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MASTER THESIS

TITLE: Design and Performance Evaluation of Passive Optical Networks

MASTER DEGREE: Master in Science in Telecommunication Engineering & Management

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Resum

Actualment, noves urbanitzacions de molts punts del món estan construïdes basades amb connexió de fibra fins la llar, i els proveïdors de serveis estan portant a terme assajos en els terrenys i experiments amb accés de fibra.

Per a poder proporcionar una bona alternativa a les infraestructures existents, la nova tecnologia hauria de ser, entre d'altres aspectes, eficient en costos, de banda ampla, i fàcil de desenvolupar i mantenir. Tant hauria de suportar també tots els serveis existents que hi ha a dia d'avui, com oferir de possibles nous serveis requerits. Aquests serveis inclouen tràfic de veu, dades, i vídeo / televisió.

En aquest projecte es durà a terme l'exploració d'alguns dels aspectes de la localització de l'ample de banda per qualitat de servei (QoS) en l'arquitectura 802.3ah EPON i l'arquitectura GPON en un entorn multimèdia. Es definiran diferents tipus de tràfic emulant tràfic real en la xarxa, cadascun amb els seus propis requeriments de QoS (ample de banda, retard, etc.). També s'usarà però, tràfic real com veu, dades i vídeo.

Un dels objectius finals del projecte serà proporcionar, també, un manual de configuració i operació de referència, facilitant la funcionalitat i resultats de l'anàlisi d'aquests tipus de xarxes. Aquest manual inclourà pas a pas la forma de descobrir el comportament d'aquestes xarxes. Tenint en compte l'extensió requerida del projecte, aquest manual s'ha inclòs a l'Annex C del projecte.

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Overview

Currently, new housing developments in many places around the world are built with fiber-based connections to the home, and network providers are conducting field-testing and experiments with fiber access.

In order to provide a worthy alternative to the existing infrastructures, the new technology should be, among other things, cost-efficient, broad-banded, and easy to maintain and deploy. It must also support all existing services as well as offer new required services. These services include voice, data, and video/television-broadcast traffic.

In this project we will carry out exploration of some of the aspects of the QoS bandwidth allocation in the 802.3ah EPON architecture and the GPON architecture in a multimedia environment. Several general traffic types will be defined, that would represent real traffic in the network, each with its own QoS requirements (bandwidth, delay, etc.). Sometimes we will use real traffic (voice, video, data).

Moreover, another goal of this project is to provide an operating and configuration reference tool-like manual facilitating the functional and performance analysis of this kind of networks. This tool-like manual will include step-by-step the way to discover the behaviour of these networks. Due to the required extension of this document, the manual has been included in Annex C.

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INTRODUCTION

Due to the continuing demand for larger bandwidth, the optical transport is gradually becoming general in the access network where optical fibre technologies can provide the solution for current and future application demands. Using optical fibre technologies, the communications infrastructure becomes powerful, providing very high speeds to transfer a high capacity of data. Some of the advantages from an optical fibre system are: a higher bandwidth capacity, longer reach, longer life, lower maintenance cost and a resistance to outside interference.

The conventional point-to-point transport solutions, such as SDH / SONET and Ethernet, are expensive to use for residential access, and therefore more economical solutions are currently being developed. To address this issue, a promising alternative to access networks is certainly the Passive Optical Network (PON), when throughput and cost are the major decision-making criteria. Several competing PON concepts have been developed, such as the Asynchronous Transfer Mode PON (APON) which uses ATM encapsulation of transported data. APON was followed by the Broadband PON (BPON), which offers improved and additional features like Wavelength Division Multiplexing (WDM) support, and upstream bandwidth allocation; the Ethernet PON (EPON), which uses Ethernet and is highly suitable for data services; and the Gigabit PON (GPON) that it is an IP-based protocol designed for IP traffic often described as combining the best attributes of BPON and EPON at gigabit rates.

The most advertised technologies are the EPON and GPON access network. EPON is commonly assumed to be a more economical alternative, and GPON in turn is a more versatile concept offering transport service for a large set of higher layer transport concepts. When considering the possible choice between EPON and GPON, it should be examined whether EPON really is more economical than GPON and in what circumstances. In evaluating this, one should consider issues such as compatibility with other transport systems, transport link utilization, cost to build a PON network, network segmentation needed when the number of connected users increases and granularity of the offered transport service.

With regards to compatibility, GPON can be considered a better choice, because it adapts to various other transport concepts while EPON supports only Ethernet. At the same time EPON is normally considered the best alternative as the broadband access network for the networks. The upstream channel has to be shared among users, thus a suitable access mechanism is required to avoid collisions, but also to meet the requirements of quality to the service. On the granularity point of view, both concepts provide connection rates from very small to very large fragments of the transport link's capacity and in this respect they can be considered equally good choices.

Considering all of these facts, this project is focused on the validation of a small part of the European projects PAIS (Plataforma Avançada Integrada de Serveis from June 2009 to June 2010) and SILVIA (Serveis Intel·ligents de Validació de la Internet Avançada from October 2010 to October 2011).

The PAIS project allows the deployment of an optical transport network connected to a FTTH (Fiber to the Home) extension. This platform provides the Catalan ICT sector access to advanced optical equipment to perform validation tasks. The platform will allow open access for field testing in a multi/technology and multi-manufacturer domain.

The SILVIA project is an industrial research project with a goal to create an advanced and open validation platform, to offer advanced services in order to validate new devices, equipment, protocols and telecommunication services and applications in a transparent manner, covering from the physical layer to the application level in a telecommunication network.

For these reasons this project will validate the optical transport network based on Ethernet (EPON), which is a widely used technology, and GPON in order to study both technologies and the advanced services offered.

Hence, the project is organised in four chapters. Chapter 1 introduces the EPON and GPON concepts including their standards and the bandwidth allocation schemes. Chapter 2 explains the concept of the triple play services and the used equipment in the development of the project. Chapter 3 explains the configuration of the possible scenarios and derives the relevant measures of the configurations, analysing the QoS obtained with a multimedia traffic in each network. It will include functional (simultaneous and separate services analysis) and performance (QoS) testing and chapter 4 provides the concluding remarks. To conclude, and being an important part of the project, Annex C develops an operating and configuration reference tool-like manual to show the functional and performance xPON behaviour.

CHAPTER 1. Passive Optical Network (PON)

Recent developments in telecommunications have produced increased capacity in backbone networks. While the capacity of backbone networks has kept pace with the tremendous growth of Internet traffic, there has been little progress in the access network, where a bottleneck occurs between the backbone network and the high-capacity local area networks [1]. The only effective solution to this bottleneck is a universal fibre-based infrastructure that is accessible to both businesses and residences.

A Passive Optical Network (PON) is a point-to-multipoint optical access network with no active elements in the signal path from source to destination. Here, all transmissions are performed between an optical line terminal (OLT) and optical network units (ONUs) mainly through an optical splitter / combiner. The OLT resides in the central office (CO) and connects the optical access network to the metropolitan area network (MAN) or wide-area network (WAN). On the other hand, each ONU is usually located at either the curb (FTTC) or the end-user location (FTTB) and fibre-to-the-home (FTTH), and deliver broadband voice, data, and video services to subscribers. Hence, PON saves costs, power supply, equipment distribution and more optimal and efficient utilization of the fibre optical infrastructure. In figure 1.1 a typical PON topology with the different elements' network is presented.

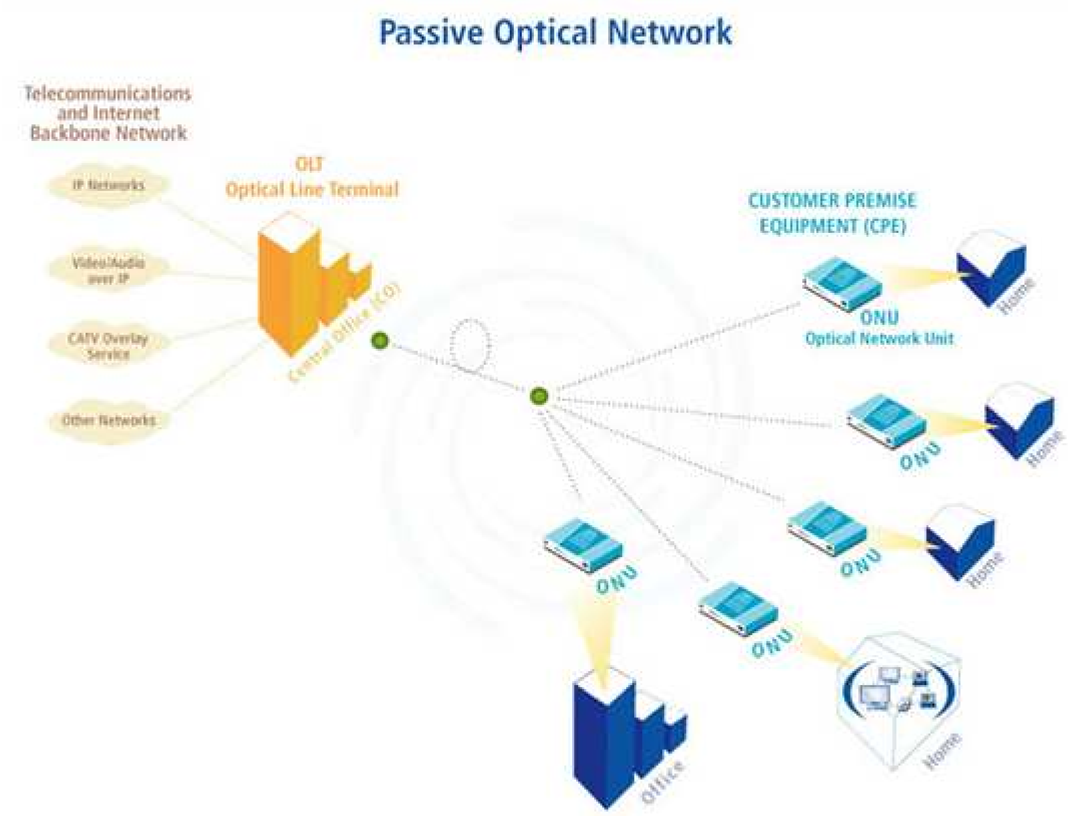


Figure 1.1 Passive Optical Network (Tree Topology)

Currently, there are two standardisation branches of PON according to the technology of layer 2 to be used: ITU-T and IEEE. The first standard incorporates PON-based ATM such as APON and BPON (G.983.x) and based on the Generic Framing Protocol (GFP) known as GPON (G.984.x). However, it is the standard of the IEEE 802.3ah which emerges as the most promising candidate for networks of broadband access for the next generation.

PON can be represented as a tree (as it can be seen in figure above 1.1) or star topologies, but it can also support topologies such as the bus, ring and redundant configurations. The key element for passive optical networks is the splitter, that in one direction a beam of light can split into several bundles (distributed to several optical fibres), and in the other direction the combination of light signals from various optical fibres to a single optical fibre output.

Another advantage of PON networks is the ability to provide a high bandwidth (of the order of 1Gbps) due to the use of fibre optic operating at a maximum distance of 20-25km. Because of its multi-point structure, it is possible to offer the service broadcast in a download direction while in the upload end-users need to share the channel.

1.1 Passive Optical Network Operation

In the downstream direction (from the OLT to the ONUs), a PON is a point-to-multipoint network and has the entire downstream bandwidth available to use all the time. In the upstream direction, a PON is a multipoint-to-point network where multiple ONUs must transmit all toward one OLT. If different data streams are transmitted at the same time from multiple ONUs, there could be the possibility of a collision of data information. Thus, in the upstream direction (from the ONUs to the OLT), a PON should employ some medium access control mechanism to avoid data collisions and fairly share the trunk fibre channel capacity and resources.

There are several general techniques for communicating to multiple subscribers sharing a single PON architecture such as Time Division Multiplexing (TDM), Wavelength Division Multiplexing (WDM), Subcarrier Multiplexing (SCM), and Code Division Multiplexing (CDM). Of these multiple techniques, TDM and WDM are the most promising candidates for practical systems. While a TDM appears to be a satisfactory solution for current bandwidth demand, the combination of future data-rate projections coupled with recent advances in WDM technology may result in WDM becoming the preferred solution for a future PON.

1.1.1 Time Division Multiplexed Passive Optical Network (TDM-PON)

Time Division Multiplexed Passive Optical Network (TDM-PON) in figure 1.2, is the most common commercial PON architecture. In the downstream direction the OLT broadcasts the traffic through an optical passive splitter to all ONU's in the access network and correspondingly, all broadcasted information is received at every ONU. The data streams for different ONU's can be virtually differentiated using ONU address labels that are embedded in the transmission. At the ONU, only the relevant data with correct address labels is processed and all other data is discarded.

The upstream ONU transmissions are coupled through the same optical passive splitter. Time Division Multiplexing (TDM) is employed in order to avoid the collisions between transmissions of different ONU's in the network. The TDM-based method for accessing the transmission medium is referred to as Time Division Multiple Access (TDMA) where a MAC protocol is required in order for TDMA to be supported. Variable length transmission time slots can be assigned for each ONU depending on the required Quality of Service (QoS) where this mechanism is commonly known as Dynamic Bandwidth Allocation (DBA) and this will be explained further in Annex B.5.

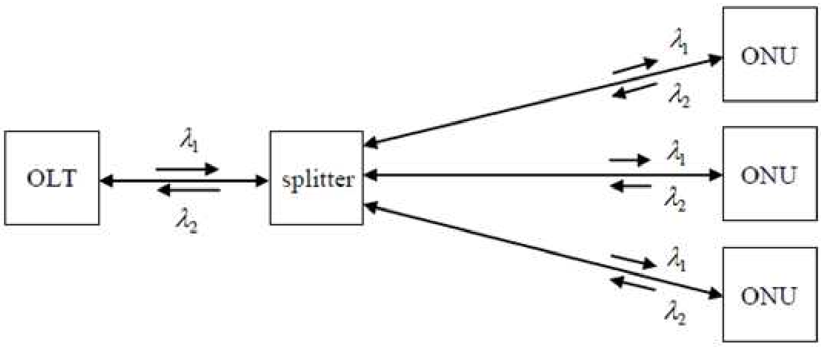


Figure 1.2 Example of a one-stage splitting TDM-PON architecture

Comparatively mature low-cost optical transmitters and receivers can be successfully used in both the OLT and the ONU. The ONU electronics must run with the aggregate bit rate of the system raising the complexity and the cost of the ONU. Due to the P2MP architecture, the cost of the TDM-PON OLT can be shared among the subscribers.

The two basic alternatives to organise P2MP connection using splitters are:

- The first alternative is a one-stage splitting architecture shown in figure 1.2
- The second possibility is to use cascaded splitters in the field as shown in figure 1.3

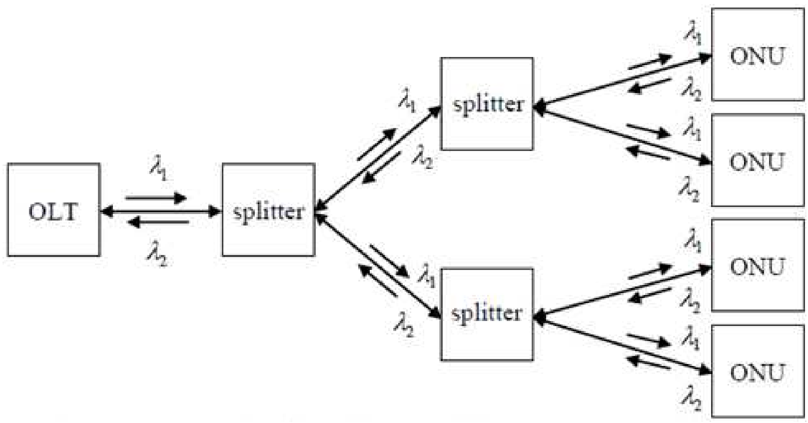


Figure 1.3 Example of a multistage splitting TDM-PON architecture

The splitting architecture used in practice strongly depends on the demographic locations of the subscribers. In the one-stage architecture, the splitter can be placed at the OLT location. This simplifies network maintenance and minimises splicing and connector losses but on the other hand increases fibre mileage. A high splitting ratio allows the reduction of fibre mileage in the field and shares the cost of the OLT among ONUs, but on the other hand it has an immediate impact on the transmission losses. Therefore, it is vital for a system with high splitting ratio to have low-loss optical components in order to cope with the losses. Furthermore, a high splitting ratio decreases the amount of available bandwidth per subscriber because all ONU's share the channel and it limits the maximum number of subscribers in the PON.

1.1.2 Wavelength Division Multiplexed Passive Optical Network (WDM-PON)

WDM-PON is used to describe a PON that employs Wavelength Division Multiplexing (WDM). A common feature of WDM-PONs (see figure 1.4) is that separated wavelengths are used for each ONU in the downstream direction (WDM-PON assigns a wavelength to each subscriber while TDM-PON assigns a time-slot). Therefore, WDM-PON can be regarded as an aggregation of point-to-point connections between each subscriber and the central office. In the upstream, traffic multiplexing can be achieved either by WDD or Time Division Duplex (TDD). Hence a variety of different WDM-PON architectures are possible.

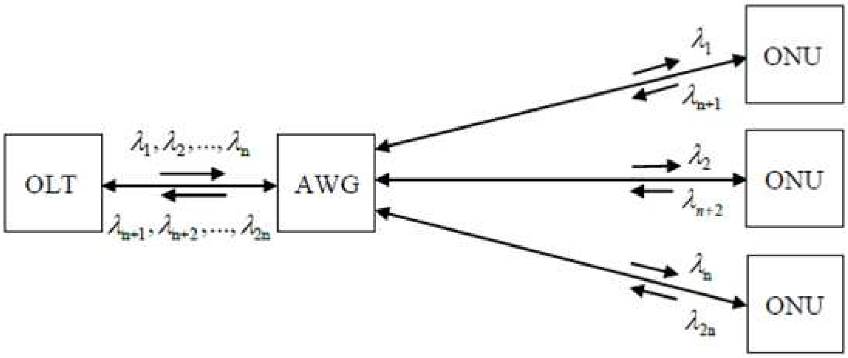


Figure 1.4 An example of WDM-PON architecture

The usage of a separate wavelength in the downstream provides information security since each ONU receives only the information that is intended. Different wavelengths can be assigned different bit rates according to the required QoS, and the ONU electronics can run at the data receive rate. The WDM-PON OLT is quite costly because it needs to have an array of transceivers to be able to operate on different wavelengths. The cost of the WDM-PON OLT can be shared among the subscribers just like the TDM-PON case. The WDM-PON ONU also needs to support operations on different wavelengths and hence requires a tuneable transceiver that is a relatively expensive component.

An Arrayed Wave Guide (AWG) router that is a wavelength routing passive optical device is usually used as a RN (Remote Node) (see figure 1.4). This router separates different wavelengths to the different ONUs in the downstream and removes the splitting loss problem that would arise if a basic optical splitter was used instead. In the upstream direction, AWG router simply passes through all transmitted wavelengths within the transmission band.

There are several standardised TDM-PON fibre access systems for FTTx but there are still no standards based on WDM-PONs. The success of TDM-PONs in standardisation is due to the fact that WDM-PONs are simply more expensive compared to TDM-PONs.

1.2 Gigabit Passive Optical Network (GPON)

The International Telecommunication Union specifies the GPON, the Telecommunication Standardisation sector (ITU-T) G.984 series 1-4. G.984.1 recommendation describes the GPON general characteristics; G.984.2 refers to the Physical Media Dependent (PMD) layer specification; G.984.3 describes the Transmission Convergence (GTC) layer specification and finally G.984.4 provides the Optical Network Termination (ONT); Management and Control Interface (OMCI) specification.

In 2001 the FSAN, formally referred to as the Full Service Access Network consortium, defined GPON with the aim and intention of PON networks to be standardised and operating at rates above 1Gbps. Therefore FSAN created the generation of G.GPON.GSR (Gigabit Service Requirements), G.GPON.GPM (Gigabit Physical Media) and G.GPON.GTC (Gigabit Transmission Convergence).

Due to the high efficiency for all services the frame transport for GPON was the GPON Encapsulated Method (GEM) which was selected in September 2002.

In comparison to APON and BPON, GPON is considered to have an improved capability and is backward compatible. ATM, TDM and even Ethernet traffic can be transported via the GPON Encapsulating Method.

Several line rates including upstream and down stream directions can be supported by GPON. Packet- based transport and legacy ATM may also be supported by GEM. The GEM encapsulating method is planned to support legacy efficiently and can be enhanced to support future technologies.

1.2.1 Architecture of GPON Networks

The recommendation ITU-T G.984.1 [2] describes a flexible optical fibre access network capable of supporting the bandwidth requirements of business and residential services and covers systems with nominal line rates of 1.2 Gbit/s in the upstream direction and 1.2 Gbit/s and 2.4 Gbit/s in the downstream direction. Both symmetrical and asymmetrical (upstream/downstream) gigabit-capable passive optical network (GPON) systems are described where this recommendation proposes the general characteristics for GPON based on operators' service requirements.

The optical access network is common to all architectures. The optical section of a local access network system can be either active or passive and its architecture can be either point-to-point or point-to-multipoint. Figure 1.5 shows the architectures considered, which range from fibre to the home (FTTH), through fibre to the building/curb (FTTB/C) to fibre to the cabinet (FTTCab) where the differences of the FTTB, FTTC, FTTCab and FTTH network options are mainly due the different services supported.

The same figure also represents the main elements and interfaces (Service Node Interface and User Network Interface, SNI and UNI respectively) that define the general network architecture.

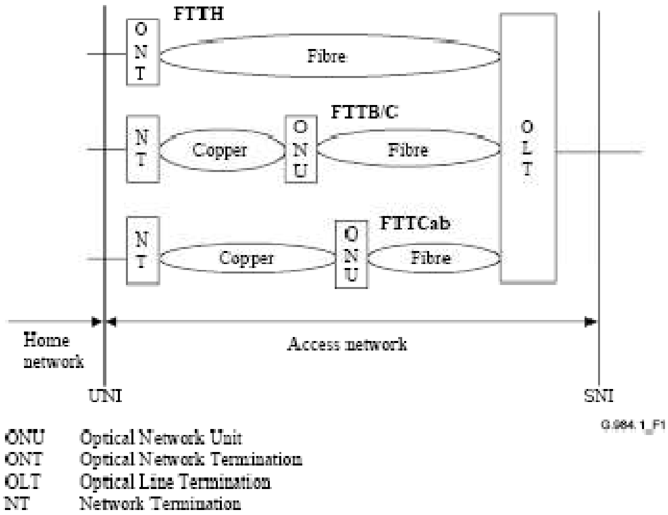


Figure 1.5 G.984.1 Network Architecture

Basically, GPON aims at transmission speeds greater than or equal to 1.2 Gbit/s. The most important bit rate is 1.2 Gbit/s upstream, 2.4 Gbit/s downstream, constituting nearly all of the deployed and planned deployment of the GPON systems but the target standardised system will have nominal line rates (downstream/upstream) of:

- 1244.16 Mbit/s / 155.52 Mbit/s
- 1244.16 Mbit/s / 622.08 Mbit/s
- 1244.16 Mbit/s / 1244.16 Mbit/s
- 2488.32 Mbit/s / 155.52 Mbit/s
- 2488.32 Mbit/s / 622.08 Mbit/s
- 2488.32 Mbit/s / 1244.16 Mbit/s
- 2488.32 Mbit/s / 2488.32 Mbit/s

GPON supports up to 60km, including 20km differential reach among ONUs. The split ratio supported by the standard is 64 but anticipating the continued evolution of optical modules, split ratios must be considered up to 1:128. Taking into account the split ratio, the larger the split ratio is for GPON, the more attractive it is for operators. However, as previously mentioned, a larger split ratio implies greater optical splitting which creates the need for an increased power budget to support the physical reach.

The following figure 1.6 summarises the main aspects of the GPON Access System as the maximum physical reach, the wavelength range etc:

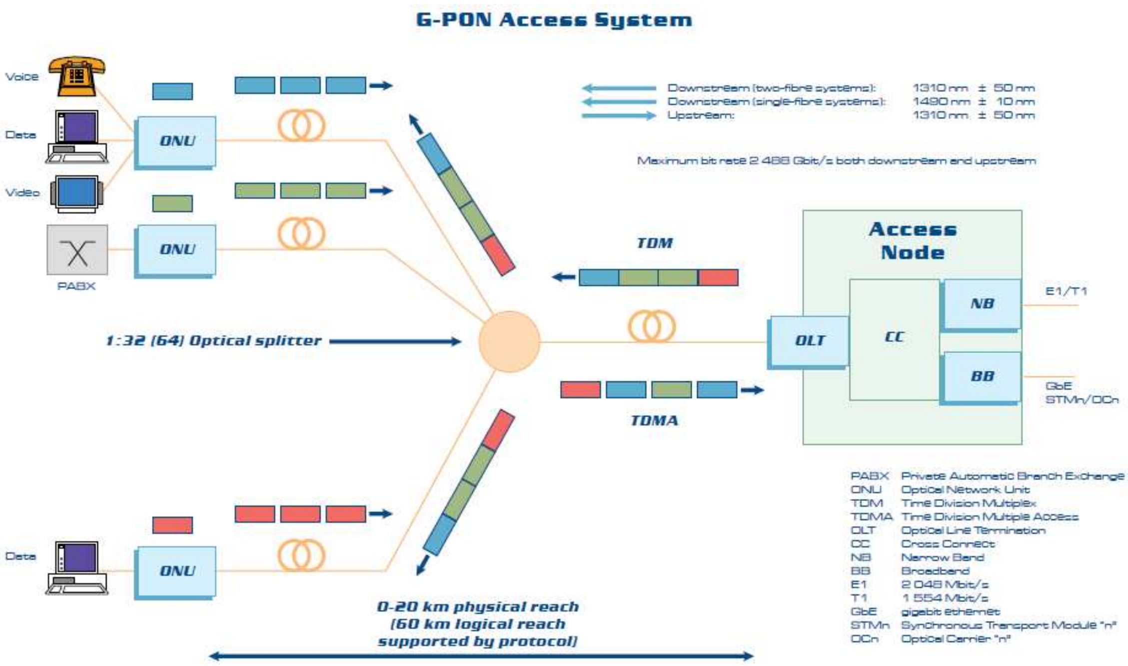


Figure 1.6 GPON physical and access network architecture

Summarising, GPON supports ATM, packet-based fragmentation and has the capability to transport Ethernet frames. As GPON has the capacity of packet fragmentation, it has an efficient utilization of transport media providing also an adequate bandwidth (and QoS) for the residential customers and business as well as several line rates for both the upstream and downstream direction. Further information of GPON technology can be found in Annex A.

1.3 Ethernet Passive Optical Network (EPON)

Ethernet PON (EPON) is a PON-based network that carries data traffic encapsulated in Ethernet frames defined in the IEEE 802.3 standard [3]. The standardisation process started when a new study group called Ethernet in the First Mile (EFM) was created in November 2000, having as its main objectives the study of Ethernet over point-to-multipoint fibre along with Ethernet over copper and Ethernet over point-to-point fibre. IEEE 802.3ah standard was first standardised in 2004 by EFM Task Force.

The purpose of the IEEE Std. 802.3ah was to expand the application of Ethernet to include subscriber access networks in order to provide a significant increase in performance while minimising equipment, operation, and maintenance costs. Any network topology defined in IEEE 802.3 standard can be used within the subscriber premises and then connected to an Ethernet subscriber access network where EFM technologies allow different types of topologies in order to obtain maximum flexibility.

IEEE 802.3ah standard includes the specifications related to the Ethernet for subscriber access networks, also referred to EFM that combines a minimal set of extensions to the IEEE 802.3 Media Access Control (MAC) and MAC Control sub-layers with a family of physical layers. EFM also introduces the concept of Ethernet Passive Optical Networks (EPONs), in which the point to multipoint network topology is implemented with passive optical splitters to support this topology. In addition, a mechanism for network Operations, Administration and Maintenance (OAM) is included to facilitate network operation and troubleshooting.

The relationships between these EFM elements and the ISO/IEC Open System Interconnection (OSI) reference model are shown in figure 1.7.

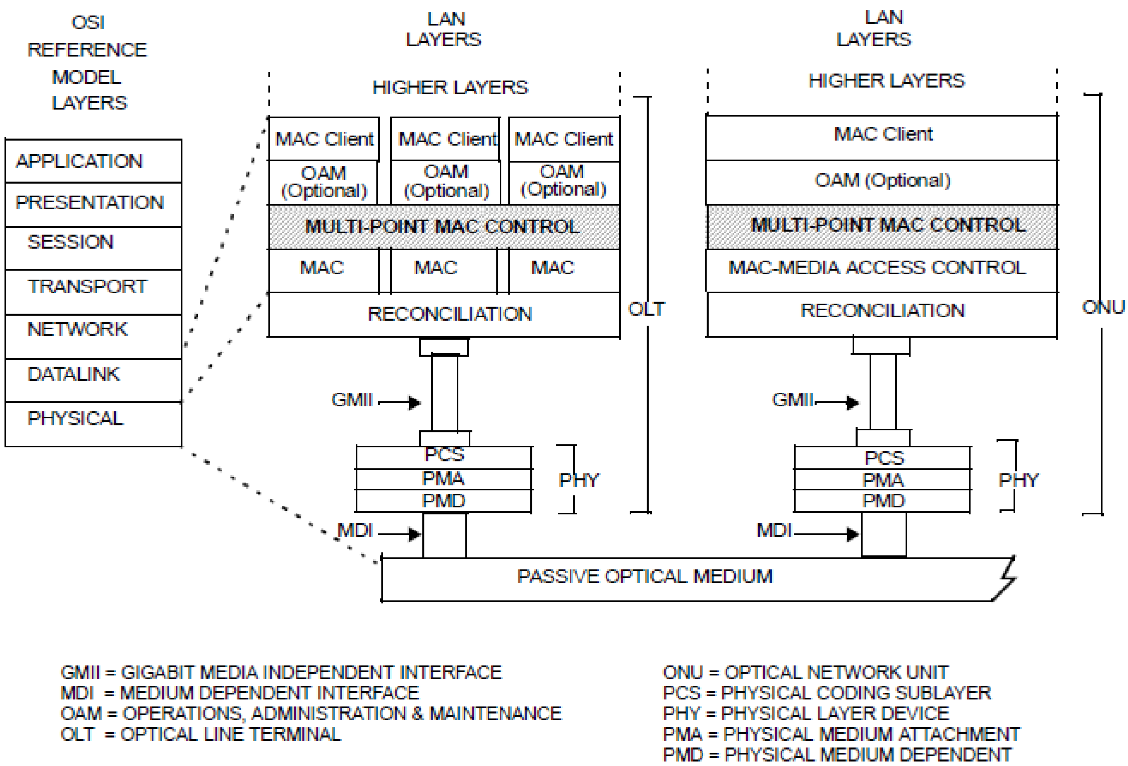


Figure 1.7 Relationship between IEEE 802.3ah and the OSI protocol stack

An important characteristic of EFM is that only full duplex links are supported, so a simplified full duplex MAC was defined. For P2MP optical fibre topologies, EFM supports a nominal bit rate of 1000 Mb/s, shared amongst the population of ONUs attached to the P2MP topology. EPON has a connectivity of a broadcast medium in the downstream direction, and it behaves as a point-to-point medium in the upstream direction. As the upstream is shared among the users it requires a Media Access Control (MAC) to avoid collisions between them.

1.3.1 EPON downstream transmission

Ethernet packets are transmitted by the OLT and passes through a 1 × N passive splitter or cascade of splitters to reach each ONU in the downstream direction. The behaviour of EPON can be considered similar to a shared medium network. Ethernet is a broadcaster by nature, and in the downstream direction (from network to user) it's an effective standard with the Ethernet PON architecture: packets are broadcasted by the OLT and selectively extracted to their ONU destination.

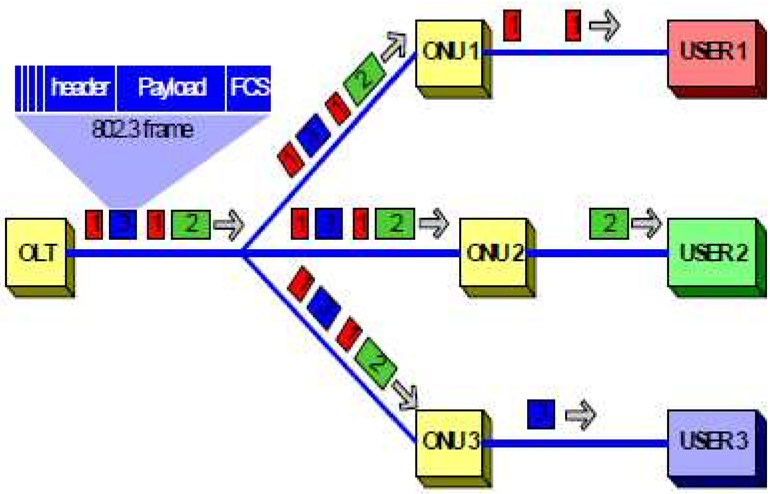


Figure 1.8 Downstream EPON operation

1.3.2 EPON upstream transmission

Data packets from one ONU will only reach the OLT, but not the remainder of ONU's due to the optical combiner when considering the upstream direction (from ONU to OLT). The behavior of EPON can be considered similar to point-to-point architecture. However, unlike a true point-to-point network, in EPON, all ONU's belong to a single collision domain, and therefore data packets from different ONU's transmitted simultaneously still may collide. Taking this information into account, in the upstream direction, EPON needs to employ some arbitration mechanism to avoid data collisions and fairly share the channel capacity among ONU's.

For this subject EPON uses a TDMA scheme, where ONU's are assigned exclusive access to the media for limited time intervals, commonly known as a transmission window or timeslot.

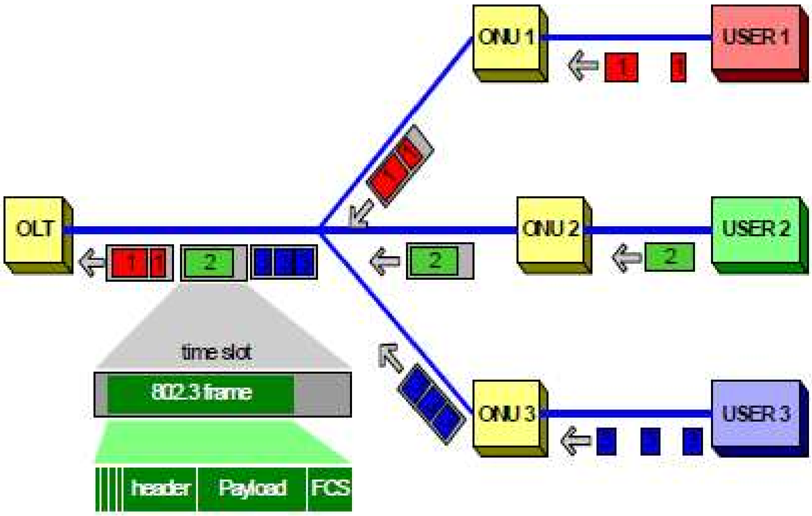


Figure 1.9 Upstream EPON operation

The performance of an EPON does depend on a particular capacity allocation scheme. The possible timeslot allocation schemes range from static allocation (fixed TDMA) to dynamic adjustment of the slot size, based on instantaneous queue loads in every ONU (statistical multiplexing scheme). Selecting the best allocation scheme however, does not have to be a trivial task. Further information of EPON technology can be found in Annex B.

CHAPTER 2. TRIPLE PLAY SERVICES AND TRIDENT 7 PLATFORM

One of the aims for this project is to build a converged network for IP, VoIP to POTS and IPTV (triple play services). Therefore, in this chapter it will be briefly described what triple play services consist of and the different hardware and software used in the design of the network, in order to evaluate different parameters in EPON and GPON technology.

2.1 Triple Play Services

A triple-play network is one in which voice, video and data are all provided in a single access subscription as shown in figure 2.1.

