	262
	BE	944

Now the next figure 4.14 shows the average traffic that receives one ONU by its Ethernet interface with the other traffic pattern.

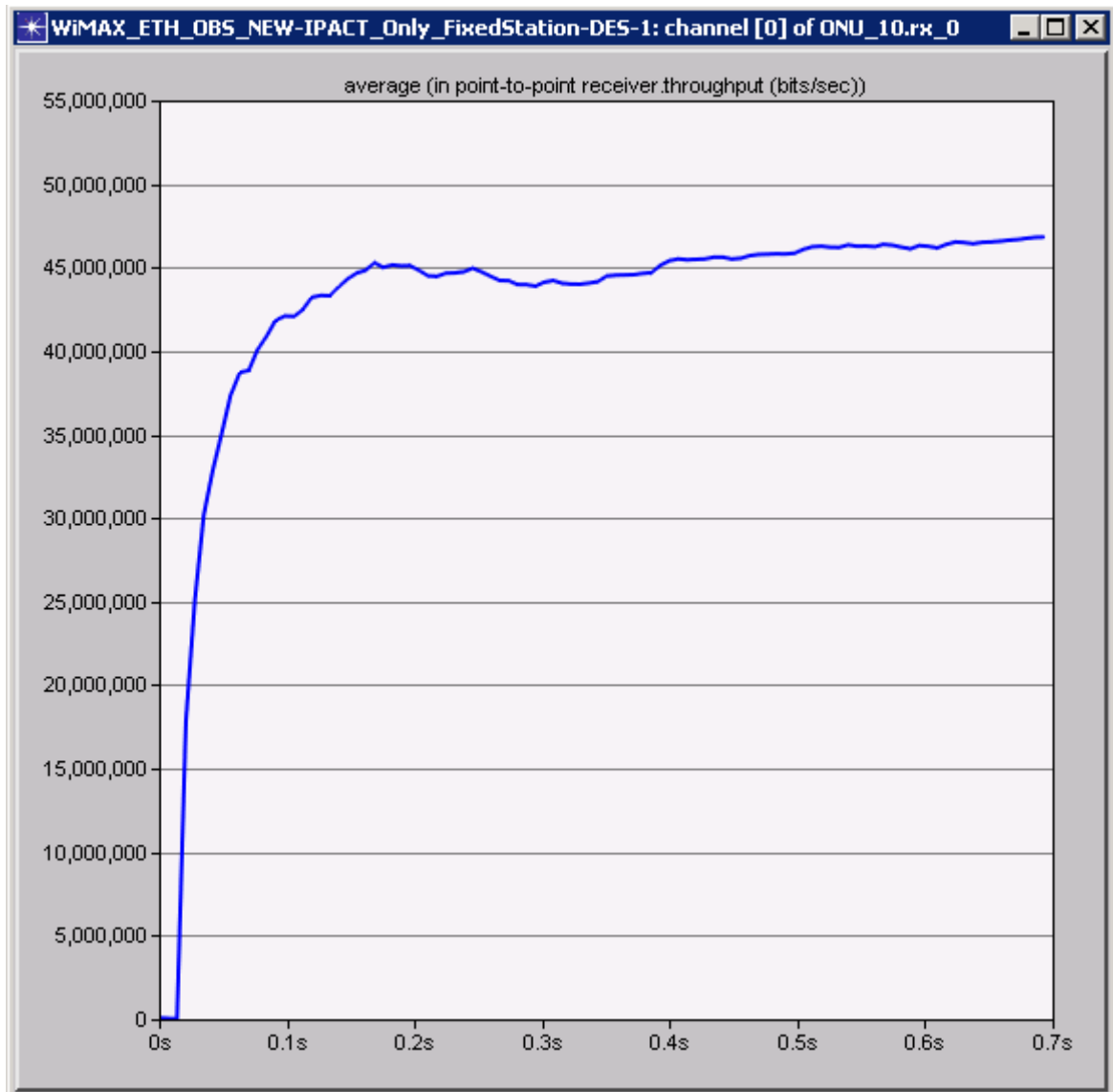


Fig. 4.14 Traffic receive average in ONU

With these two traffic patterns defined in the thirty two fixed sources and due the use of the dynamic bandwidth allocate IPACT that was implemented in [22] that only is possible send the packets to the OLT of one queue of each ONU. This queue stores all the packets of a ToS AF that are sending to the OLT. The packets that are stored in the other two queues in the ONU (EF and BE) are not sending to the OLT.

Now in the figure 4.15, we can see the behavior of the queue AF belongs at an ONU that receive the first traffic pattern (figure 4.8) of the sources connected to this ONU.

