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Conference Paper

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23rd European Regional Conference of the International Telecommunications Society (ITS), Vienna, Austria, 1st-4th July, 2012

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Rendon Schneir, Juan; Xiong, Yupeng (2012) : Strategic and economic aspects of network sharing in FTTH/PON architectures, 23rd European Regional Conference of the International Telecommunications Society (ITS), Vienna, Austria, 1st-4th July, 2012, International Telecommunications Society (ITS), Calgary

This Version is available at:

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Strategic and economic aspects of network sharing in FTTH/PON architectures

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Keywords: FTTH, cost, network sharing, PON

Abstract:

Due to the high costs associated with the deployment of the passive infrastructure of FTTH networks, operators ponder the possibility of making co-investments based on a network sharing model. This article describes the strategic and economic aspects of network sharing in FTTH/PON architectures. The capabilities of present and future versions of PON architectures and the cost implications of a network sharing model are described. Moreover, the minimum price of the access line necessary to recover the investment is derived.

The views expressed in this article are those of the authors and do not necessarily reflect the opinion of Huawei Technologies.

1.- Introduction

The European Commission is promoting in Member States the deployment of high-speed broadband access networks through the initiatives defined in the Digital Agenda (European Commission, 2010). Due to its high transmission capacity, a Fiber to the Home (FTTH) network meets the goals set by the European Commission for the year 2020. Distinct operators have already deployed FTTH networks in Europe, but the high costs associated with the civil works of passive infrastructure, which in many cases amount to at least to 60% or 70% of the whole initial investment, are considered a limiting factor by several current and potential operators. In this sense, network sharing schemes that help to reduce the total investment per operator might be a way to overcome the financial limitations.

FTTH/Passive Optical Networks (PONs) are being deployed or considered for deployment by distinct operators in Europe. PON architectures evolve constantly. The Full Service Access Network (FSAN) defined, for example, two phases for Next Generation (NG) PONs: NG-PON1 and NG-PON2 (Huawei, 2010). PON techniques based on Wavelength Division Multiplexing (WDM) technologies that enable the use of several wavelengths on the same fiber, and which help improve the transmission capacity per user, have been discussed in the standardisation groups.

Operators that need to make investment decisions over the next few years and policymakers that wish to create the necessary regulatory framework for investment in FTTH infrastructure are interested in a number of topics related to the strategic and financial implications of network sharing of current and future FTTH/PON architectures. The objective of this article is to contribute to the clarification of some of these concerns. In particular, the research questions that are addressed in the article are the following:

- 1) *What are the technical possibilities for sharing FTTH/PON architectures? Is it possible to unbundle a single fiber? When will the physical unbundling be possible?*
- 2) *What are the cost implications of FTTH/PON sharing? If operators co-invest in FTTH/PON deployments, what are the minimum market share and the price per access line necessary to recover the investment?*

This article tackles these questions by explaining first, the technical and strategic implications of current and future PON architectures and second, by using a cost model to derive the deployment cost of an FTTH/PON architecture that is being shared by several operators. Three geotypes, based on the average values of European countries, were considered: urban, suburban and rural.

A few authors have addressed some topics related to the subjects that are described in this article. Breuer et al. (2011) and Analysis Mason (2008) compare the costs of different fiber-based access network architectures. Chen et al. (2010) analyse fault management aspects related to Capital Expenditures (CAPEX) and Operational Expenditures (OPEX) in FTTH/PON architectures. A few studies have analysed some aspects of FTTH unbundling. Technical and regulatory concerns of the unbundling of different FTTH PON and Point-to-Point (P2P) architectures are described in Analysis Mason (2009a); and a cost analysis associated with these possibilities is presented in Analysis Mason (2009b). Hoernig et al. (2012) use a multi-

player oligopoly model to study competition issues of FTTH networks that can be physically unbundled, and of those that cannot be unbundled and that enable only a bitstream mode for the sharing of the infrastructure.