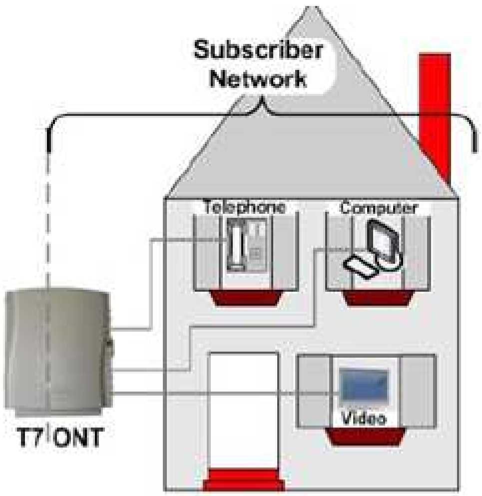


Figure 2.1 Subscriber Network Overview

In terms of types of traffic, different general circumstances may occur with triple-play services. Different types of isolated or combined traffic can be created and the performance could be considered in terms of latency, data loss and throughput. In order to ensure that the traffic flows provide the proper quality of service and to implement police functions, the availability of prioritization of streams in a triple play environment must be measured. Several quality-of-service parameters must be applied to quantify throughput and response times for different traffic combinations. Internet traffic is given the lowest priority, since data services are not drastically affected by packet delays. Video traffic has the next highest priority, since the minimum loss of video packets does not negatively affect the perceived appearance, as long as the streaming audio track is not broken. Finally, voice over IP will have the highest priority, since voice services are very sensitive to latency and loss of packets.

2.1.1 Data

As previously stated, triple play services require a technologically enabled network capable of transporting all three basic communication flows (voice, video and data). Data traffic is basic for everyone being the most commonly used traffic for the general subscribers.

To provide and test the data traffic in this project, the Multi-Generator (MGEN) tool has been used to simulate this type of traffic. MGEN is an open source software which provides the ability to perform IP network performance tests and measurements using UDP and TCP IP traffic. The toolset generates real-time traffic patterns so that the network can be loaded in a variety of ways. The MGEN program can generate, receive, and log test traffic and can be used to calculate performance statistics on throughput, packet loss rates, and more. Script files are used to drive the generated loading patterns over the course of time. These script files can be used to emulate the traffic patterns of unicast and/or multicast UDP and TCP IP applications.

The following line is an example of one script used in this project.

For example, to generate an UDP periodic flow starting at instant 0.0 at an average rate of ~40Mb/s, using the source port 5000, to the destination IP 10.0.0.5 and destination port 5001, the command is the following:

0.0 ON 1 UDP SRC 5000 DST 10.0.0.5/5001 PERIODIC [4750 1024]

2.1.2 IPTV

IPTV is made up of a flexible combination of two major elements, including the IP suite of protocols and digital television:

1. The IP suite of protocols is responsible for packaging TV signals that will be routed from the head-end to the customer's site. The IP protocol also provides interactivity features between subscribers, network, service and content providers.

2. Digital television is responsible for the audio, video, data compression and transmission formats according to standards, such as MPEG, that manage image resolution and programme arrangements. It is important to clarify that currently the public Internet cannot support real-time television services for several reasons. Firstly, the Internet is a best effort network that cannot permanently guarantee the delivery of television with an appropriate quality of service. Second, there is not enough bandwidth for standard or high definition TV. Third, there are some protocols and multicasting methodologies that are not supported.

The underlying network for IPTV distribution must be a converged network, IP centric, QoS-enabled, and based on the multicast distribution and delivery of the television signals. This requirement today can only be fulfilled by privately managed IP networks.

This project will use just the IPTV service to check its higher priority than data traffic. As IPTV has a highest priority than data traffic, it will be useful to test the queue priorities in different ONUs and check their availability and use.

The VLC media player [4] used to stream video will be considered. A free portable multimedia player, encoder, and a streamer supporting many audio and video codecs using various streaming protocols will also be considered. These devices are able to stream over networks and to transcode multimedia files and save them into various formats.

2.1.3 VoIP

Voice over Internet Protocol is one of a family of internet technologies, communication protocol, and transmission technologies for delivery of voice communications and multimedia sessions over IP networks.

Internet telephony refers to communications services, voice, fax, SMS, and/or voice-messaging applications that are transported via internet rather than the public switched telephone network (PSTN). The steps involved in originating a VoIP telephone call are signaling and media channel setup, digitization of the analog voice signal, encoding, packetization, and transmission as IP packets over a packet-switched network. On the receiving side, similar steps (usually in the reverse order) such as reception of the IP packets, decoding of the packets and digital-to-analog conversion reproduce the original voice stream.

IP telephony products for carriers are designed to provide voice services to the general public and businesses. There are two important requirements that any carrier-class solution for IP telephony must address:

1. Interworking: IP telephony has its own signalling protocols based on SIP or other standards.

2. QoS: the performance provided to subscribers must be at least as good as the performance given by traditional telephony. This involves careful planning and dimensioning, deployment of QoS mechanisms in the transport network or even segregation of the packet-switched voice network and the data network if necessary.

A solution to the first point mentioned above in this project has been the configuration of the Asterix Open Source [5] as a server to provide a signalling protocol based on SIP and DCHP for the whole network. Asterix is free software that transforms a computer into a communication server and allows applications to build and develop like PBX, VoIP gateway, DHCP etc. Further information can be reviewed in Annex D.

Next Section 2.2, TRIDENT7 fullfils all the requirements to solve the QoS for the subscribers.

2.2 Trident7 Platform

The hardware used in this project comes from Enablence Tecnologies. One issue that many operators face when implementing an all-optical network is selecting which technology standard to use for delivering FTTP services: Gigabit Passive Optical Network (GPON), Gigabit Ethernet Passive Optical Network (GEPON), or Active Ethernet Optical Network. TRIDENT7 COLT allows service providers to run their network on one or any combination of these three FTTP standards.

The Enablence TRIDENT7TM Compact OLT (T7 COLT) (see figure 2.2) affords network operators the most options by supporting both GE-PON, and GPON Port Interface Modules (PIMs) from a compact platform. The T7 COLT allows services to smaller pockets of up to 512 ONUs using 1 x 64 splits and it is managed via a comprehensive, easy-to-use management system. The T7 COLT works with a variety of Optical Network Terminals (ONUs) supporting high-speed data, IPTV and Industry standard VoIP capabilities as well as multi-layer QoS for SLA assurance.

Figure 2.2 Enablence TRIDENT7TM (T7 COLT)

On the other hand, and for the subscriber network, in this project will be available following ONUs for both EPON and GPON technology:

- ONU 221 (EPON) which includes:
    - 2 ports of Data traffic
    - 2 ports of Voice traffic
    - 1 port of RFR-Return

Figure 2.3 ONU 221 (EPON)

- ONU 1800 (EPON) which includes:
  - 9 ports of Data traffic

Figure 2.4 ONU 1800 (EPON)

- ONU 1320 (EPON) which includes:
  - 4 ports of Data traffic
  - 2 ports of Voice traffic

Figure 2.5 ONU 1320 (EPON)

- ONU 420 (GPON) which includes:
  - 4 ports of Data traffic
  - 2 ports of Voice traffic

Figure 2.6 ONU 420 (GPON)

2.2.1 Unified Element Management System

The TRIDENT7™ Compact Optical Line Terminal (COLT), and all ONUs, are managed via the TRIDENT7 Element Management Suite (T7 EMS). The T7 EMS is a full-featured element management platform, including a web-based customer care application for viewing subscriber service settings. IEEE 802.3 EFM (GE-PON and Point-to-Point) and ITU G.984 GPON elements are supported by the T7 EMS.

In addition to CLI and SNMP provisioning capabilities, the T7 EMS provides a user-friendly and individually customizable Graphical User Interface (GUI) for point-and-click provisioning of voice, video, and data services in real time. (See Annex C to check how to configure EMS).

The T7 EMS allows the user to customize client views, as well as set system preferences, including:

• Automatic software upgrade on discovery
• Configuring an external interface for northbound provisioning requests
• Configuring an FTP Server for software upgrades
• Automatic move of pending ONUs to a provisioned state, thereby allowing the ONUs to be automatically upgraded and configured without manual intervention

Furthermore, there are different key features for the EMS where they are summarized as follows:

- FLEXIBLE PROVISIONING

The T7 EMS enables fully automated device configuration and service provisioning. When the system is set up for automated provisioning, service packages are sent via a northbound interface to the T7 EMS where the packages are translated into the appropriate VLAN, QoS, and service settings on the ONT and OLT

- FAULT MANAGEMENT AND SECURITY

The T7 EMS features advanced fault management, including alarm notification, event history browsing, and user configurable reports. There are user permissions for management functions may be customized for individual users and user groups

- TROUBLESHOOTING

Real-time device status icons and an event history log clearly indicate when devices or modules have associated alarms. The alarms are acknowledged and cleared through the alarm panel, and the user may set up notifications for specified alarm conditions.

- SCALABILITY

The T7 EMS is a highly modular platform that allows a single server to support many T7 devices. A portion of the management platform resides on the management module of the OLT while the SQL database can be run on a separate server. Because of this distribution model, the T7 EMS platform running on a high-end Windows server can support as many as fifty (50) fully populated OLTs and their associated ONUs.

CHAPTER 3. SCENARIO FTTH

3.1 General Scenario Configuration

The main objective of the study presented in this chapter is to compare the availability of the bandwidth of EPON and GPON and the impact of priority queuing on the overall performance of the network. This study lays the foundations for a fair comparison of these technologies under common scenarios as well as to derive relevant metrics for obtaining quantitative performance comparison results. Several scenarios have been carried out under a varied set of parameters to cover many operational conditions. Figure 3.1 displays the scenario used in order to provide the test proposals using FTTH devices located in the laboratory 334/335 of EETAC. In section 3.2, the different tests in these several scenarios with the performance evaluations can be seen.

The scenario is composed of 2 OLT's (EPON and GPON) being each one remotely configurable to control the services and clients in the network. Through an optical passive splitter, different ONUs are connected and can be monitored, supervised and modified as desired. In EPON three different ONUS have been used: ONU 1800, 221 and 1320, and in GPON, only ONU 420 has been used in all the scenarios. Both OLT's are connected to one switch (SMC8126L2) in order to route traffic out of the laboratory. The main characteristics of this configuration are as follows:

- VLAN 2270 provides the header's management of both EPON and GPON technology
- VLAN 2271 routes the traffic to a Dell ESXi Server providing SIP and DHCP protocols
- VLAN 2273 routes traffic to Campus Nord
- VLAN 2268 routes traffic to Orange

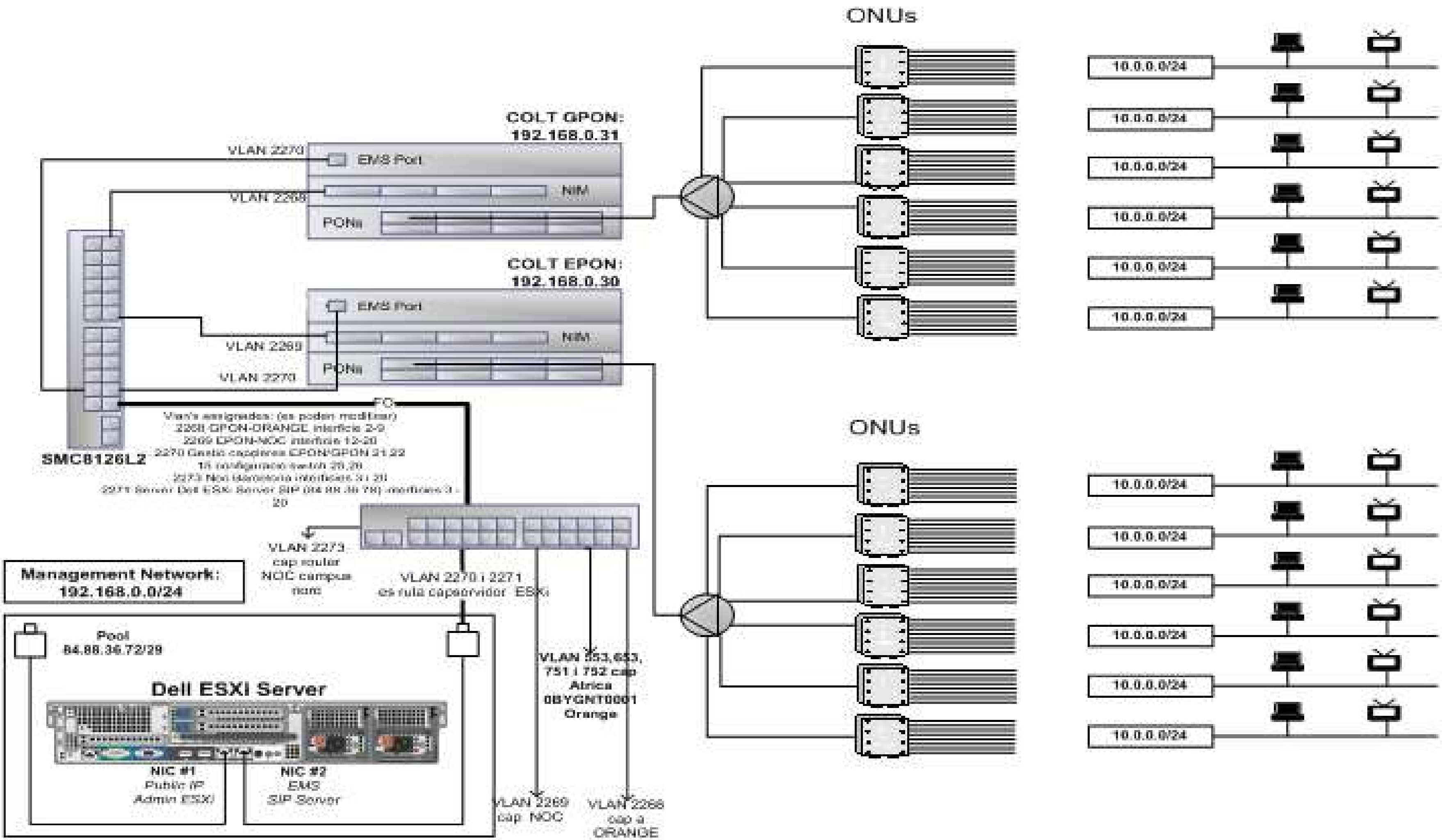


Figure 3.1 General Scenario using FTTH

3.2 Performance Evaluation

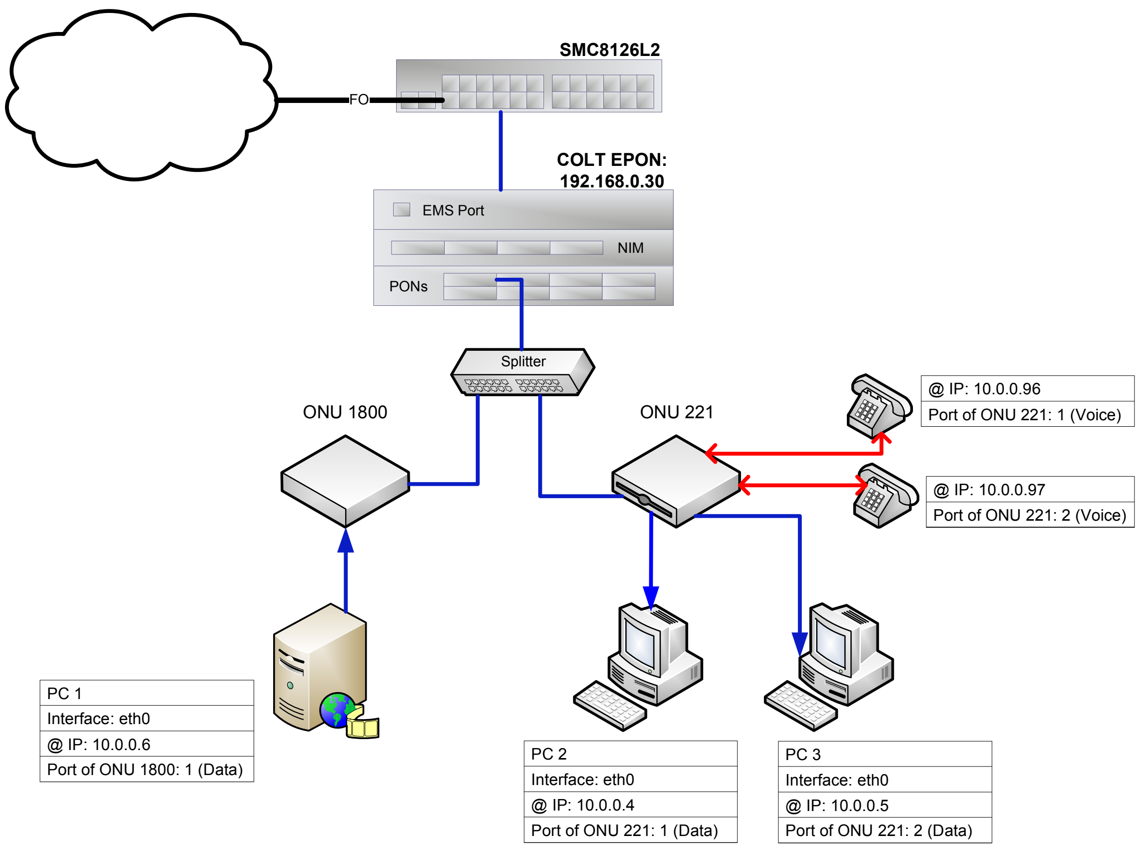
3.2.1 One ONU with same traffic overflow (same priorities)

3.2.1.1. The behaviour of ONU 221 with traffic overflow (same priorities) within EPON

Goal: Test and check the ONUs behaviour in conditions of traffic congestion (2 ports of ONU 221 saturated with data traffic) with the same port priority in each one (priority equal to 1)

Software used: mgen, VLC, Wireshark

Scenario:



Configuration of the different parameters:

Video Streaming PC 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1800 ; 1	EFM	Data	1	Tagged	2273	**200 Mbps**	600 Kbps

PC 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
221 ; 1	EFM	Data	1	Tagged	2273	1 Mbps	**25 Mbps**

PC 3:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
221 ; 2	EFM	Data	1	Tagged	2273	1 Mbps	**50 Mbps**

Telephone 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 1	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	106	

Telephone 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 2	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	103	

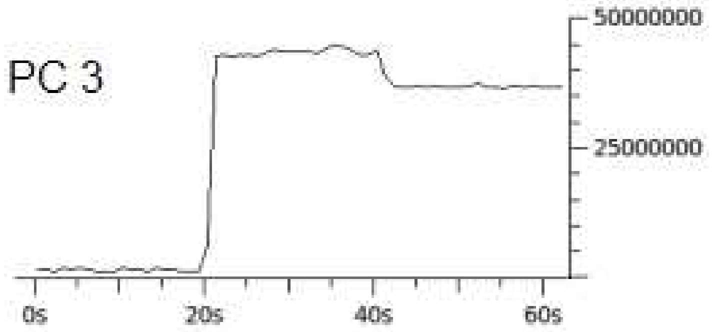
This scenario provides a connection between ONU 1800 and ONU 221 within an EPON configured with a VLAN 2273 for data traffic. There is also a connection of VoIP through a VLAN 2271 that connects the equipment to the Elastix Server. It provides the registration and VoIP service for the telephones.

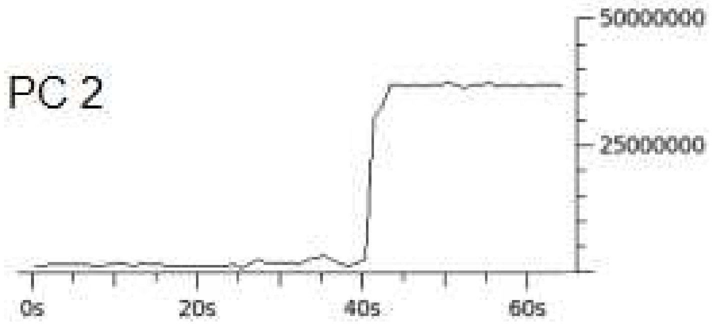
During this test a video will be transmitted from PC1 to PC 2 and 3 at the same time and data traffic will be introduced (provided by mgen) to overflow ONUs port's capacity. Furthermore calls from both telephones will be tested. The idea is to see what happens with all this traffic at the same time. As it can be seen in the *configuration of the parameters*, the difference about PC 2and 3, is that PC 2 is limited at 25 Mbps and PC 3 at 50 Mbps in a bandwidth downstream direction. The next procedure indicates the following steps for this test:

- PC 1 Video Server streams a file to PC 2 and 3 at the same time (at approximately 2 Mbps of the video bandwidth) for the first 20 seconds
- PC 1 sends traffic of 40 Mbps to PC 3 for the next 20 seconds

- PC 1 sends traffic of 40 Mbps to PC 2 for the next 20 seconds
- The whole transmitted traffic in this test is approximately 1 minute

Results:





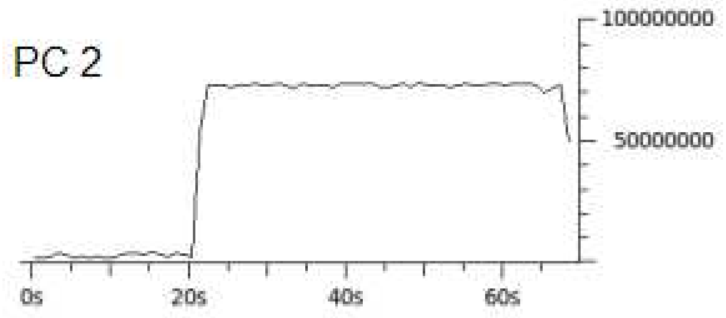
Conclusions:

Once the video is streaming without any other data traffic, the video can be correctly observed for both PC 2 and 3. At second 20, PC 3 receives an extra 40 Mbps of data received from the Server (PC 1). As PC 3 is limited at 50 Mbps, the video can be watched without any problem because total downstream traffic is around 42 Mbps.

At second 40, 40 Mbps to PC 2 is provided taking into consideration that the full capacity is limited to 25Mbps. The video in PC 2 does not work properly at this point because the packets that overflow the 25 Mbps downstream bandwidth should be discarded in the ONU. When 40 Mbps are provided, ONU 221 discards packets that overflow at 37 Mbps instead of 25 Mbps (this was not possible regarding PC 2 was limited at 25Mbps).

Moreover, a reduction of traffic in PC 3 from 42Mbps to 37-38Mbps can be seen. If we add the traffic of each ONU when the procedure is processed, the total traffic received to both ports of the ONU is 75 Mbps which is the addition of the bandwidth limit for each ONU (50+25). As both of them have 37 Mbps, it can be concluded that this ONU shares the whole bandwidth among the ports as needed and does not take into account the limitation of certain ports.

The next figure shows another test to prove the previous conclusions. 73 Mbps will be provided to PC 2 (that is limited at 25 Mbps) plus the traffic of the video to PC 2 and 3.



The total traffic in PC 2 is almost 75 Mbps and this test corroborates the last conclusion (ONU share the bandwidth within all active ports).

It has been considered that this ONU works differently when both data ports are active or could have internal problems.

On the other hand, the phone was been used whilst this test was being conducted. Phone calls are allowed and work correctly in all cases explained previously. Therefore there is no problem for the telephony when ONUs are congested with traffic.

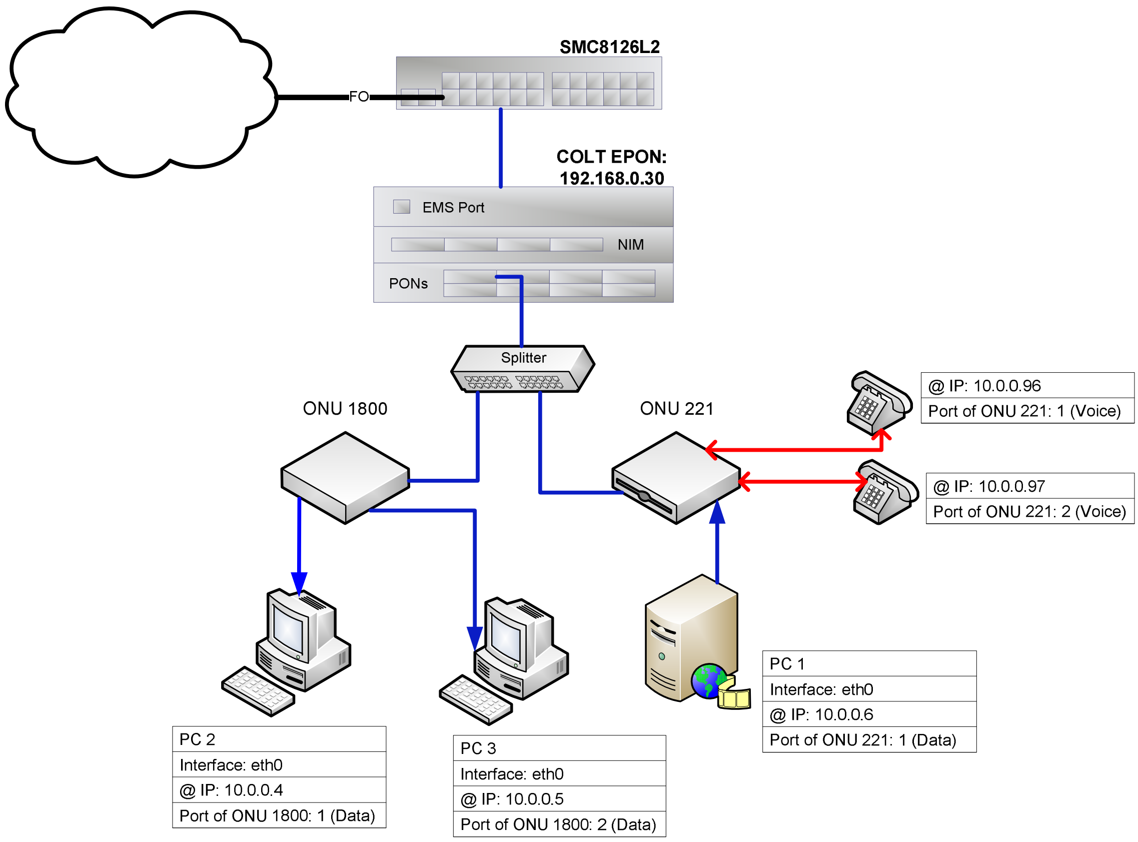
To remark the final conclusion; if a port from the ONU 221 is saturated with traffic, this situation provides a shared bandwidth for the rest of the data ports in the same ONU and therefore it can not be considered a viable ONU. The same test with ONU 1320 instead 221 will be carried out in 3.2.1.3 in order to analyse the behaviour of the ONU.

3.2.1.2. The behaviour of ONU 1800 with traffic overflow (same priorities) within EPON

Goal: Test and check the ONUs behaviour in conditions of traffic congestion (2 ports of ONU 1800 saturated with data traffic) with the same port priority in each one (priority equal to 1)

Software used: mgen, VLC, Wireshark

Scenario:



Configuration of the different parameters:

Video Streaming PC 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
221 ; 1	EFM	Data	1	Tagged	2273	**200 Mbps**	600 Kbps

PC 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1800 ; 1	EFM	Data	1	Tagged	2273	1 Mbps	**25 Mbps**

PC 3:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1800 ; 2	EFM	Data	1	Tagged	2273	1 Mbps	**50 Mbps**

Telephone 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 1	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	106	

Telephone 2:

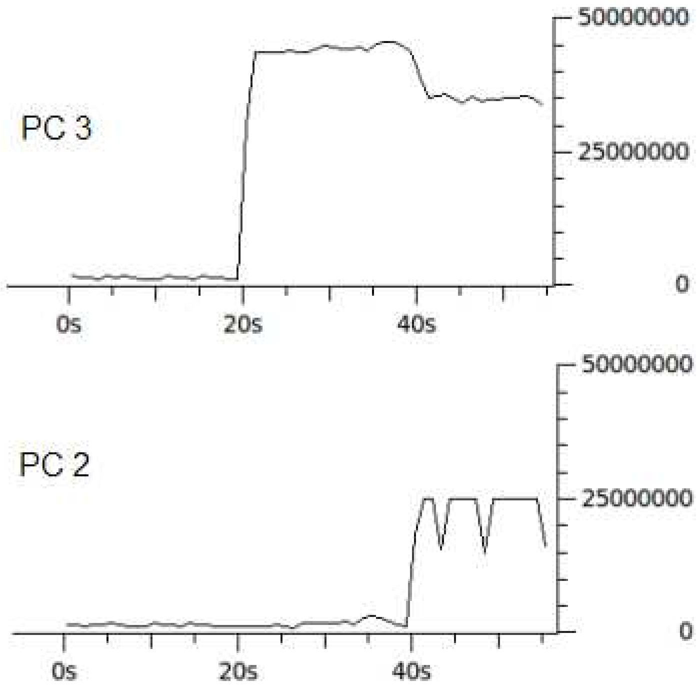
ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 2	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	103	

This scenario provides a connection between ONU 1800 and ONU 221 within an EPON configured with a VLAN 2273 for data traffic. There is also a connection of VoIP through a VLAN 2271 that connects the equipment to the Elastix Server. It provides the registration and VoIP service for the telephones.

During this test a video will be transmitted from PC1 to PC 2 and 3 at the same time and data traffic will be introduced (provided by mgen) to overflow ONUs port's capacity. Furthermore calls from both telephones will be tested. The idea is to see what happens with all this traffic at the same time. As it can be seen in the *configuration of the parameters*, the difference about PC 2and 3, is that PC 2 is limited at 25 Mbps and PC 3 at 50 Mbps in a bandwidth downstream direction. The next procedure indicates the following steps for this test:

- PC 1 Video Server streams a file to PC 2 and 3 at the same time (at approximately 2 Mbps of the video Bandwidth) for the first 20 seconds
- PC 1 sends traffic of 40 Mbps to PC 3 for the next 20 seconds
- PC 1 sends traffic of 40 Mbps to PC 2 for the next 20 seconds
- The whole transmitted traffic in this test is approximately 1 minute

Results:



Conclusions:

Once the video is streaming without any other data traffic, the video can be correctly observed for both PC 2 and 3. At second 20, PC 3 receives an extra 40 Mbps of data received from the Server (PC 1). As PC 3 is limited at 50 Mbps, the video can be watched without any problem because total downstream traffic is around 42 Mbps.

At second 40, 40 Mbps to PC 2 is provided taking into consideration that the full capacity is limited to 25Mbps. The video in PC 2 does not work properly at this point because the packets that overflow the 25 Mbps downstream bandwidth are discarded in the ONU.

Moreover a reduction of traffic in PC 3 from 42Mbps to 33-34Mbps can be seen. PC 2 has the capacity of 25 Mbps, when more than 25 Mbps of traffic is used in PC 2 the remainder of traffic (17 Mbps in this case) restricts the capacity of PC 3. As the PC 3 port is limited to 50Mbps the final Bandwidth available is approximately 33Mb (50-17) as seen in results above.

On the other hand, the phone was been used whilst this test was being conducted. Phone calls are allowed and work correctly in all cases explained previously. Therefore there is no problem for the telephony when ONUs are congested with traffic.

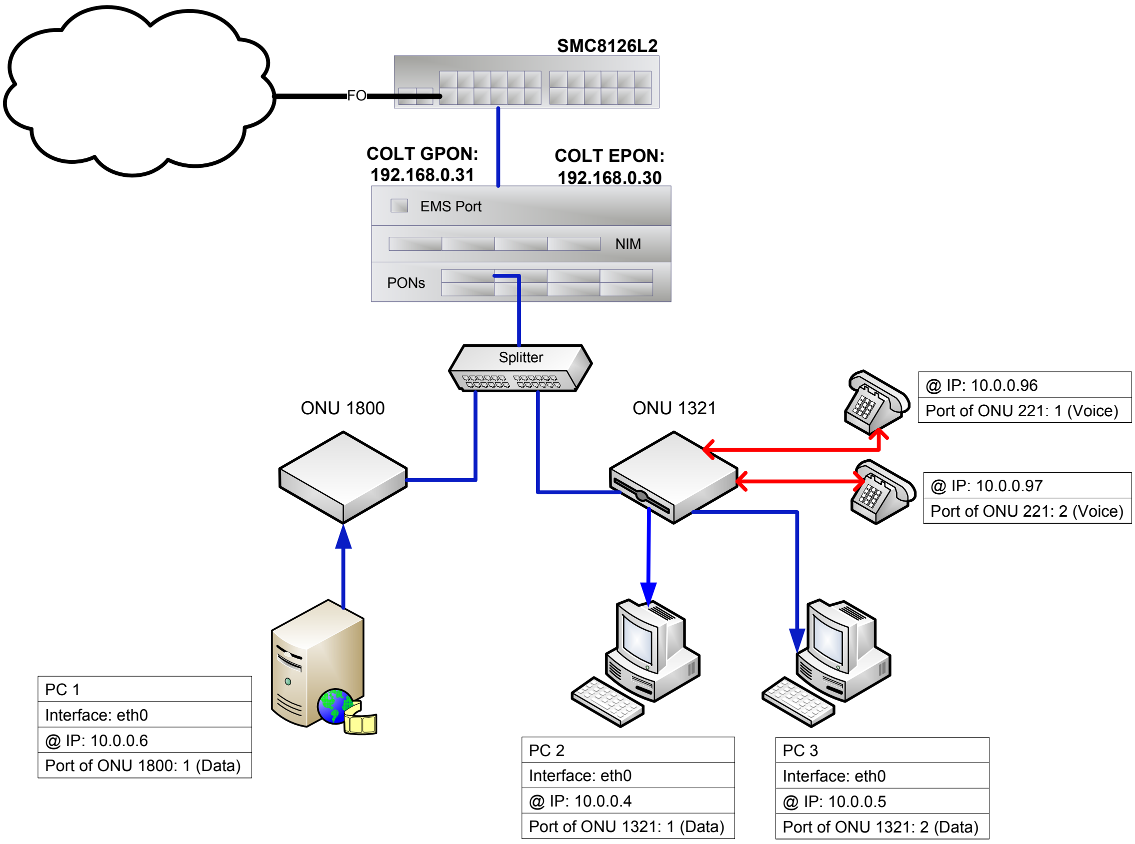
To remark the final conclusion; if a port from the ONU 1800 is saturated with traffic, this situation affects the bandwidth of the rest of the data ports in the same ONU.

3.2.1.3. The behaviour of 1 ONU with traffic overflow (same priorities) within EPON & GPON

Goal: In EPON, test and check the ONUs behaviour in conditions of traffic congestion (2 ports of ONU 1320 saturated with data traffic) with the same port priority in each one (priority equal to 1). The objective of this test is to repeat test number 3.2.1.1 with a different ONU. In this test ONU 1320 is used instead of ONU 221 and the rest of parameters previously used remain the same. Also the same test will be processed for GPON with the same configurations in EPON but with its corresponding ONU (420).

Software used: mgen, VLC, Wireshark

Scenario:



Configuration of the different parameters:

Video Streaming PC 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1800 ; 1	EFM	Data	1	Tagged	2273	**200 Mbps**	600 Kbps

PC 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1320 ; 1	EFM	Data	1	Tagged	2273	1 Mbps	**25 Mbps**

PC 3:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1320 ; 2	EFM	Data	1	Tagged	2273	1 Mbps	**50 Mbps**

Telephone 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 1	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	106	

Telephone 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 2	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	103	

GPON will use the same scenario but using ONUs 420 instead of the different ONUs previously used in EPON.

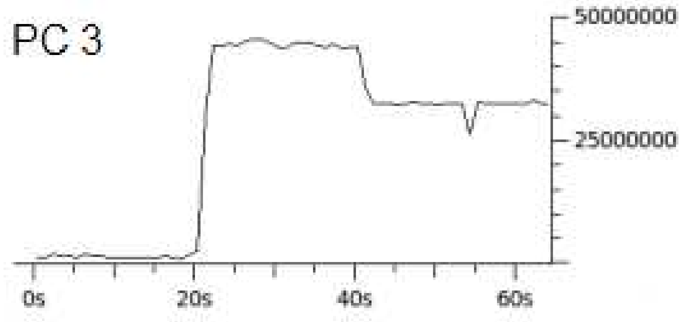
This scenario provides a connection between ONU 1800 and ONU 1320 within an EPON configured with a VLAN 2273 for data traffic. There is also a connection of VoIP through a VLAN 2271 that connects the equipment to the Elastix Server. It provides the registration and VoIP service for the telephones.

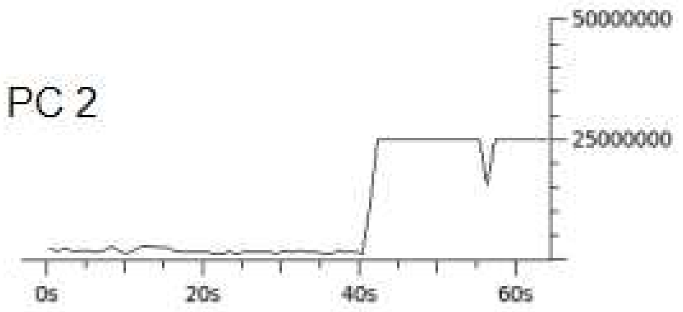
For GPON the scenario provides exactly the same connections, configurations and services but using ONU 420 instead of all other ONUs.

