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Economic Implications of a Co-investment Scheme for FTTH/PON Architectures

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Abstract

Due to the high costs associated with the deployment of the passive infrastructure of FTTH networks, a few alternative operators have pondered the possibility of making co-investments based on a network sharing model. The purpose of this article is to explore economic aspects of a co-investment scheme for present and future FTTH/PON architectures. The article describes the cost reductions that can be achieved when a co-investment scheme is used, as well as the relationship between market shares and the cost per home connected. A cost model was employed to calculate the investment per home passed and the investment per home connected. The investment per home passed for an alternative operator indicates significant cost reductions when a co-investment scheme is used. On the other hand, the results show that when the incumbent's market share is equal or higher than the total market share of all the alternative operators that share the network infrastructure, the investment per home connected for an alternative operator is higher than that for the incumbent operator. Moreover, to be cost competitive with the incumbent operator, the necessary market share that each alternative operator should achieve is much lower than that of the incumbent operator.

***Keywords**:* co-investment, network sharing, FTTH, PON, cost model

1. Introduction

Broadband deployment plans have been defined at the national or regional levels in several jurisdictions. For example, the European Commission is promoting the deployment of high-speed broadband access networks in Member States of the European Union through the initiatives defined in the Digital Agenda (European Commission, 2010). Due to their high transmission capacity, fibre to the home (FTTH) networks meet the goals set by the European Commission for the year 2020. Different 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%–70% of the whole initial investment, are considered a limiting factor by several current and potential operators. In this sense, co-investment schemes that help to reduce the total investment per operator might be a way to overcome these economic limitations.

FTTH/passive optical networks (PONs) are being deployed or considered for deployment by different operators in Europe. PON architectures – which include new features and can have distinct network designs – evolve constantly. The pre-standards Full-Service Access Network (FSAN) forum, for example, defined two phases for next-generation (NG) PONs: NG-PON1 and NG-PON2. PON techniques based on wavelength division multiplexing (WDM) technologies which enable the use of several wavelengths on the same fibre and help to improve the transmission capacity per user have been discussed in standardisation groups. Therefore, one of the questions that should be investigated is the financial implications of the deployment of FTTH/PON architectures when alternative operators decide to make a co-investment.

A few authors have addressed some topics related to the economic and regulatory implications of fibre-based access networks. Analysys Mason (2008), Elixmann, Ilic, Neumann and Plückebaum (2008), and Breuer et al. (2011) compare the costs of different fibre-based access network architectures. Moreover, Chen, Wosinska, Mas Machuca, and

Jaeger (2010) analyse fault management aspects related to capital expenditures (CAPEX) and operational expenditures (OPEX) in FTTH/PON architectures. Rokkas, Neokosmidis, Katsianis, and Varoutas (2012) present a few results of the cost of deploying different types of FTTH networks. In addition, 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 Analysys Mason (2009a); a cost analysis associated with these possibilities is also presented in Analysys Mason (2009b). Hoernig et al. (2012) use a multiplayer oligopoly model to study competition issues of FTTH networks that can be physically unbundled, as well as 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 fibre 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 regulator and the industry agree on the long-term investment requirements to deploy fibre. BEREC (2011b) describes different types of co-investment scenarios for NGA network deployment in the European Union. Ilic, Neumann and Plückebaum (2009a) describe the implications of risk sharing and co-investment in NGA network deployments. Moreover, Bourreau, Cambini and 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, whereas Lebourges (2010) suggests that a combination of individual investment with co-investment models could be the proper solution for FTTH roll-out.

Bourreau, Cambini and Hoernig (2012) study the effect of NGA infrastructure co-investment decisions on market outcomes. Pereira and Ferreira (2012) study the cost composition of FTTH/PON and long-term evolution (LTE) network deployments that have an infrastructure-sharing scheme. Ilic, Neumann and 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 fibre-based access networks in Europe.