Several studies have analysed the regulatory implications of Next Generation Access (NGA) networks and fiber co-investment models. BEREC (2011a) explains how the concept of “open access” is being used in the European Union to accelerate the roll-out of NGA networks. Oxera (2011) examines a NetCo model where the regulators and the industry agree on the long-term investment requirements to deploy fiber. BEREC (2011b) describes different types of co-investment scenarios for NGA network deployment in the European Union. Ilic, Neumann & Plückebaum (2009a) describe the implications of risk sharing and co-investment in NGA network deployments. Bourreau, Cambini & Hoernig (2010) discuss the strategies adopted in France, Italy and Portugal to promote co-investment between competing operators. Mölleryd (2011) presents different co-investment agreements of operators in Europe for Next Generation Network (NGN) deployment. Lebourges (2010) suggests that a combination of individual investment with co-investment models could be the proper solution for FTTH roll-out. Bourreau, Cambini & Hoernig (2012) study the effect of NGA infrastructure co-investment decisions on market outcomes. Pereira & Ferreira (2012) study the cost composition of FTTH/PON and Long-Term Evolution (LTE) network deployments that have an infrastructure-sharing scheme. Ilic, Neumann & Plückebaum (2009b) analyse the conditions under which the deployment of FTTH networks in Switzerland would be profitable. Neumann (2010) analyses different aspects of the economics of FTTx networks in Europe. With regard to mobile networks, BEREC (2011c) analyses the situation of infrastructure and spectrum sharing in mobile and wireless networks in Europe.

This article is organised as follows. Section 2 provides an overview of the following present and future FTTH/PON architectures that are under consideration by distinct operators in Europe: Gigabit PON (GPON), 10-Gigabit-capable PON (XG-PON), Time and Wavelength Division Multiplexing PON (TWDM-PON), and Arrayed Waveguide Grating (AWG)-based WDM-PON. It is not the purpose of this section to provide a detailed technical description of PON architectures, but rather to explain which technical features can have an impact on strategic decisions related to future investments of fiber-based networks. Section 3 describes the network scenarios and the costing methodology used to calculate the costs. Section 4 examines the effects of a network sharing model on deployment costs, and the market share value that enables a return of investment in a reasonable period. The conclusions are addressed in Section 5.

2.- Overview of FTTH/PON architectures

The four PON architectures used for the analysis carried out in the article are explained in this section. The four networks have been studied or are being studied in the Study Group 15 (SG15) of the ITU-T. XG-PON and TWDM-PON have been studied initially in FSAN. The FSAN specifications are submitted to the International Telecommunication Union – Telecommunication Standardization Sector (ITU-T) to proceed with the standardisation. GPON and XG-PON belong to the subgroup referred to as Question 2 (Q2) of the SG15 and

named "Optical Systems for fibre access networks". TWDM-PON is being defined by the FSAN. The standardisation task related to TWDM-PON is also being addressed in the ITU-T SG15 Q2. AWG-based WDM-PON belongs to the Question 6 (Q6) subgroup of the SG15 named "Characteristics of optical systems for terrestrial transport networks".

2.1 GPON

GPON is a standardised network that is already commercially available. The downlink capacity is 2.5 Gbps, whereas the uplink capacity is 1.2 Gbps. Theoretically the splitting factor is up to 128, but in practice it employs a value of 64 or lower. The logical reach is 60 km; however, operators use it for a distance of 20 km. All the signals work with the same wavelength pairs, therefore it is not possible for operators to physically share the same fiber.

2.2 XG-PON

XG-PON belongs to the NG-PON1 standardisation path. It was standardised in 2010 by the ITU-T through the G.987 recommendation. It is expected that the product would be commercially available in 2012 or 2013. The downlink and uplink transmission capacities are 10 Gbps and 2.5 Gbps, respectively. The splitting factor can be 128 or more. The logical reach is 60 km. The same wavelength pairs are used for all the transmissions, hence it is not possible to physically share the same fiber. The same passive infrastructure (fiber cables and splitters) employed for GPON can be reused for an XG-PON deployment.

2.3 TWDM-PON

TWDM-PON is the primary solution for the NG-PON2 standardisation path. The standardisation process should be finalised in 2013 or 2014, and the product might be commercially available in the period 2016-2018. It is based on TWDM and makes it possible to stack 4 XG-PON signals. It is under discussion whether it would be possible to stack 8 or 16 signals. Ma et al. (2012) describe a TWDM-PON prototype that coexists with GPON and XG-PON systems.