During this test a video will be transmitted from PC1 to PC 2 and 3 at the same time and data traffic will be introduced (provided by mgen) to overflow ONUs port's capacity. Furthermore calls from both telephones will be tested. The idea is to see what happens with all this traffic at the same time. As it can be seen in the *configuration of the parameters*, the difference about PC 2and 3, is that PC 2 is limited at 25Mbps and PC 3 at 50Mbps in a bandwidth downstream direction. The next procedure indicates the following steps for this test:

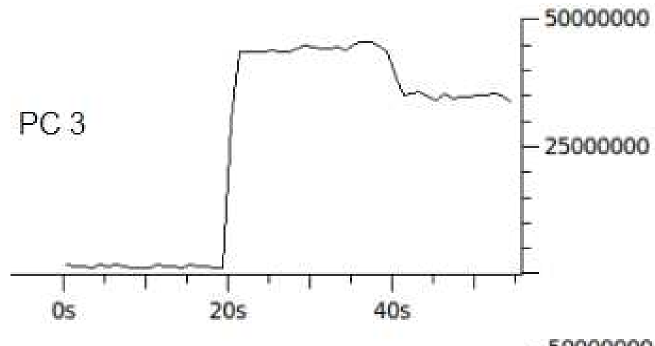
- PC 1 Video Server streams a file to PC 2 and 3 at the same time (at approximately 2 Mbps of the video Bandwidth) for the first 20 seconds
- PC 1 sends traffic of 40 Mbps to PC 3 for the next 20 seconds
- PC 1 sends traffic of 40 Mbps to PC 2 for the next 20 seconds
- The whole transmitted traffic in this test is approximately 1 minute

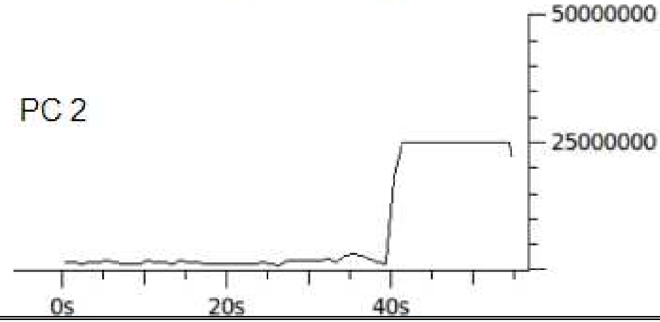
Results in EPON:





Results in GPON:





Conclusions:

Once the video is streaming without any other data traffic, the video can be correctly observed for both PC 2 and 3. At second 20, PC 3 receives an extra 40Mb of data received from the Server (PC 1). As PC 3 is limited at 50 Mbps, the video can be watched without any problem because total downstream traffic is around 42 Mbps.

At second 40, 40 Mbps to PC 2 is provided taking into consideration that the full capacity is limited to 25Mbps. The video in PC 2 does not work properly at this point because the packets that overflow the 25 Mbps downstream bandwidth are discarded in the ONU.

Moreover, a reduction of traffic in PC 3 from 42Mbps to 33-34Mbps can be seen. PC 2 has the capacity of 25Mbps, when more than 25 Mbps of traffic is used in PC 2 the remainder of traffic (17Mbps in this case) restricts the capacity of PC 3. As the PC 3 port is limited to 50Mbps the final Bandwidth available is approximately 33Mb (50-17) as seen in results above.

On the other hand, the phone was been used whilst this test was being conducted. Phone calls are allowed and work correctly in all cases explained previously. Therefore there is no problem for the telephony when ONUs are congested with traffic.

Taking these results into account, the comparison between both types of ONUs concludes that ONU 221 does not follow a reasonable bandwidth result and suggests probable internal problems when both ports of data traffic are active.

To remark the final conclusion in both EPON and GPON; if a port from the ONU 1320 (or 420 in GPON) is saturated with traffic, this situation affects the bandwidth of the rest of the data ports in the same ONU.

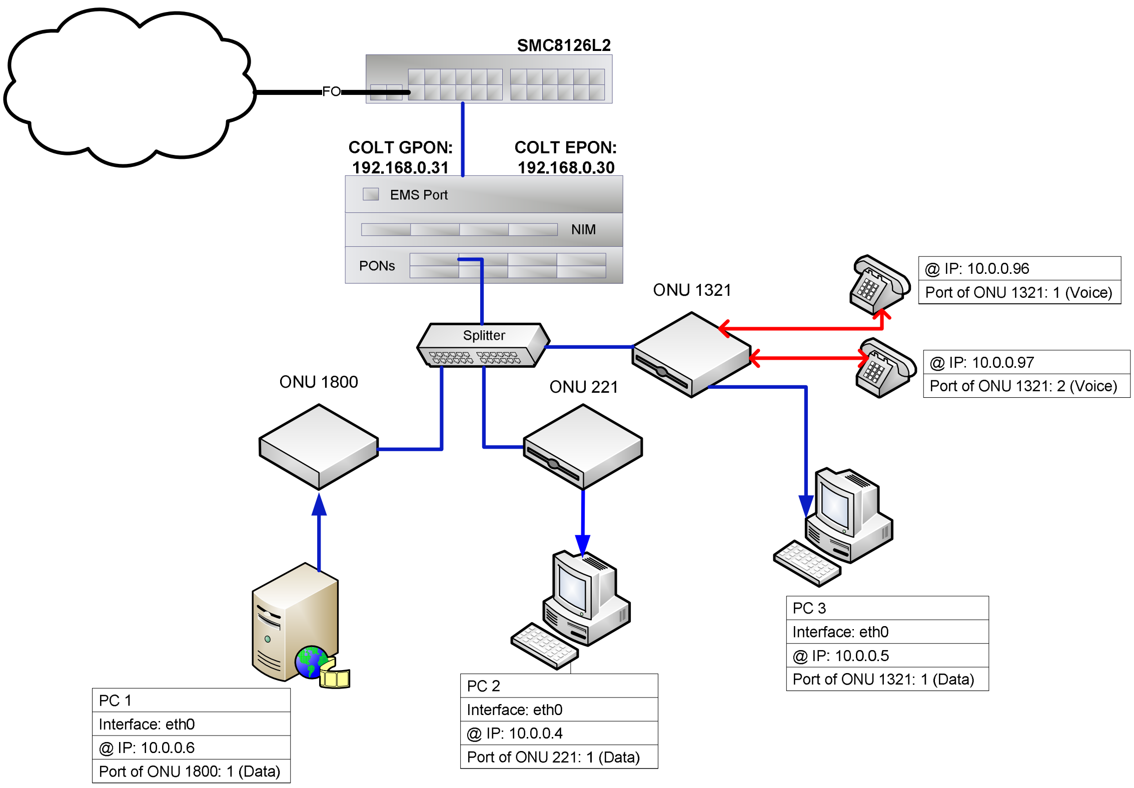
3.2.2 Two ONUs with same traffic overflow (same priorities)

3.2.2.1. The behaviour of 2 ONUs with traffic overflow (same priorities) within EPON & GPON

Goal: Test and check the ONUs behaviour in conditions of traffic congestion (a port of ONU 1320 and a port of ONU 221 saturated with data traffic) with the same port priority in each one (priority equal to 1). Also the same test will be processed for GPON with the same configurations in EPON but with its corresponding ONU (420).

Software used: mgen, VLC, Wireshark

Scenario:



Configuration of the different parameters:

Video Streaming PC 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1800 ; 1	EFM	Data	1	Tagged	2273	**200 Mbps**	600 Kbps

PC 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
221 ; 1	EFM	Data	1	Tagged	2273	1 Mbps	**25 Mbps**

PC 3:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1320 ;1	EFM	Data	1	Tagged	2273	1 Mbps	**50 Mbps**

Telephone 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 1	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	106	

Telephone 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 2	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	103	

GPON will use the same scenario but using ONUs 420 instead of the different ONUs previously used in EPON.

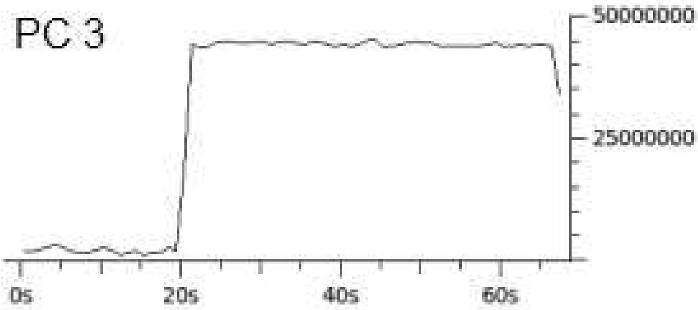
This scenario provides a connection between ONU 1800, ONU 1320 and ONU 221 within an EPON configured with a VLAN 2273 for data traffic. There is also a connection of VoIP through a VLAN 2271 that connects the equipment to the Elastix Server. It provides the registration and VoIP service for the telephones.

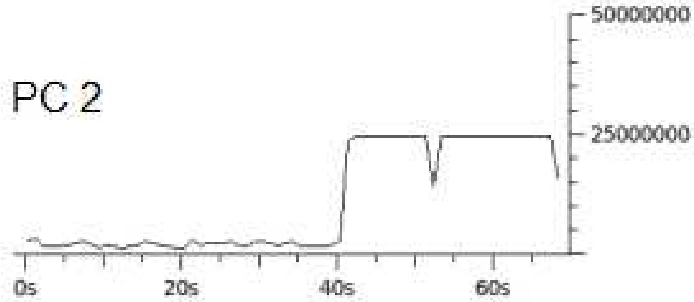
For GPON the scenario provides exactly the same connections, configurations and services but using ONU 420 instead of all other ONUs.

During this test a video will be transmitted from PC1 to PC 2 and 3 at the same time and data traffic will be introduced (provided by mgen) to overflow ONUs port's capacity. Furthermore calls from both telephones will be tested. The idea is to see what happens with all this traffic at the same time. As it can be seen in the *configuration of the parameters*, the difference about PC 2and 3, is that PC 2 is limited at 25Mbps and PC 3 at 50Mbps in a bandwidth downstream direction. The next procedure indicates the following steps for this test:

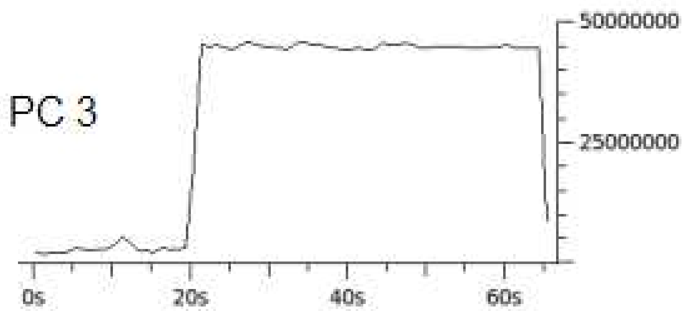
- PC 1 Video Server streams a file to PC 2 and 3 at the same time (at approximately 2 Mbps of the video Bandwidth) for the first 20 seconds
- PC 1 sends traffic of 40 Mbps to PC 3 for the next 20 seconds
- PC 1 sends traffic of 40 Mbps to PC 2 for the next 20 seconds
- The whole transmitted traffic in this test is approximately 1 minute

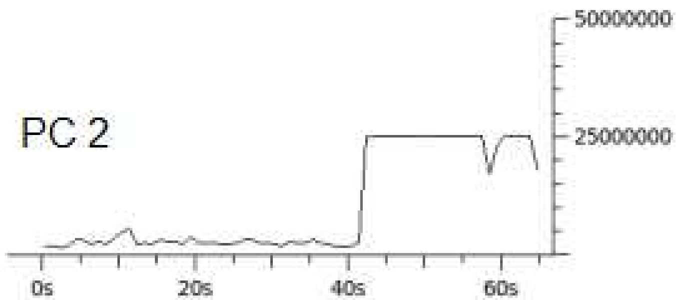
Results in EPON:





Results in GPON:





Conclusions:

Once the video is streaming without any other data traffic, the video can be correctly observed for both PC 2 and 3. At second 20, PC 3 receives an extra 40Mb of data received from the Server (PC 1). As PC 3 is limited at 50 Mbps, the video can be watched without any problem because total downstream traffic is around 42 Mbps.

At second 40, 40 Mbps to PC 2 is provided taking into consideration that the full capacity is limited to 25Mbps. The video in PC 2 does not work properly at this point because the packets that overflow the 25 Mbps downstream bandwidth are discarded in the ONU.

In this case, there is no reduction of traffic in PC·3 because both PCs are connected to different ONUs and can not be limited by overflow created by each other. For this reason PC 3 is not affected with the overflow that occurs in PC 2 as expected.

Moreover, an extra 20 Mbps to PC 3 is provided taking into consideration that the full capacity is limited to 50 Mbps. After that, video does not work because ONU 1320 is receiving around 62 Mbps and the port becomes saturated.

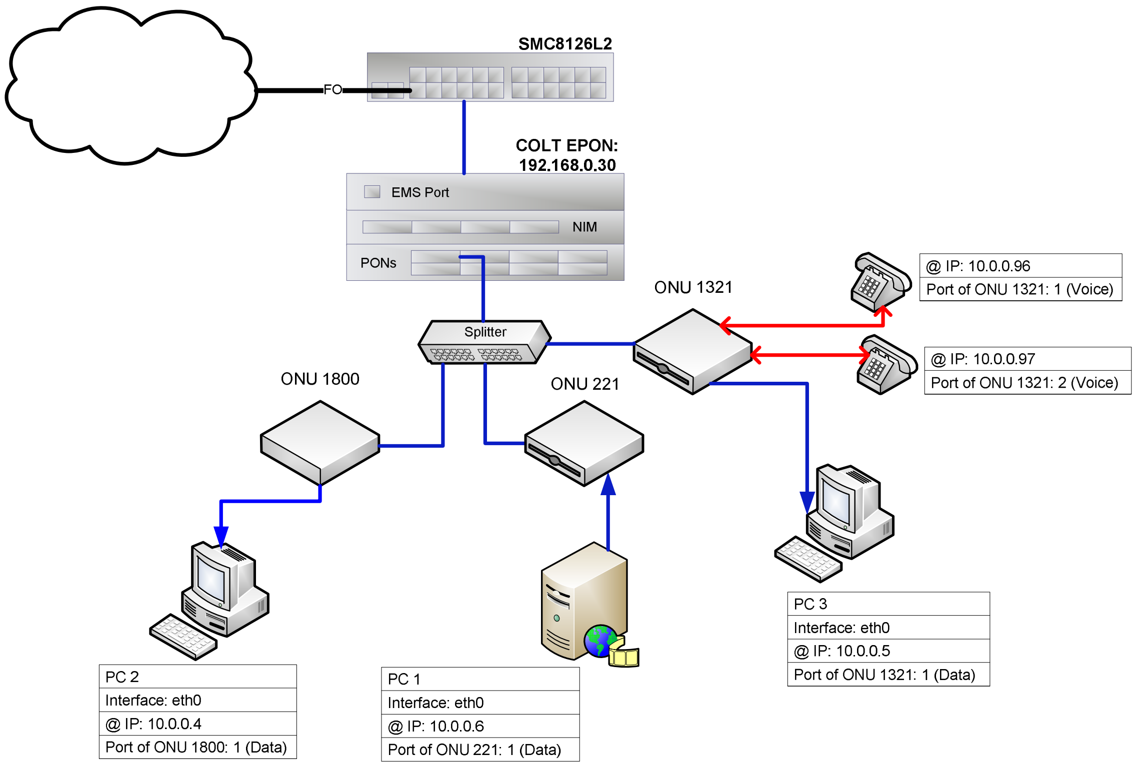
To remark the final conclusion in both EPON and GPON; if a port from a certain ONU is saturated with traffic, this situation does not affect the bandwidth of the rest of the ONUs.

3.2.2.2. The behaviour of 2 ONUs with traffic overflow (same priorities) within EPON

Goal: Test and check the ONUs behaviour in conditions of traffic congestion (saturate a port of ONU 1320 and a port of ONU 1800 with data traffic) with the same port priority in each one (priority equal to 1).

Software used: mgen, VLC, Wireshark

Scenario:



Configuration of the different parameters:

Video Streaming PC 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
221 ; 1	EFM	Data	1	Tagged	2273	**200 Mbps**	600 Kbps

PC 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1800 ; 1	EFM	Data	1	Tagged	2273	1 Mbps	**25 Mbps**

PC 3:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1800 ; 2	EFM	Data	1	Tagged	2273	1 Mbps	**50 Mbps**

Telephone 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 1	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	106	

Telephone 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 2	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	103	

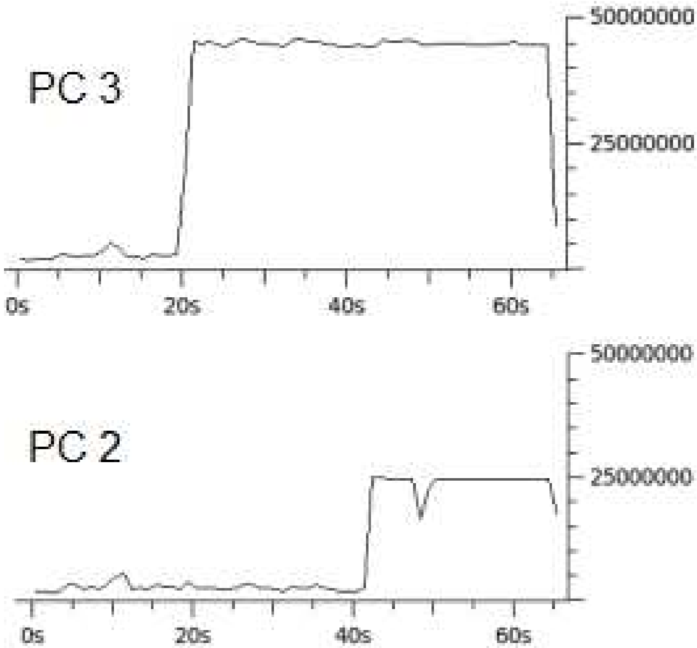
This scenario provides a connection between ONU 1800, ONU 1320 and ONU 221 within an EPON configured with a VLAN 2273 for data traffic. There is also a connection of VoIP through a VLAN 2271 that connects the equipment to the Elastix Server. It provides the registration and VoIP service for the telephones.

In this case the Video Streaming Server will be placed in ONU 221 and the receivers will be placed in ONUs 1320 and 1800. This test is concentrated on the same scenario as in 3.2.2.1 and also has the objective to check the server placed within a different ONU.

During this test a video will be transmitted from PC1 to PC 2 and 3 at the same time and data traffic will be introduced (provided by mgen) to overflow ONUs port's capacity. Furthermore calls from both telephones will be tested. The idea is to see what happens with all this traffic at the same time. As it can be seen in the *configuration of the parameters*, the difference about PC 2and 3, is that PC 2 is limited at 25Mbps and PC 3 at 50Mbps in a bandwidth downstream direction. The next procedure indicates the following steps for this test:

- PC 1 Video Server streams a file to PC 2 and 3 at the same time (at approximately 2 Mbps of the video Bandwidth) for the first 20 seconds
- PC 1 sends traffic of 40 Mbps to PC 3 for the next 20 seconds
- PC 1 sends traffic of 40 Mbps to PC 2 for the next 20 seconds
- The whole transmitted traffic in this test is approximately 1 minute

Results:



Conclusions:

Once the video is streaming without any other data traffic, the video can be correctly observed for both PC 2 and 3. At second 20, PC 3 receives an extra 40Mb of data received from the Server (PC 1). As PC 3 is limited at 50 Mbps, the video can be watched without any problem because total downstream traffic is around 42 Mbps.

At second 40, 40 Mbps to PC 2 is provided regarding that it is limited at 25Mbps. The video in PC 2 does not work properly at this point because the packets that overflow the 25 Mbps downstream bandwidth are discarded in the ONU.

In this case, there is no reduction of traffic in PC·3 because both PCs are connected to different ONUs and can not be limited by overflow created by each other. For this reason PC 3 is not affected with the overflow that occurs in PC 2 as expected.

Moreover an extra 20 Mbps to PC 3 is provided taking into consideration that full capacity is limited to 50 Mbps. After that, video does not work because ONU 1320 is receiving around 62 Mbps and the port becomes saturated.

To remark the final conclusion; if a port from a certain ONU is saturated with traffic, this situation does not affect the bandwidth of the rest of the ONUs.

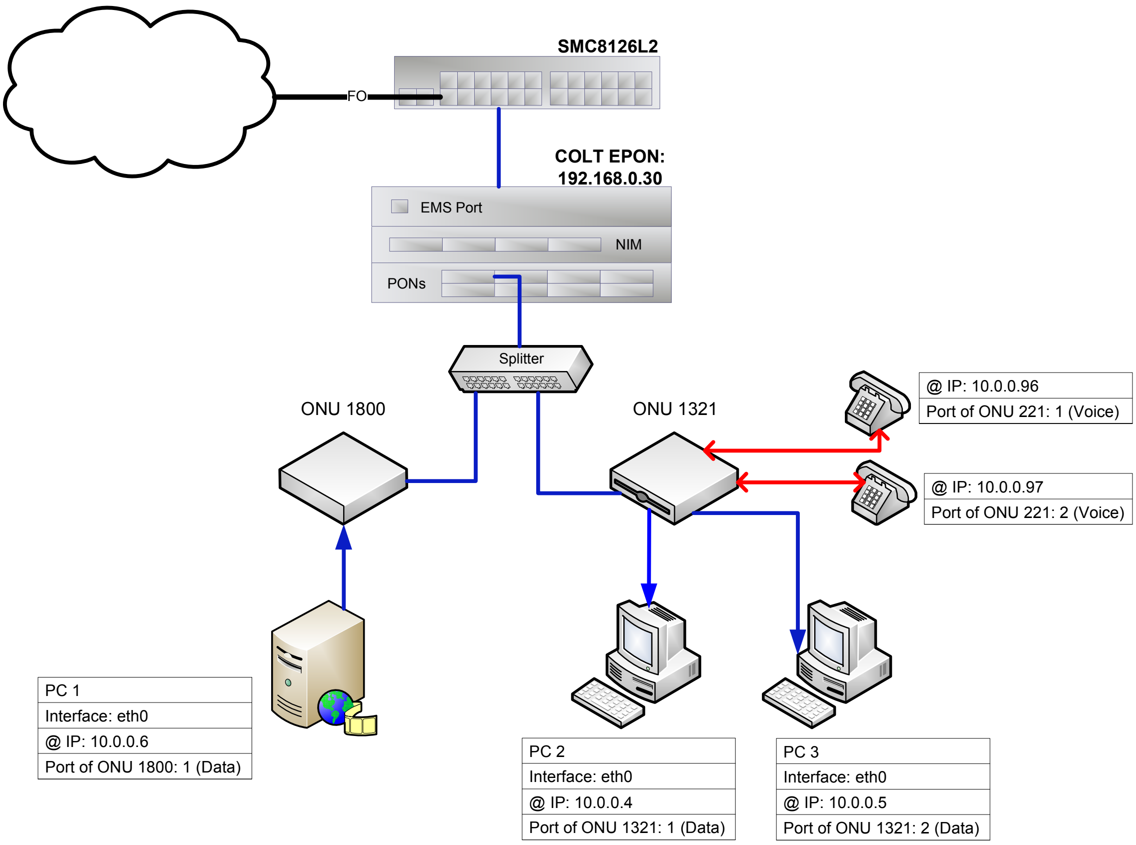
3.2.3 One ONU with same traffic overflow (different priorities)

3.2.3.1. The behaviour of 1 ONU with traffic overflow (different priorities) within EPON & GPON

Goal: Test and check the ONUs behaviour in conditions of traffic congestion (2 ports of ONU 1320 saturated with data traffic) with different port priority in each port (priority equal to 1 and 3). Also the same test will be processed for GPON with the same configurations in EPON but with its corresponding ONU (420).

Software used: mgen, VLC, Wireshark

Scenario:



Configuration of the different parameters:

Video Streaming PC 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1800 ; 1	EFM	Data	1	Tagged	2273	**200 Mbps**	600 Kbps

PC 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1320 ; 1	EFM	Data	1	Tagged	2273	1 Mbps	**25 Mbps**

PC 3:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1320 ; 2	EFM	Data	3	Tagged	2273	1 Mbps	**50 Mbps**

Telephone 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 1	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	106	

Telephone 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 2	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	103	

GPON will use the same scenario and ONUs 420 instead of the different ONUs previously used in EPON.

This scenario is to attempt a connection between ONU 1800 and ONU 1320 within an EPON configured with a VLAN 2273 and different QoS priorities for data traffic in both ports. There is also a connection of VoIP through a VLAN 2271 that connects the equipment to the Elastix Server. It provides the registration and VoIP service for the telephones.

For GPON the scenario provides exactly the same connections, configurations and services but using ONU 420 instead of all other ONUs.

During this test there was no connection with the 3 PCs, so this test can not be carried out successfully. Different port priorities (1,2,3) for data traffic in both ports were tested but produced the same results. Also different parameters as ‘Network VLAN Tagging’ had been changed in order to check if there was

connection but negative results were provided. There was only connection when both ports had a priority equal to 1 (that corresponds to test 3.2.1.3).
Conclusions: Due to no connection between ONU 1800 and ONU 1320 in this scenario, we can only conclude that providing different priorities within the same traffic in an ONU is not possible. When two or more ports are configured as data traffic, port priority must remain equal to 1 and traffic can not be differentiated within one particular ONU. On the other hand, the phone had been used whilst this test was being conducted. Phone calls are allowed and work correctly in all cases explained previously. Therefore there is no problem for the telephony in this case.

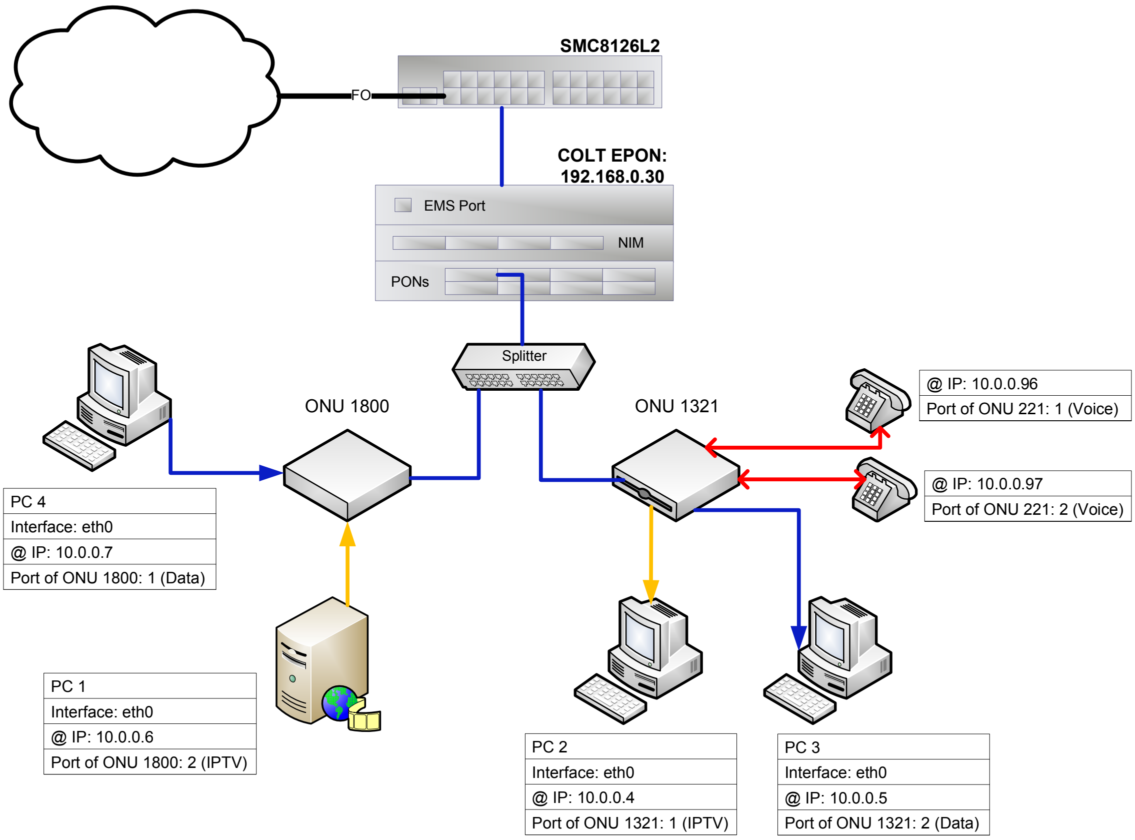
3.2.4 One ONU with different traffic overflow (different priorities)

3.2.4.1. The behaviour of 1 ONU with different traffic overflow within EPON & GPON

Goal: Test and check the ONUs behaviour in conditions of traffic congestion (1 port of ONU 1320 saturated with data traffic). In this case 1 port will be defined as data traffic and the other one will be defined as IPTV traffic. Data traffic will have port priority equal to 1 and IPTV traffic equal to 4. Also the same test will be processed for GPON with the same configurations in EPON but with its corresponding ONU (420).

Software used: mgen, VLC, Wireshark

Scenario



Configuration of the different parameters:

Video Streaming PC 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1800 ; 2	EFM	IPTV	4	Tagged	10	**200 Mbps**	600 Kbps

PC 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1320 ; 1	EFM	IPTV	4	Tagged	10	1 Mbps	**6 Mbps**

PC 3:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1320 ; 2	EFM	Data	1	Tagged	2273	1 Mbps	**25 Mbps**

PC 4:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID	Upstream Bandwidth	Downstream Bandwidth
1800 ; 1	EFM	Data	1	Tagged	2273	**200 Mbps**	600 Kbps

Telephone 1:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 1	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	106	

Telephone 2:

ONU and Port	Device Type	Service Type	QoS priority	Network VLAN Tagging	VLAN ID
221 ; 2	EFM	VoIP	6	Tagged	2271
Upstream Bandwidth	**Downstream Bandwidth**	**Proxy and Server Register**	**Register Port**	**Username**	
500 Kbps	500 Kbps	10.0.0.1	5060	103	

This scenario provides a connection between ONU 1800 and ONU 1320 within an EPON configured with a VLAN 2273 for data traffic and VLAN 10 for IPTV traffic. There is also a connection of VoIP through a VLAN 2271 that connects the equipment to the Elastix Server. It provides the registration and VoIP service for the telephones.

For GPON the scenario provides exactly the same connections, configurations and services but using ONU 420 instead of all other ONUs.

In this test the difference between PC 2 and 3 are as follows:

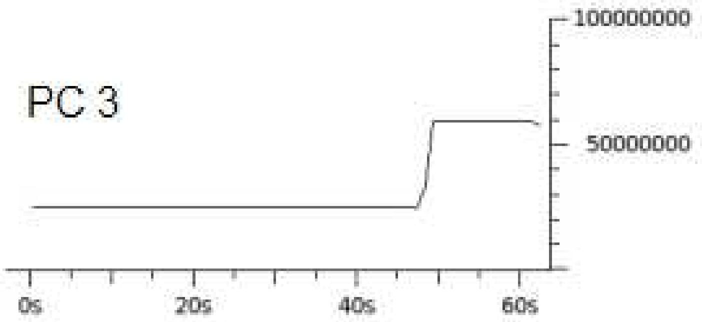
- PC 2 is limited to 6 Mbps and PC 3 to 25 Mbps and 60 Mbps (after 50 seconds running this test) in a bandwidth downstream direction
- PC 2 is defined to receive IPTV traffic (VLAN 10) and PC 3 for Data traffic (VLAN 2273)
- PC 2 has a port priority of 4 and PC 3 of 1 in ONU 1320

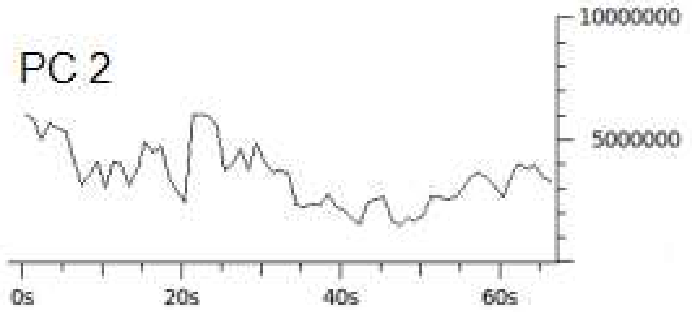
During this test, 2 videos will be transmitted from PC1 to PC 2, in order for PC 2 to receive approximately 4 Mbps of video traffic. At the same time data traffic will be introduced in PC 3 (provided by mgen) to overflow ONUs data port's capacity. Furthermore calls from both telephones will be tested. The idea is to see what happens with all this traffic at the same time.

The next procedure indicates the following steps for this test:

- PC 1 Video Server streams two files to PC 2 (at approximately 4 Mbps to the video bandwidth)
- PC 1 sends traffic of 70 Mbps to PC 3 at the same time as the first condition stated above
- PC 3 changes its downstream bandwidth to 60 Mbps (receiving more incoming traffic at this point) at second 50

Results in EPON & GPON:





Conclusions:

The video streaming in PC 2 (IPTV with priority port equal to 4) can be correctly observed for the whole test duration. From the beginning of the test, PC 3 receives data traffic where as ONU 1320 in port 2 can let only permit 25 Mbps to pass through. In this case no alteration can be seen in the traffic to PC 2 and there was no overflow of traffic from port 2 to 1. At approximately second 50, PC 3 received extra data traffic due to the increase of bandwidth in this port to 60 Mbps. Even with this increase, there is no reduction of traffic in PC 2 and video can be viewed without any problem within the IPTV port configuration.

On the other hand, the phone was been used whilst this test was being conducted. Phone calls are allowed and work correctly in all cases explained previously. Therefore there is no problem for the telephony when ONU´s are congested with traffic.

To remark the final conclusion in both EPON and GPON; different port priorities with different types of traffic (data with priority equal to1, IPTV with priority equal to 4 and voice with priority equal to 6) work successfully and has an important role for the traffic and bandwidth assignment. From now it can be derived to the conclusion that, if the ports are configured for different traffic, a selection can be made to gain the highest priority to receive benefits for the traffic preferences.

CONCLUSIONS

Due to the continuing demand for larger bandwidth, the optical transport is gradually becoming general in the access network where optical fibre technologies can provide the solution for current and future application demands.

The conventional point-to-point transport solutions are expensive to use for residential and business access, and therefore more economical solutions are currently being developed. To address this issue, an alternative to access networks is the Passive Optical Network (PON).

During the course of this project the two more useful optical fibre technologies (GPON and EPON) that have higher bandwidth capacity, lower maintenance cost and longer life have been selected for this study.

The reason to consider this project in line with the PAIS and SILVIAs projects was to deploy an optical transport network testbed connected to a FTTH extension with a triple play services. The scope of this project was to build and configure a scenario for the EPON and GPON technologies and their evaluation, mainly in terms of bandwidth and port priorities of ONUs' attributes in order to check the viability of these networks. Voice, IP and Ethernet completely dominate data communications networks, the Internet, VoIP and IPTV which have the following key features: low cost, easy installation, simple maintenance, direct bandwidth provisioning, high flexibility in topologies and scalability in terms of speed and distance.

To conduct the tests, an Elastix Server has been implemented to be able to offer voice within a FTTH network. In the scenarios proposed they offered triple play services (voice, video and data).

Having analysed all the mechanisms and scenarios for EPON and GPON, it was concluded that:

- If a port from a specific ONU is saturated with traffic (apart from voice), the overflow of the traffic in this port, affects the bandwidth of the other ports in the same ONU

- On the other hand and with the same conditions as above, the overflow does not affect the bandwidth of other ONUs

- When two or more ports are configured as data traffic or to an IPTV in a specific ONU, port priority must remain equal to 1 and traffic can not be differentiated within a particular ONU

- When using a specific ONU, and ports are configured for different types of traffic, a selection of priorities can be made to gain benefits for the traffic preferences (highest priority). Both technologies can guarantee quality of service when voice, video and data are provided

- Reminder that ONU 221 from the laboratory 334/335 works differently as expected or could have internal problems

Hence, both technologies have been analysed and retrieves satisfactory results in terms of guarantee quality of service. FTTH network has been validated an access solution to residential access.

