GPON and EP2P: A Techno-Economic Study

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Abstract— **New services like Video on demand/Internet Protocol Television, Voice over IP and high speed Internet access demand very high bandwidth to provide Triple Play services to the customers. The ADSL/ADLS2+ and the VDSL/VDSL2 copper-wire technologies deteriorate quickly with the distance and will be soon obsolete for supporting the ultra-high bandwidth requirements of the next future. One suitable long term solution for such a high bandwidth demand is employing optical fibers to customers premises (FTTH). In particular, two optical distribution network architectures, GPON (gigabit passive optical network) and EP2P (Ethernet point-to-point), are competing for the network access segment. This paper surveys the two technologies and evaluates them from a quantitative techno-economic point of view, trying to identify which market scenarios are best served by EP2P and which are best served by GPON architectures for supporting the requirement of Triple Play applications**.

Keywords-component; GPON, EP2P, QoS, FTTX, OPNET, TriplePlay

I. INTRODUCTION

The most currently used access network technologies are ADSL/ADSL2+ and, recently, VDSL/VDSL2 over copper wire. Anyway, xDSL technologies offer either limited bandwidth (ADSL2+ reaches 24 Mbps) or fast signal deterioration (starting from 1 mile, VDSL2 performance is equal to the maximum bitrate of ADSL2+ [1]). With the developments of multimedia applications, Triple Play services (voice over IP (VoIP), video on demand (VoD)/IP television (IPTV), and broadband Internet access) are requiring more and more capacity and QoS guarantees for end users connectivity. Fiber to the Home (FTTH) optical technologies can fill this gap. Apart from providing the required bandwidth, optical technologies are much more energy-efficient than copper-based technologies [2][3], since optical fibers replace copper links to provide connectivity to the users' premises, enabling very high bandwidth availability in the last mile. Among several FTTH implementations, two main architectures are emerging as the most promising ones to be implemented in the access networks by telecommunications operators: GPON (gigabit passive optical network) and EP2P (Ethernet point-to-point).

This paper presents a qualitative and quantitative comparison of these two technologies and identifies what is the more suitable technology for providing Triple Play services to different market scenarios. At this aim, we analyze GPON and EP2P technologies and provide a techno-economic study to identify advantages and drawbacks of the two solutions.

II. GIGABIT PASSIVE OPTICAL NETWORK (GPON) TECHNOLOGY

Passive Optical Network (PON) appears in the mid 90s. In 2008, the ITU-T defined the G.984 series recommendations for the GPON technology, an extension of PON architecture enabling bidirectional gigabit transmissions on the same fiber link [4][5][6][7].

A. GPON Features

The GPON standard defines different line transmission rates for downstream and upstream directions. The most common combination, which has been chosen also for this study, is 2,4 Gbps for downstream and 1,2 Gbps for upstream in the same link. The operating wavelength range is 1480-1500 nm for the downstream and 1260-1360 for upstream, using actually wavelength division multiplexing (WDM) on a single nondispersion-shifted fiber (ITU-T G.652). The distance that can be supported from the point-of-presence (POP) of the central office (CO) to the customer premise equipment (CPE) is around 20 km, although the standards already include support for 60 km and it is possible to reach up to 100 Gbps serving 1024 users at 10GBit/s [8]. GPON supports: Internet Protocol (IP) traffic over 10/1 Gbit/s or 100 Mbit/s Ethernet; standard time division multiplexed (TDM) interfaces such as synchronous optical networking (SONET) or synchronous digital hierarchy (SDH) protocols, asynchronous transfer mode (ATM) user–network interface (UNI) at 155–622 Mbit/s, and GPON encapsulation method (GEM) protocol to encapsulate data over GPON supporting voice traffic, video traffic and data traffic without any extra level of encapsulation [9].