The capacity of a downlink port is 40 Gbps (4×10 Gbps), and the uplink capacity is 10 Gbps (4×2.5 Gbps). Theoretically the splitting factor might be up to 512, and it should be at least 128. The maximum distance has yet to be defined, but it would possibly be between 40 km and 60 km. Operators can work with different wavelengths; therefore, physical unbundling of a fiber is possible. The capacity of the WDM mux used to combine the signals that arrive from different operators is 4 or 8 XG-PON ports. The system works with colorless Optical Network Units (ONUs). The same passive infrastructure (fiber cables and splitters) that has been used in GPON and XG-PON architectures can be employed in a TWDM architecture.

2.4 AWG-based WDM-PON

AWG-based WDM-PON has been defined as a transport technology by the ITU-T. It is still not clear when the product will be commercially available for residential customers. The downlink and uplink transmission capacity per subscriber, which is assigned to one subscriber and is not shared with other subscribers, is 1.25 Gbps. Every fiber has a total

transmission capacity of 40 Gbps (32*1.25 Gbps). It is not clear yet whether there would be 16, 32, or 48 wavelengths per fiber. The distance might be up to 40 km. Table 1 summarises the main features of the above-mentioned PON architectures. A splitting factor of 32 was used to derive the downlink transmission capacity per user in GPON, XG-PON, and TWDM-PON architectures.

Table 1: Features of PON architectures

	GPON	XG-PON	TWDM-PON	AWG-based WDM-PON
Downlink transmission capacity per user	78 Mbps (minimum value with splitting factor 32, the peak bandwidth can be higher)	312 Mbps (minimum value with splitting factor 32, the peak bandwidth can be higher)	1.25 Gbps (minimum value with splitting factor 32, the peak bandwidth can be higher)	1.25 Gbps (guaranteed value, capacity assigned exclusively to one user)
Standardisation process	Already standardised	Already standardised (NG-PON1)	Standard still under discussion (NG-PON2). It should be finished in 2013-2014	Already standardised as a transport technology
Commercial availability	Product already available	in 2012 or 2013	Probably in 2016-2018	Probably in 2016-2018
Physical unbundling of a fiber possible?	No	No	Yes	Yes

The information provided in this section can be used for strategic planning related to the roll-out of present and future PON architectures. If an operator intends to deploy a PON in the years 2012 or 2013, it can use GPON, or XG-PON if it intends to have a higher transmission capacity. PON architectures that enable a higher transmission capacity, such as TWDM-PON or AWG-based WDM-PON, will be commercially available in the period 2016-2018. One of the advantages of the TWDM-PON architecture is that it can reuse the passive infrastructure (fiber and splitters) that has been deployed previously for GPON or XG-PON. The advantage of AWG-based WDM-PON is the minimum capacity that is assigned to one subscriber. TWDM-PON can reach the same transmission capacity as AWG-based WDM-PON, but if a higher splitting factor is used, e.g. 64 or 128, the guaranteed transmission capacity per subscriber will be lower. Physical network sharing in GPON and XG-PON architectures is only possible when using a multi-fiber deployment. If operators intend to share a fiber a bitstream transmission scheme should be used. In WDM-based networks it is possible to physically unbundle a fiber.

3.- Network scenarios and costing methodology

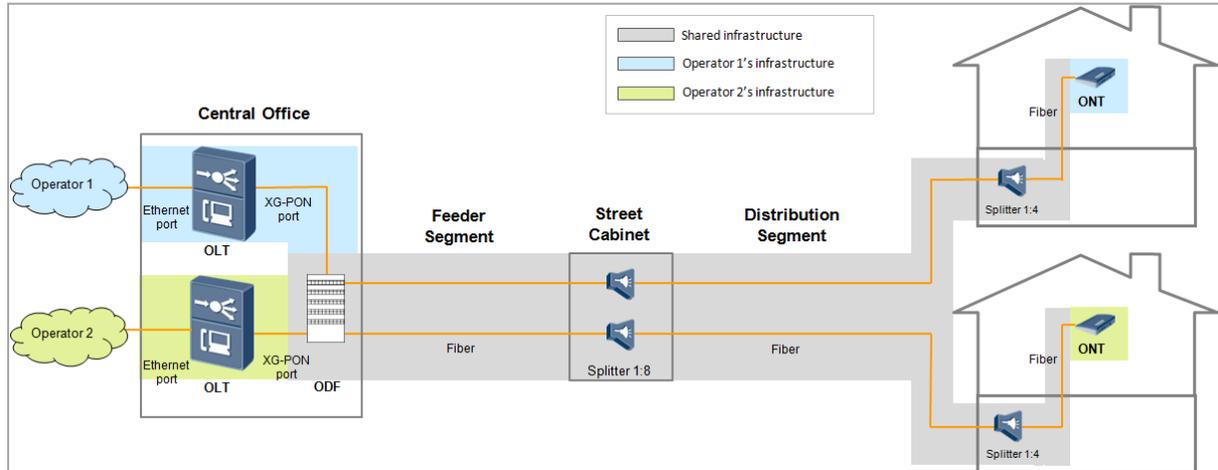
This section describes the network scenarios and the features of the costing methodology employed for the analysis.