This project follows a clear line for further investigation using FTTH in line with the SILVIA project. For instance, the SILVIA project has the aim to provide a real test environment in order to validate the own services of the companies as well as to promote organisational expansion within the Catalan TIC sector, using FTTH scenarios with the support of several different companies.

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Escola d'Enginyeria de Telecomunicació i Aeroespacial de Castelldefels

UNIVERSITAT POLITÈCNICA DE CATALUNYA

ANNEX

TITLE: Design and Performance Evaluation of Passive Optical Networks

MASTER DEGREE: Master in Science in Telecommunication Engineering & Management

AUTHOR: Víctor Cobos Melià

DIRECTOR: Cristina Cervelló i Pastor

DATE: June 14th 2011

ANNEX A. GPON TECHNOLOGY

A.1 Physical Media Dependent (PMD)

The physical layer requirements and specifications for GPON are defined in the G.984.2 recommendation covering the range on GPON upstream and downstream bit rates and the optical parameters for the different rate combinations [6].

As previously mentioned, the nominal bit rate of the OLT-to-ONU (Downstream) and the nominal bit rate of the ONU-to-OLT (Upstream) are specified as follows:

Transmission direction	Nominal bit rate
Downstream	1244.16 Mbit/s
	2488.32 Mbit/s
Upstream	155.52 Mbit/s
	622.08 Mbit/s
	1244.16 Mbit/s

Table A.1 Nominal bit rate with the two transmission direction

The operating wavelength range for the downstream direction on single fibre systems shall be 1480-1500 nm and the operating wavelength range for the downstream direction on two fibre systems shall be 1260-1360 nm, so bidirectional transmission could be accomplished by use of either wavelength division multiplexing (WDM) technique on a single fibre, or unidirectional transmission over two fibres.

A.2 GPON Transmission Convergence (GTC)

GTC performs the adaptation of user data onto the PMD layer and additionally provides basic management of the GPON and it is positioned between the physical media dependent (PDM) layer and the G-PON clients. The G.984.3 recommendation [7] describes GTC functionality and deals with specifications for frame format, media access control method, ranging method, ONU activation methods, physical layer OAM messaging channel and finally, the issues related to the security. The GTC has modes to support both frame transport (GEM) and cell transport (ATM). More recently, however, it has been clear that ATM transport is almost not needed for much services of interest and few if any systems ever supported it. Therefore, the ATM transport features of GTC are deprecated, so the description will be focused on GEM that allows low overhead adaptations of various protocols, including Ethernet and TDM.

A.2.1 GTC sub layers

This section describes the transmission convergence layer architecture in the G-PON system. Figure A.1 shows the protocol stack for the overall G-PON transmission convergence (GTC) layer. The GTC layer is comprised of two sub-layers, the GTC framing sub-layer and the GTC adaptation sub-layer. From another point of view, GTC consists of a control and management plane (C/M-plane), which manages user traffic flows, security and OAM features, and a user data plane (U-plane) which carries user traffic.

In the GTC framing sub-layer the GEM, embedded OAM and PLOAM sections are recognised according to the location on a GTC frame. The embedded OAM is terminated at this sub-layer for local control purposes, because information of embedded OAM is included in the GTC frame header directly. PLOAM information is processed at the PLOAM block located as a client of this sub-layer. Service data units (SDUs) in GEM sections are converted from/to conventional GEM protocol data units (PDUs) at the GTC adaptation sub-layer. Moreover, these GEM PDUs carry the OMCI channel data where it is recognised at the adaptation sub-layer and then interchanged from/to OMCI entity. Embedded OAM, PLOAM and OMCI are categorised into the C/M-plane and SDUs, except for OMCI over GEM, are categorised into the U-Plane. The GTC framing sub-layer has global visibility to all data transmitted, and the OLT GTC Framing sub-layer is a direct peer of all the ONU GTC framing sub-layers. Moreover, the DBA control block is specified as a common functional block in the GTC adaptation sub-layer.

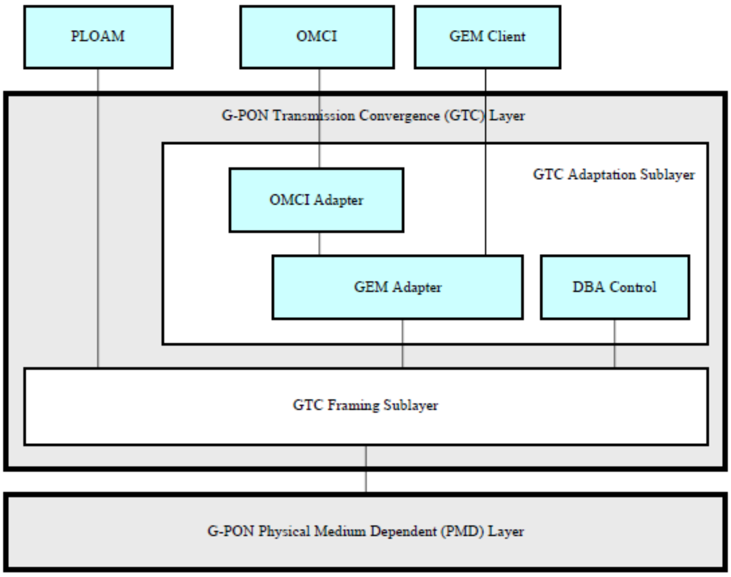


Figure A.1 Protocol Stack for the GTC

The remaining paragraphs, describe the architecture of the C/M-plane and the U-Plane, the relationship between these planes, the functional features of GTC and including operations that focus on GTC.

A.2.2 Protocol stack for the C/M-plane

The control and management plane in the GTC system consists of three parts: embedded OAM, PLOAM and OMCI. The embedded OAM and PLOAM channels manage the functions of the PMD and the GTC layers. The OMCI provides a uniform system for managing higher (service-defining) layers. Functional blocks in the C/M plane are shown in figure A.2.

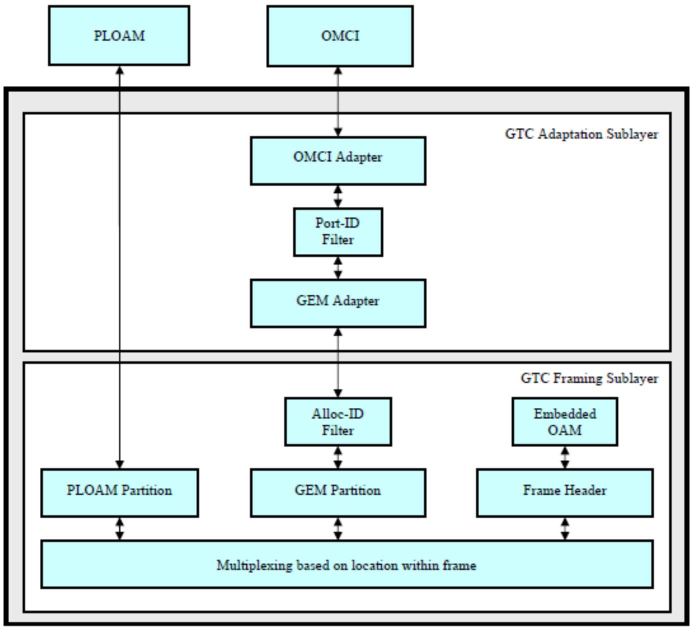


Figure A.2 Functional blocks in the C/M-plane

The embedded OAM channel is provided by field-formatted information in the header of the GTC frame. This channel offers a low latency path for time-urgent control information, because each information piece is definitely mapped into a specific field in the header of the GTC frame. The functions that use this channel include: bandwidth allocation, security key switching, and dynamic bandwidth assignment signalling. The PLOAM channel is a message-formatted system carried in a dedicated space of the GTC frame. This channel is used for all other PMD and GTC management information that is not sent via the embedded OAM channel. The ONU management and control interface (OMCI) channel is used to manage the service-defining layers, which reside above the GTC.

However, the GTC must provide a GEM-based transport interface for this management traffic, including configuration of appropriate transport protocol flow identifiers (GEM Port-IDs). The detailed OMCI specification can be found in [8].

A.2.3 Protocol stack for the U-plane

Traffic flows in the U-plane are identified by their GEM Port-IDs and payload type, as shown in figure A.3. In addition, the concept of T-CONT originally introduced in the B-PON is employed. A T-CONT represents a group of traffic flow associated with an allocation ID and appears as a single entity for the purpose of upstream bandwidth assignment on the PON. Bandwidth assignment and QoS control are performed in every T-CONT by fixed and dynamic methods.

Based on assignable bandwidth, T-CONTs are classified into five types:

- T-CONT type 1 supports fixed bandwidth only
- T-CONT type 2 supports assured bandwidth only
- T-CONT type 3 supports assured bandwidth and non-assured bandwidth
- T-CONT type 4 supports best-effort bandwidth only
- T-CONT type 5 supports all types of bandwidth

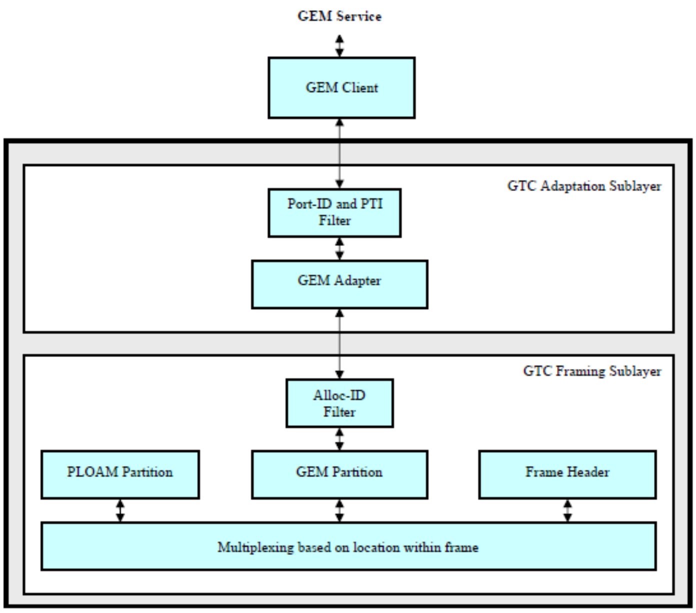


Figure A.3 The U-plane protocol stack and identification by Port-ID

In the protocol stack for the U-plane, the operations are summarised as follows:

In the downstream direction, the GEM frames are carried in the GTC payload and arrive at all the ONUs. The ONU framing sub-layer extracts the frames, and the GEM TC adapter filters the frames based on their 12-bit Port-ID. Only frames with the appropriate Port-IDs are allowed through to the GEM client function.

In the upstream direction, the GEM traffic is carried over one or more T-CONTs. The OLT receives the transmission associated with the T-CONT and the frames are forwarded to the GEM TC adapter and then to the GEM client.

A.3 Media Access Control (MAC) flow

Media access control for upstream traffic can be provided by the GTC system. Synchronised upstream frames with downstream frames indicating permitted locations for upstream traffic can achieve the media access control provided by the GTC system.

Only one ONU can access the required medium at that time with no contention within normal operations. For the medium to be controlled at an effective static bandwidth granularity of 64 kbps by the OLT, the pointers are provided in units of bytes.

In GPON each ONU has multiple queues identified by unique allocation identifiers (AllocIDs). The queue is also known as the T-CONT in FSAN terminology where each T-CONT has one of five T-CONT types depending on the QoS requirements. An incoming frame is queued in one of the T-CONTs based on the QoS class of the frame. In the downstream direction, the OLT broadcasts frames through the splitter–coupler to all ONUs. Each ONU accepts only frames that match the AllocID of the T-CONT that belongs to the ONU. In the upstream direction, only one ONU can transmit frames to the OLT at any time because of the splitter property. To avoid transmission collisions between ONU's, the MAC controller of the OLT assigns a non-overlapping transmission time slot to each ONU.

Resources, statically or dynamically are assigned to all logical links. In consideration of dynamic resource allocation to links, an investigation of congestion status is processed by an OLT. The congestion status is examined by the Dynamic Bandwidth Assignment (DBA) reporting from the ONU and/or the use of self monitoring of incoming traffic that can allocate adequate resources when required.

DBA functionalities are performed in every T-CONT and are categorized into:

- Detection of congestion status by OLT and/or ONU
- Report of congestion status to OLT
- Update of assigned bandwidth by OLT according to provisioned parameters
- Issues of grants by OLT according to updated bandwidth and T-CONT types
- The management issues for DBA operations.

There are two modes in DBA operations: SR (Status Reporting)-DBA, and NSR (Non Status Reporting)-DBA. All OLTs must support both status reporting and non-status reporting systems, so that all ONUs can provide some level of DBA functionality. To operate DBA, some parameters should be provisioned or negotiated by management functionalities i.e., the OLT and ONU agree on the DBA mode of operation, and respond accordingly to requests from each other.

The MAC downstream frame (see figure A.4) is transmitted to all frame durations of 125 s and has a fixed size of 125 s. The frame consists of a physical control block downstream (PCBd) and a payload field. The PCBd contains a bandwidth map (BWmap) that represents the start and stop times of the upstream transmission for a particular T-CONT. The BWmap also indicates whether the particular T-CONT reports its queue length using a dynamic bandwidth report upstream (DBRu) field of an upstream frame. The MAC controller of the OLT not only allocates the data transmission time but also determines the DBRu transmission time for each T-CONT of each ONU to every frame duration of 125 s.

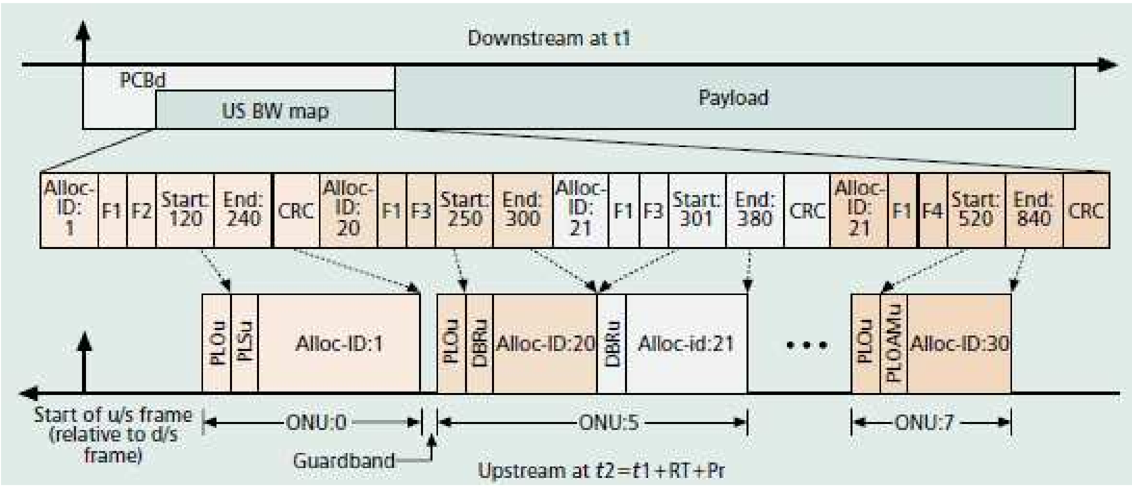


Figure A.4 Downstream Media Access Control Concept

The upstream frame (see figure A.5) is synchronised with the downstream frame and has a fixed size of 125 s. Each frame consists of a number of transmissions from ONUs as indicated by the BWmap of the downstream frame. In the upstream transmission, some overheads are inserted and when the ONU starts the upstream transmission, a physical layer overhead upstream (PLOu) is required at the start of the transmission. Also, the DBRu field is added when a T-CONT reports its queue length according to the BWmap.

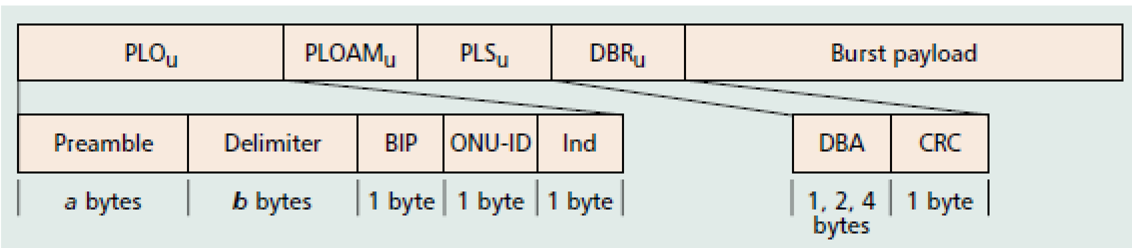


Figure A.5 Upstream GTC frame

The payload of each T-CONT contains a number of GEM frames that have a GEM header as shown in figure A.6. The payload length indicator (PLI) indicates the length of the accompanying frame fragment. The port ID is used to provide an identification of the frame fragment. The port ID supports 4096 unique traffic identifiers. The payload type indicator (PTI) indicates whether the accompanying frame fragment is the end of a frame. The OLT uses the port ID and PTI fields to reassemble a frame from the frame fragments. The header error control (HEC) is used for the correction of errors.

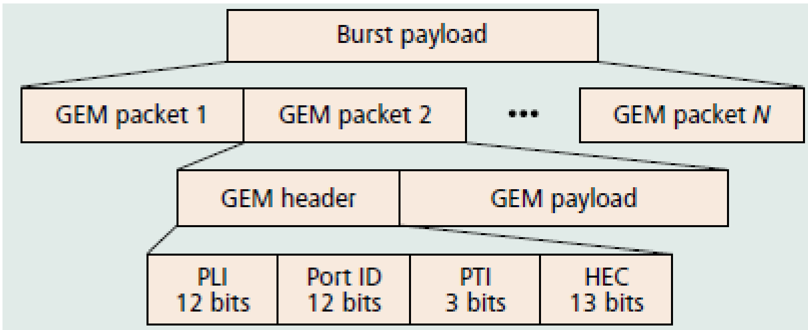


Figure A.6 FSAN GEM payload framing up/downstream

A.4 GEM (G-PON Encapsulation method)

The method in which data encapsulates over GPON is formally referred to as GEM. It is considered that all types of data can be encapsulated, however, specific data types are dependent on the service situation. GEM can provide both connection-oriented of communication as well as ATM.

Using the GEM payload partition, frames can be transmitted from the OLT to the ONUs in the downstream. The allocation of duration from the OLT is submitted as needed in the downstream, up to and including the majority of the downstream frame. This can be delivered by the following process; framing sub-layer filters by the ONU to the incoming frames based on the Port –ID. This ensures the delivery of appropriate frames to the ONU GEM client.

Frames that are transmitted in the upstream from the ONU to the OLT are processed using the configured GEM allocation time. GEM frames are then buffered by the ONU on arrival, to allow the frames to be sent in bursts to the allocated time indication set by the OLT. The frames are then received by the OLT to multiplex them with various other bursts from other ONUs. All of these bursts are passed to the OLT GEM client. The protocol stack for the User Plane can be reviewed in Figure A.7. This figure displays the protocol stack for User Plane where the ATM, GEM services including its respective TC and DTC sub-layer is identified.

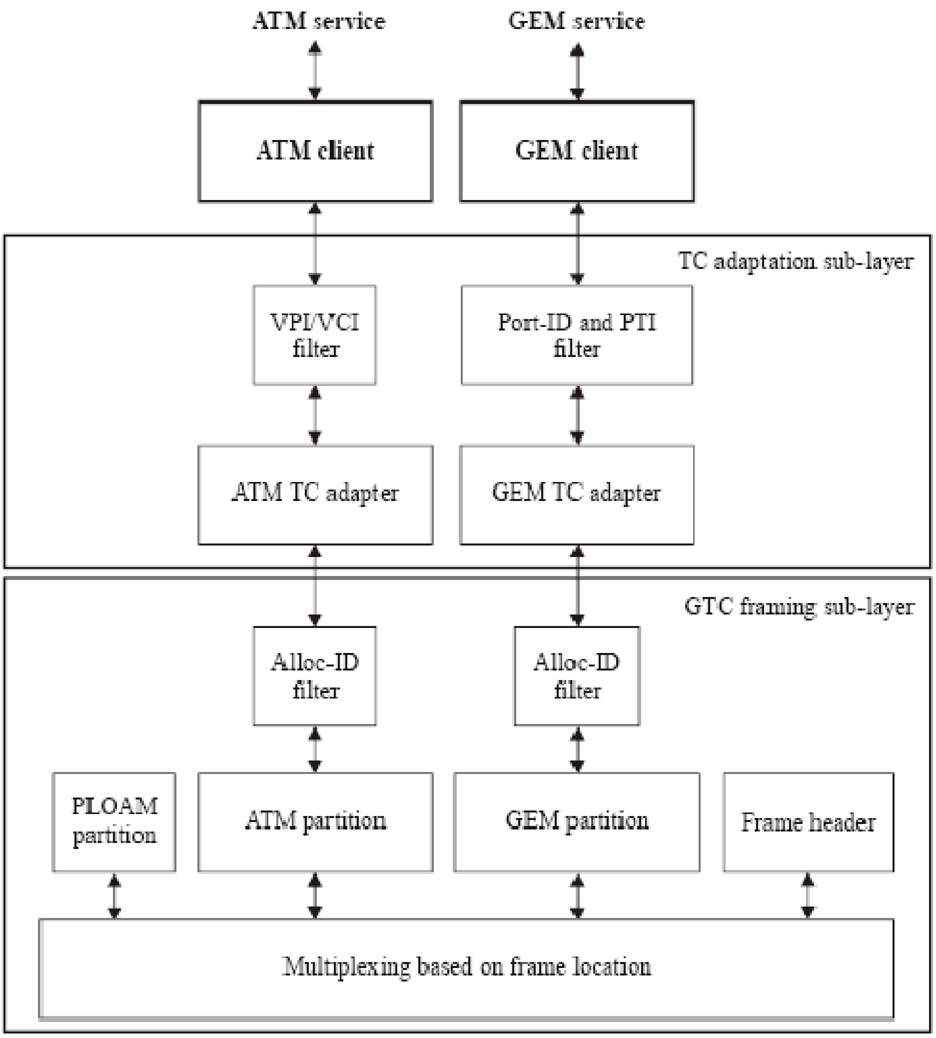


Figure A.7 G.984.3 – Protocol stack for U-Plane and identification by partition and Port-ID or VPI

A.5 GPON MANAGEMENT

GPON management is specified through the recommendation G.984.4 [8]. This recommendation specifies the optical network termination management and control interface (OMCI) for the GPON system to enable multi-vendor interoperability between the OLT and the ONT. The OMCI specification addresses the ONT configuration management, fault management and performance management for GPON system operation and for several services including: ATM adaptation layer 5, G-PON encapsulation method (GEM) adaptation layers, circuit emulation service, Ethernet services (including MAC Bridged LAN), voice services and wavelength division multiplexing.

The OMCI is used by the OLT to control an ONT where this protocol allows the OLT to:

- Establish and release connections across the ONT

- Manage the UNIs at the ONT
- Request configuration information and performance statistics
- Autonomously inform the system operator of events such as link failures

The OMCI protocol runs across a GEM connection between the OLT controller and the ONT controller that is established at ONT initialization. The OMCI protocol is asymmetric: the controller in the OLT is the master and the one in the ONT is the slave. A single OLT controller using multiple instances of the protocol over separate control channels may control multiple ONTs.

The OMCI should be defined to allow vendors to offer modular, incremental capabilities to meet different levels of customer needs. The recommendation - G.984.4 [8] defines a protocol necessary to support capabilities being important for interoperability, yet it allows for optional components and future extensions.

A protocol-independent MIB is used to describe the exchange of information across the OMCI. It forms the basis from which protocol-specific models are defined and it is intended to make the OMCI relatively simple while maintaining consistency with the MIB used by the interface between the network-element manager and the OLT.

OMCI models physical aspects of the ONUs like their equipment configuration, power, plain old telephone service (POTS), Ethernet, xDSL, T1/E1, radio frequency (RF) video, among others. At the service layer, OMCI covers high-speed Internet access using quality of service (QoS) schemes, TDM-voice, voice over IP (VoIP), IPTV, etc.

For each of those aspects, OMCI supports: configuration, fault, security and performance management. Configuration management provides functions to exercise control over, identify, collect data from and provide data to the ONT. This involves the following: configuration of equipment, UNI's, GEM port network CTPs, physical ports, traffic descriptors, among others.

The ONT supports 'limited' fault management and performance monitoring only. The OMCI supports failure reporting and performance monitoring on many managed entities and ITU-T G.984.3 [7] specifies some mechanisms from the viewpoint of security that includes the downstream data encryption of the ONT.

ANNEX B. EPON TECHNOLOGY

B.1 Physical Layer

EFM introduces a family of Physical Layer signalling systems in P2MP topologies which are derived from 1000BASE-X. Extensions to the reconciliation sub-layer (RS), PMA an PCS is included, mapping of the characteristics interface by the 1000BASE-X PMA and PCS sub-layers for the PMD sub-layer (including MDI) to the expected services of the RS.

Medium Dependant Interface (MDI) is a physical interface associated with a PMD that is comprised of a electrical or optical medium connection. On the other hand, Physical Medium Dependent (PMD) generates electrical or optical signals depending on the nature of the physical medium connected. PMD signals are sent to the Medium Dependent Interface (MDI) which is the actual medium connected, including connectors, for the various media supported.

PMD represents the part of the PHYsical layer (PHY) that dictates the way bits are converted to physical signals, such as light in the case of fibre being responsible for the transmission and reception of the information.

The PMA provides a medium-independent means for the PCS to support the use of a range of serial-bit oriented physical media. Some of the functions that 1000BASE-X PMA performs are as follows:

a) Mapping of transmit and receive code-groups between the PCS and PMA via the PMA Service Interface

b) Recovery of clock from the 8B/10B-coded data supplied by the PMD

c) Mapping of transmit and receive bits between the PMA and PMD via the PMD Service Interface

d) Data loopback at the PMD Service Interface

The *Physical Coding Sub-layer* (PCS) interface is the Gigabit Media Independent Interface (GMII) that provides a uniform interface to the Reconciliation sub-layer for all 1000 Mb/s PHY implementations including the codification of bits function.

In reference to the interface between the physical gigabit layer and the MAC gigabit layer, the *Gigabit Media Independent Interface* (GMII) provides the allocation of the 1000BASE-X PCS to transfer the required information back and forth from the PCS client.

The *Reconciliation Sub-layer* (RS) provides a mapping between the signals provided at the GMII and the MAC service definition. GMII and RS interface are used to provide media independence so that an identical media access controller may be used with any of the copper and optical PHY types.

B.2 Data Link Layer: Multipoint MAC Control

Multi-point MAC Control defines the MAC control operation for optical point-to-multi-point networks. Figure 1.7 shown in chapter 1, depicts also the architectural positioning of the Multi-point MAC Control sub-layer with respect to the MAC and the MAC Control client. The Multi-point MAC Control sub-layer takes the place of the MAC Control sub-layer to extend it to support multiple clients and additional MAC control functionality.

Multi-point MAC Control is defined using the mechanisms and precedents of the MAC Control sub-layer. The MAC Control sub-layer has extensive functionality designed to manage the real-time control and manipulation of MAC sub-layer operation. The Multi-point MAC Control sub-layer is specified such that it can support new functions to be implemented and added like the Multi-Point Control Protocol (MPCP); the management protocol for P2MP that will be explained in Annex B.3.

Although figure 1.7 describes multiple MACs within the OLT, a single unicast MAC address may be used by the OLT. Within the EPON Network, MACs are uniquely identified by their LLID which is dynamically assigned by the registration process.

Figure B.1 provides a functional block diagram of the Multi-point MAC Control architecture.

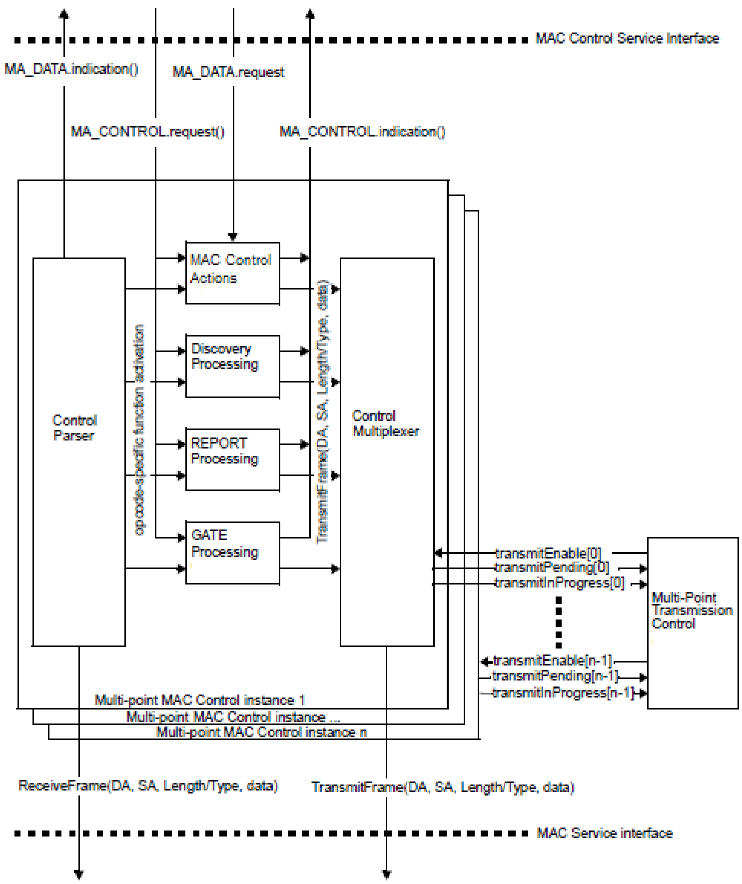


Figure B.1 Multipoint MAC Control Functional Block Diagram

The MAC Client communicates with the Control Multiplexer using the standard service interface. Multi-point MAC Control communicates with the underlying MAC sub-layer using the standard service interface specified in the IEEE 802.3 Standard. Similarly, Multi-point MAC Control communicates internally using primitives and interfaces consistent with definitions in MAC Control Actions

As depicted in figure B.1, the Multi-point MAC Control functional block comprises the following functions:

a) *Multi-point Transmission Control*. This block is responsible for synchronising Multi-point MAC Control instances associated with the Multi-point MAC Control. This block maintains the Multipoint MAC Control state and controls the multiplexing functions of the instantiated MACs.

b) *Multi-point MAC Control Instance n*. This block holds all the variables and is state associated with operating all MAC Control protocols for that instance.

c) *Control Parser*. This block is where MAC control frames are is analysed and where the interface to the MAC client is.

d) *Control Multiplexer*. This block is responsible for selecting the source of the forwarded frames.

e) *MAC Control Actions*. This block holds MAC Control actions for support of legacy and future services.

f) *Discovery, Report and Gate Processing*. These blocks are responsible for handling the MPCP in the context of the MAC.

B.3 MPCP: Multipoint Control Protocol

The multi-point control protocol (MPCP) specifies a control mechanism between a master unit and slave units connected to a point-to-multi-point (P2MP) segment to allow efficient transmission of data. In other words, Multi-point MAC Control enables a MAC Client to participate in a point-to-multi-point optical network by allowing it to transmit and receive frames as if it was connected to a dedicated link. In doing so, it employs the following principles and concepts:

a) A MAC client transmits and receives frames through the Multi-point MAC Control sub-layer.

b) The Multi-point MAC Control decides when to allow a frame to be transmitted using the client interface Control Multiplexer.

c) Given a transmission opportunity, the MAC Control may generate control frames that would be transmitted in advance of the MAC Client's frames, utilizing the inherent ability to provide higher priority transmission of MAC Control frames over MAC Client frames.

d) Multiple MACs operate on a shared medium by allowing only a single MAC to transmit upstream at any given time across the network using a time-division multiple access (TDMA) method.

e) Such gating of transmission is orchestrated through the Gate Processing function.

f) New devices are discovered in the network and allowed transmission through the Discovery Processing function Fine control of the network bandwidth distribution can be achieved using feedback mechanisms supported in the Report Processing function.

g) The operation of P2MP network is asymmetrical, with the OLT assuming the role of master, and the ONU assuming the role of slave.

As depicted in figure B.1, the Multi-point MAC Control functional block comprises the following functions:

a) *Discovery Processing:* This block manages the discovery process, through which an ONU is discovered and registered with the network while compensating for RTT.

b) *Report Processing*: This block manages the generation and collection of report messages, through which bandwidth requirements are sent upstream from the ONU to the OLT.

c) *Gate Processing*: This block manages the generation and collection of gate messages, through which multiplexing of multiple transmitters is achieved.

B.3.1 Discovery process

Discovery is the process whereby newly connected or off-line ONUs is provided access to the PON. The process is driven by the OLT, which periodically makes available Discovery Time Windows during which off-line ONU's are given the opportunity to make themselves known to the OLT. The periodicity of these windows is unspecified and left up to the implementer. The OLT signifies that a discovery period is occurring by broadcasting a discovery gate message, which includes the starting time and length of the discovery window. Off-line ONUs, upon receiving this message, will wait for the period to begin and then transmit a REGISTER_REQ message to the OLT. Discovery windows are unique in that they are the only times where multiple ONUs can access the PON simultaneously, and transmission overlap can occur. In order to reduce transmission overlaps, a contention algorithm is used by all ONU's. Measures are taken to reduce the probability for overlaps by artificially simulating a random distribution of distances from the OLT. Each ONU shall wait a random amount of time before transmitting the REGISTER_REQ message that is shorter than the length of the discovery time window. It should be noted that multiple valid REGISTER_REQ messages can be received by the OLT during a single discovery time period. Included in the REGISTER_REQ message is the ONU's MAC address and number of maximum pending grants. Upon receipt of a valid REGISTER_REQ message, the OLT registers the ONU, allocating and assigning new port identities (LLIDs), and bonding corresponding MACs to the LLIDs.

The next step in the process is for the OLT to transmit a Register message to the newly discovered ONU, which contains the ONU's LLID, and the OLT's required synchronization time. Also, the OLT echoes the maximum number of pending grants. The OLT now has enough information to schedule the ONU for access to the PON and transmits a standard GATE message allowing the ONU to transmit a REGISTER_ACK. Upon receipt of the REGISTER_ACK, the discovery process for that ONU is complete, the ONU is registered and normal message traffic can begin. It is the responsibility of Layer Management to perform the MAC bonding, and start transmission from/to the newly registered ONU. The discovery message exchange is illustrated in figure B.2.

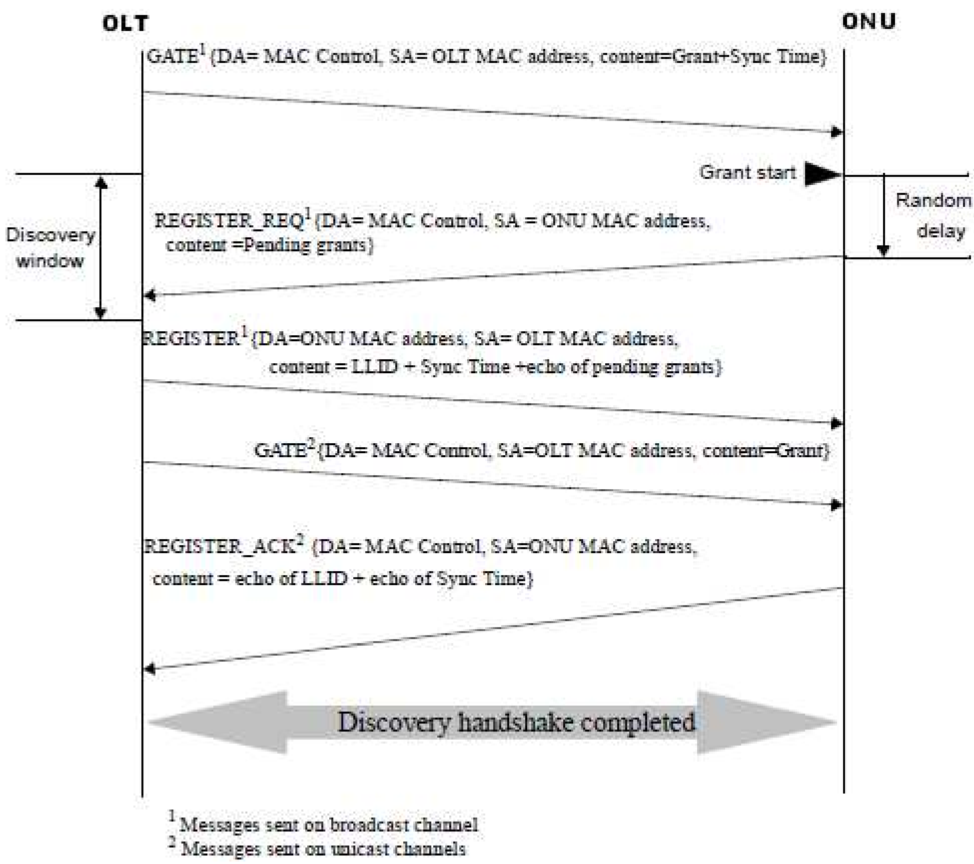


Figure B.2 Discovery Handshake Message Exchange

There may, exist situations when the OLT requires that an ONU go through the discovery sequence again and reregister. Similarly, there may be situations where an ONU needs to inform the OLT of its desire to deregister. The ONU can then reregister by going through the discovery sequence. For the OLT, the REGISTER message may indicate a value, Reregister or Deregister that if either is specified will force the receiving ONU into reregistering. For the ONU, the REGISTER_REQ message contains the Deregister bit that signifies to the OLT that this ONU should be deregistered.