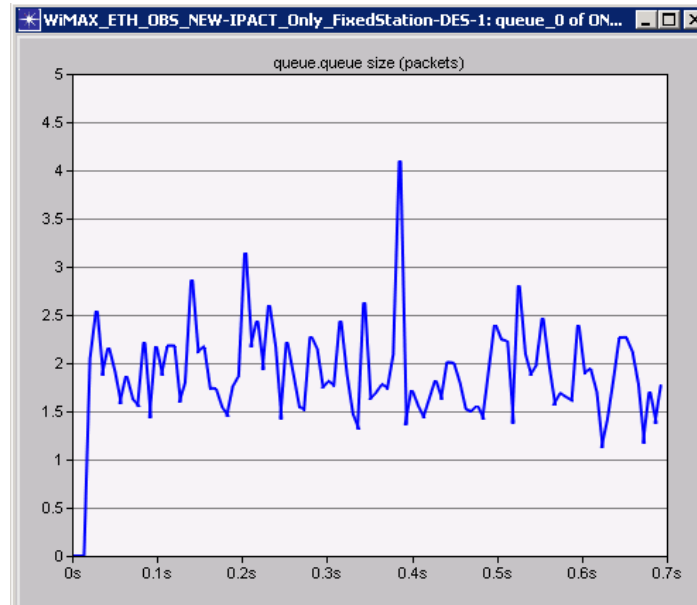


Fig. 4.15 Number of packets in a queue AF of an ONU

For the behavior of a queue AF that belongs at ONU that receive the second traffic pattern (figure 4.9) of the sources connected to this ONU is see in the next figure 4.16.

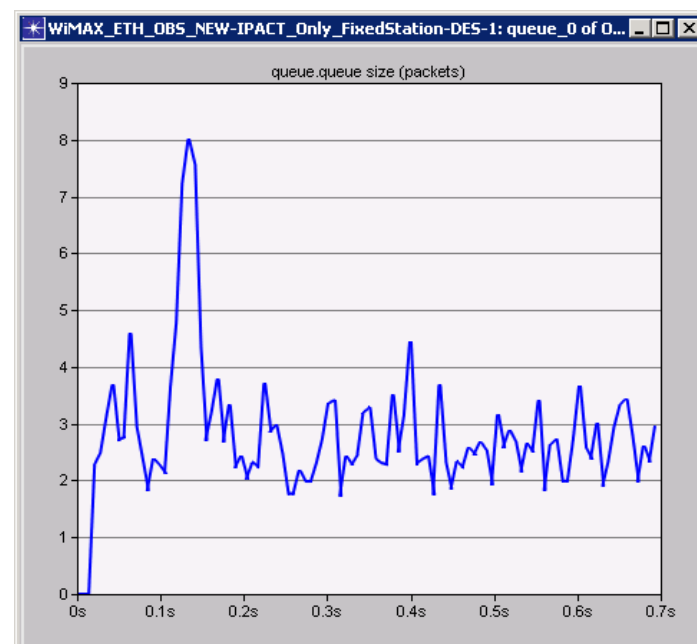


Fig. 4.16 Number of packets in a queue AF of an ONU

The queues of type of service EF or BE of an ONU has the behavior shows on figure 4.17 and figure 4.18 due at the implementation of IPACT in [22]

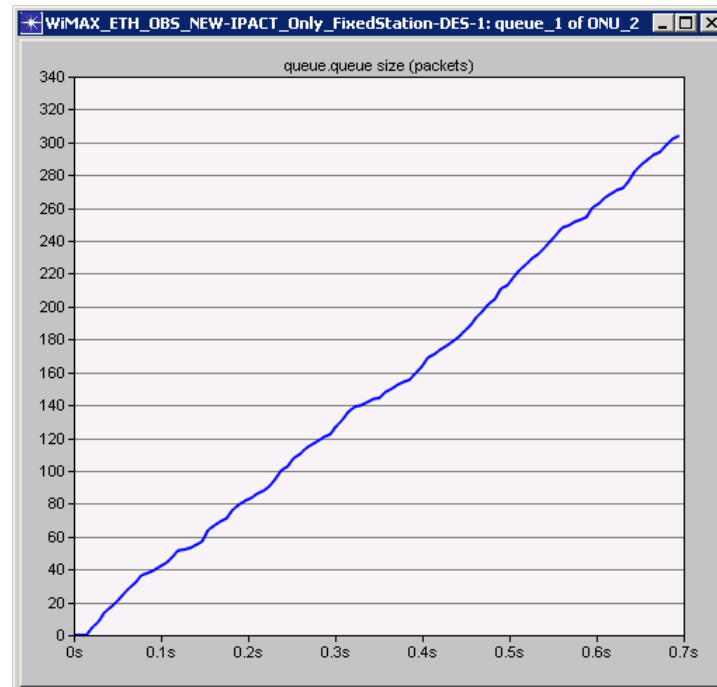


Fig. 4.17 Queue of type of service EF at an ONU that receive packets with the first pattern traffic