3.1 Network scenarios

The following four networks have been modeled: GPON, XG-PON, TWDM-PON, and AWG-based WDM-PON. Figure 1 shows the network architecture of the XG-PON architecture with a multi-fiber model that enables several operators to share the passive infrastructure. The same network architecture can be used for the GPON architecture. It is shown that all the operators share the passive infrastructure, whereas each operator controls its own active infrastructure. The main components of the passive infrastructure are the Optical Distribution Frame (ODF) in the central office, the feeder segment, the street cabinet, the distribution segment, the splitters in the basement of the building and the in-house cabling. The active elements include the Optical Line Terminal (OLT) with XG-PON and upstream Ethernet ports, and the Optical Network Terminal (ONT) in the housing of the subscriber.

For GPON, XG-PON and TWDM-PON there are two splitting levels: 1:8 in the street cabinet and 1:4 in the basement of the building. This creates a total splitting factor of 1:32 per PON port. The value derived for the cost of a home connected includes all the network elements shown in Figure 1, from the ONT to the Ethernet upstream port in the OLT.

Figure 1: An XG-PON architecture with a multi-fiber model



The TWDM-PON architecture is depicted in Figure 2. The WDM mux receives the signals that arrive from the OLTs of the operators and multiplexes them in a single fiber.

Figure 2: TWDM-PON architecture

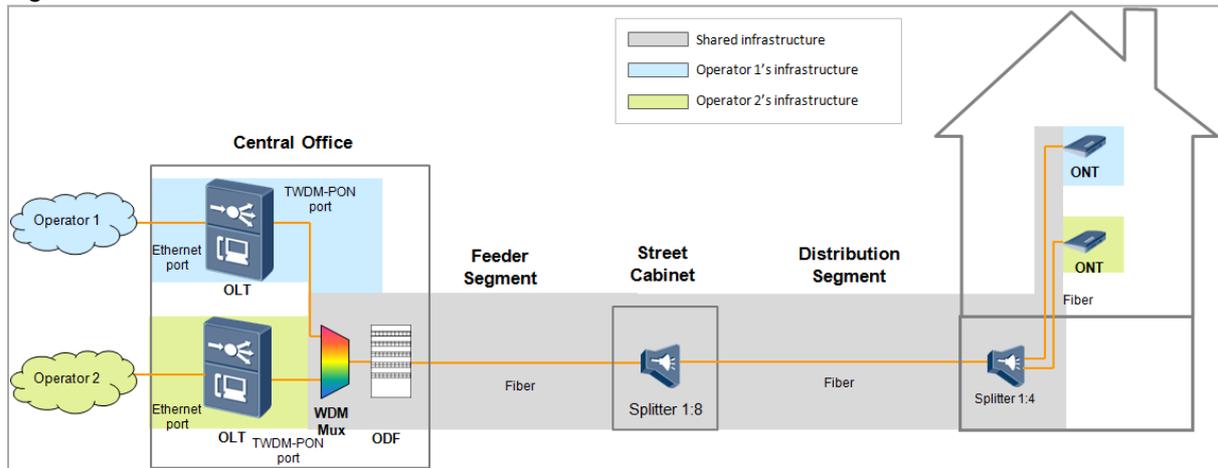
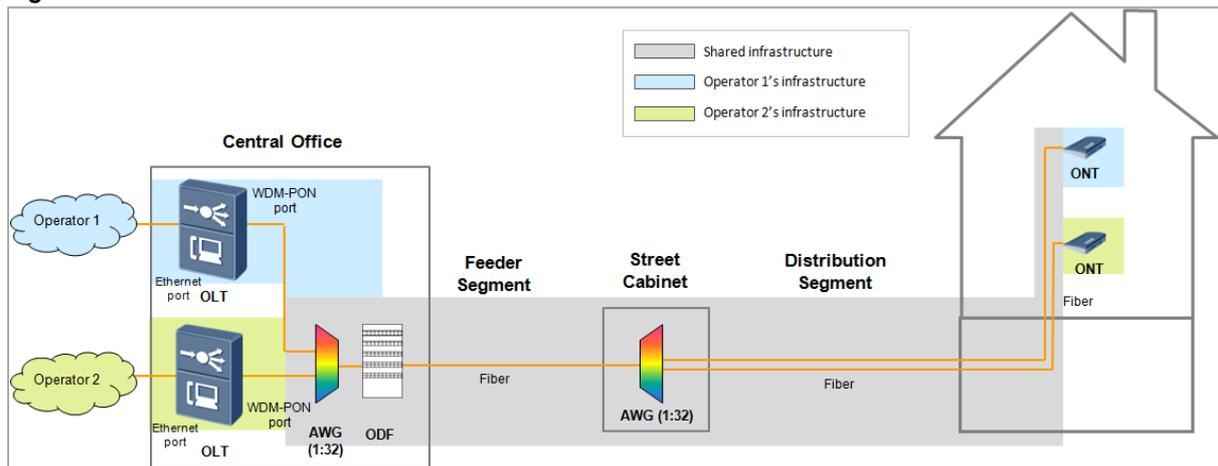