B.3.2 Report Processing

The Report Processing functional block has the responsibility of dealing with queue report generation and termination in the network. Reports are generated by higher layers and passed to the MAC Control sub-layer by the MAC Control clients. Status reports are used to signal bandwidth needs as well as for arming the OLT watchdog timer.

Reports shall be generated periodically, even when no request for bandwidth is being made. This keeps a watchdog timer in the OLT from expiring and deregistering the ONU. For proper operation of this mechanism the OLT shall grant the ONU periodically.

REPORT messages have several other functionalities: Time stamp in each REPORT message is used for round trip (RTT) calculation. In the REPORT messages ONUs indicate the upstream bandwidth needs they request per 802.1Q priority queue. REPORT messages are also used as keep-alive from ONU to OLT. ONUs issue REPORT messages periodically in order to maintain link health at the OLT and, in addition, the OLT may specifically request a REPORT message.

B.3.3 Gate Processing

A key concept pervasive in Multi-point MAC Control is the ability to arbitrate a single transmitter out of a plurality of ONUs. The OLT controls an ONU’s transmission by the assigning of grants. The transmitting window of an ONU is indicated in GATE message where start time and length are specified. An ONU will begin transmission when its local time counter matches start time value indicated in the GATE message. An ONU will conclude its transmission with sufficient margins to ensure that the laser is turned off before the grant length interval has elapsed. Multiple outstanding grants may be issued to each ONU and the OLT shall not issue more than the maximal supported maximal outstanding grants as advertised by the ONU during registration. In order to maintain the watchdog timer at the ONU, grants are periodically generated and for this purpose empty GATE messages may be issued periodically. When registered, the ONU ignores all gate messages where the discovery flag is set.

The purpose of GATE message is to grant transmission windows to ONUs for both discovery messages and normal transmission. Up to four grants can be included in a single GATE message. The number of grants can also be set to zero for using the GATE message as an MPCP is kept alive from OLT to the ONU.

B.4 OAM

OAM is intended for point-to-point and emulated point-to-point IEEE 802.3 links, which provides mechanisms useful for monitoring link operation such as remote fault indication and remote loopback control. In general, OAM provides network operators the ability to monitor the health of the network and quickly determine the location of failing links or fault conditions. The OAM provides data link layer mechanisms that complement applications that may reside in higher layers and the OAM information is conveyed in slow protocol frames called OAM Protocol Data Units (OAMPDUs) where contains the appropriate control and status information used to monitor, test and troubleshoot OAM. OAMPDUs traverse a single link, being passed between peer OAM entities, and as such, are not forwarded by MAC clients (e.g., bridges or switches). On the other hand, OAM does not include functions such as station management, bandwidth allocation or provisioning functions, which are considered outside the scope of the IEEE 802.3ah.

Next figure B.3 depicts the usage of interlayer interfaces by the OAM sub layer.

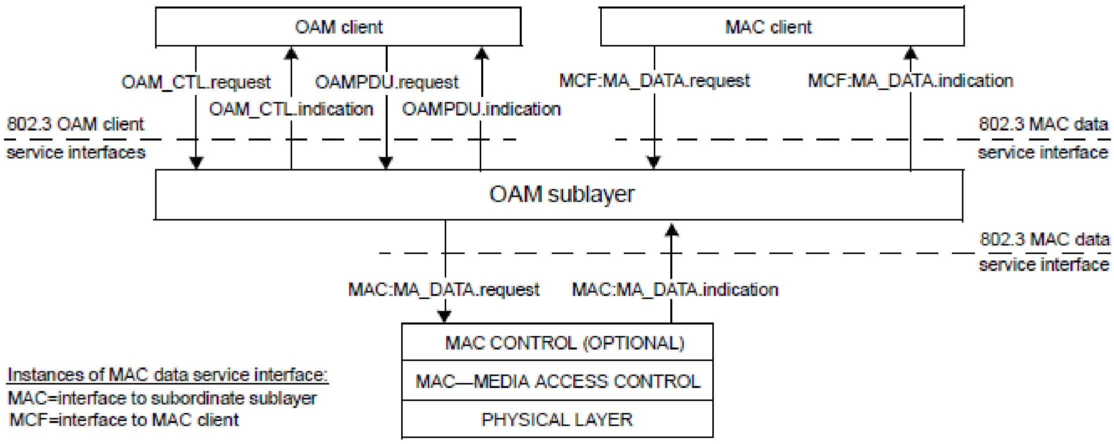


Figure B.3 OAM sub-layer support of interlayer service interfaces

In EPON, the OAM sub-layer provides details and functional requirements as follows:

a) Remote Failure Indication

   1. A mechanism is provided to indicate to a peer that the receive path of the local DTE is nonoperational.

   2. Physical layer devices may support unidirectional operation that allows OAM remote failure indication during fault conditions.

   3. Subscriber accesses physical layer devices to support unidirectional operation in the direction from OLT to ONU that allows OAM remote failure indication from OLT during fault conditions.

   4. Physical layer devices other than those listed above do not support unidirectional operation allowing OAM remote failure indication during fault conditions. Some physical layer devices have specific remote failure signalling mechanisms in the physical layer.

b) Remote Loopback: A mechanism is provided to support a data link layer frame-level loopback mode.

c) Link Monitoring

   1. A mechanism is provided to support event notification that permits the inclusion of diagnostic information.

d) Miscellaneous

   1. Implementation and activation of OAM is optional.

   2. A mechanism is provided that performs OAM capability discovery.

   3. An extension mechanism is provided and made available for higher layer management applications.

B.5 Dynamic Bandwidth Allocation (DBA)

IEEE 802.3ah standard does not specify any particular dynamic bandwidth allocation for EPON and it leaves it open for suppliers to develop and investigate different algorithms to offer the best service to the users.

As previously explained, an EPON is a point-to-multipoint network where the upstream channel is shared by all ONUs. To avoid data collision, scheduling is needed to prevent simultaneous transmissions from different ONUs. A available solution is to assign a time slot to each ONU, and each ONU can only transmit in its assigned time slot. While assigning every ONU a fixed time slot regardless of its demand is simple, this scheme cannot adapt to highly concentrated traffic and may waste bandwidth. Consequently, a more suitable scheme is to assign a variable and dynamic time slot for each ONU according to its demand.

Since EPON is expected to support diverse applications, various traffic sessions are aggregated into a limited number of classes to be serviced with differentiated services. Accordingly, there are multiple queues for different classes in an ONU. A newly arriving packet is first classified according to its QoS requirement and then placed into the corresponding queue. When the correct time slot arrives to an ONU, it begins to transmit packets at full channel speed. Hence an optimal bandwidth allocation scheme can improve the throughput and shorten the packet delay. Therefore, a key issue in EPON is to make the bandwidth to be used efficiently and fairly by all ONUs. DBA scheme is effective and flexible because the bandwidth is allocated according to the demands of ONUs (a variable size time slot is allocated dynamically to each ONU based on its instantaneous bandwidth demand).

Many DBA algorithms [9–13] have been developed especially for EPONs to cope with the challenges explained before of high bandwidth utilisation and QoS provisioning. However, it is difficult to pick a single best algorithm due to the multidimensional performance requirements expected of a DBA algorithm. In addition, some algorithms introduce increased complexity when supporting higher concentrations of traffic demand, QoS, fairness, and so on.

The general taxonomy for DBA is depicted in figure B.4. It has been categorized the DBA algorithms for EPONs into algorithms with statistical multiplexing and algorithms with quality of service (QoS) assurances. The latter are further subdivided into algorithms with absolute and relative QoS assurances. For EPON, Interleaved Polling with Adaptive Cycle Time (IPACT) is considered one of the most efficient DBA algorithms (Statistical Multiplexing) in terms of bandwidth utilisation. Therefore, the following, IPACT will be discussed in greater detail.

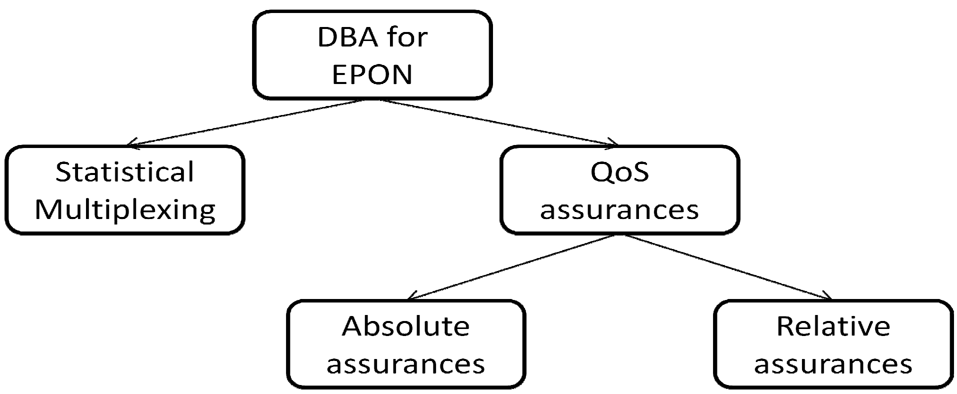


Figure B.4 Taxonomy of dynamic bandwidth allocation algorithm for EPON

B.5.1 Statistical MULTIPLEXING METHODS

For statistical multiplexing methods, the grant window size of each ONU's first grant is set to some arbitrary value. The cycle period adjusts to the bandwidth requirements of the ONUs and what is more interesting of IPACT [14] is that it uses an interleaved polling approach, in which the next ONU is polled before the transmission of the previous one is finished, as depicted in figure B.5.

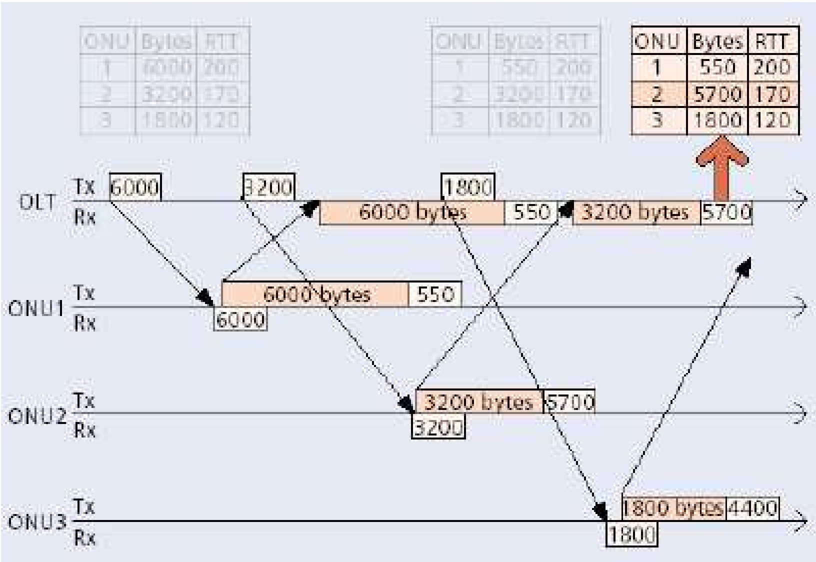


Figure B.5 Interleaved polling mechanism in IPACT

In this scheme, the OLT knows exactly how many bytes are waiting in each ONU's buffer and the Round Trip Time (RTT) for each ONU, keeping the data in a polling table.

Supposing that at the time the OLT sends a control message (a Grant) to ONU 1, allowing it to send 6000 bytes (see figure B.5), OLT calculates the transmission window length and its start time for the ONUs as next indications.

The ONU upon receiving the Grant from the OLT, it can start sending its data with a maximum size of the granted window. At the end of its transmission window, it will generate a control message (a Report) telling the OLT how many bytes still left to transmit in its buffer.

- Bandwidth is dynamically assigned to ONUS according to their queue occupancies. If a given ONU's queue is empty, the OLT still grants a transmission window of zero byte to that ONU such that the ONU is able to report its queue occupancy for the next grant.

- The OLT keeps track of the RTTs of all ONU's. As a result, the OLT can send out a grant to the next ONU in order to achieve a very tight guard band between consecutive upstream transmissions, resulting in improved bandwidth utilisation. The guard band between two consecutive upstream transmissions is needed to compensate for RTT fluctuations and to give the OLT enough time to adjust its receiver to the transmission power level of the next ONU.

In IPACT each ONU is served once per round-robin polling cycle. The cycle length is not static but adapts to the instantaneous bandwidth requirements of the ONUs. By using a maximum transmission window (MTW), ONUs with high traffic volumes are prevented from monopolising the bandwidth. The OLT allocates the upstream bandwidth to ONUs in one of the following ways:

- ***Fixed service:*** This DBA algorithm ignores the requested window size and always grants the MTW size. As a result, the cycle time is constant.

- ***Limited service:*** This DBA algorithm grants the requested number of bytes but no more than the MTW.

- ***Credit service:*** This DBA algorithm grants the requested window plus either a constant credit or a credit that is proportional to the requested window.

- ***Elastic service:*** This DBA algorithm attempts to overcome the limitation of assigning at most one fixed MTW to an ONU in a round.

In summary, IPACT improves channel utilisation efficiency by reducing the overhead arising from walk times (propagation delay) in a polling system. This is achieved by overlapping multiple polling requests in time. IPACT allows for statistical multiplexing and dynamically allocates upstream bandwidth according to the traffic demands of the ONUs within adaptive polling cycles. Furthermore, using an MTW, throughput fairness among ONUs is achieved.

B.5.2 ABSOLUTE QoS ASSURANCE

B.5.2.1 Bandwidth Guaranteed Polling

In the Bandwidth Guaranteed Polling (BGP) method, ONUs are categorised such as bandwidth guaranteed ONUs and non-bandwidth-guaranteed (Best Effort). The bandwidth guaranteed is characterised by the SLA with the network provider where the total upstream bandwidth is divided into equivalent bandwidth units and it also indicates a fixed cycle length to be distributed among ONUs. In the case of bandwidth guaranteed ONUs, according to the SLA, can obtain more than one bandwidth unit and at the same time if one of the bandwidth units is not occupied, it can be dynamically assigned to best effort nodes.

Overall, the advantage of the bandwidth guaranteed polling approach is that it ensures an ONUS receiving the bandwidth specified by its SLA and that the spacing between transmission grants corresponds to SLA’s has a fixed-bound. The approach also allows for the statistical multiplexing of traffic into unreserved bandwidth units as well as unused portions of a guaranteed bandwidth unit (i.e., if an ONU does not have enough traffic to use all the bandwidth specified in its

SLA). One drawback of upstream transmission grants of fixed bandwidth units is that the upstream transmission tends to become fragmented, with each fragment requiring a guard band, which tends to reduce throughput and bandwidth utilization.

B.5.2.2 Deterministic Effective Bandwidth

In Deterministic Effective Bandwidth (DEB), a given ONU maintains several queues, typically one for each traffic source or each class of traffic sources. A given queue is categorized as either a QoS queue or a best effort queue, depending on the requirements of the corresponding traffic source (class). A given traffic source feeding into a QoS queue is characterized by leaky bucket parameters. The leaky bucket parameters are traffic descriptors widely used in QoS networking; they give the peak rate of the source, the maximum burst the source can send at the peak rate, as well as the long run average rate of the source. A source also specifies the maximum delay it can tolerate. The leaky bucket traffic characterization together with the delay limit of the source (class) are used to determine whether the system can support the traffic in the QoS queues at all ONUs without violating delay bounds (and also without dropping any traffic at a QoS queue) using techniques derived from the general theory of deterministic effective bandwidths.

The advantage of the DEB approach is that individual flows (or classes of flows) are provided with deterministic QoS guarantees, ensuring lossless bounded-delay service. In addition, best effort traffic flows can utilise bandwidth not needed by QoS traffic flows. One main drawback of the DEB approach is that it requires increased complexity to conduct admission control and update proportions of effective bandwidths of ongoing flows.

B.5.3 RELATIVE QoS ASSURANCE

B.5.3.1 DBA for Multimedia

In dynamic bandwidth allocation for multimedia [15], traffic in each ONU is placed into one of three priority queues (high, medium, and low). These priorities are then used by the DBA algorithm to assign Bandwidth. The sizes of the three priority queues in each ONU are reported to the OLT. Based on these factors the OLT separately issues grants to each priority within each ONU. In particular, bandwidth is first handed out to the high-priority queues, satisfying all the requests of high-priority flows. The DBA algorithm then considers the requests from medium-priority flows. If it can satisfy all of the medium- priority requests with what is left over from high-priority requests, it does so. Otherwise, it divides the remaining bandwidth between all medium-priority flows, where the fraction of the bandwidth granted to each medium-priority flow is related to the fraction requested by each flow to the total of all medium-priority requests. Finally, if there is any bandwidth left over after satisfying high- and medium-priority requests, it is distributed among low-priority flows in a manner identical to the case where all medium-priority flows requests cannot be fully satisfied.

Note that in the DBA for multimedia approach, bandwidth is essentially allocated using strict priority based on the requirements of each priority traffic class of the entire PON (all the ONUs connected to a single OLT). One feature of this approach is that the OLT controls the scheduling within the ONU. This comes at the expense of reporting the occupancies of the individual priority queues and issuing multiple grants to each ONU per cycle.

B.5.3.2 DBA for QoS

DBA for QoS [16] is a method of providing per-flow QoS in an EPON using differentiated services. Within each ONU, priority packet queuing and scheduling is employed per the differentiated services framework. This is similar to DBA for multimedia, but recall that in DBA for multimedia priority scheduling was performed at the PON level (all ONUs connected to a single OLT). In contrast, in DBA for QoS priority scheduling is performed at the ONU level.

ANNEX C. MANUAL CONFIGURATION OF EMS

This manual provides the basic procedures to configure and process the Trident7 network devices using the EMS. To ensure that PON technology processes correctly with all required devices it's necessary to provisionally construct the OLT within a specific procedure depending on the desired traffic types. The EMS system can provide four types of traffic and has the ability to automatically set various parameters associated with each type of traffic. The four types of traffic are: Data, IPTV, VoIP, RF-return.

The RF return however, is not included within the scope of this project because the device includes a circuitry process that manages the return path of the standard cable interface for premium services such as Pay-per-View or Video-on-Demand, therefore this was not considered an applicable traffic type to use within this project. The configuration of the traffic type will be explained in a matter of comparison to others during the course of this chapter.

All services must follow a concrete procedure, and currently the EMS Provisioning system consists of the following features:

- VLAN Service Definition
- VLAN Service Group
- Service Provider Manager
- Trident 7 Packages

The following figure C.1 outlines the steps of the procedure from the 'New VLAN definition' to the 'Package assigned to the ONU'.

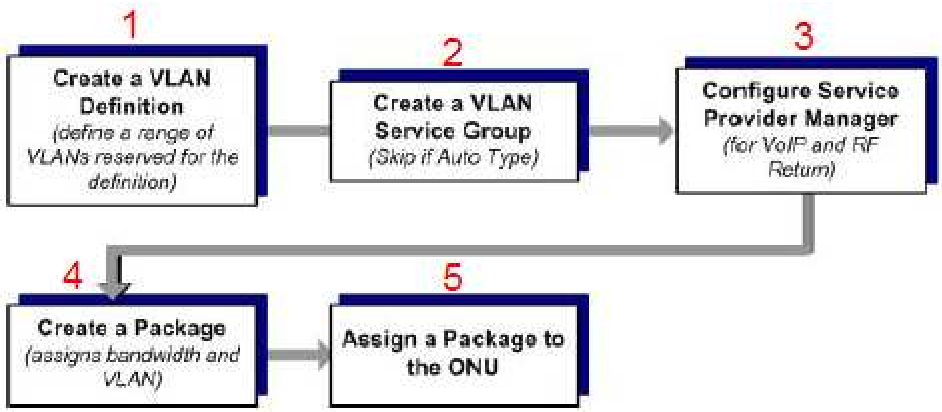


Figure C.1 Circuit to assign a Package to the ONU

Annex C will describe in a step by step process the outlined review in figure C.1 and will include the relevant information regarding this configuration. Firstly figure C.1, it is necessary to verify if the ONU devices are connected and capable to activate to the OLT in order to gain the ability to configure. Also the main window looking is displayed in figure C.2.

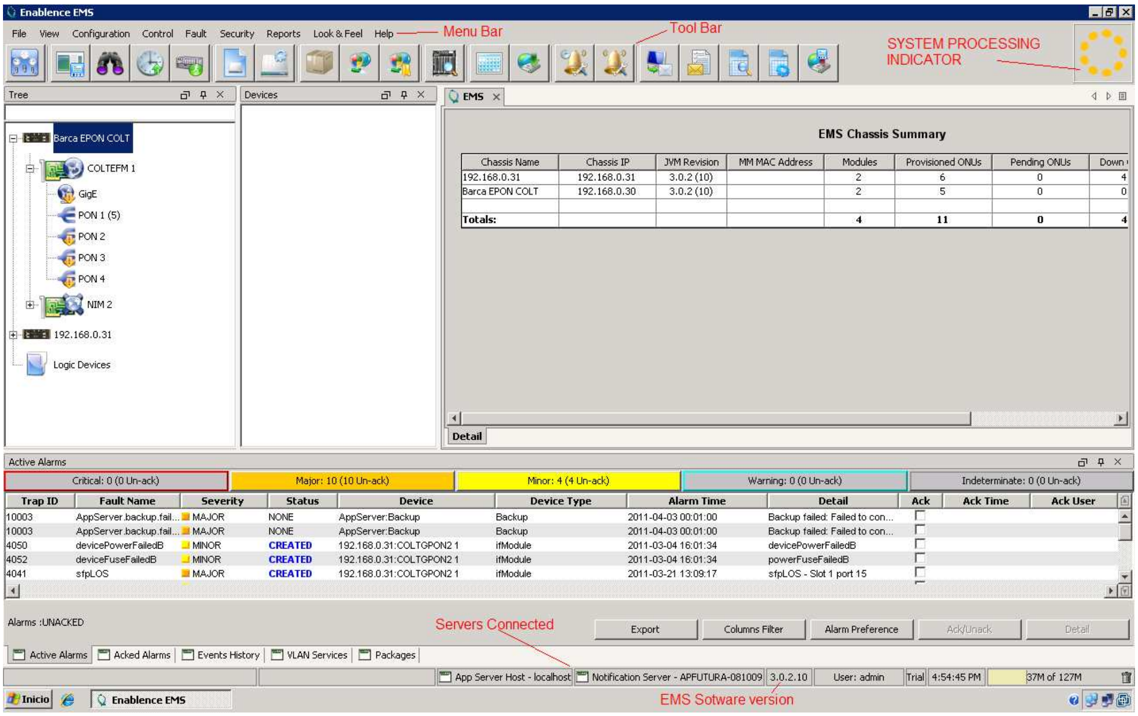


Figure C.2 Parts of the Main Window

Figure C.3 demonstrates when the devices area is populated with ONUs and for instance in the ‘EFM ONU Details’ it can be seen that the ONU 221 device State is *Active.*

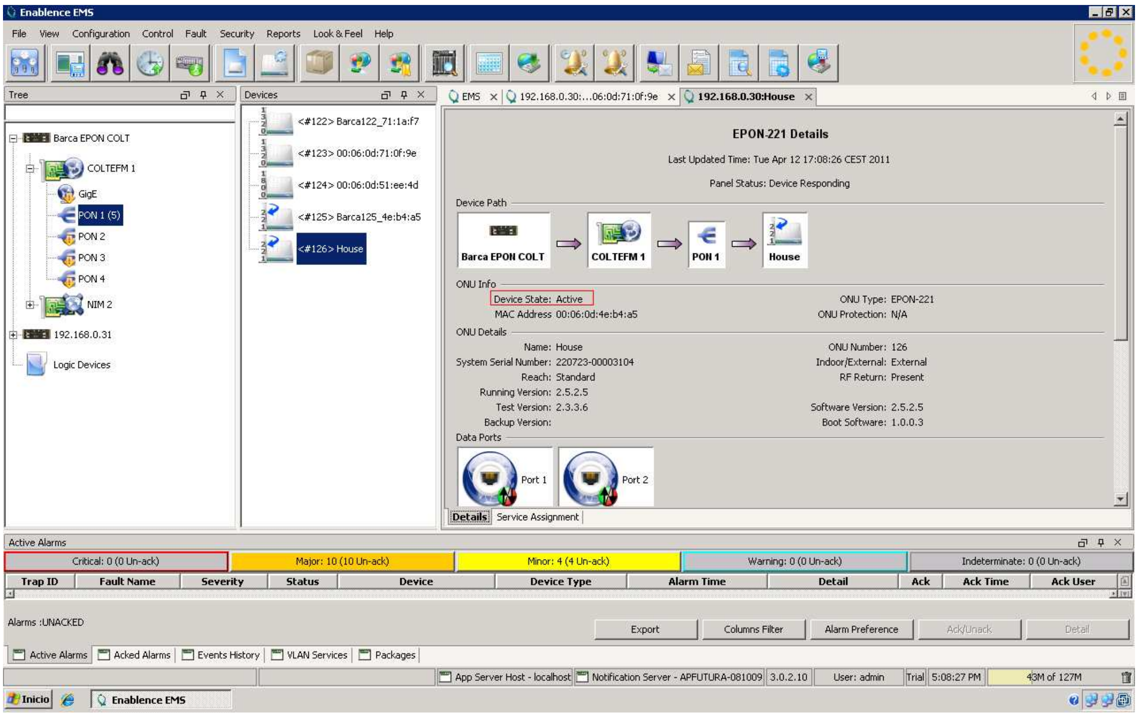


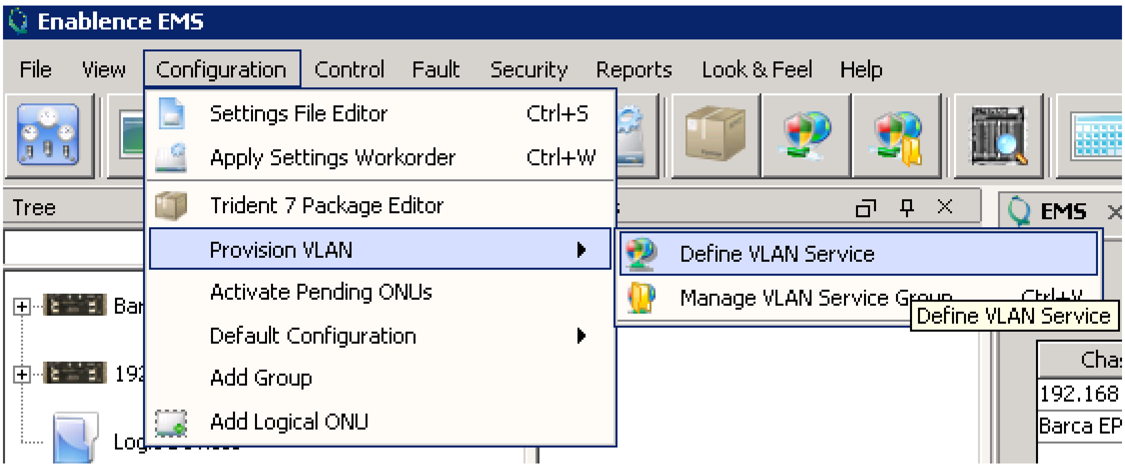
Figure C.3 Active ONU; ready to be configured

ONUs can be configured and provisioned when connected correctly and visible from the OLT.

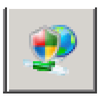
C.1 VLAN Service Definition

VLAN configurations are assigned to a group of devices on a LAN that are configured using software. This configuration allows devices on a different number of LAN segments to communicate as if they were on the same LAN segment, thereby ensuring that broadcast frames are switched only between ports within the same VLAN. The Trident 7 is setup mainly using VLANs to isolate traffic within the system. Single tag, or a double tagging scenario are both supported and tagging can be terminated at the ONU or forwarded. The VLANS in the system will be divided by Region, Chassis, Interface Module, PON and ONUs. Considering this information and due to the fact that this project is built with one PON, a sensible and constructive proposal could be to complete all configurations with ONU VLAN (can assign a different VLAN to each ONU on a chassis). Therefore each ONU can be configured with different VLANs in order to test the different parameters in Trident 7 OLT. Otherwise the use of a singular VLAN configured for the whole scenario would prove impossible when testing the network.

The main way to access to the VLAN configuration Services is from the menu bar selecting: *Configuration > Provision VLAN > Define VLAN Service*



Another possible way to access to the *Define VLAN Service* is clicking the button below placed on the tool bar of the main window:



The *VLAN Service Definition* window allows you to:

- View a list of currently configured VLAN services
- Add a new VLAN service
- Access detail information for a selected VLAN service
- Delete a VLAN service
- Create a service group (Point number two of figure C.1)

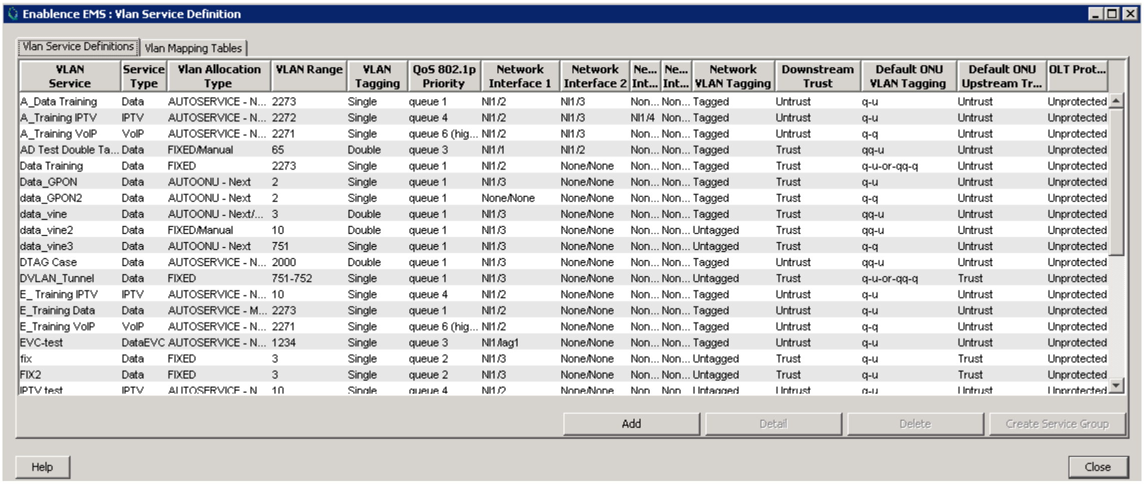


Figure C.4 Viewing of VLAN Services

Next table C.1 describes all different parameters of *VLAN Service Definition* Window Fields.

Field	Description
VLAN Service	User-assigned service name
Service Type	The type of service for which the VLAN is created. **Data:** VLAN is created for a Data service **IPTV:** VLAN is created for a IPTV service **VoIP:** VLAN is created for a Voice service **RFReturn:** VLAN is created for a Video service that supports RF Return
VLAN Allocation Type	Indicates the manner in which the VLAN is created **Fixed:** User manually creates the VLAN **Auto by name:** VLAN Service is created automatically by name **Auto by Chassis:** VLAN Service is created automatically for each chassis **Auto by Interface Module:** VLAN Service is created automatically for each Interface Module **Auto by PON:** VLAN Service is created automatically for each PON **Auto by ONU:** VLAN Service is created automatically for each ONU **Auto by Service:** VLAN Service is created automatically for each Service

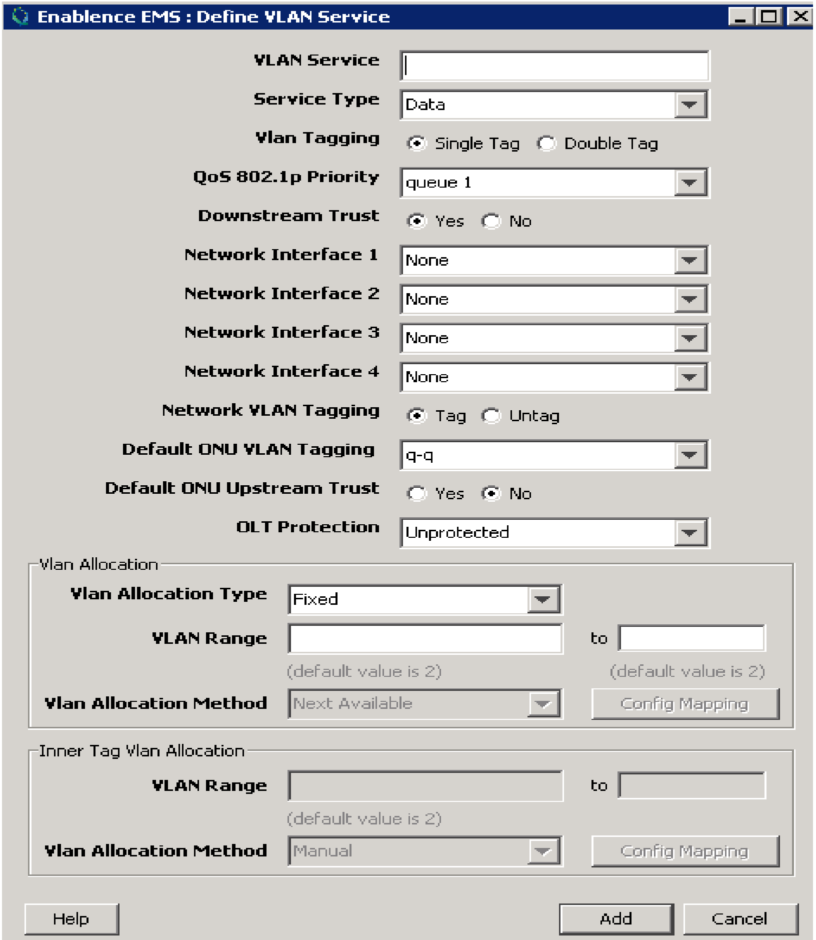
VLAN range	Range of VLAN Ids reserved for this service. Valid values: 2…4000
QoS priority	Priority assigned to traffic on this VLAN. Seven queues are available (Queue 0 -Queue 6) meaning that Queue 0 is the lowest priority, while Queue 6 is the highest one
Network Port 1	The network port on the Switch Module that the VLAN traffic uses
Network Port 2	The secondary network port on the Switch Module(s) that the VLAN traffic can use
Network VLAN Tagging	Type of network tagging defined on the Define VLAN Service window
Downstream Trust	Whether to use Diffserv to remark downstream traffic with the 802.1p priority tag. If yes, all traffic is passed and tag is 'trusted' from the connected network device. IF no, all traffic is tested and remarked using Diffserv Class Policy (DSCP)
Default ONU VLAN Tagging	Identifies the type of VLAN tagging used by this ONU. **q-q** tag forwarded through the system **q-u** tag traffic at the NI has tag removed at ONU **qq-q** double tagged traffic outer tag removed at ONU
Default ONU Upstream Trust	Whether to use Diffserv to test and reclassify upstream traffic. If yes, all traffic is passed and the 802.1p priority is 'trusted'. If no, all traffic is tested and the 802.1p priority tag is remarked with DSCP

Table C.1 Parameters of VLAN Service Definition

At the bottom of figure C.4 there are four different buttons with the command to add, delete or view the details of services. There is also a button to *Create a Service Group*.