B. GPON Network Architecture

Network equipment in GPON consists of:

- *OLT* (Optical Line Termination): located in the operator central premise, it provides the service provider endpoint of a PON;
- *ONU* (Optical Network Unit): located in the customers premises, it terminates the PON and presents the *customer* service interface to the users by converting the optical signals into electronic interface;
- *ONT* (Optical Network Terminal): ONT is an ITU-T term to describe a special, single-user case of an ONU;
- *Splitter*: it divides the optical signal into *n* separate paths to the subscribers. It is located between CO and CPE (Fig. 1); thanks to the splitters, it is possible to share the same fiber among *n* customers, reducing the

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amount of required fibers and central office equipment compared to point to point architectures (EP2P).

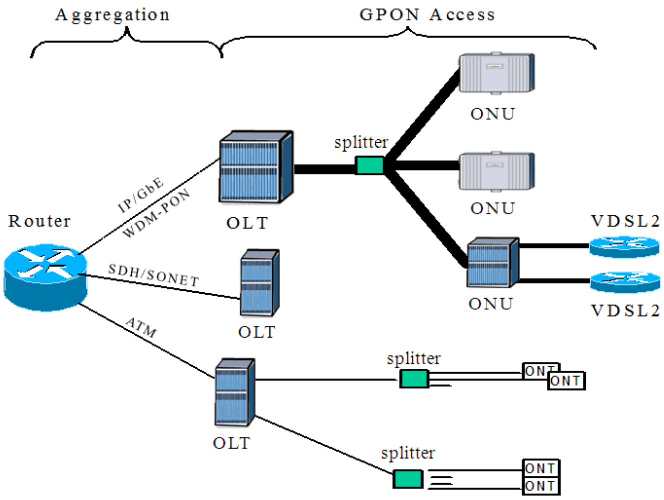

Figure 1. GPON architecture.

There are different logical network architectures, called FTTx, depending on the optical link ends [10]; we differentiate two:

- FTTH (Fiber to the home); it is a pure fiber installation, i.e., no copper wire are employed: the installation of optical fiber ends directly into the subscriber home;
- FTTB (Fiber to the building) and FTTC (Fiber to the curb or cabinet); they are hybrid solutions in which the optical fiber terminates respectively to the curb or to the cabinet; then, the path continue over copper links (such as in most xDSL installations);

In this study, we focus on FTTH, since it offers more bandwidth to the end users [11].

C. GPON Transmission

The procedure for data transmission in GPON networks depends on the direction of the communications. Downstream transmission (from the OLT to the ONUs) employs TDM (Time Division Multiplexing) to broadcast the signal to all the ONUs sharing the same fiber (encryption is used to prevent eavesdropping). ONUs filter the received data and extract only their own traffic. The upstream channels are combined using a multiple access protocol such as TDMA (Time Division Multiple Access), in which each ONU transmits in an assigned time slot windows to avoid collisions, and the OLT controls the upward capacity assigning bandwidth for all users [12][13].

III. Ethernet Point-to-Point (EP2P) Technology

ETTH (Ethernet to the home), also referred to as EFM (Ethernet in the first mile), is a solution that uses Ethernet transport protocol between the operator and the customers premises. ETTH may employ copper wires or fiber optic cables, with either active (EP2P, Ethernet point-to-point) or passive (EPON, Ethernet passive optical network) network elements (NEs). In EPON, passive NEs are connected through optical fibers with a point-to-multipoint (P2MP) topology. In EP2P, active NEs are connected by a point-to-point (P2P) topology. ETTH over fiber optics permits to exploit the advantages of fibers optics with respect to copper wires, such as higher bandwidth, electromagnetic disturbance immunity, minor space occupancy, less weight of cables, lower cost, etc. Ethernet for access networks was first defined in the IEEE 802.3ah-2004 recommendations [14], which were later included in the IEEE 802.3-2008 standard [15] and, in 2009, an even higher-speed 10 Gbps Ethernet passive optical network known as XEPON or 10G-EPON was eventually ratified as IEEE 802.3av [16]. We focus on EP2P since it is one of the most widespread access networks technologies.