However, the above-mentioned studies still do not address the question of co-investing on FTTH/PON networks when alternative operators decide to follow a network-sharing approach in detail. 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 broadband infrastructure are interested in a number of topics related to the financial implications of sharing current and future FTTH/PON architectures. The objective of this article is to contribute to the clarification of these concerns. In particular, the research question that is addressed in the article is as follows:

- *For alternative operators interested in co-investing in FTTH/PON architectures, what are the cost implications of a network-sharing approach? What are the advantages and disadvantages in relation to the incumbent operator's costs?*

The present article tackles this question by using a cost model to derive the deployment cost of an FTTH/PON architecture that is being shared by several operators. The metrics used to assess the implications of the network sharing scheme are the investment per home passed and the investment per home connected. Current and next-generation PON technologies are employed in the analysis. Urban, suburban and rural geotypes, which have been defined by using values taken from different regions in Europe, are considered in the study.

This article is structured as follows. Section 2 provides an overview of present and future FTTH/PON architectures under consideration by different operators in Europe. It is not the purpose of this section to provide a detailed technical explanation of PON architectures, but rather to describe the major technical features that can have an effect on the cost calculation of the deployment of these networks. Section 3 describes the network scenarios and the costing methodology used to calculate the costs. Section 4 examines the effect of a network-sharing model on the investment per home passed and the investment per home connected. Finally, Section 5 sums up the article.

2. Overview of FTTH/PON Architectures

The four PON architectures used for the analysis carried out in this article are the 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. These networks have been or are being studied by Study Group 15 (SG15) of the International Telecommunication Union–Telecommunication Standardization Sector (ITU-T).

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. All of these signals work with the same wavelength pairs; therefore, it is not possible for operators to physically share the same fibre. A multi-fibre deployment is necessary to physically share the access network.

XG-PON belongs to the NG-PON1 standardisation path. It was standardised in 2010 by the ITU-T through the G.987 recommendation, and it is expected that the product will be commercially available in 2013. The downlink and uplink transmission capacities are 10 Gbps and 2.5 Gbps, respectively. In practice the splitting factor will be up to 128. The same wavelength pairs are used for all transmissions; hence, it is not possible to physically share the same fibre. Operators need a multi-fibre deployment to share the XG-PON architecture. The same passive infrastructure (fibre cables and splitters) employed for GPON can be reused for an XG-PON deployment.

TWDM-PON is the primary solution for the NG-PON2 standardisation path. It is expected that the standardisation process will be finalised in 2013 or 2014, and the product might be commercially available in 2016–2018. It is based on TWDM and makes it possible to stack four XG-PON signals. Whether it would be possible to stack 8 or 16 signals is currently under discussion. 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. Operators can work with different wavelengths; therefore, physical unbundling of a fibre is possible. By physical unbundling, it is understood that it is possible to use the same fibre by means of wavelength unbundling. The capacity of the WDM mux used to combine the signals that arrive from different operators is four or eight XG-PON ports. One of the features of the TWDM-PON architecture is that it can reuse the passive infrastructure (fibre and splitters) that has been deployed previously for GPON or XG-PON.

AWG-based WDM-PON has been defined as a transport technology by the ITU-T. The product could be commercially available for residential customers in 2016–2018. The downlink and uplink transmission capacity per subscriber, which is assigned to one subscriber and is not shared with others, is 1.25 Gbps. Every fibre has a total transmission capacity of 40 Gbps (32*1.25 Gbps). It is not yet clear whether there would be 16, 32 or 48 wavelengths per fibre. 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, such as 64 or 128, the guaranteed transmission capacity per subscriber in TWDM-PON will be lower. More details on the differences between the AWG-based WDM-PON and the TWDM-PON architectures are provided in Section 3.1.