Figure 3 shows the network architecture of the AWG-based WDM-PON architecture. For comparison purposes it was considered in the cost calculation that the Arrayed Waveguide Grating in the AWG-based WDM-PON architecture supports up to 32 users. There are three main differences between the TWDM-PON and the AWG-based WDM-PON architectures described in this article: 1) The AWG-based WDM-PON architecture does not have splitters; 2) instead of having a WDM mux, the AWG-based WDM-PON architecture has an AWG in the central office and a second AWG located in the street cabinet; and 3) as the AWG is located in the street cabinet, the distribution segment should have at least one fiber per subscriber, i.e., there is no sharing of fiber in the distribution segment. It can be said that from the AWG in the street cabinet to the ONT, the network has a P2P connection.

Figure 3: AWG-based WDM-PON architecture



3.2 Costing methodology

A greenfield approach has been considered for the deployment of the FTTH/PON architectures. The following three geotypes, based on mean values of network deployments in Europe, have been used: urban, suburban, and rural. The main differences between the three geotypes are the length of the feeder and distribution segments, and the number of

subscribers, street cabinets and central offices. All the network elements, for example, the splitters and the WDM muxes, have been dimensioned according to the capacity that should be provided in every geotype. It was considered that the network was deployed in equal proportions over the first four years, and that an operator achieves a target market share of 25%, 50%, 75%, and 100% over the first, second, third, and fourth years, respectively. After the fourth year the market share per operator remains the same.

The total cost per home connected includes CAPEX and OPEX values. A timeframe of 15 years was used to recover the investment. The value of the Weighted Average Cost of Capital (WACC) is 9%. OPEX values of network elements were derived by using mark-up values: 1% for the passive infrastructure and 4% for the active infrastructure. In the central office, the costs of the floor space rental and of the energy consumption of the active elements are part of the OPEX values. The energy consumption of the PON ports increases with the transmission capacity.

The values of the components that still are not commercially available, such as the PON line cards and ONTs, have been derived by identifying current market costs of the components of the products, and by considering, based on trends of previous years, that the price will decrease with an increase of the volume of the sales.