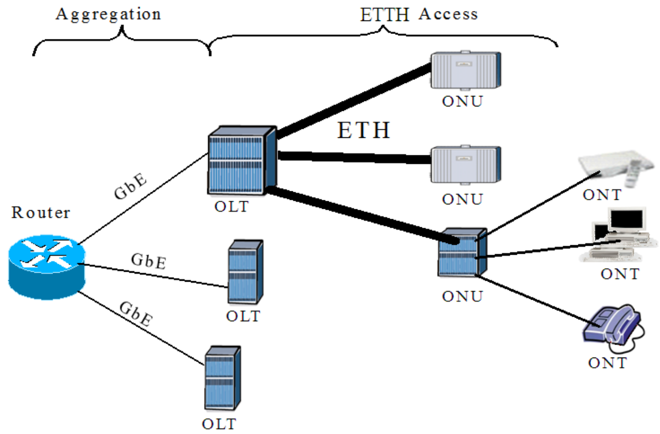

Figure 2. EP2P topology.

A. EP2P Features

Ethernet supports different line transmission rates depending on the medium used. For optical fibers, bitrates are among 100 Mbps to 1 Gbps. Ethernet supports both directions of transmission in the same link (full duplex), splitting the capacity of the link. The system uses Ethernet protocol transport for carrier data, with a maximum reach from the central office to the user of 150 km.

B. EP2P Network Architecture

The basic network equipment for EP2P is composed of two nodes: OLT and ONU, both realizing the same functions described in GPON. Since one fiber link is dedicated for each user (point-to-point connection), the splitter disappears between the central and the users premises (Fig. 2).

IV. Triple Play Services

GPON and EP2P are emerging as the most promising FTTH access networks technologies to provide Triple Play services, which allow the provisioning of two bandwidth-intensive services, such as high-speed Internet access and IPTV, and a less bandwidth-demanding (but more latency-sensitive) service, such as telephone, over a single broadband connection [17].

Accordingly, we modeled such three services with different bandwidth and latency requirements:

- Voice: 16 Kbps with G.726 voice codec (low latency);
- IPTV: 8 Mbps for high definition channel and 1,5 Mbps for standard definition channel with MPEG4 compression;
- Internet Access: from 6 Mbps up to 10 Mbps for downstream and 1 Mbps for upstream.

V. MODELING GPON NETWORKS

In this section, we illustrate the design of the simulation environment employed for modeling GPON access networks. In GPON, the bandwidth is shared among several users, and simulations are needed to probe the exact bandwidth allocation after protocol overhead for downstream and upstream flows with varying number of connected users. On the other hand, EP2P are unshared networks and simulations are not necessary since that each fiber link is able to deliver enough bandwidth (30 Mbps) per user [18][19].

For this goal, the packet simulation software OPNET Modeler 14.0 has been employed [20]. OPNET offers hierarchical structure of patterns for creating new simulation scenarios. We define tree levels:

- Network model: it is the first level of design. It is the most abstract and generic layer. The goal of this level is to define the network topology, comprising nodes and their communication links;
- Node model: in this second level, the goal is to define the functionalities for every node of the network. For every node, we build a scheme for designing internal functions and creating the specific modules required;
- Process model: in the third and last level, the graphs for the modules used in the second level are defined and implemented in C++. The graphs specify the jobs executed by the module along with the information that will be processed.

A. *Modeling Network Topology*

To create the simulation scenario, we used the three levels described above. We chose FTTH topology since the optical fiber arrives directly at user's home and it is the solution that offers more bandwidth capacity.

The modeled network nodes are OLTs, ONUs and optical splitters. The communication between central office and customers has been implemented with two packet types called "report" and "gate".

The "report" packet goes from the ONUs to the OLT and carries information about upstream bandwidth request. The "gate" packet goes from OLT to ONUs and carries information about the upstream and downstream bandwidth assignment.