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)	The NG-PON2 standard should be finished in 2013–2014	Already standardised as a transport technology
Commercial availability	Product already available	Available in 2013	Probably in 2016–2018	Probably in 2016–2018
Physical unbundling of a fibre possible?	No	No	Yes (wavelength unbundling)	Yes (wavelength unbundling)

3. Network Scenarios and Costing Methodology

3.1 Network Scenarios

In this article, there are three different approaches to classifying the network scenarios according to: the geotype employed, the PON architecture used or the number of operators using the network. The following three geotypes have been used: urban, suburban and rural. These geotypes were chosen because they reflect in a single way the different scenarios that are found by operators within a country. In this study, the main differences between the geotypes are the length of the feeder and distribution segments, as well as the number of subscribers, street cabinets and central offices.

Table 2 shows different input parameters employed for the cost model. These values were derived by obtaining information from eight service companies that design and deploy FTTH infrastructures in France, Germany, and the United Kingdom. A questionnaire was sent to these companies and the information provided was later verified by means of conference calls conducted with these companies. All the service companies that provided information used a geographic information system (GIS) to derive the lengths of the feeder and distribution segments. The values provided by the service companies were combined in order to obtain average values. Therefore, the values shown in Table 2 do not correspond to any particular fibre deployment in Europe, and should be considered as values that are in the order of magnitude of fibre deployments that can be found in a few European countries. Table 2 illustrates that the cost of preparing the trench and deploying the ducts in urban areas is higher than the cost in suburban and rural areas. This is because more precision is needed for deployment in urban areas. Due do the same factor, there is also a difference in costs between suburban and rural areas.

Table 2

Input Values of the Cost Model.

Item	Value	Item	Value
Length of the feeder segment	Urban: 850 m Suburban: 1,200 m Rural: 2,500 m	Lifetime of passive equipment	20 years
Length of the distribution segment	Urban: 80 m Suburban: 145 m Rural: 220 m	Lifetime of active equipment	At most 10 years OLT: 10 years ONT: 6 years
Cost of trenching and duct deployment	Urban: 90 €/m Suburban: 75 €/m Rural: 65 €/m	OPEX mark-up values	Passive elements: 1% Active elements: 4%
Cost of a manhole	€ 850	Cost of the in-house fibre cable	€ 95

Fig. 1 shows the PON architectures used for cost calculation. 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 PON and upstream Ethernet ports, and the optical network terminal (ONT) in the subscriber's home. In this article, it is considered that the alternative operators involved in a co-investment scheme share the passive infrastructure, whereas each operator controls its own active infrastructure.

For the GPON, XG-PON and TWDM-PON architectures, 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. In the TWDM-PON architecture, the WDM mux, which is located in the central office, receives the signals that arrive from the OLTs of the operators and multiplexes them in a single fibre.