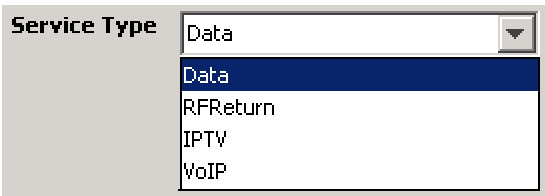
To add a VLAN Service follow next steps:

1. Click [Add] from the *VLAN Service Definition window*. The *Define VLAN Service* window displays:



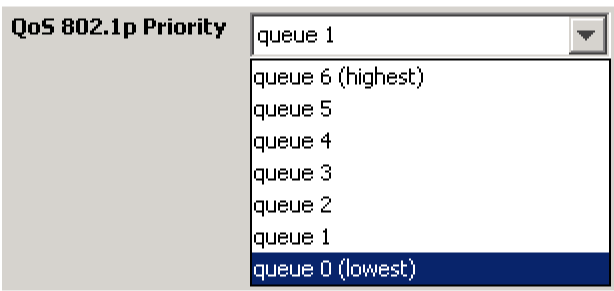
2. Enter a *VLAN Service Name*

3. Select the *Service Type* from the drop down list



4. Leave the option *VLAN tagging* by default of Single Tag unless you want to work with Double Tag

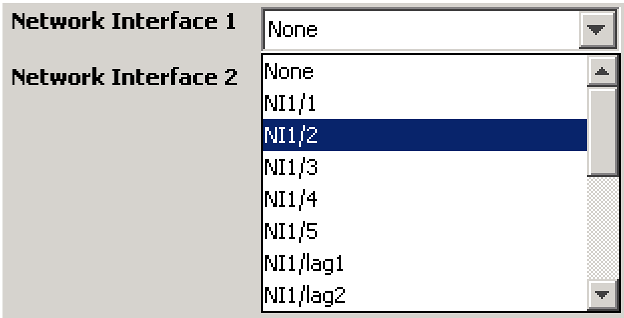
5. Choose the *QoS Priority* from the drop down list



Q6 and Q5	VoIP
Q4	IPTV / Return
Q0-Q3	Data

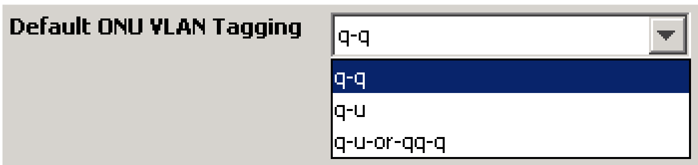
6. *Downstream Trust* indicates whether the traffic's 802.1p priority tag can be trusted. Choose YES or NO for *Downstream Trust*

7. From the *Network Port 1 and 2* drop down lists, select the network port on the Switch Module(s) that the VLAN traffic uses.



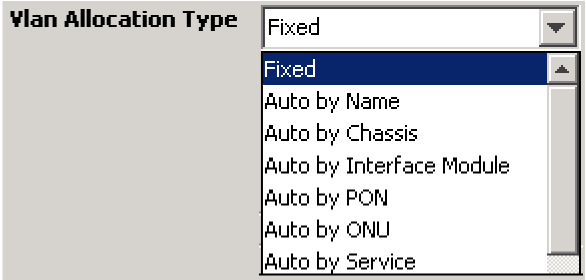
8. Indicate if *VLAN tagging* is required for traffic passing through switch port (the network port or network interface)

9. Choose the *ONU VLAN tagging* from the drop down list



10. Indicate if ONU Upstream traffic is to be trusted by selecting YES or NO

11. Use the drop down list to select the *VLAN Allocation Type*. This field indicates the manner in which the VLAN is created



Auto VLAN creation occurs when a port of the ONU is being assigned services, thus, VLANs do not have to be created beforehand. The VLAN Service Group step can be skipped unless a Fixed VLAN is required on the device.

12. Enter the *VLAN Range* and click [Add] to add the *VLAN Service*

If you want to view the details of a *VLAN Service*, on the *VLAN service Definition* window (see figure C.4), select a VLAN service and then click [Details]; you may modify the data as desired, but you must be aware that changes could affect other VLAN services. Then click [update] to save any changes. On the same window if you want to delete a VLAN Service, select it to remove, and then click [Delete] (the service should be removed from the list).

In figure C.5 and C.6 you can see examples of Data and VoIP VLAN Services:

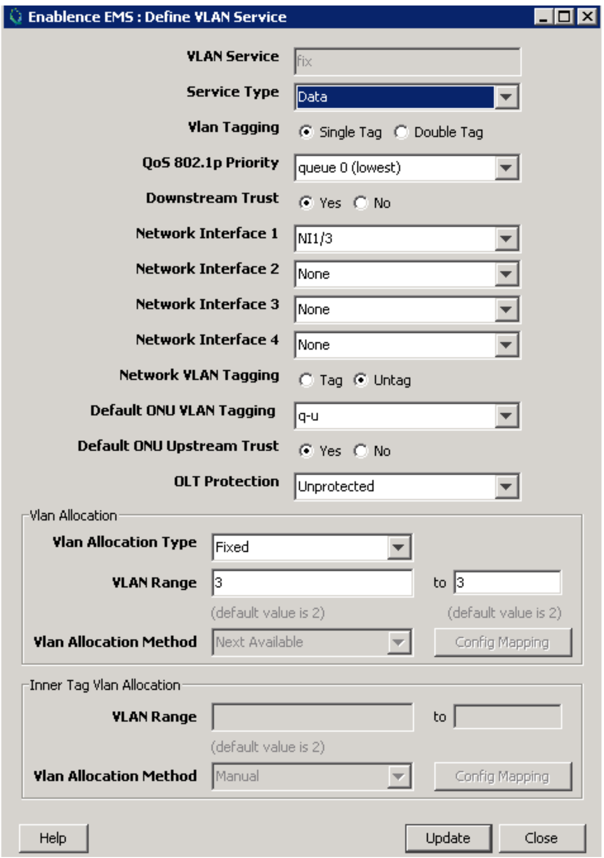


Figure C.5 Example of a Data VLAN Service

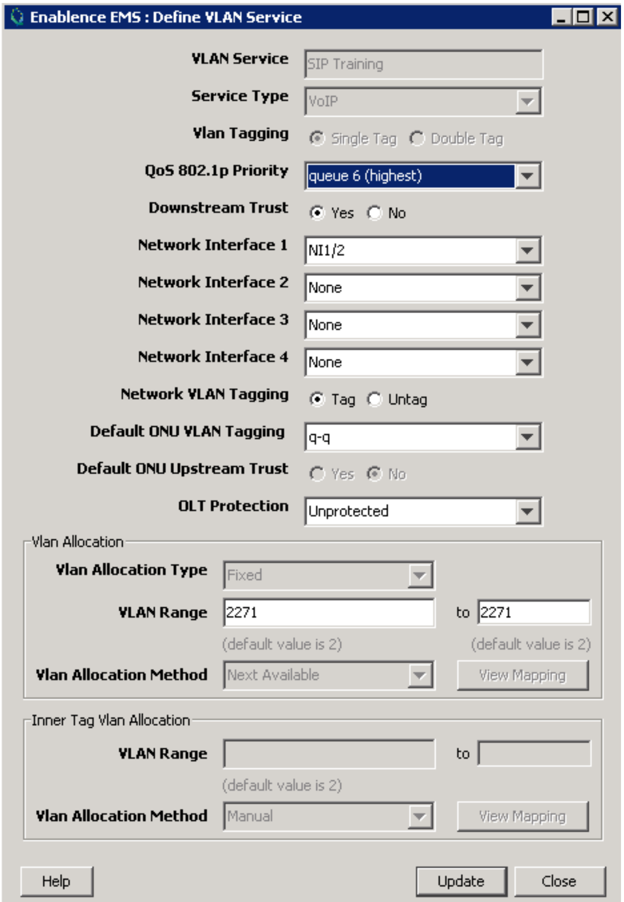
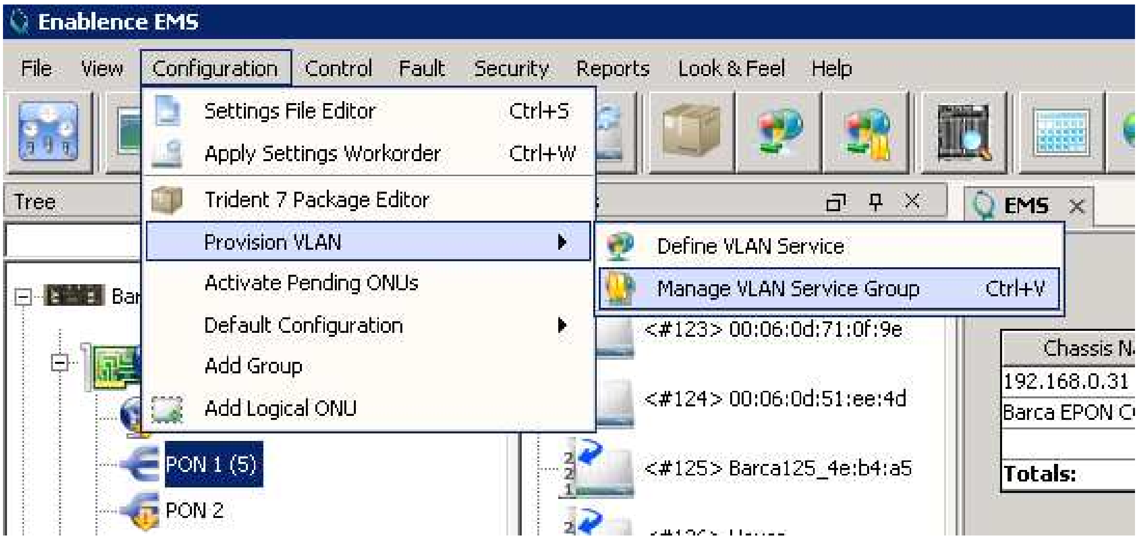


Figure C.6 Example of a VoIP VLAN Service

C.2 VLAN Service Group

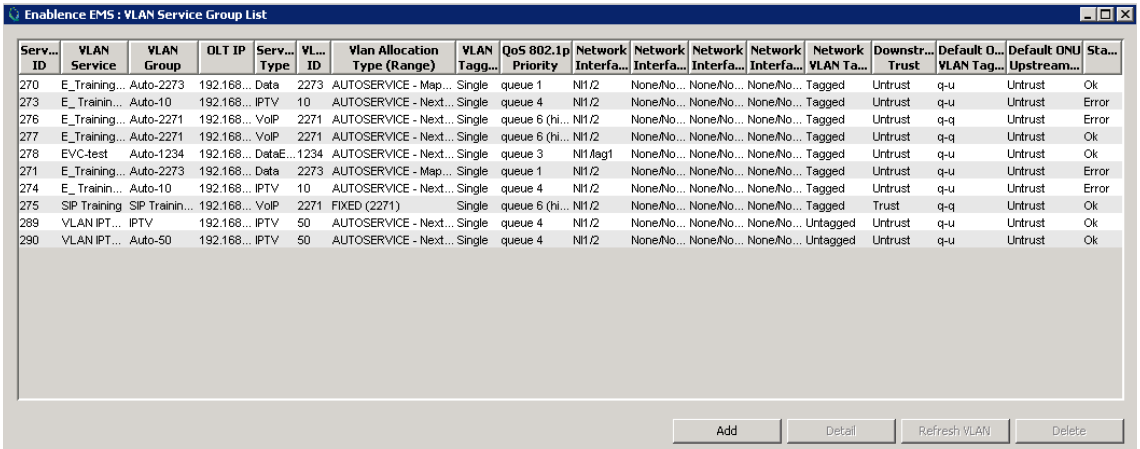
VLAN Service Groups must be created for a 'Fixed' type VLAN definition before a service package (point number four of figure C.1) is created. For auto types including auto by Name, auto by PON, auto by ONU etc, the VLAN Service Group step can be skipped. The Auto type will have the Service Group entry for the packages set to *Aut'*.

The main way to access the VLAN Service groups is from the menu bar selecting: *Configuration > Provision VLAN > Manage VLAN Service Group*



Another possible way to access to the *Manage VLAN Service Group* is clicking the button below placed on the tool bar of the main window:

The *VLAN Service Group* List window displays:



Serv... ID	VLAN Service	VLAN Group	OLT IP	Serv... Type	VL... ID	Vlan Allocation Type (Range)	VLAN Tagg...	QoS 802.1p Priority	Network Interfa...	Network Interfa...	Network Interfa...	Network Interfa...	Network VLAN Ta...	Downstr... Trust	Default O... VLAN Tag...	Default ONU Upstream...	Sta...
270	E_Training...	Auto-2273	192.168...	Data	2273	AUTOSERVICE - Map...	Single	queue 1	NI1/2	None/No...	None/No...	None/No...	Tagged	Untrust	q-u	Untrust	Ok
273	E_ Trainin...	Auto-10	192.168...	IPTV	10	AUTOSERVICE - Next...	Single	queue 4	NI1/2	None/No...	None/No...	None/No...	Tagged	Untrust	q-u	Untrust	Error
276	E_Training...	Auto-2271	192.168...	VoIP	2271	AUTOSERVICE - Next...	Single	queue 6 (hi...	NI1/2	None/No...	None/No...	None/No...	Tagged	Untrust	q-q	Untrust	Error
277	E_Training...	Auto-2271	192.168...	VoIP	2271	AUTOSERVICE - Next...	Single	queue 6 (hi...	NI1/2	None/No...	None/No...	None/No...	Tagged	Untrust	q-q	Untrust	Ok
278	EVC-test	Auto-1234	192.168...	DataE...	1234	AUTOSERVICE - Next...	Single	queue 3	NI1/lag1	None/No...	None/No...	None/No...	Tagged	Untrust	q-u	Untrust	Ok
271	E_Training...	Auto-2273	192.168...	Data	2273	AUTOSERVICE - Map...	Single	queue 1	NI1/2	None/No...	None/No...	None/No...	Tagged	Untrust	q-u	Untrust	Error
274	E_ Trainin...	Auto-10	192.168...	IPTV	10	AUTOSERVICE - Next...	Single	queue 4	NI1/2	None/No...	None/No...	None/No...	Tagged	Untrust	q-u	Untrust	Error
275	SIP Training	SIP Trainin...	192.168...	VoIP	2271	FIXED (2271)	Single	queue 6 (hi...	NI1/2	None/No...	None/No...	None/No...	Tagged	Trust	q-q	Untrust	Ok
289	VLAN IPT...	IPTV	192.168...	IPTV	50	AUTOSERVICE - Next...	Single	queue 4	NI1/2	None/No...	None/No...	None/No...	Untagged	Untrust	q-u	Untrust	Ok
290	VLAN IPT...	Auto-50	192.168...	IPTV	50	AUTOSERVICE - Next...	Single	queue 4	NI1/2	None/No...	None/No...	None/No...	Untagged	Untrust	q-u	Untrust	Ok

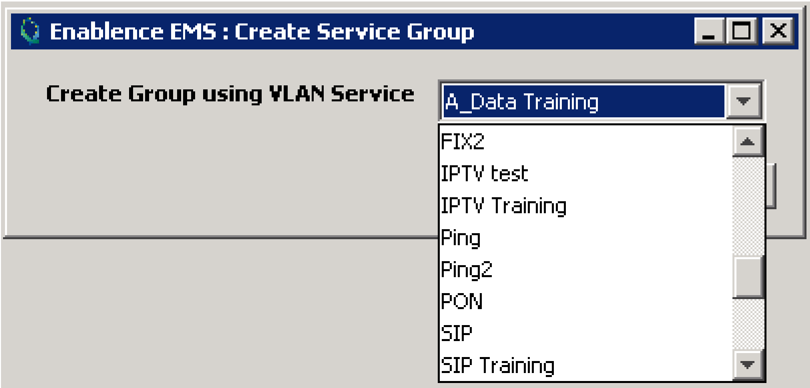
Figure C.7 Viewing of VLAN Service Groups list

This window (see figure C.7) provides the following functions:

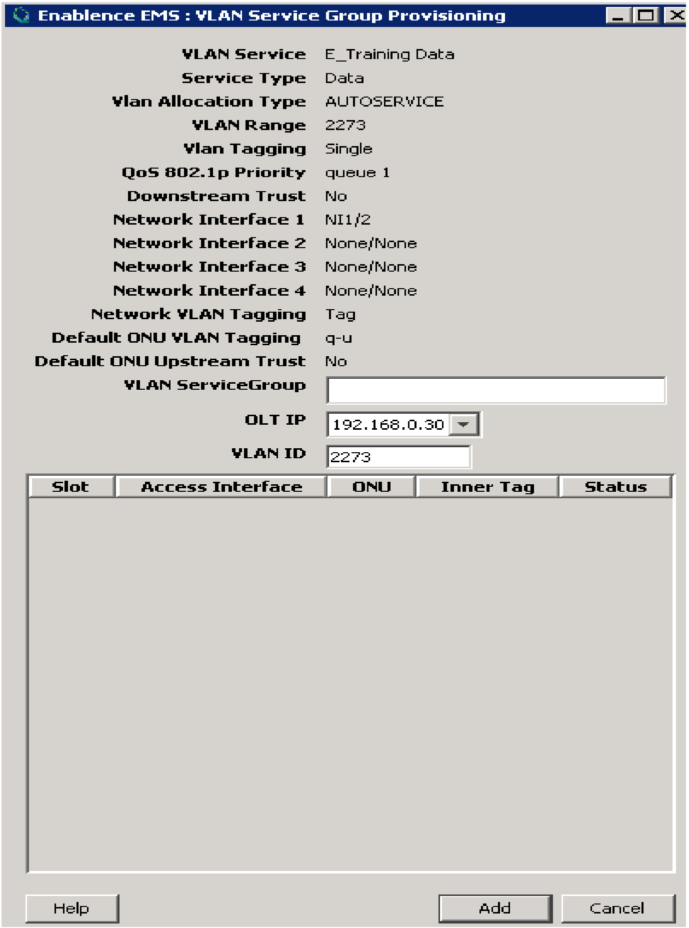
- Add a VLAN Service group
- View details for a selected group
- Delete a VLAN group

To add a *VLAN Service group* follow next steps:

1. Click [Add] from the *VLAN Service Group* List window. The *Create Service Group* window displays:



2. From the drop drown list, select the VLAN Service for the group and then click [Ok]. The *VLAN Service Group Provisioning* window displays:



3. Enter a name for the *VLAN Service Group*

4. From the drop down list, select the OLT IP address where the VLAN service group is to be created. In this case, it can be selected the address 192.168.0 30 for the EPON and the 192.168.0.31 for the GPON.

5. By default, the VLAN ID is filled with the next available ID in the range or you can also enter any number that is in the range.

6. Click [Add] to save the group information

If you want to view the details of a *VLAN Service group list*, on the VLAN service group list window (see figure C.7), select a VLAN service group and then click [Details]. This window does not support any changes to the data displayed. On the same window if you want to delete a VLAN Service group list, select it to remove, and then click [Delete] (the service should be removed from the list).

In figure C.8 you can see an example of Data VLAN Service group:

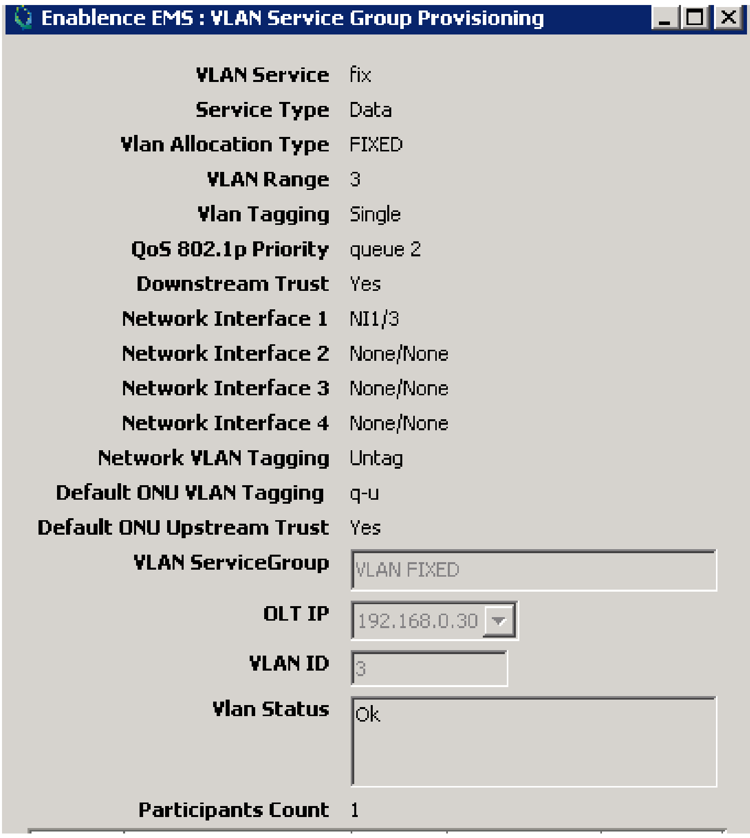
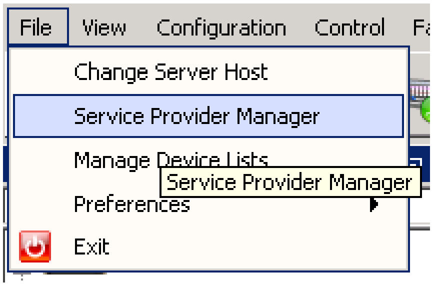


Figure C.8 Example of a Data VLAN Service group

C.3 Configure Service Provider Manager

The Service Provider Manager feature is where you will identify VoIP call agent settings and RF endpoints for ONUs that have RF Return. In this project RF is not included within the scope but the configuration procedure of the Service Provider Manager for VoIP will be explained further on in the chapter. If you are configuring another traffic type, this step C.3 can be skipped and pass to the next one C.4.

From the *File* menu on the menu bar, select *Service Provider Manager*.



The following figure C.9 displays a Service Provider List:

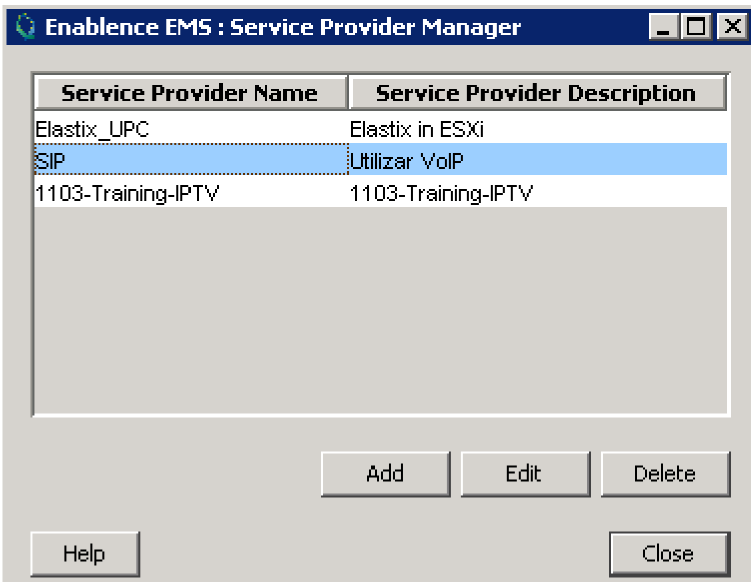


Figure C.9 Service Provider List

From this figure C.9, you can:

- Add new service providers
- Edit data for existing service providers
- Delete service providers

To add a new *Service Provider,* follow the next steps:

1. Click [Add] button and the following window displays:

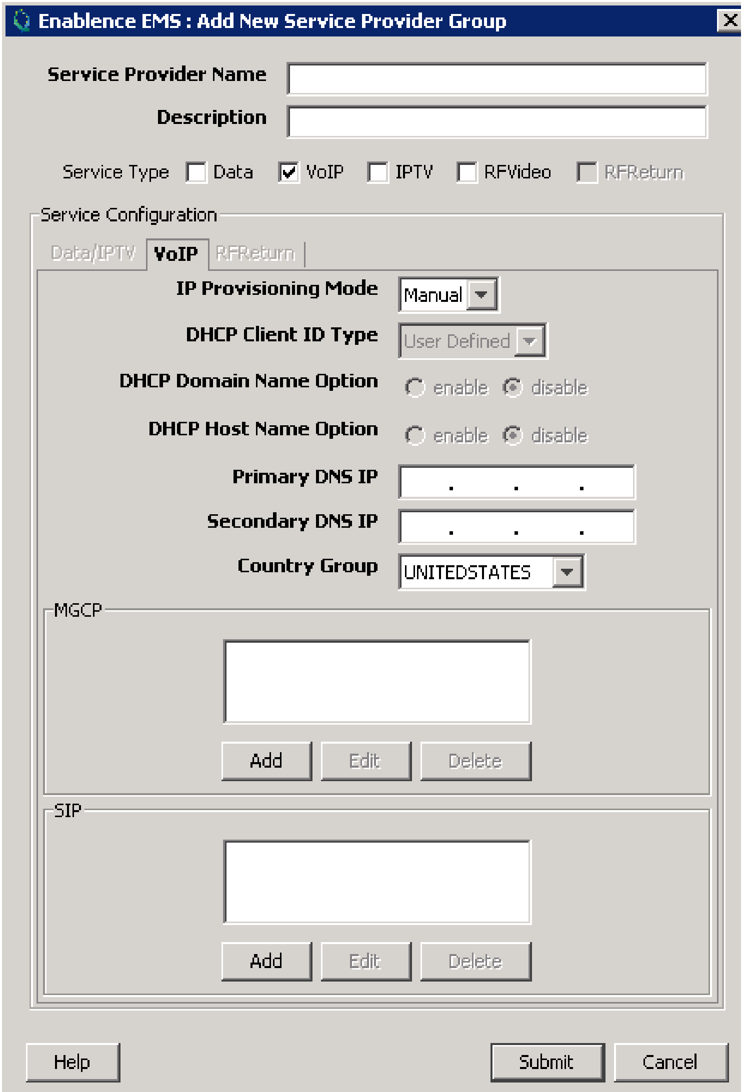
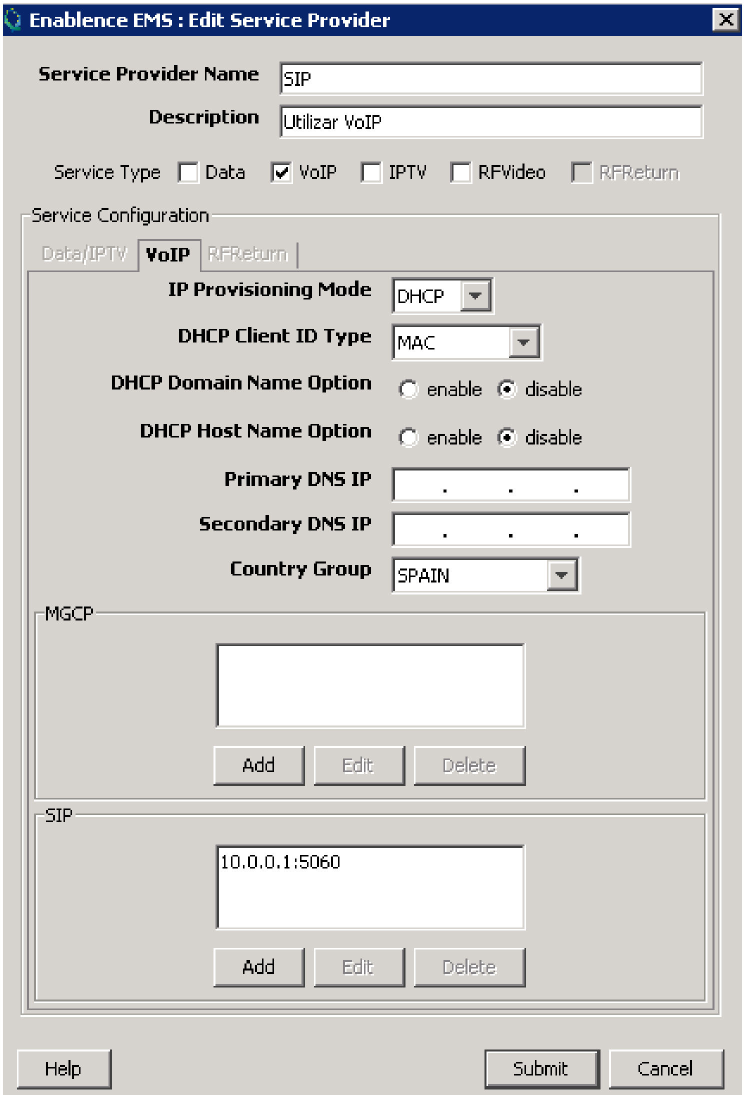


Figure C.10 Adding a New Service Provider Group

For this project these parameters are configured as follows:



2. Enter the *Service Provider's name* and the *Description* of the service provider

3. Select the *type of service* provided by clicking in the checkbox

In this case you must select VoIP. If VoIP is provided, then you must configure the parameters for either MGCP or SIP. Also RFReturn becomes available when RFVideo is checked.

4. Select the type of *IP Provisioning Mode* (Manual or DHCP). If you select Manual type, all different devices that are going to be connected to VoIP network must have a manual IP address in advance. If you select DCHP, SIP server can assign automatically an IP address to the device that wants to attach to the VoIP network (if DCHP runs in the server)

5. Select the type of *DHCP Domain Client ID type* (*user define* or *MAC*). If you have selected Manual in point 4 then select > user define. If you have selected DHCP in point 4 then select > MAC

6. You can specify a desired *Primary or secondary DNS IP*

7. Select your *Country group* from the drop down list

8. The process to add the parameter SIP can be explained in the following steps. Click the [Add] button for SIP and the following window displays:

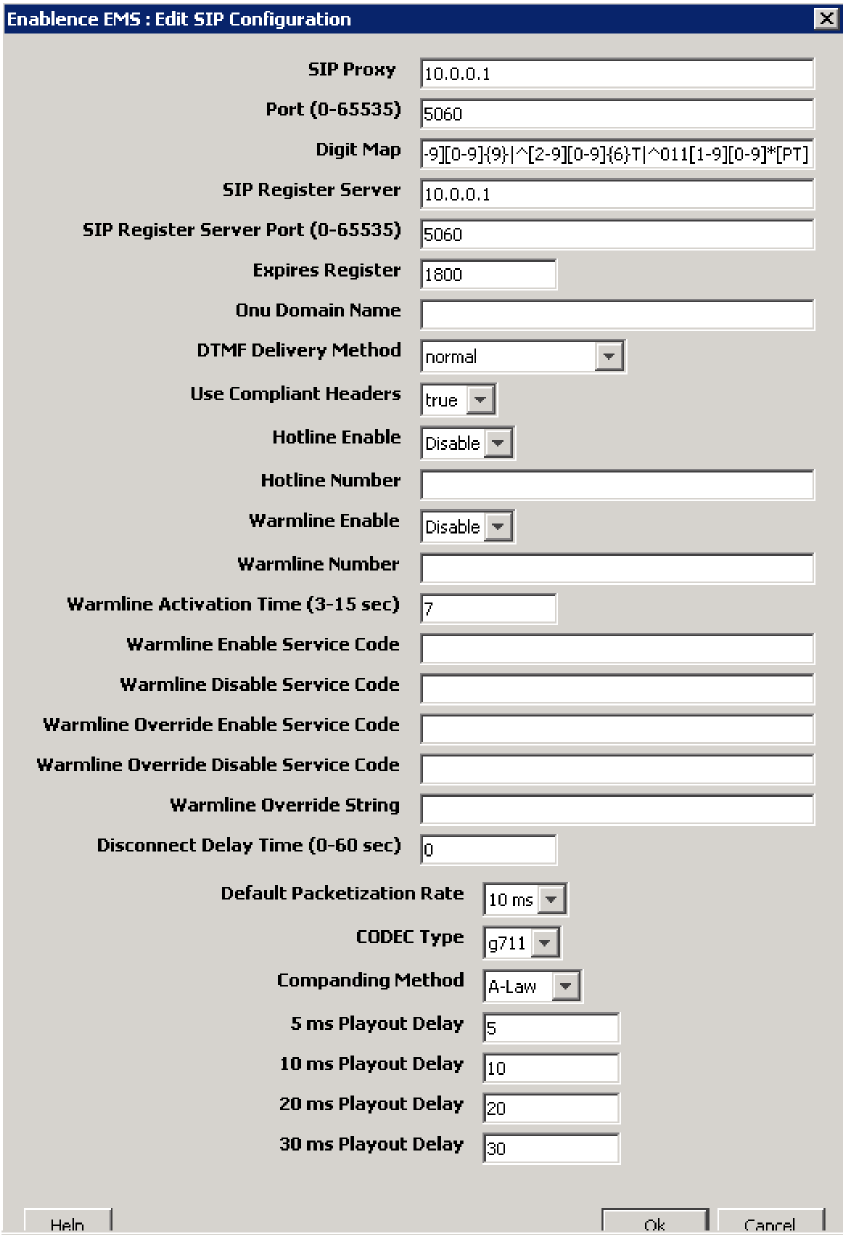


Figure C.11 Configure SIP

a) Identify an IP address and a *Port* number for the *SIP Proxy* server assigned to this user agent. This port number is associated with the Proxy Host Address

b) Identify either an IP address or a host name for the *SIP Register* server assigned to this user agent. In this case the SIP Proxy and SIP Register are the same one (10.0.0.1)

c) You can leave the rest of the parameters by default. If you want to change it there are some definitions for the parameters:

   i. You can indicate the value used in the *Expires* header field. A value of zero indicates that the *Expires* header should not be used

   ii. From the drop down list, indicate the *Default Packetization Rate* that should be used to communicate with the Call Server

   iii. Select the *CODEC Type* from the dropdown list (currently, g711 is the only available value)

   iv. Select the *Companding Method.*

      - A-law – the ITU-T companding standard in the conversion process used primarily in European telephone networks

      - U-law – the companding standard used in Japan and North America

   v. Indicate the *Playout Delays* to be applied to the voice RTP stream when using the selected packetization rate

5) When all the parameters are configured click [Submit] button and the *Service Provider* will be created

To edit *Service Provider* information:

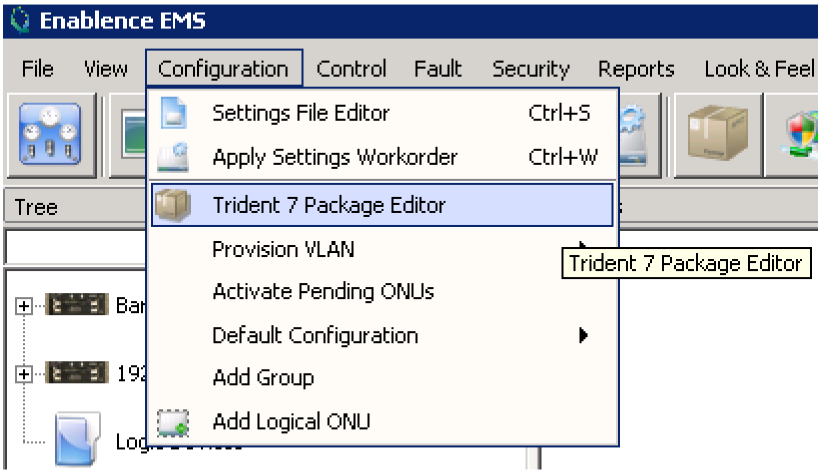
1) From the *Service Provider* list window, select the service provider and click [Edit] (Depending on the service provider´s capabilities, different fields will be shown).

2) To make a change in any section, select the data to change and click [Edit] to modify the data and [Delete] to remove data.

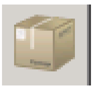
3) Once changes are made, click [Ok] from Edit window, and then click [Submit] on the *Edit Service Provider* window.