B. *ONU Design*

Optical network unit is the devices that implement the user to network interface (UNI), and it is located at customer's home. It allows connecting the user with the rest of the access network. ONUs receive data downstream and request upstream traffic according to their needs (Fig. 3).

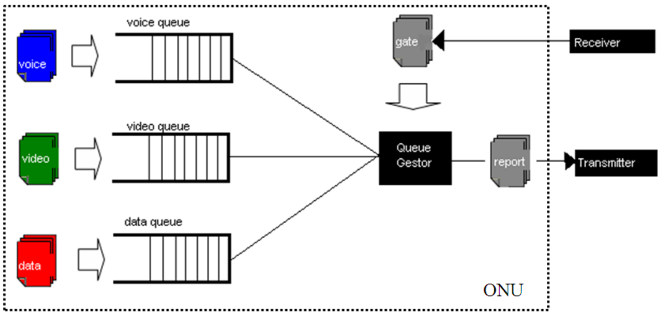

Figure 3. ONU functional schema.

ONUs have three traffic packet queues, one for each type of (Triple Play) traffic (voice, video and data), which contain the packets that wait to be transmitted. The queue manager module "queue gestor" receives the "gate" packet with upstream bandwidth allocation. According to this information, the "queue gestor" sends the packets from the queues at the specified rate and also creates the "report" packet with information about the requested upstream bandwidth after analyzing the queues status. To simplify simulation management, we modeled the ONUs in OPNET with two different parts, one for downstream and other one for upstream. As for the upstream (Fig. 4), the ONU has two sections: reception and transmission.

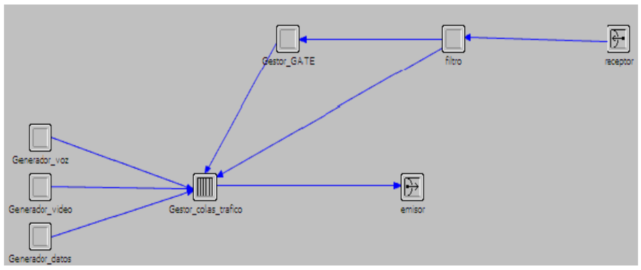

Figure 4. ONU upstream.

- The reception section has three modules: "receptor", which gets incoming packets from the link; "filtro", which filters incoming packets; and "gestor_GATE", which extracts upstream bandwidth info allocation from the received packets.
- The transmission section has three modules: "generadores", which creates voice, data and video packets for sending; "gestor_colas_trafico", which classifies packets types, sends packets and controls upstream bandwidth allocation; "emisor", which sends packets to the OLT.

The ONU downstream module (Fig. 5) has the same parts of upstream and a very similar design. However, in the reception part, "gestor_GATE" is not necessary, since the received traffic comes in directly at "gestor_consumo" which distributes it to the "consumidores" modules and records the new downstream bandwidth request. The "consumidores" modules consume downstream traffic and "emisor" module sends packets to the OLT.

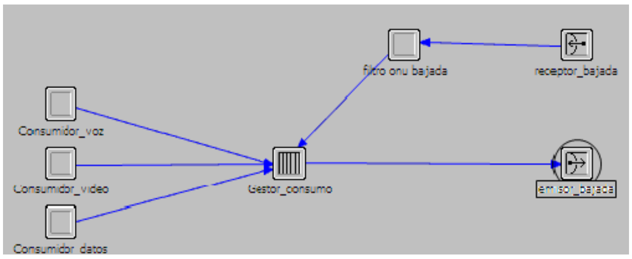

Figure 5. ONU downstream.

C. *OLT Design*

Optical line termination is the device situated in the operator switching central. It provides the different services to all the customers. Its main task is to calculate and assign upstream and downstream bandwidth according to the requests (Fig. 6).