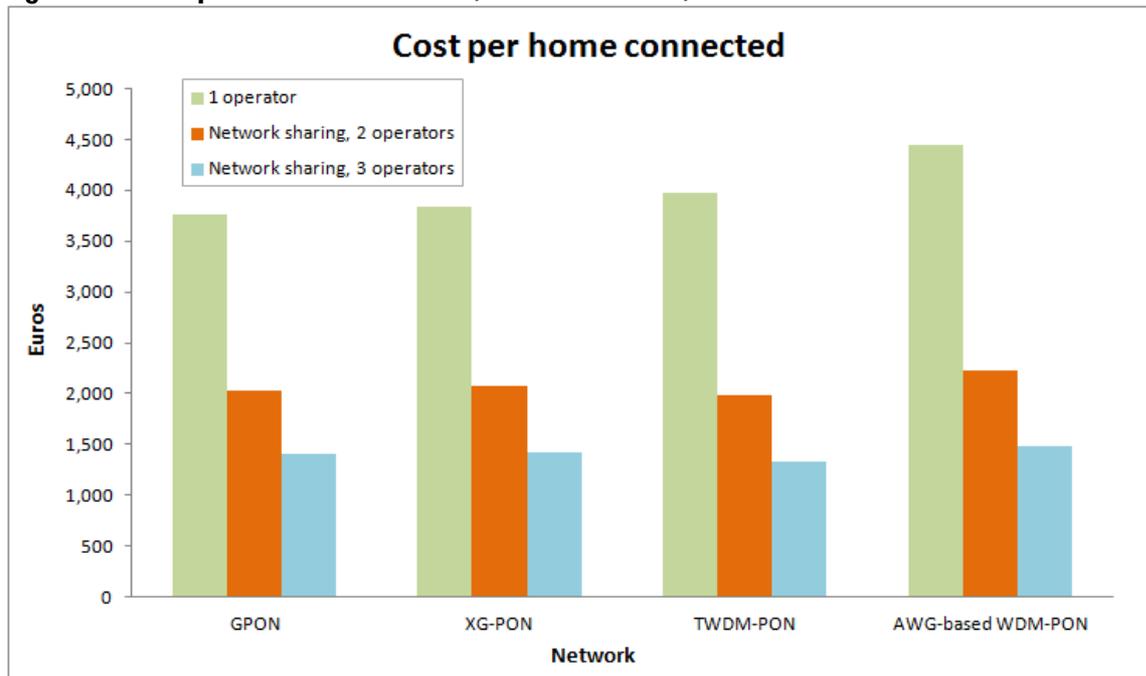
We have considered three scenarios: in the first scenario, there is only one operator, and the passive infrastructure deployed supports only one operator in a single fiber mode. In the other two co-investment scenarios, there is enough passive infrastructure for four operators in the feeder and distribution segments by using a multi-fiber scheme if the network architecture requires it. In the second scenario, the network is shared by two operators, whereas in the third scenario the network is shared by three operators.

This study was carried out taking into account exclusively the cost of the fiber-based access line. The cost of the metro aggregation network and core network, as well as the cost of providing specific services such as video, broadband or telephony were not included in the calculation.

4.- Effect of network sharing on costs

In this section we analyse the costs of deploying the different PON architectures. Figure 4 shows the cost per home connected by the deployment of GPON, XG-PON, TWDM-PON and AWG-based WDM-PON architectures in a suburban area when the market share of all the operators add up to 50%.

Figure 4: Cost per home connected, suburban area, 50% market share



A comparison of average costs of the three scenarios shows that the costs of XG-GPON and TWDM-PON are 2% and 1.3% higher than GPON, respectively. Table 2 shows the cost composition of the scenarios presented in Figure 4. The values reflect the percentage of the total cost. The active network elements of XG-PON (ONT and OLT) have a higher cost than the cost of the active network elements of the GPON architecture, but the passive network infrastructure (feeder and distribution segments, splitters in the street cabinet and in the basement of the building, and in-house cabling) is the same. As more than 90% of the whole cost corresponds to the passive infrastructure, the effect of the cost of the active network elements in the GPON and XG-PON architectures is relatively low.

The cost of TWDM-PON deployment for the three scenarios is 0.6% lower than the cost of deploying XG-PON. Even though the cost of the active elements of the TWDM-PON architecture is higher than that of XG-PON, TWDM-PON can assign the use of the same fiber in the feeder and distribution segments to several operators, which reduces the costs of the passive infrastructure. When comparing the scenarios where two or three operators share the network, TWDM-PON is 5% lower than XG-PON.

The cost of AWG-based WDM-PON is on average 12% higher than the other technologies. In AWG-based WDM-PON architectures, there are no splitters and there is a single fiber in the feeder segment; however, in the distribution segment there is one fiber assigned to every end-user. Moreover, the cost percentage of the active elements of the AWG-based WDM-PON architecture is higher than the cost percentage of the other three PON architectures. Table 2 shows that the cost percentage of the central office, where the OLT is located, is 14% with the AWG-based WDM-PON architecture. For the other three PON architectures, this value ranges from 2% to 5%.