C.4 Package Creation

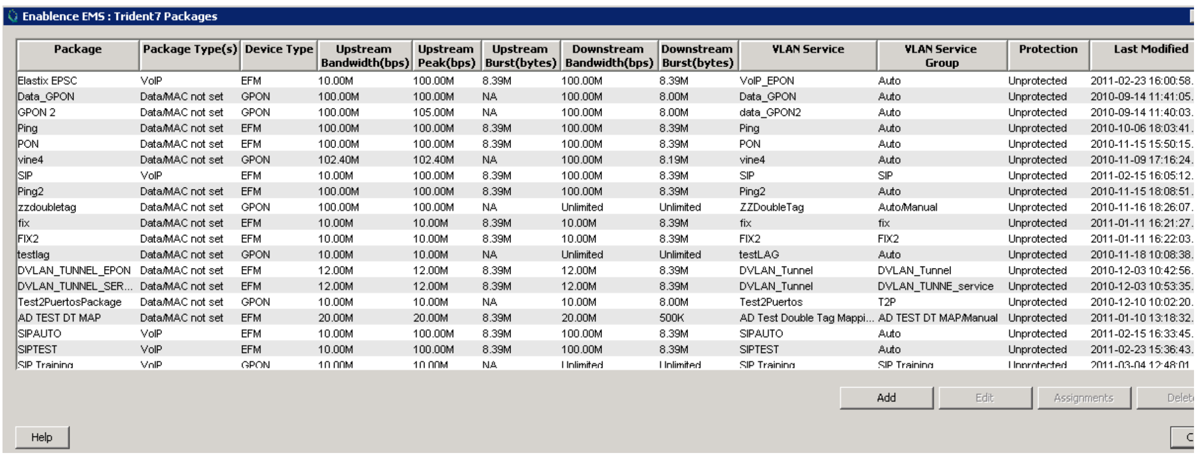
A package creation is needed to assign bandwidth and VLAN to different ONUs. The main way to access to the Service Package is from the menu bar selecting: *Configuration > Trident7 Package Editor*



Another possible way to access to the *Define VLAN Service* is clicking the button below placed on the tool bar of the main window:



Regardless of the method used, the following window displays:



Package	Package Type(s)	Device Type	Upstream Bandwidth(bps)	Upstream Peak(bps)	Upstream Burst(bytes)	Downstream Bandwidth(bps)	Downstream Burst(bytes)	VLAN Service	VLAN Service Group	Protection	Last Modified
Elastix EPSC	VoIP	EFM	10.00M	100.00M	8.39M	100.00M	8.39M	VoIP_EPON	Auto	Unprotected	2011-02-23 16:00:58.
Data_GPON	Data/MAC not set	GPON	100.00M	100.00M	NA	100.00M	8.00M	Data_GPON	Auto	Unprotected	2010-09-14 11:41:05.
GPON 2	Data/MAC not set	GPON	100.00M	105.00M	NA	100.00M	8.00M	data_GPON2	Auto	Unprotected	2010-09-14 11:40:03.
Ping	Data/MAC not set	EFM	100.00M	100.00M	8.39M	100.00M	8.39M	Ping	Auto	Unprotected	2010-10-06 18:03:41.
PON	Data/MAC not set	EFM	100.00M	100.00M	8.39M	100.00M	8.39M	PON	Auto	Unprotected	2010-11-15 15:50:15.
vine4	Data/MAC not set	GPON	102.40M	102.40M	NA	100.00M	8.19M	vine4	Auto	Unprotected	2010-11-09 17:16:24.
SIP	VoIP	EFM	10.00M	100.00M	8.39M	100.00M	8.39M	SIP	SIP	Unprotected	2011-02-15 16:05:12.
Ping2	Data/MAC not set	EFM	100.00M	100.00M	8.39M	100.00M	8.39M	Ping2	Auto	Unprotected	2010-11-15 18:08:51.
zzdoubletag	Data/MAC not set	GPON	100.00M	100.00M	NA	Unlimited	Unlimited	ZZDoubleTag	Auto/Manual	Unprotected	2010-11-16 18:26:07.
fix	Data/MAC not set	EFM	10.00M	10.00M	8.39M	10.00M	8.39M	fix	fix	Unprotected	2011-01-11 16:21:27.
FIX2	Data/MAC not set	EFM	10.00M	10.00M	8.39M	10.00M	8.39M	FIX2	FIX2	Unprotected	2011-01-11 16:22:03.
testlag	Data/MAC not set	GPON	10.00M	10.00M	NA	Unlimited	Unlimited	testLAG	Auto	Unprotected	2010-11-18 10:08:38.
DVLAN_TUNNEL_EPON	Data/MAC not set	EFM	12.00M	12.00M	8.39M	12.00M	8.39M	DVLAN_Tunnel	DVLAN_Tunnel	Unprotected	2010-12-03 10:42:56.
DVLAN_TUNNEL_SER...	Data/MAC not set	EFM	12.00M	12.00M	8.39M	12.00M	8.39M	DVLAN_Tunnel	DVLAN_TUNNE_service	Unprotected	2010-12-03 10:53:35.
Test2PuertosPackage	Data/MAC not set	GPON	10.00M	10.00M	NA	10.00M	8.00M	Test2Puertos	T2P	Unprotected	2010-12-10 10:02:20.
AD TEST DT MAP	Data/MAC not set	EFM	20.00M	20.00M	8.39M	20.00M	500K	AD Test Double Tag Mappi...	AD TEST DT MAP/Manual	Unprotected	2011-01-10 13:18:32.
SIPAUTO	VoIP	EFM	10.00M	100.00M	8.39M	100.00M	8.39M	SIPAUTO	Auto	Unprotected	2011-02-15 16:33:45.
SIPTEST	VoIP	EFM	10.00M	100.00M	8.39M	100.00M	8.39M	SIPTEST	Auto	Unprotected	2011-02-23 15:36:43.
SIP Training	VoIP	GPON	10.00M	10.00M	NA	Unlimited	Unlimited	SIP Training	SIP Training	Unprotected	2011-03-04 12:48:01

Figure C.12 Packages List

To add a *Package,* follow the next steps:

1. From the packages list window, click [Add] and the following window displays:

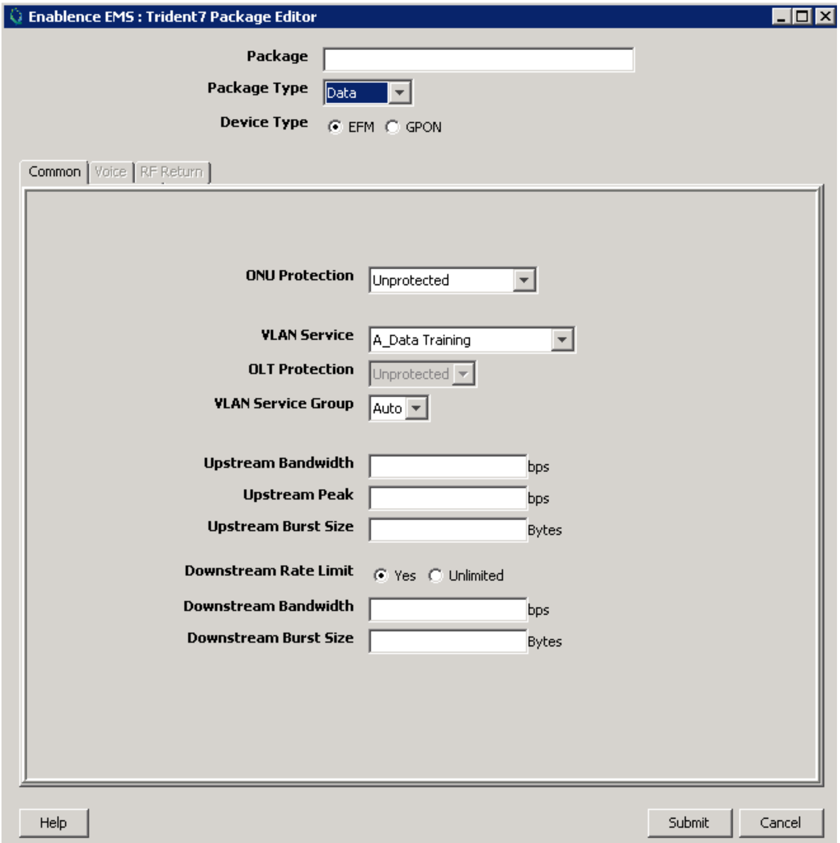
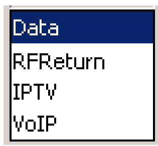


Figure C.13 Package Editor Example

2. Enter a name for the *package*, and from the *Package type* drop down list, select the type of traffic to which the package applies



At this point, the tabs and windows become available as they apply to the *Package Type* selected. It will be described how to add data (and IPTV) and VoIP package in the next steps.

C.4.1 Data package and IPTV package

The window displayed in figure C.13 also serves as the Data package by default. When creating an IPTV package these same instructions are applicable:

1. From *VLAN Service* drop down list , select the VLAN service to apply to this package

2. Select the *VLAN Service Group* from the drop down list. If the VLAN Definition is an auto type (Auto-Chassis, Auto-PON, Auto-Service, Auto-ONU etc), then de *VLAN Service Group* setting is set to *Auto* as in Figure C.13. If the setting is Fixed or Auto-name, the *VLAN Service Group* Name must be selected.

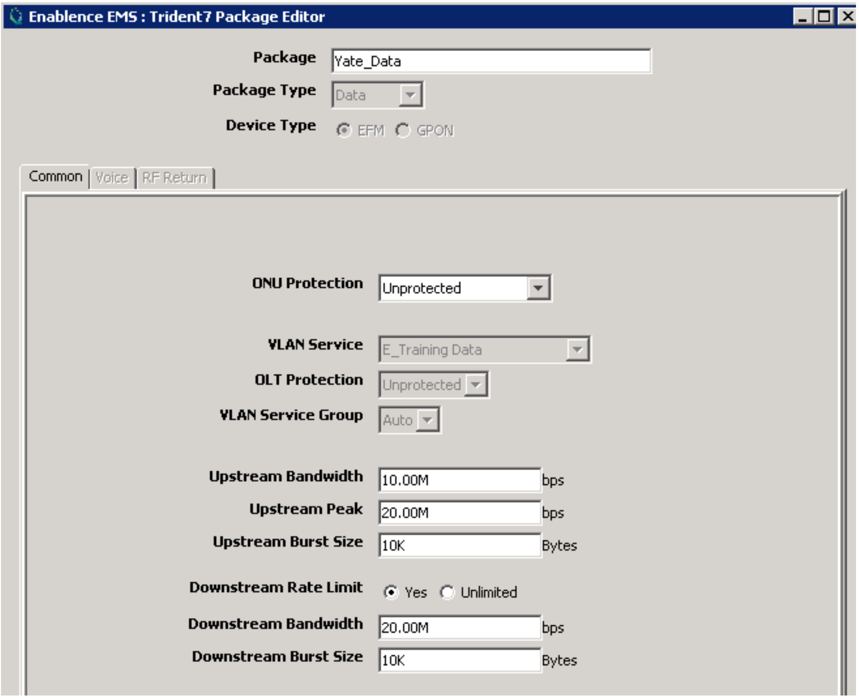
3. Set the *Upstream Bandwidth, Upstream Peak and Upstream Burst Size* to the desired value rate

4. Set the *Upstream Bandwidth, Upstream Peak and Upstream Burst Size* to the desired value rate

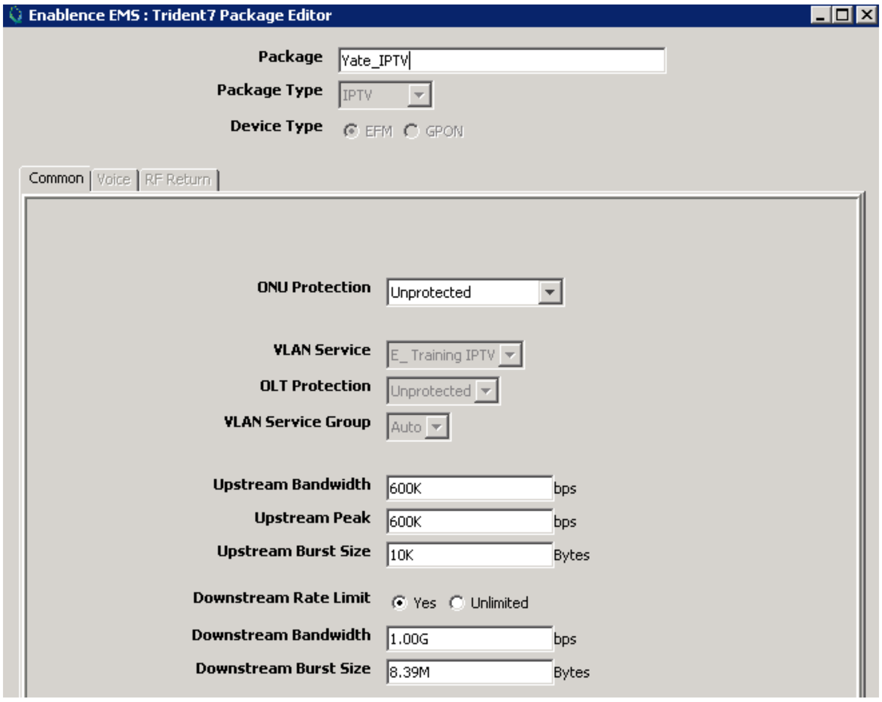
5. Click [Submit]

For this project one of the Data and IPTV package are configured as follows (being able to modify all rates):

Data package:



IPTV package:



C.4.2 VoIP package

From figure C.13 change the *Package type* to VoIP from the drop down list and the following window displays:

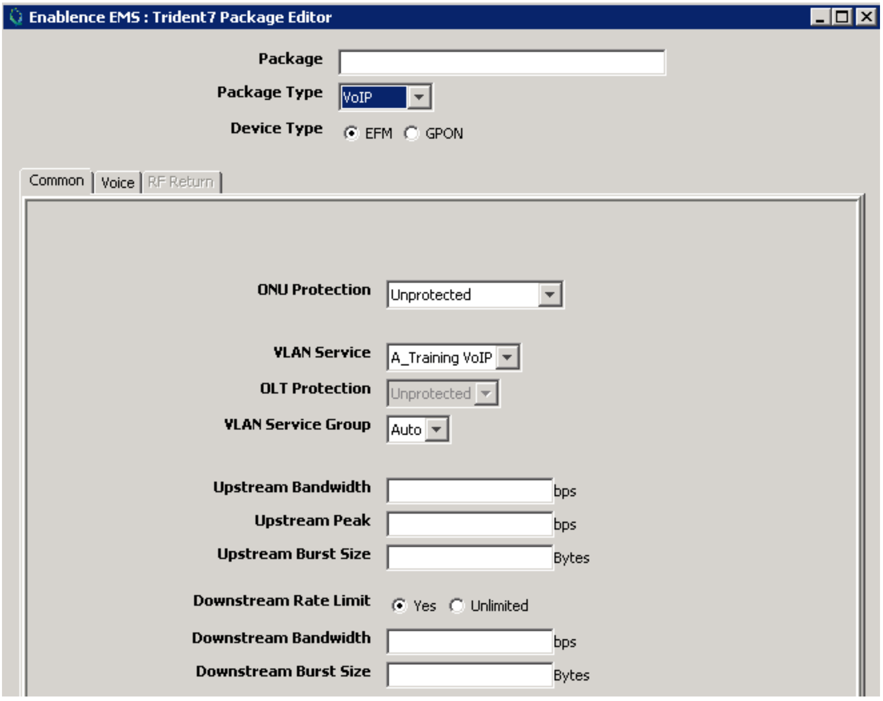


Figure C.14 Create a VoIP Package

1. Enter a name for the *package*, and set the values (rates) for both upstream and downstream VoIP traffic, peak and burst size.

2. Select a *VLAN Service* and *VLAN Service Group*. As in data / IPTV package, if the VLAN Definition is an auto type (Auto-Chassis, Auto-PON, Auto-Service, Auto-ONU etc), then de *VLAN Service Group* setting is set to *Auto*. If the setting is Fixed or Auto-name, the *VLAN Service Group* Name must be selected.

3. Select the Voice tab and following window displays:

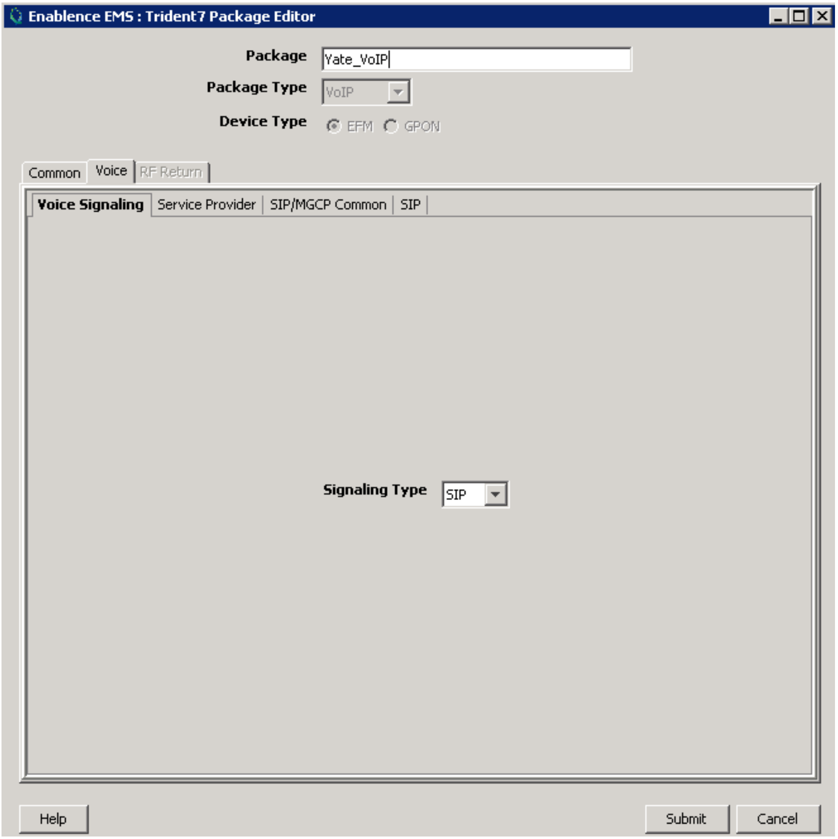
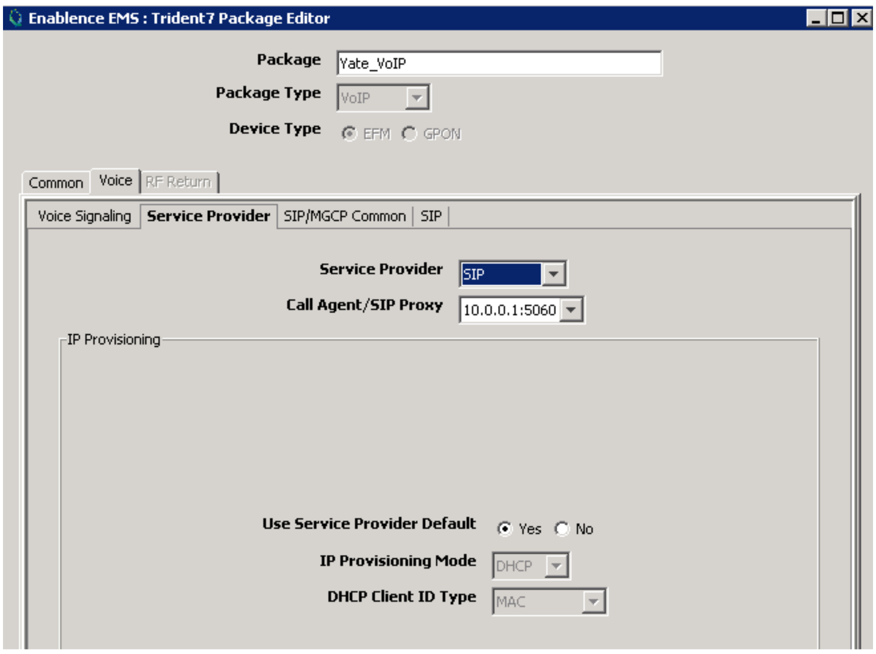


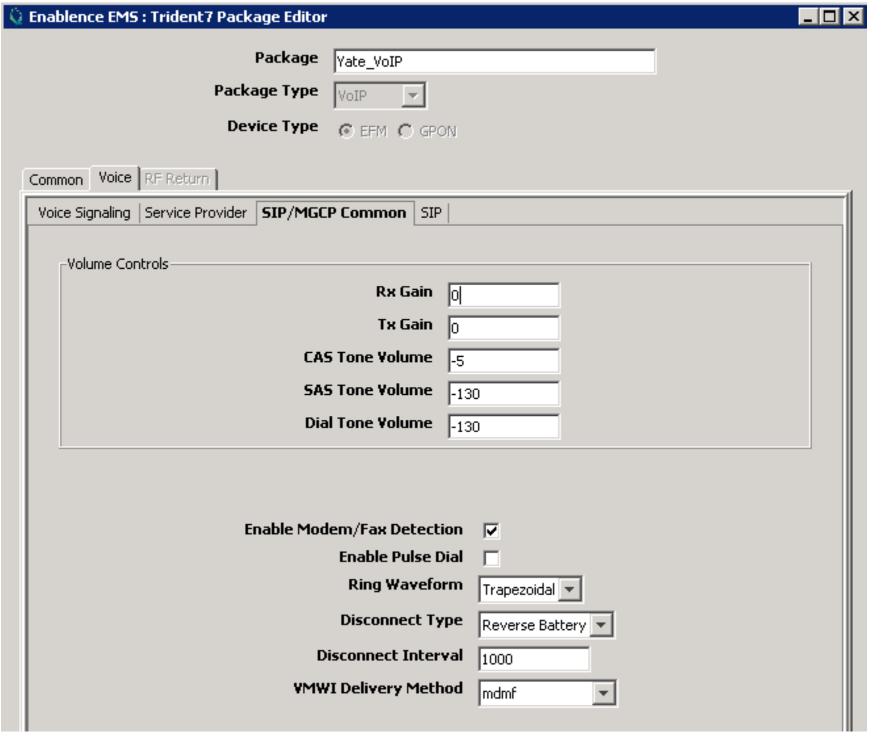
Figure C.15 Package Voice Settings

Select the *Signalling Type* for the VoIP package from the Voice Signalling tab. The available protocols are: MGCP and SIP, and all next procedures are focused in SIP.

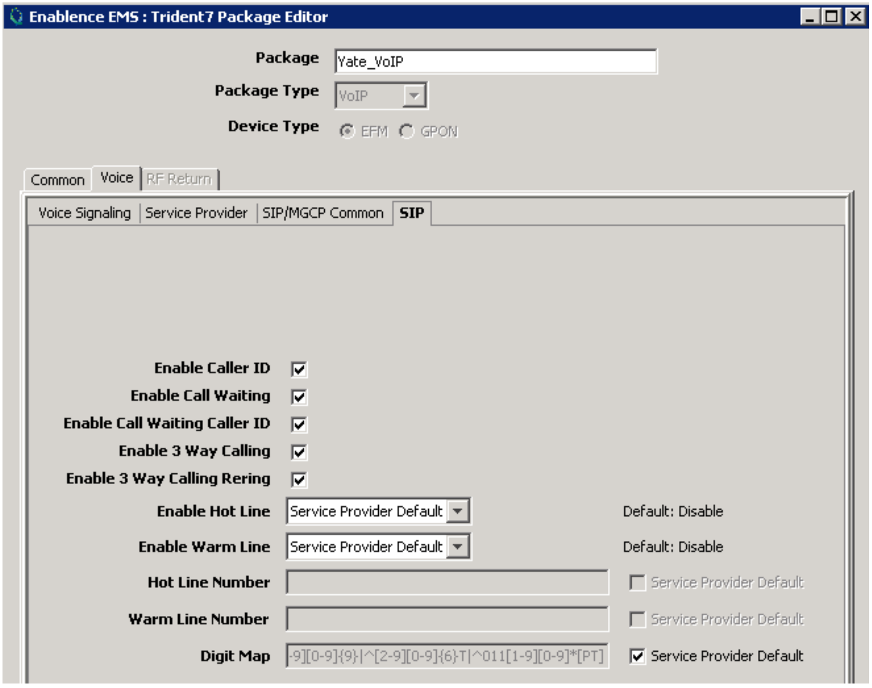
4. From *Service* Provider tab, select the *Service Provider* for the package and *Primary Call Agent* IP address for MGCP, or *SIP Proxy* IP address for SIP.



5. From *SIP/MGCP* Common tab, if necessary, check the box *Enable Modem / Fax Detection* and *Enable Pulse Dial*. Also you can select the *Ring Waveform, Disconnect Type* from drop down list and the *Disconnect Interval* (time in milliseconds)



6. From *SIP* tab, if necessary, check the box *Enable Caller ID, Call Waiting, Call waiting Caller ID, 3 way Calling, 3 way Calling Re-ring*.



7. Click [Submit]

To edit a *Package* (A package with assignments can not be edited):

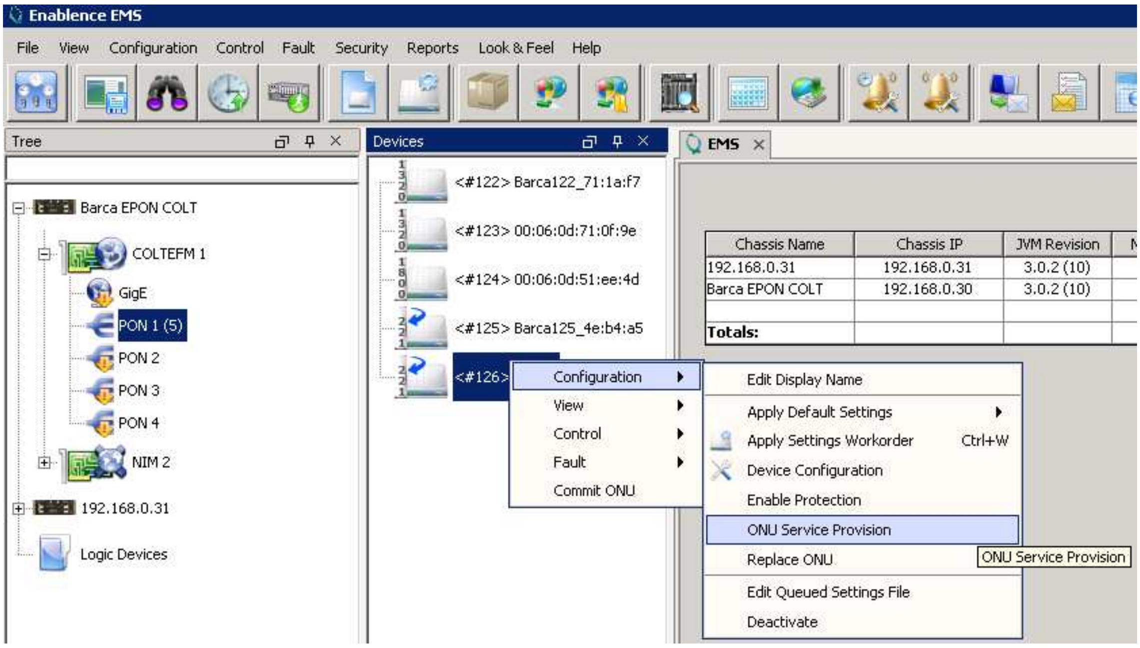
1. Select the package to edit on the packages list window and click [Edit]. The window displaying is the same used when adding a service.

2. Make the appropriate changes, and then click [Submit].

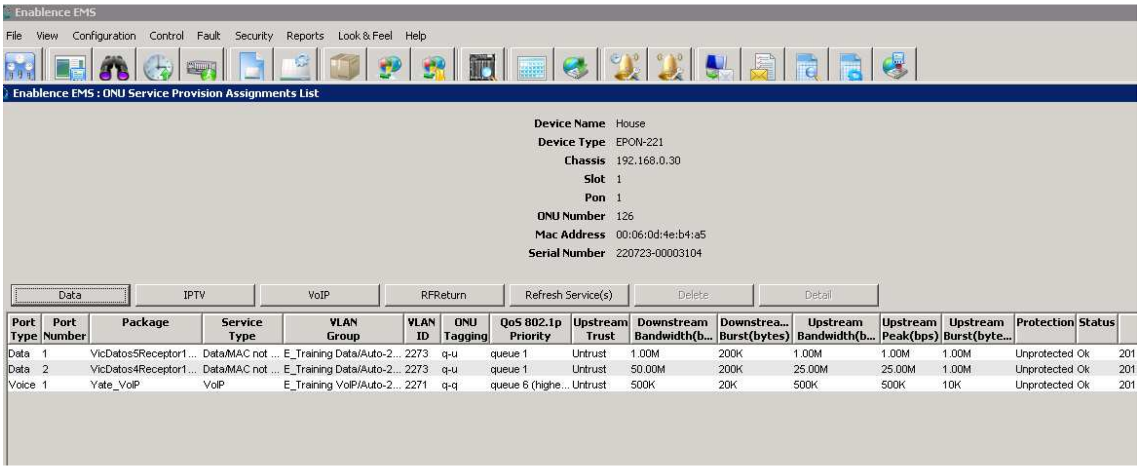
C.5 Assign a Package to the ONU

Assigning a Package to the ONU is the last point to get all the configurations completed in Trident 7. All ONU's must be provisioned with the concrete service required in order to work and make the network available to use.

The main way to access the Service Assignment feature is in the Devices list area of the main view. You must do a right-click on the desired ONU, and select *Configuration > ONU Service Provision.*



The following window displays:



Port Type	Port Number	Package	Service Type	VLAN Group	VLAN ID	ONU Tagging	QoS 802.1p Priority	Upstream Trust	Downstream Bandwidth(b...	Downstrea... Burst(bytes)	Upstream Bandwidth(b...	Upstream Peak(bps)	Upstream Burst(byte...	Protection	Status	
Data	1	VicDatos5Receptor1...	Data/MAC not ...	E_Training Data/Auto-2...	2273	q-u	queue 1	Untrust	1.00M	200K	1.00M	1.00M	1.00M	Unprotected	Ok	201
Data	2	VicDatos4Receptor1...	Data/MAC not ...	E_Training Data/Auto-2...	2273	q-u	queue 1	Untrust	50.00M	200K	25.00M	25.00M	1.00M	Unprotected	Ok	201
Voice	1	Yate_VoIP	VoIP	E_Training VoIP/Auto-2...	2271	q-q	queue 6 (highe...	Untrust	500K	20K	500K	500K	10K	Unprotected	Ok	201

Figure C.16 ONU Service Assignment from ONU Menu bar

It will be differentiated how to provision a package for data (and IPTV) and VoIP.

C.5.1 Provision a data (and IPTV) package

Click to a Data or IPTV button and the following window displays:

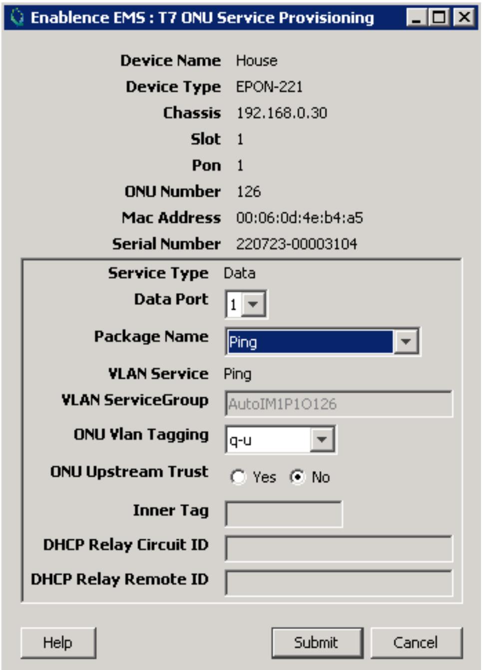


Figure C.17 Provision a Data package

Select the *Data Port* you want to apply the package and the *Package Name* for the service. You can also change the *ONU VLAN tagging* and *ONU Upstream Trust* if desired.

C.5.2 Provision a VoIP package

Click to a VoIP button and the following window displays:

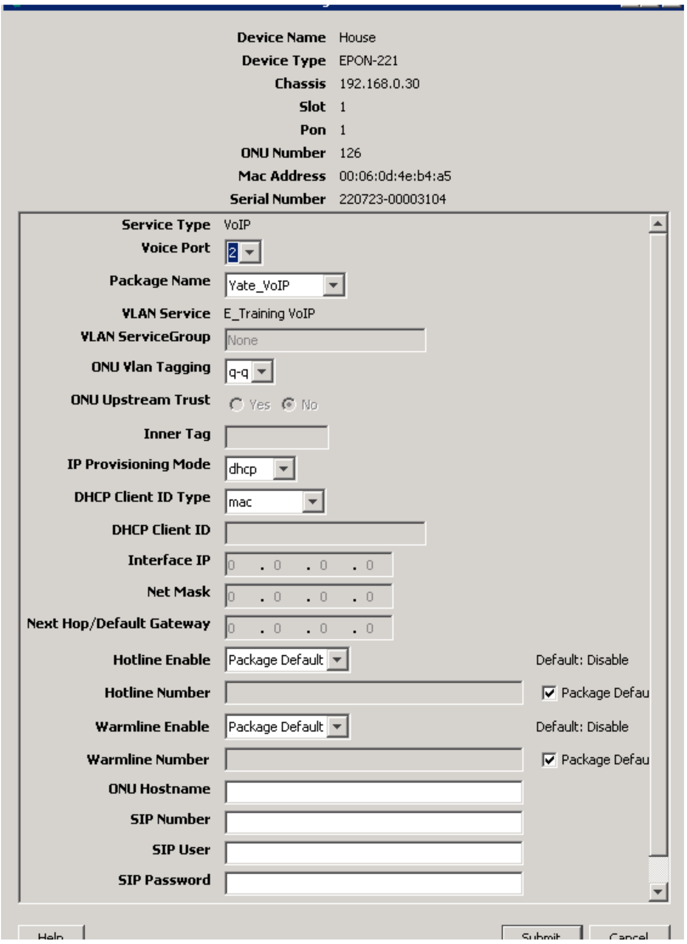


Figure C.18 Provision a VoIP package

From this window you can select the *Voice Port* number of the ONU and the Package name to apply in this port. You can also change de *ONU VLAN Tagging* and the *IP Provisioning Mode* to *Manual*. If you do this, you must provide a manual *Interface IP, Netmask* and a *Default Gateway.* You must configure the *SIP number* and *Password* for this port of the ONU. A real example for this project is displayed in figure C.19:

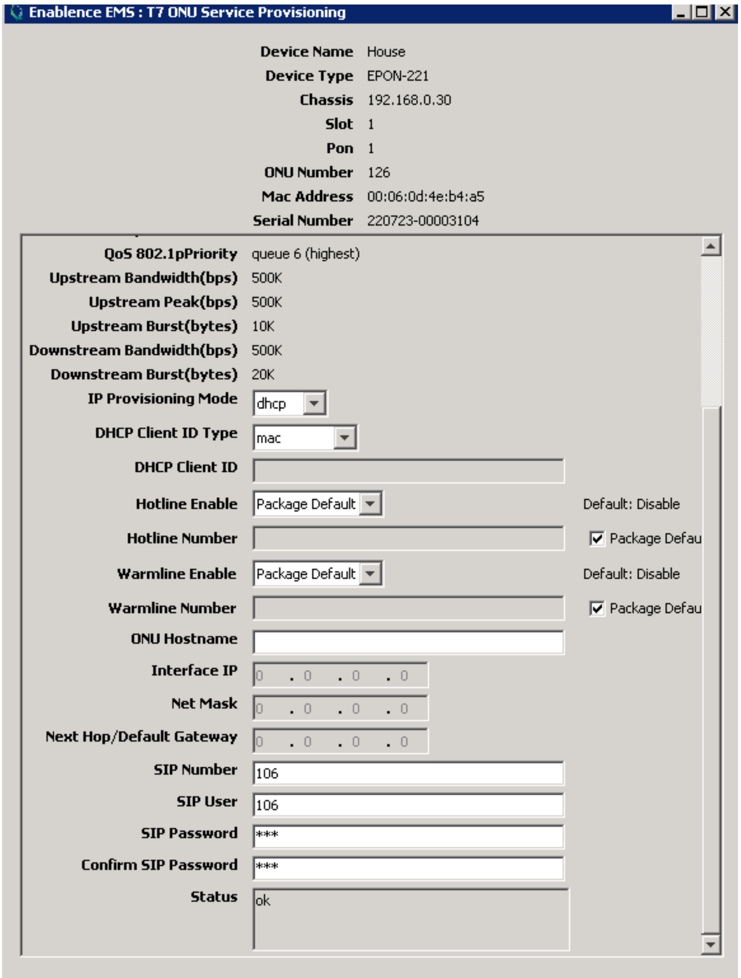


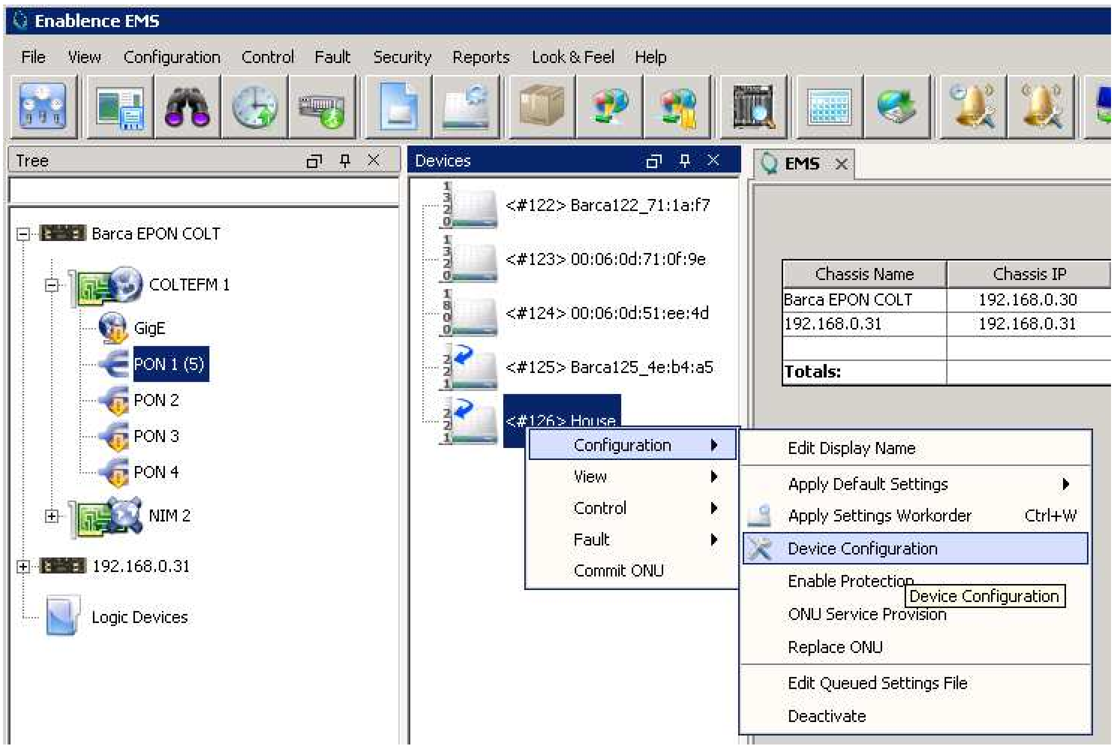
Figure C.19 Example for a VoIP package

As it can be seen the *upstream and downstream bandwidth* has been assigned, the *IP Provisioning Mode* and the *SIP Number* and *Password*. If you want to have a SIP number you must first create an extension (user) in Elastix in order to gain the ability for registration in the server. Further information for Elastix can be found in Annex D.