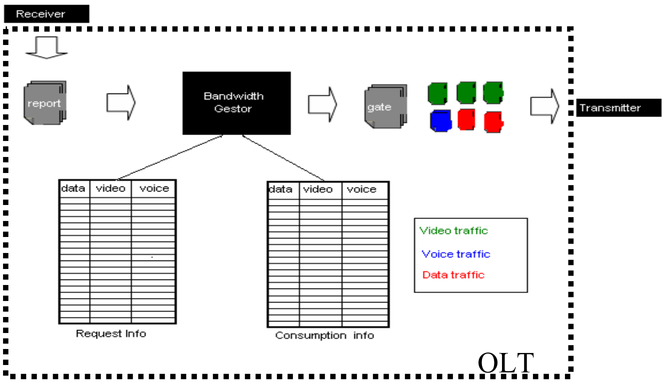

Figure 6. OLT Functional schema.

This device receives all the "report" packets from the ONUs, with the information about the requested bandwidths. Then, the "gestor ancho banda" module calculates and assigns the upstream and downstream bandwidths by preparing and sending the appropriate "gate" packets (Fig. 7).

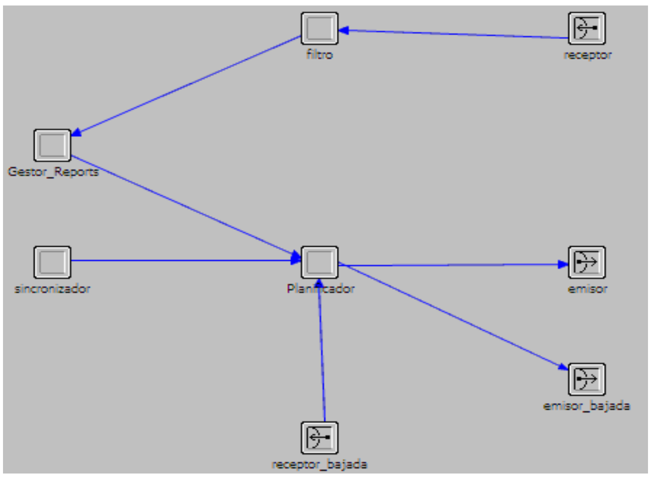

Figure 7. OLT Opnet design.

We modeled the simulation in OPNET into three different parts, each with its specific functions:

- *Reception:* it has three modules. The "receptor" and "filtro" modules get incoming packets and identify the ONU id in the packets; "gestor_report" extracts the bandwidth allocation and saves this information for later use;
- *Transmission:* this module sends the generated packets for the node through its modules "emisor" and "emisor_bajada";
- *Management:* this is a critical module in the design, since its "planificador" module realizes the calculations for establishing the bandwidth allocations for each ONU.

D. *Optical Splitter Design*

Optical splitter is the network element that stays between OLT and ONUs and splits the optical signal. It has two different functions according to the communication direction. In the way from OLT to ONUs, it replicates incoming packets and sends it to all ONUs, realizing a point-to-multipoint connection. In the way from ONUs to OLT, it combines the traffic coming from the ONUs and sends it to OLT in a multipoint-to-point fashion. Therefore, its main function is to correctly split and combine the traffic between OLT and ONUs, in both directions.

VI. GPON SIMULATION SCENARIO

In this section, we present the simulation results on the GPON network. Simulations are performed in order to precisely quantify the incidence of the medium access protocol (MAC) on the (shared GPON) network performance. Simulation parameters are reported in Table I.

TABLE I. SIMULATION PARAMETERS.

Parameters	**Values**
Downstream bitrate	2,5 Gbps
Upstream bitrate	1,2 Gbps
Generated traffic	Poisson distribution
Real time simulated	2 hours
Network congestion	at 80% of total capacity
Number of ONU devices	{3, 8, 16, 32, 64, 70, 72}

A. *GPON Simulation Results*

Figure 8 shows the maximum achievable upstream and downstream bandwidths as a function of the connected ONUs. For example, with 32 ONUs, the maximum bandwidth for downstream is 68,16 Mbps, and for upstream is 32,92 Mbps.