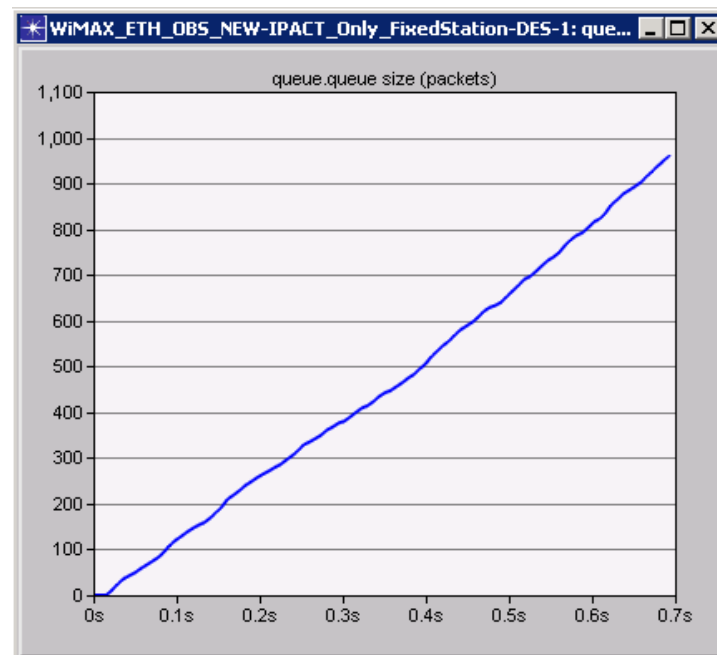


Fig. 4.18 Queue of type of service BE at an ONU that receive packets with the second pattern traffic

Then the OLT only will receive packets of type of service AF in their three queues, where in each queue store packets to the same destination.

Table 4.7 Number of packets in each queue on the OLT

OLT queues	Number of Packets
Q_dest1	3340
Q_dest2	7677
Q_dest3	7688
Total packets on OLT	18705

As could see, all the packets of Type of Service AF received on all the ONUs were sent to the OLT and it stored all these packets in their respective queues. The total packets in OLT is equals the sum of all AF traffic received at all the ONUs (Tables 4.4, 4.6 and 4.7)

The second scenario (network topology with WiMAX sub-network and fixed sources) has two traffic patterns, one by the fixed sources (figure 4.11) and the other by the WiMAX sub-network where is defined the services showed in the table 4.1 with their characteristics showing in the Appendix. The ONU that has connected a fixed sources, receive the quantity of packets that is show in the table 4.8.

Table 4.8 Number of packets received of fixed sources

ONUs	Queue	Number of Packets	Total Packets
ONU_4	AF	412	1243
	EF	435	
	BE	396	

The ONU that has connected a WiMAX sub-network received the quantity of packets that is show in the table 4.9.

Table 4.9 Number of packets received of WiMAX sub-network.

ONUs	Queue	Number of Packets	Total Packets
ONU_3	AF	344	523
	EF	64	
	BE	115	

For this scenario the OLT receive the packets of type of service AF from the ONUs and the packets are stored in their three queues by destination address.

Table 4.10 Number of packets received by the OLT

Queue	Number of Packets	Total Packets
q_dest1	267	756
q_dest2	279	
q_dest3	210	

Comparing tables 4.8, 4.9 and 4.10 we can see that the total number of packets that are stored in all the queues of the OLT are the total number of packets of type of service AF that were sent by the all ONUs.

V. CONCLUSIONS AND FUTURE DIRECTIONS

5.1. Summary of Contributions

The network topology implemented in Opnet for this Master Thesis permit interconnect a EPON network with different networks of access or metro by its Ethernet interface that we implemented in the ONU and OLT devices.

For do this new implementation of interconnect different networks technologies, we analyzed the media access control used by WiMAX, EPON and OBS technologies and for achieve a good performance of this network in bandwidth use and quality of service end to end, we made specifications for elaborate a new algorithm of bandwidth allocation to interconnect these three technologies.

For give support to the development of a new algorithm of bandwidth allocation, we implemented a different queues in the ONU and OLT devices, for classification packets first by quality of service and after by destination address.

On the case of this Master Thesis, for the test of this network topology, we used the interconnection of three different technologies (WiMAX, EPON and OBS) used the IPACT how inter ONUs algorithm for bandwidth allocation and development Round Robin algorithm for intra ONU bandwidth allocation.

The proposal for interconnecting a wireless network with optical fiber network permit lessening the impact on the change of land where planning to bury fiber optics.

Also allow to provide internet access to economical lower-income groups and thus providing development aid to society as a whole.