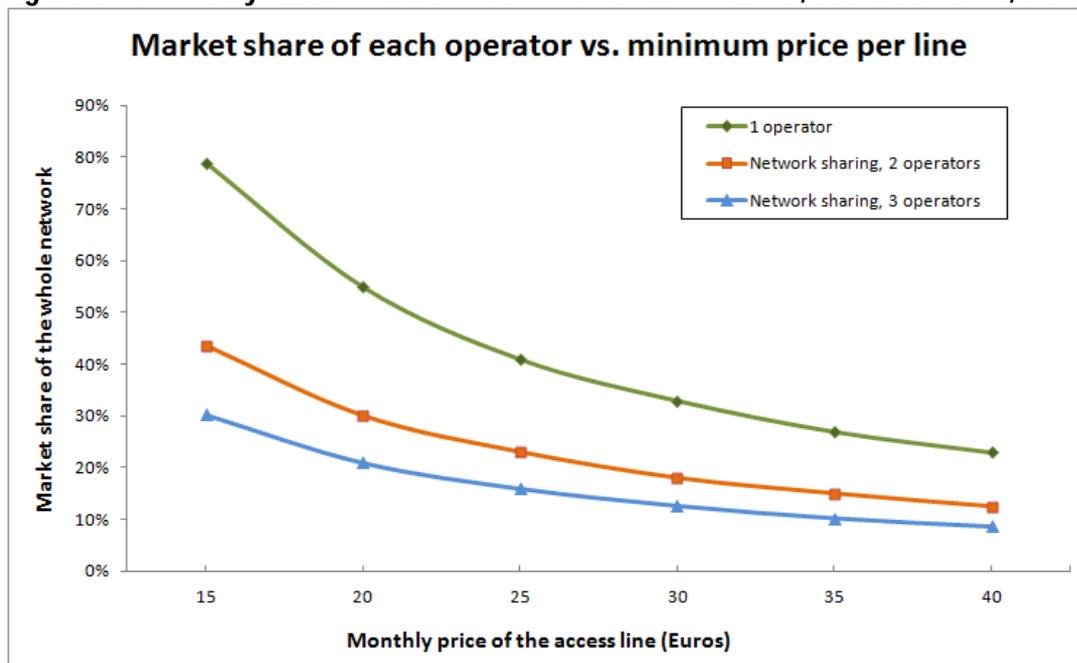
Table 2: Cost composition of PON architectures, suburban area, 50% market share

	GPON			XG-PON			TWDM-PON			AWG-based WDM-PON		
	1 op	2op	3op	1 op	2op	3op	1 op	2op	3op	1 op	2op	3op
Central Office	2%	2%	2%	3%	3%	3%	5%	5%	5%	14%	14%	14%
Feeder segment	26%	25%	24%	25%	24%	24%	24%	24%	24%	22%	22%	22%
Street Cabinet	1%	2%	2%	1%	2%	2%	1%	1%	1%	1%	1%	1%
Distribution segment	60%	58%	57%	59%	57%	55%	57%	57%	57%	53%	53%	53%
In-house segment	8%	11%	13%	9%	11%	13%	8%	8%	8%	5%	5%	5%
ONT	3%	2%	2%	3%	3%	3%	5%	5%	5%	5%	5%	5%

The cost reduction per home connected achieved when a co-investment scheme is used can be appreciated in Figure 4. In comparison with the scenario with one operator, the total cost reduction is on average 48% when two operators share the network, and 65% when three operators share it.

One of the questions that operators try to answer is the minimum market share necessary to recover the investment. Figure 5 shows the relationship between the minimum value that should be charged monthly for the fiber access line in order to recover the investment, and the corresponding market share that should be achieved. Figure 5 is based on the roll-out of an XG-PON architecture in a suburban area. The x-axis contains values that range from 15 to 40 Euros. For any specific value of the price of the access line, it is possible to obtain with the co-investment scenarios lower market share values than with the scenario where one operator deploys the network alone.