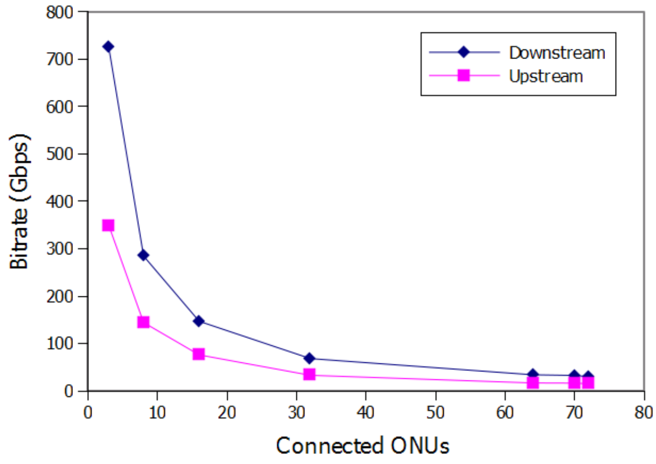

Figure 8. Achievable bitrates with varying number of connected ONUs.

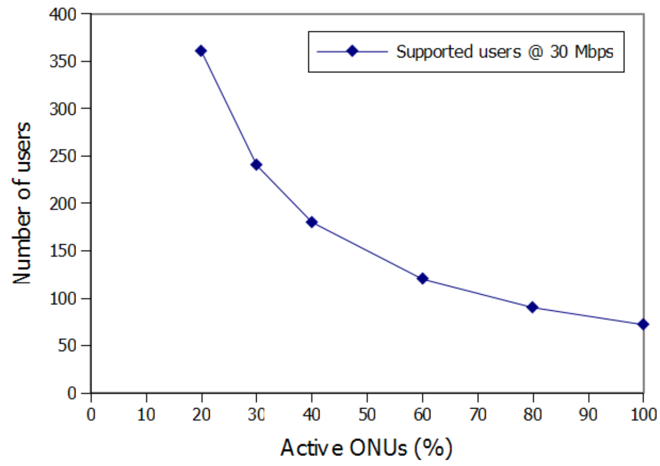

Figure 9. Supported users at 30Mbps with varying active ONUs.

If the number of installed ONUs increases, the maximum supported bandwidth decreases in both directions. Note, however, that the decrease in the bandwidths is not linear, since the MAC protocol overhead is amortized among all the users. The exact values are reported in Table II, in which we can observe that, in order to provide Triple Play services at 30 Mbps per user, the maximum number of employed ONUs cannot exceed the number of 72 when all the ONUs are active at the same time.

TABLE II. MAXIMUM SUPPORTED BANDWIDTHS (MBPS) AT VARYING NUMBER OF ONUS.

Number of connected ONUs	Downstream	Upstream
3	724,48	348,91
8	284,6	144,33
16	146,89	76,04
32	68,16	32,92
64	34,03	16,8
70	32,62	16,48
72	30,1	15,19

Anyway, it would be too pessimistic to dimension the network considering that all the ONUs are active at the same time. This leads to Fig. 9, which shows the number of users served at 30 Mbps as function of the concurrent active ONUs. Here, the decrease is proportional to the percentage of active ONUs, having already accounted for the protocol overhead in the previous results. As we can observe from Table III, for 60% of ONU actives the number of supported users increases from 72 to 120. If the percentage of connected ONU decreases further, then the number of supported users proportionally increases. Note that, with 30% of concurrent active ONUs, which is a quite fair share, the number of supported customers raises up to 240.

TABLE III. NUMBER OF SUPPORTED USERS AT 30 MBPS DOWNSTREAM AS FUNCTION OF THE ACTIVE ONUS.