5.2. Applications and Future Directions

The develop of this network topology in this Master Thesis will permit make tests with new proposed bandwidth allocation algorithm for obtain the performance of the network in terms of delay end to end.

Also this network topology will permit test different bandwidth allocation algorithm for interconnect WiMAX, EPON and OBS networks and then only in an EPON network. Also will permit interconnect another access technology that used as interface of interconnection at Ethernet protocol like WiFi and interconnect to EPON and test the performance of this whole network in terms on delay end to end.

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APPENDIX

Properties of all the services used in WiMAX sub-network.

(Video Conferencing) Table

Attribute	Value
Frame Interarrival Time Information	[...]
Frame Size Information (bytes)	352X240 pixels
Symbolic Destination Name	Video Destination
Type of Service	Interactive Voice (6)
RSVP Parameters	None
Traffic Mix (%)	All Discrete

Details Promote OK Cancel

(Voice) Table

Attribute	Value
Silence Length (seconds)	None
Talk Spurt Length (seconds)	default
Symbolic Destination Name	Voice Destination
Encoder Scheme	G.711
Voice Frames per Packet	1
Type of Service	Interactive Voice (6)
RSVP Parameters	None
Traffic Mix (%)	All Discrete
Signaling	None
Compression Delay (seconds)	0.02
Decompression Delay (seconds)	0.02
Conversation Environment	[...]

Details Promote OK Cancel

(Video Conferencing) Table

Attribute	Value
Frame Interarrival Time Information	10 frames/sec
Frame Size Information (bytes)	128X120 pixels
Symbolic Destination Name	Video Destination
Type of Service	Excellent Effort (3)
RSVP Parameters	None
Traffic Mix (%)	All Discrete

Details Promote OK Cancel

(Http) Table

Attribute	Value
HTTP Specification	HTTP 1.1
Page Interarrival Time (seconds)	exponential (0.001)
Page Properties	[...]
Server Selection	[...]
RSVP Parameters	None
Type of Service	Best Effort (0)

(Page Properties) Table

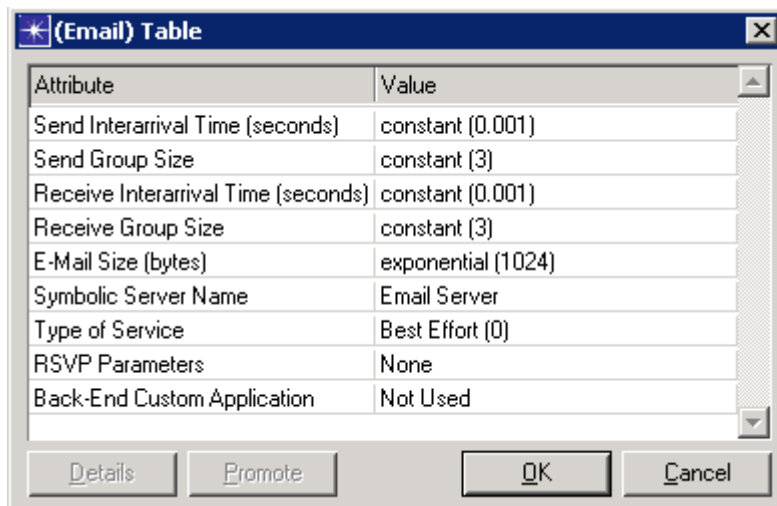
	Object Size (bytes)	Number of Objects (objects per page)	Location	Back-End Custom Application
Medium Image	Medium Image	constant (1)	HTTP Server	Not Used

☒ Show row labels

1 Rows

(Ftp) Table

Attribute	Value
Command Mix (Get/Total)	100%
Inter-Request Time (seconds)	exponential (0.001)
File Size (bytes)	constant (1480)
Symbolic Server Name	FTP Server
Type of Service	Best Effort (0)
RSVP Parameters	None
Back-End Custom Application	Not Used



The screenshot shows a dialog box titled "(Email) Table" with a close button (X) in the top right corner. The dialog contains a table with two columns: "Attribute" and "Value". The table lists several parameters for email simulation, including interarrival times, group sizes, email size distribution, server name, service type, RSVP parameters, and a custom application. At the bottom of the dialog, there are four buttons: "Details", "Promote", "OK", and "Cancel".

Attribute	Value
Send Interarrival Time (seconds)	constant (0.001)
Send Group Size	constant (3)
Receive Interarrival Time (seconds)	constant (0.001)
Receive Group Size	constant (3)
E-Mail Size (bytes)	exponential (1024)
Symbolic Server Name	Email Server
Type of Service	Best Effort (0)
RSVP Parameters	None
Back-End Custom Application	Not Used

Details Promote OK Cancel