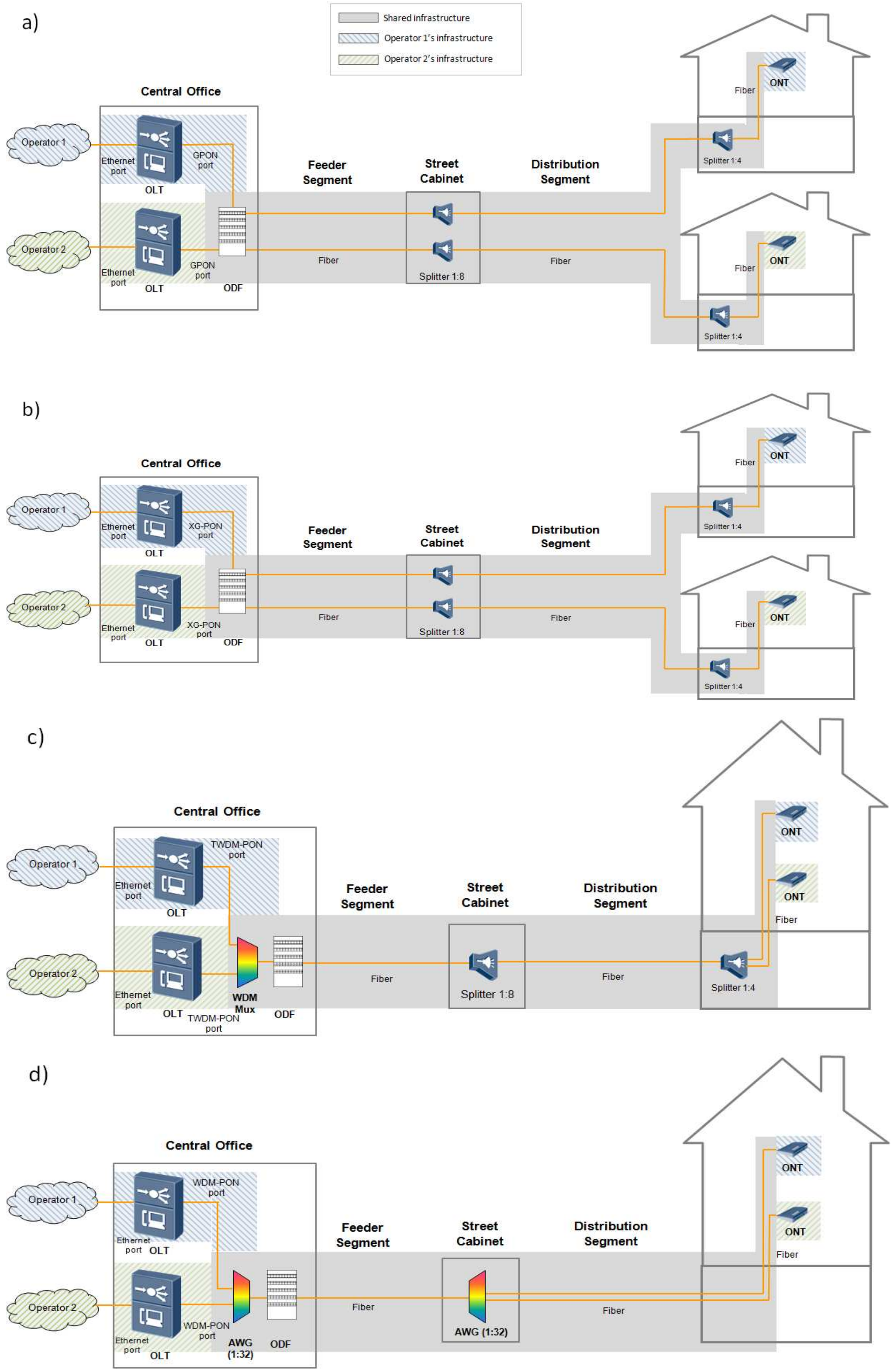
For comparative purposes, it was considered in the cost calculation that the AWG in the AWG-based WDM-PON architecture supports up to 32 users. There are three main differences between the TWDM-PON and the AWG-based WDM-PON architectures described in this article: 1) the AWG-based WDM-PON architecture 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 fibre per subscriber, i.e. there is no sharing of fibres 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.

For the GPON and XG-PON architectures, there is a multi-fibre deployment in the feeder and distribution segments. This means that in the initial deployment, there should be at least one fibre per operator for every end-user. In the TWDM-PON architecture, there is a single-fibre deployment in the feeder and distribution segments, i.e. all the alternative operators share the same fibre. In the AWG-based WDM-PON architecture, there is a single-fibre deployment in the feeder segment, and there is one fibre per end-user in the distribution segment.

Regarding the number of operators, three cases were considered: In the first case, there is only one operator – the incumbent operator – and the passive infrastructure deployed supports only one operator in a single-fibre mode. In the other two co-investment cases, there is sufficient passive infrastructure for up to four alternative operators in the feeder and distribution segments when a multi-fibre scheme is used if the network architecture requires it. In the second case, the network is shared by two alternative operators, whereas in the third case, the network is shared by three alternative operators.