Percentage of actives ONUs	Supported users @ 30 Mbps
100	72
80	90
60	120
40	180
30	240
20	360

VII. GPON AND EP2P COMPARISON

A. *Technical comparison*

From a technical point of view, GPON and EP2P present similarities in the optical infrastructure [14], but also some important differences, highlighted in the following:

- EP2P solution have the network architecture more simple than GPON, because they do not require any device between central office and customers;
- The management of EP2P network is easier than GPON, because dynamic bandwidth allocation is not necessary in EP2P;
- The number of costumers in GPON topology is limited, because of its shared architecture;
- GPON offers more possibilities to efficiently use the network infrastructure than EP2P, because the optical fiber link is shared for the users;
- EP2P presents more expansion capacity and has more bandwidth capacity per user than GPON.

B. *Economical*

As for the economical study, GPON and EP2P were compared under two financial terms: CAPEX and OPEX.

There are no important differences between GPON and EP2P in terms of CAPEX. Connecting one home with GPON costs €1.500 for user, and connecting one home by EP2P costs €1.600 for user (these costs are calculated in urban context and without any existing infrastructure [21]). In Fig. 10, a breakdown of CAPEX costs for GPON, EP2P and VDSL technologies is reported. As we can see, the slight difference in CAPEX is due to network equipment and construction: the savings in optical splitters not necessary for EP2P is not compensated by the higher number of required fibers with respect to GPON. Analyzing the OPEX costs, important differences emerge between the two technologies [22]. For one central office providing Triple Play connectivity to 16.000 customers, GPON technology would require 1 rack and 1.500 optical fibers, while to serve the same amount of users with EP2P, it would require 24 racks and 16.000 optical fiber links and transreceivers. In summary, EP2P uses more energy and more floor space in central office than GPON environment. According to Alcatel-Lucent [18], EP2P OPEX costs 35 € more per year per subscriber compared to GPON.

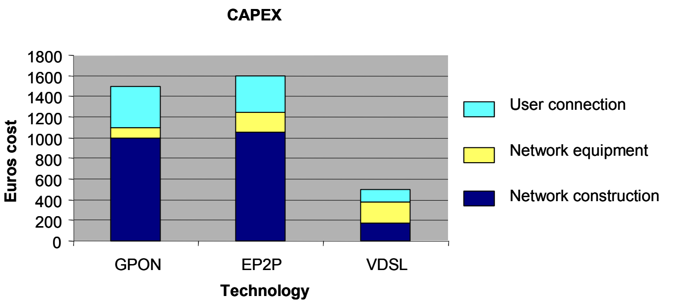

Figure 10. CAPEX costs for GPON, EP2P and VDSL.

VIII. Conclusions

This paper presents a survey and a techno-economical assessment on GPON and EP2P access network technologies. This problem arises with the development of multimedia applications like video on demand, fast Internet access, television and voice over IP, in which end users require more and more bandwidth capacity. EP2P has virtually no practical bandwidth limitations, since a dedicated optical fiber is employed between the central and each user, but its economic cost may be not adequate for small and medium scale deployments. According to the simulations results, GPON technology supports 72 users at 30 Mbps each, with 100% of actives ONUs, and 240 users at 30Mbps with 30% of actives ONUs. Assuming 30% as a realistic percentage of active users, then GPON is a good solution for access networks with less than 240 users. This value represents a threshold between GPON and EP2P. EP2P technology offers more bandwidth capacity than GPON, and the management of the network is easier, but for most of the current services requirements the GPON technology is enough. In summary, from the economical point of view, the cheaper solutions is GPON, since its CAPEX and OPEX are lower than EP2P's ones. From a technical point of view, the more performing solution is EP2P, since it offers more bandwidth, scalability and easy-of-use than GPON. Analyzing both environment, technical and economical aspects, with the actual requirements in terms of bandwidth and number of concurrent connected users, the optimal short term solutions is GPON, although, given the growth forecasts of requirements and number of users, the best choice as long term solution is represented by EP2P.

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