C.6 Enable Peer-to-Peer Communication

The final issue to describe is that Trident 7 does not permit any Peer-to-Peer communication traffic by default. If you want to communicate two devices connected to the same ONU, first you must enable this Peer to Peer communication in the desired ONUs.

The way to enable the Peer-to-Peer Communication feature is in the Devices list area of the main view. You must right-click on the desired ONU, and select *Configuration > Device Configuration*



The following window displays:

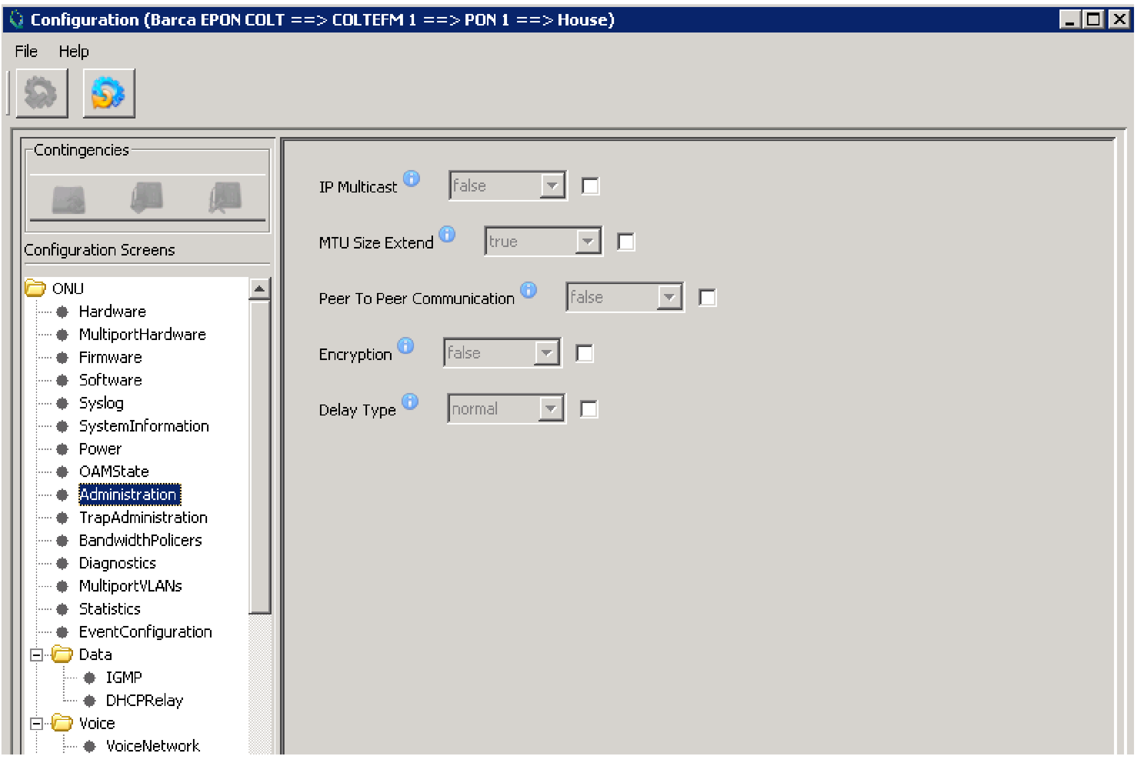


Figure C.20 ONU device configuration view

Select the option *Administration > Peer to Peer Communication* and from the drop down list choose '*True*'. Once you have changed it, save the modification and you will have the Peer to Peer communication enabled (see figure C.21). You must complete the same procedure for all desired ONUs to have the Peer to Peer communication.

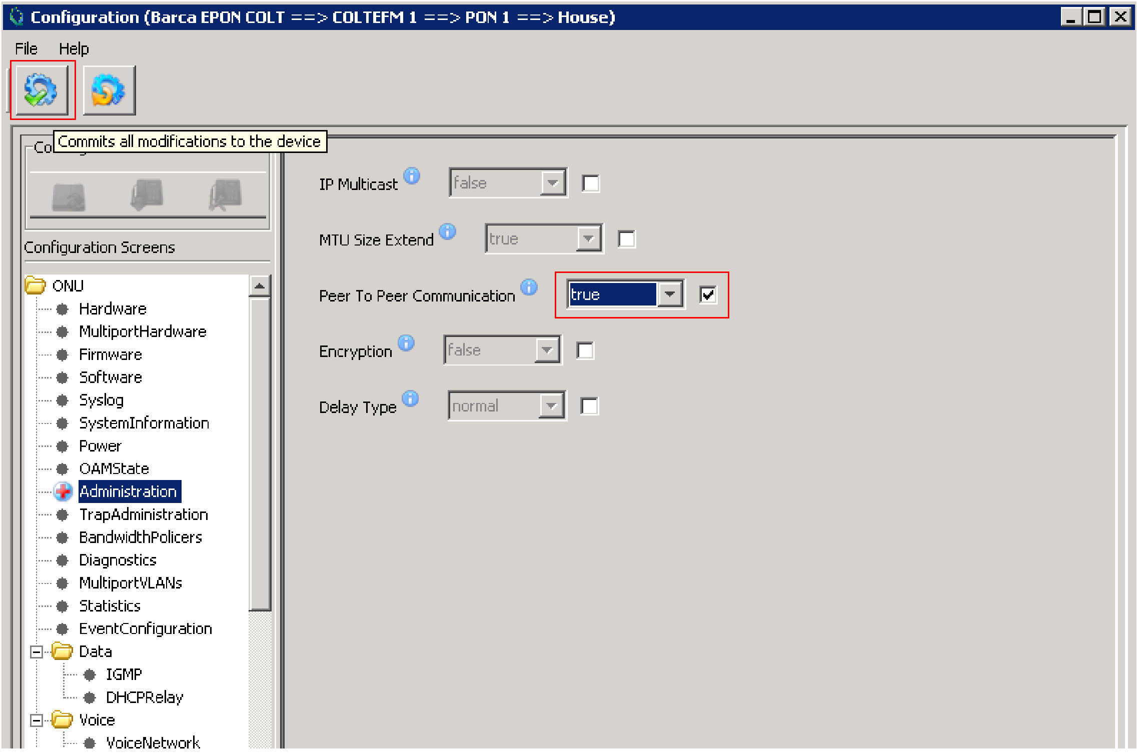


Figure C.21 Enable Peer To Peer Communication

ANNEX D. QUICK START GUIDE OF ELASTIX FOR VoIP

Elastix is an Open Source Software to establish Unified Communications. The goal of Elastix is to incorporate all the communication alternatives into a unique solution.

Elastix include the following communication media:

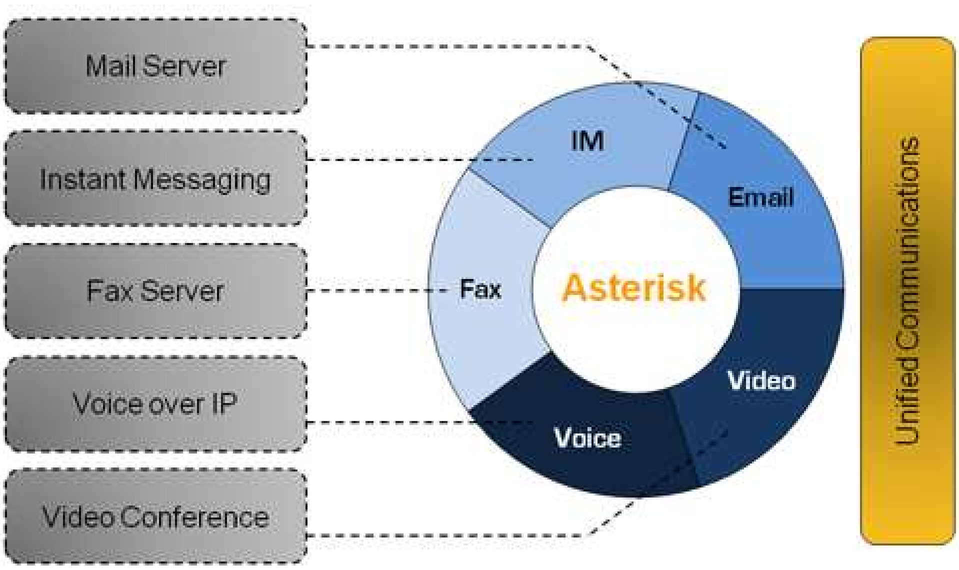


Figure D.1 Basic Communication media

Annex B will describe the configuration of Elastix PBX to provide VoIP in the network. To start configuring the PBX portion of Elastix, select and click on the PBX group tab and you will be presented with the PBX configuration screen featuring embedded free PBX.

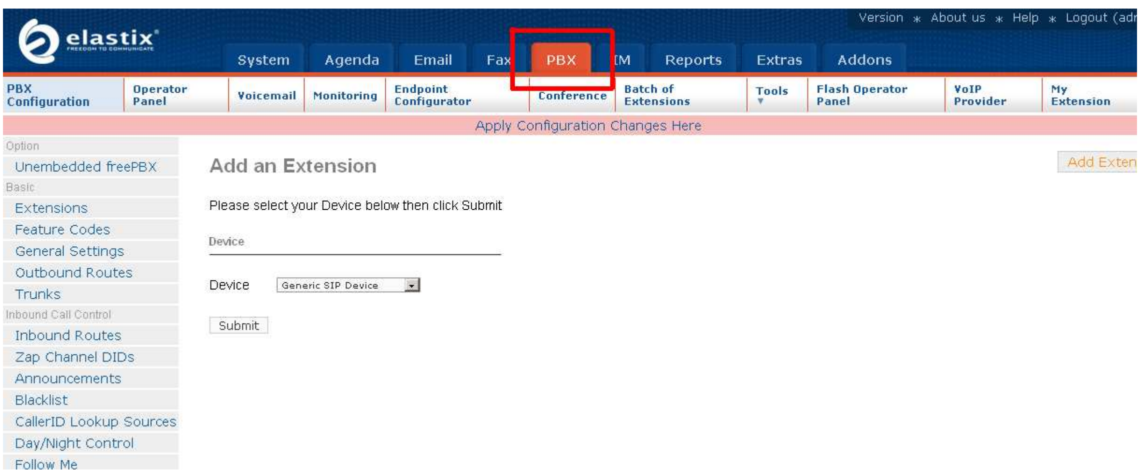


Figure D.2 PBX group tab

The choice to complete the task using the embedded free PBX or the un-embedded version is totally dependent on the users where the functionalities are similar either way.

D.1 General Settings

Firstly you need to select *General Settings*:

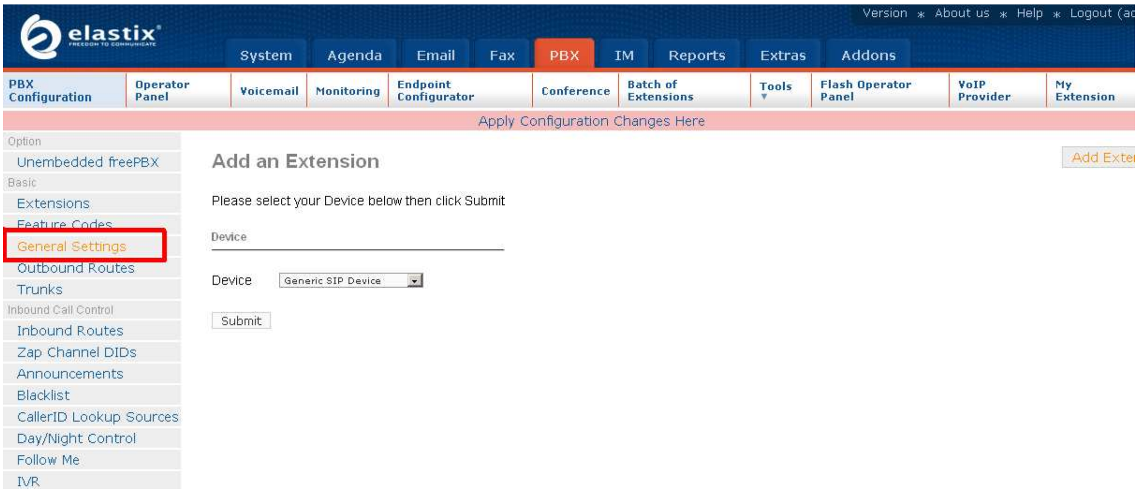


Figure D.3 General Settings view in Elastix

When presented with the *General Setting* screen, it is a wise to leave the default setting as provided except of a few of the fields that needs changing to suit local conditions. These fields are as illustrated in figure D.4:

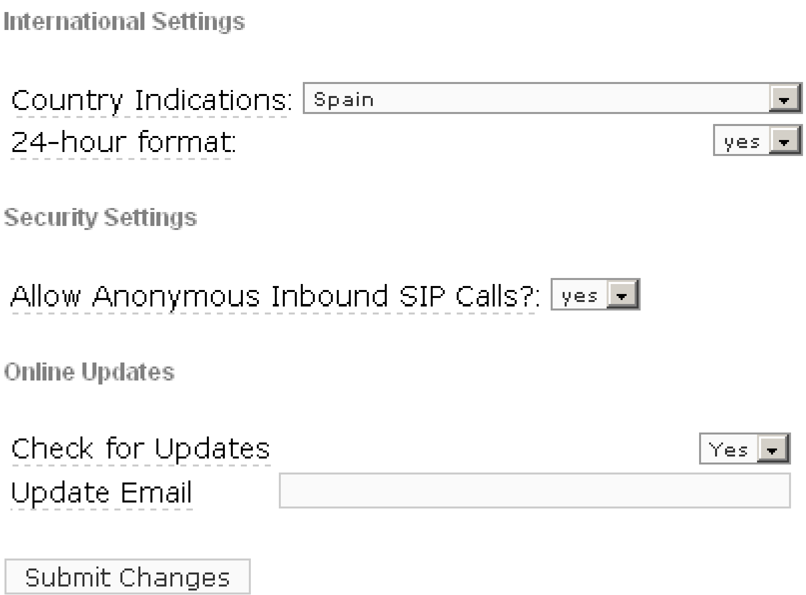


Figure D.4 Fields that need to change to suit local conditions

Country Indications: Spain

Allow Anonymous Inbound SIP Calls? Yes *(if this is set to 'No', all inbound unidentified SIP calls will not be accepted).*

Apart from what has been indicated above, you may need to customise to your own specific needs such as the *Asterisk Outbound Dial command option*:

"r" which generates the ring when you dial out, or "m" if you want music instead. There are other options of course, however, it is recommended to leave them at the default values.

Generally the default values are sufficient to get you started. These values can be changed later to suit your purposes. However, the value that is an example above is required to ensure that Elastix will function as expected.

In Elastix, help is available. Hover your mouse on the corresponding field description with a dotted underline (e.g. *Asterisk Outbound Dial Command options*) will display the purpose of the fields and the various switches related to it (see figure D.5).

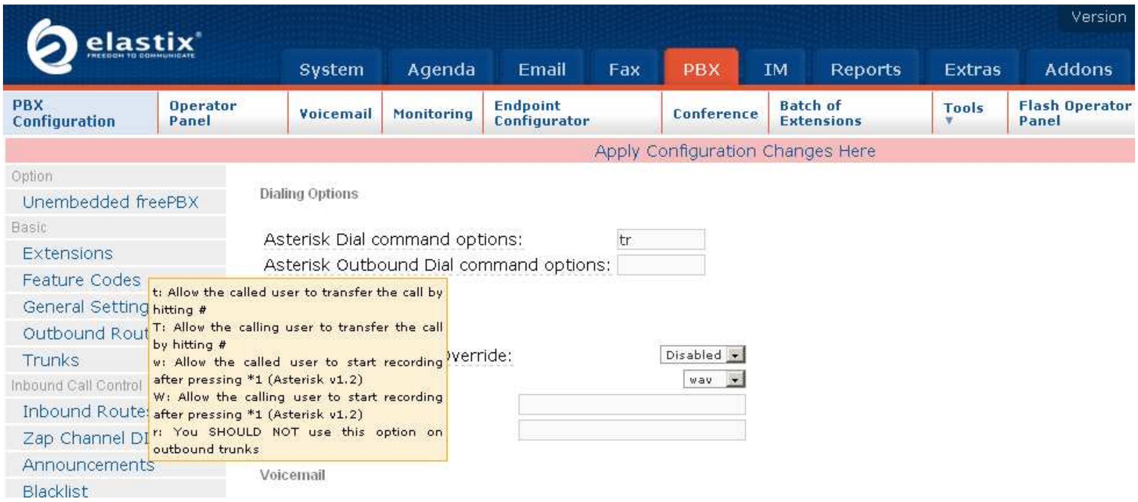
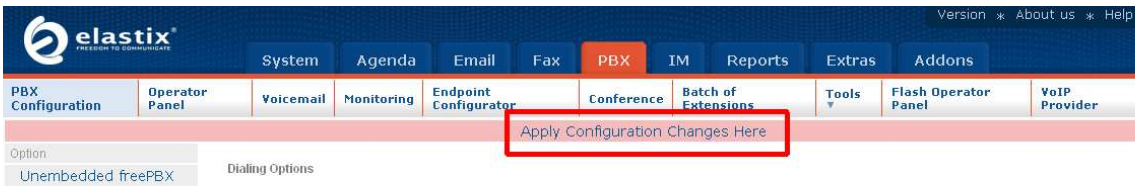


Figure D.5 Asterisk Outbound Dial Command option

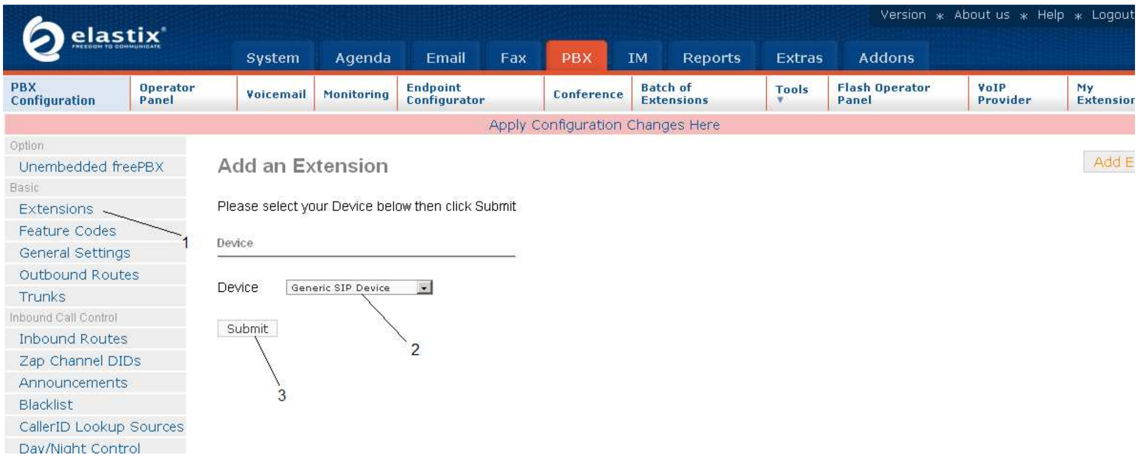
Once completed, click on the Submit Change button followed by the "Apply Configuration Changes Here" (red bar under the sub-tabs for the changes to take effect).



D.2 Extensions

The number of extensions to be set up depends on you. You can have soft phones installed in 4 or 5 computers or mixture of POTS Phone and SIP Soft Phones.

To create extensions, the type of trunk for instance SIP, IAX22, ZAP or Custom, is completed from the Create Extension Menu illustrated below:



There are a different device types for the extensions. It is needed to determine prior to creating the extensions.

• **Generic SIP Device**: SIP is the Standard protocol for VoIP handsets and ATA's.

• **Generic IAX2 Device**: IAX is 'Inter Asterisk Protocol', a newer protocol supported by a few devices (eg, PA1688 based phones, and the IAXy ATA).

• **Generic ZAP Device**: ZAP is a hardware device connected to your Asterisk machine eg, X100P TDM400, TE110P etc.

• **Other (Custom) Device**: Custom is a general term used for any non standard device, such as H323. It can also be used for "mapping" an extension to an external number (eg: to route extension 2010 to 1300151151, we can create a custom extension 2010 and in the "dial" text box enter: ***Local/1300151151@outbound-allroutes***.

This project needs to create a few SIP extensions for the Phones. Therefore you should select Generic SIP Device from the device drop down list then click “Submit”. The illustration below is where you create the extension.

You will notice a few fields that you will need to populate. The important ones are:

• User Extension: 106 (that’s an extension number possible for the network)

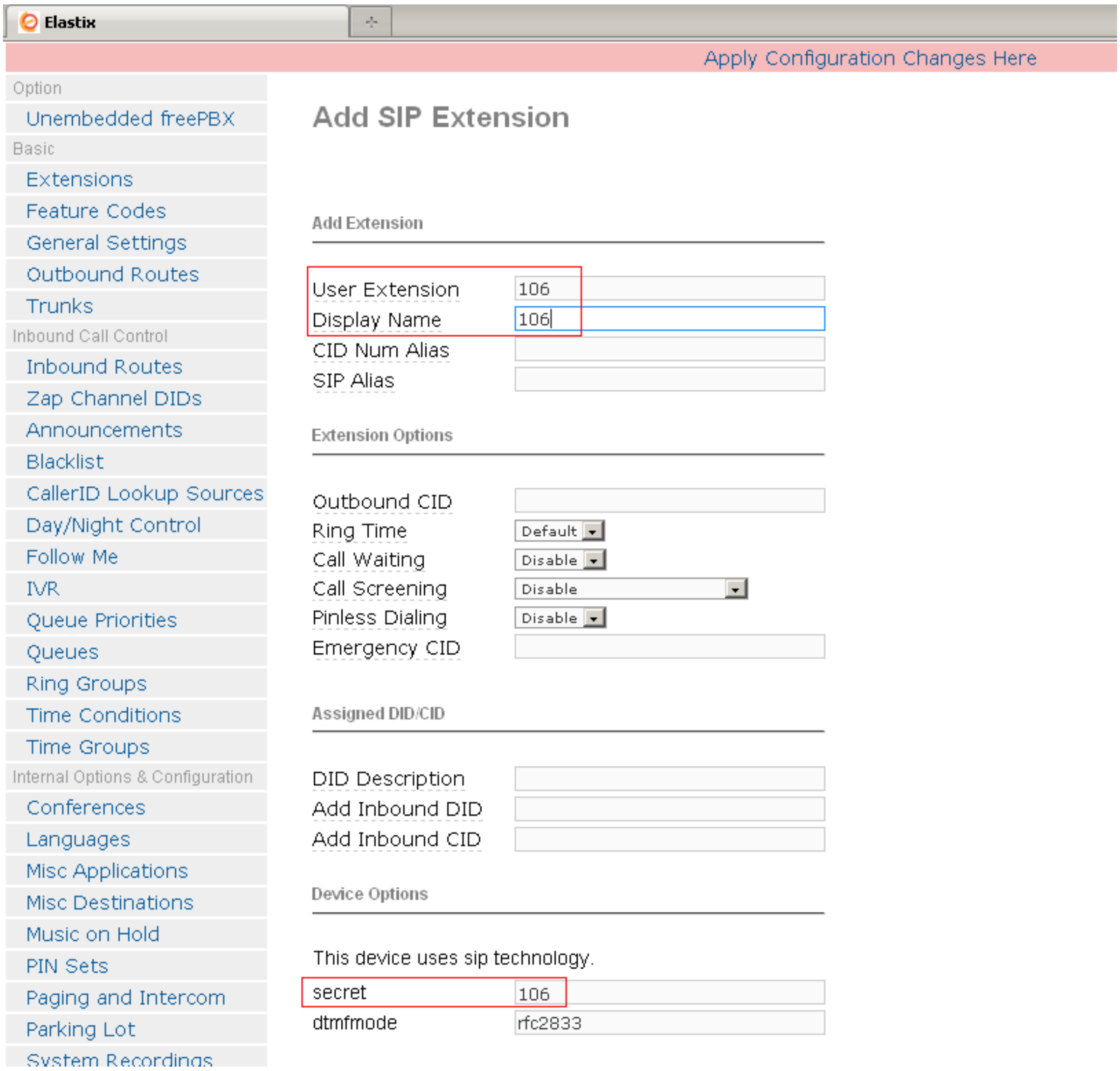
• Secret: 106 (for simplicity, it is used the extension number as the secret password)

• Disabled the FAX extension as there will be no FAX attached to this

extension.

• Voicemail is not required.

You should leave the rest of the fields at their default values:



Submit when done and click the red bar to apply the changes. You can repeat this process as many times as you want to create SIP extensions numbers for the project (click on the Add Extension button to add more extensions).

D.3 Follow me

After setting up the extensions, you need to decide if you want Elastix to call another prearranged extension, if the extensions previously called do not answer. This is described in figure D.6:

Select the *PBX -> PBX Configuration -> Follow Me* and the following window displays:

Figure D.6 Follow me view

Select the extensions that you want to define (the extension selection is on the right of the screen). In this case the 102 extension has been selected – **'102 <102> add'**

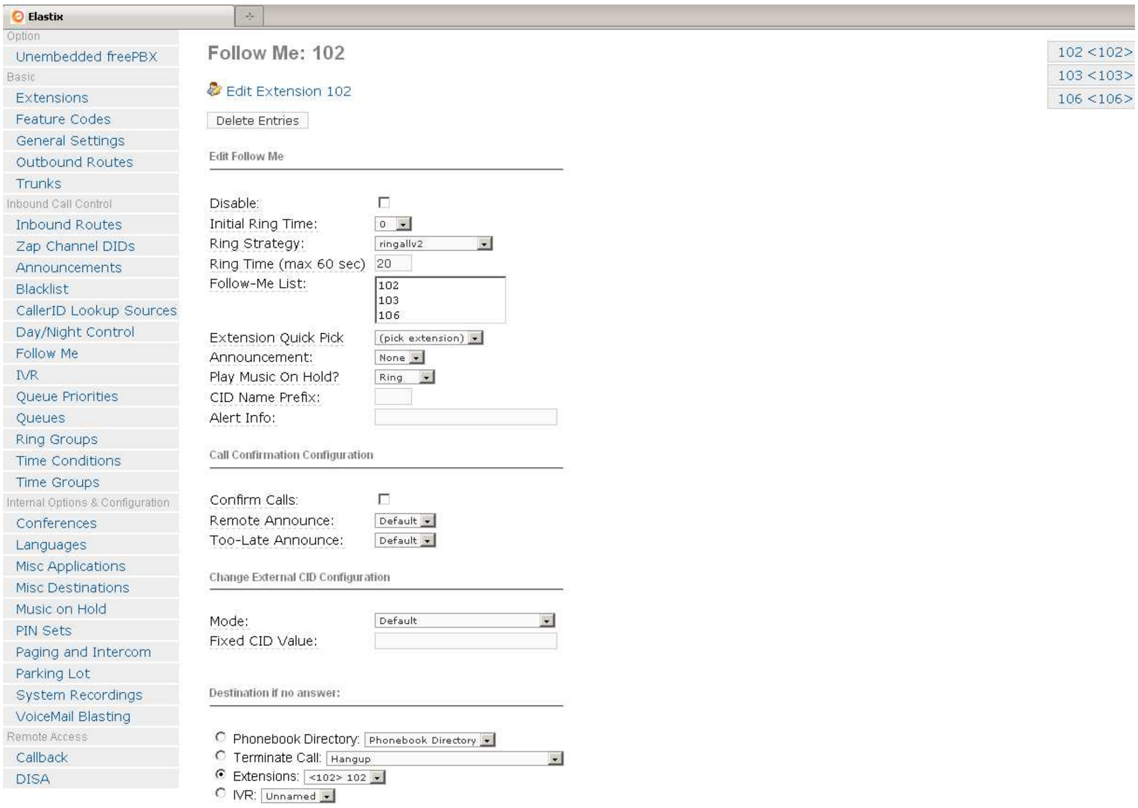


Figure D.7 Follow me list

In the screen that follows (see figure D.7), enter the following information.

• **Ring strategy:** ringallv2 (to call the main numbers and then the other numbers)

• **Extension List:** 102 followed by 103 and 106 numbers

• **Ring time:** 20 seconds

• **Destination if no answer**: Terminate Call – Hangup

Every time the 102´s extension is called, Asterisk will try to connect to extension 102 and if no answer, it will call Ext. 103 and 106. If still no answer, it will simply hang up.

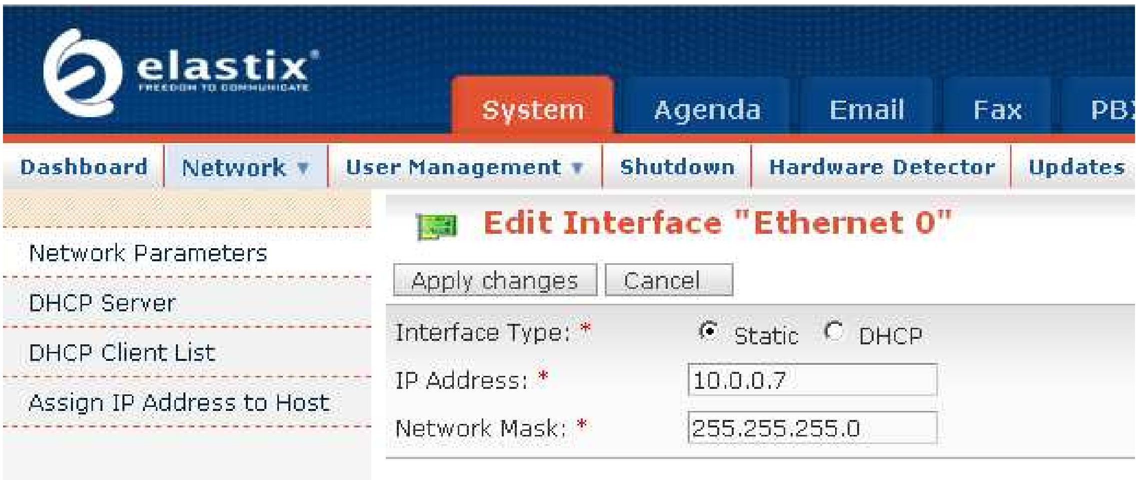
Click “submit” followed by clicking the red bar on top of the screen to finalise this selection.

D.4 DHCP Server

DHCP is an automatic configuration protocol used on IP networks. Computers that are connected to IP networks must be configured before they can communicate with other computers on the network. DHCP allows a computer to be configured automatically, eliminating the need for intervention by a network administrator. It also provides a central database for keeping track of computers that have been connected to the network. This prevents two computers from accidentally being configured with the same IP Address.

The main way to access to the DHCP parameters in Elastix is: *System > Network*

First of all this section will start with the network tab because it is needed to change the DHCP address to a static address (must be an static IP for the ethernet 0 network interface in order to have the DHCP server).



At the left side of the illustration above you can check different parameters for DHCP like DHCP Server and Client List.

In DCHP Server tab (see figure D.8), you can select a range of IP addresses to assign them to new devices to be connected to the network.

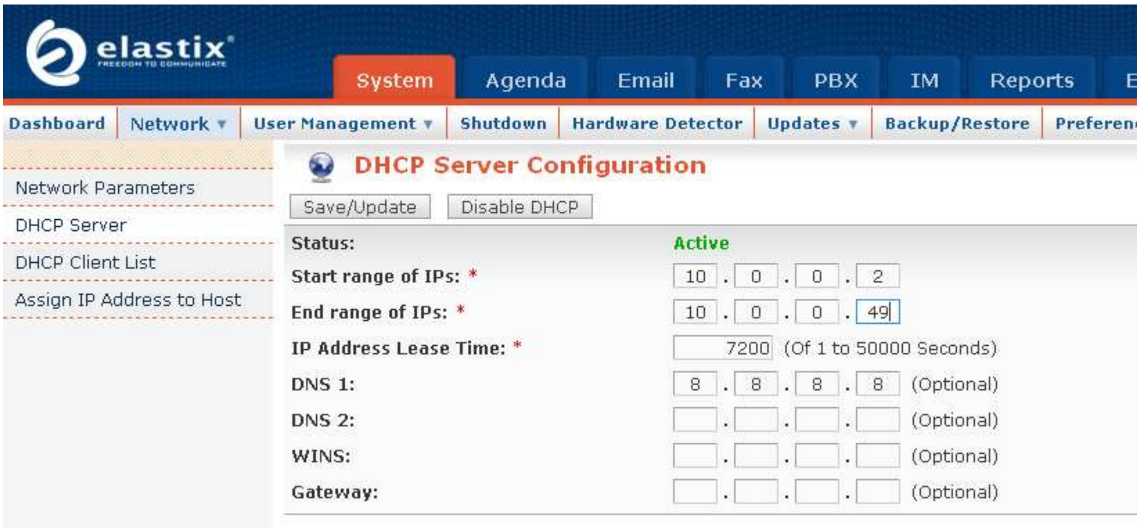


Figure D.8 DCHP Server Configuration

In DHCP Client List (see figure D.9), you can check the list of all the devices that have been connected to the network (with an automatically IP address).

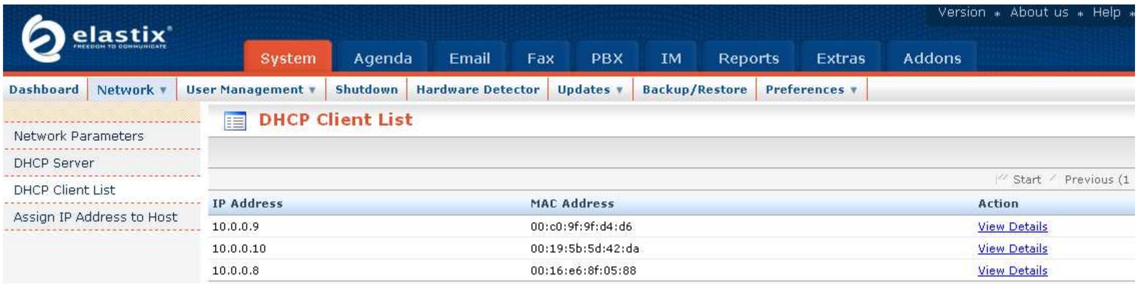


Figure D.9 DHCP Client List