Figure 5: Necessary market share to recover the investment, suburban area, XG-PON



Considering the fact that a subscriber could use alternative access networks, such as cable, copper-based, and wireless networks, it was considered that fiber operators could achieve a market share of at most 70% of the potential market share. For our analysis we have obtained the corresponding price for each case. If there is only one fiber operator in the network, the market share considered in this study is 66%. If two operators share the network, then the market share, considering that both operators share it equally, is 33% per operator. For three operators, the market share per operator is 22%. Table 3 shows the derived values for the urban, suburban and rural geotypes.

Table 3: Market share of each operator and monthly price of the access line, XG-PON

	1 operator	Network Sharing 2 operators	Network Sharing 3 operators
Urban	66% (9.8 €)	33% (10.8 €)	22% (11.5 €)
Suburban	66% (17.2 €)	33% (18.5 €)	22% (19.1 €)
Rural	66% (30.5 €)	33% (32.5 €)	22% (33.3 €)

For the urban geotype, one operator with a market share of 66% needs to allocate monthly 9.8 Euros to the access line to recover the investment in 15 years. If two operators share the network, the price of the access line is 10.8 Euros, and each operator needs a market share of 33%. When three operators share the network, the price of the access line is 11.5 Euros, and each operator has a market share of 22%. These values show how the minimum market share that each operator needs to achieve changes when sharing the investment. For suburban areas the price ranges from 17.2 to 19.1 Euros, whereas for rural areas the minimum price is between 30.5 and 33.3 Euros. The price increase between the scenario with three operators and the scenario with one operator is 17.3%, 11.0%, and 9.1% for the urban, suburban, and rural geotypes, respectively. This gives an average increase of 12.4% for the three geotypes.

The reason for this increase in the price of the fiber line for each geotype can be explained by analysing the cost structure of each scenario. According to the costing methodology used in this study, the cost per subscriber of the ONT and of the elements in the central office are the same in the three scenarios. In XG-PON architectures, a multi-fiber scheme requires more investment in the feeder and distribution segments. Therefore, in comparison with the scenario with one operator, these costs are higher with the co-investment model. Moreover, in a network sharing scheme the number and the total cost of the splitters in the street cabinet and in the basement of the building depend on the number of operators that share the network. Each operator needs to deploy enough resources to cover all the areas, even though they will reach, in the co-investment scenarios shown in this analysis, a market share of 33% or 22%. These differences explain the different results per geotype shown in Table 3. The cost per home passed decreases when using a co-investment scenario. However, the cost per home connected, which depends on the market share of each operator, increases in a co-investment scenario.

5.- Conclusions

Operators that are in the process of determining the type of investment they will make to provide high-speed broadband services are pondering the technical possibilities and financial implications of different access networks. A few strategic and economic implications of network sharing from the perspective of the evolution of FTTH/PON architectures have been addressed in the article.

GPON and XG-PON architectures have been already standardised. TWDM-PON is still in the process of standardization, and AWG-based WDM-PON has been standardised as a transport technology. WDM-based network architectures will probably be commercially available in the period 2016-2018. There are significant differences between these networks in terms of transmission capacity. Physical unbundling of a single fiber is not possible with GPON and XG-PON. Operators that intend to share a fiber can use a bitstream transmission scheme. With TWDM-PON and AWG-based WDM-PON it is possible to physically unbundle a fiber due to the different wavelengths pairs that can be employed in the same fiber.

The cost of a home connected with XG-GPON and TWDM-PON is on average 2% and 1.3% higher than with GPON, respectively. The cost of a home connected with AWG-based WDM-PON is on average 12% higher than with the other three technologies. These differences can be explained by the cost differences of the active elements, and by the different requirements for the passive infrastructure. When comparing XG-PON and TWDM-PON in a network sharing scheme, it was observed that the effect of the rise in active elements' costs is mitigated by the cost reduction achieved with the deployment of the passive infrastructure. In comparison with the scenario with one operator in a suburban area, the total cost reduction is on average 48% when two operators share the network, and 65% when three operators share it.

The article has also examined the relationship between the minimum price that should be considered for the access network in order to recover the investment and the corresponding market share. It has been explained why when using co-investment models the price of the access line is higher than when deploying the network alone. The price increase between the scenario with three operators and the scenario with one operator is on average 12.4% when using an XG-PON architecture. On the other hand, in the example shown in the article the market share that each operator should achieve in a network sharing scheme is lower: 33% and 22% in scenarios with two and three operators, respectively. The results show the cost implications of a network sharing scheme when a co-investment model is used in FTTH/PON architectures.

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