Fig. 1

Network Architectures: a) GPON; b) XG-PON; c) TWDM-PON; d) AWG-based WDM-PON.



3.2 Costing Methodology

The cost of investing in a home passed and a home connected was derived in the article. Typically, in a home passed, the point of interconnection of the end-user with the access network is very close to the location of the end-user; with relatively little engineering effort, it is possible to connect the end-user to the access network. Among operators, there is no strict definition for the location of the point of interconnection. This point is usually on the street in close proximity to the building where the end-user is located, in front of the building, in the basement of the building, or even on the floor where the end-user is located. To physically connect the end-user to the access network, it is necessary to deploy the cable in the last few metres and provide the ONT. For the cost calculation in this article, it was assumed that the point of interconnection in a home passed is located in the basement of the building (see Fig. 1). Therefore, to physically connect the end-user, it is necessary to provide an in-house cable and the ONT. The value derived for the cost of a home connected includes all the network elements from the ONT to the Ethernet upstream port in the OLT. The cost of the in-house cabling and the ONT were not taken into account for the calculation of the cost of a home passed.

In order to derive the investment needed to deploy and maintain the network infrastructure, CAPEX and OPEX values were calculated over a timeframe of 15 years. Then, the cumulative present value (CPV) formula was employed to determine the present value of the total investment (see equation (1)). The discount rate (DR) used, 9%, is in the order of magnitude of weighted average cost of capital (WACC) values employed for the deployment of fixed broadband access networks in several European countries.

$$CPV = \sum_{t=1}^{15} \frac{CAPEX_t + OPEX_t}{(1+DR)^t} \tag{1}$$

The CAPEX include the cost of the active and passive infrastructures and the necessary manpower for the roll-out. In this study, a greenfield approach was used for the deployment of the FTTH/PON architectures, i.e. it did not consider the reuse of any existing infrastructure, such as ducts or fibres. The components of the CAPEX in the feeder and distribution segments are the cost of digging, the deployment of ducts, and the roll-out of fibre and manholes. The OPEX include the cost of the maintenance of the active and passive infrastructures. 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. For the calculation of the energy consumption of the active elements located in the central office, it was assumed that the price of the kWh is €0.16. The lifetime of the passive equipment is 20 years, whereas the lifetime of the active equipment is lower and changes according to the equipment. For example, for the OLT and ONT, the lifetimes considered in this study are 10 and 6 years, respectively.

To derive the investment per home per operator, the cumulative present value of the total investment, which was obtained by using equation (1), was divided by the total number of operators that deploy the infrastructure and also by the number of subscribers that each operator has. This latter value was obtained by multiplying the total number of households in a region by the market share achieved by an operator. Eq. (2) shows the formula used to derive the values of the investment per home passed and the investment per home connected for the incumbent and alternative operators.

$$\text{Investment per home per operator} = \frac{\frac{\text{CPV of the cost of deploying the network}}{\text{Number of operators that share the network}}}{(\text{Total number of households})*(\text{market share of every operator})} \tag{2}$$

Regarding the network roll-out, it was assumed that the network was deployed in equal proportions over the first four years, i.e. the network coverage was 25% in year one, 50% in year two, 75% in year three and 100% in year four. Moreover, it was considered that an operator achieves 25%, 50%, 75% and 100% of the market share over the first, second, third and fourth years, respectively. After the fourth year, the market share per operator remains the same because it was considered that the rate of adoption of new users is similar to the churn rate.

The costs of the metro aggregation network, the core network and a backhaul network were not considered, nor were sales and marketing costs. Moreover, the cost of providing specific services, such as video, broadband or telephony, was not included in the calculation. This study exclusively took into account the cost of the fibre-based access line and the network elements that enable the transmission of the signal in the access network. This value is employed by operators in order to derive at a later stage other costs, such as retail or wholesale prices. In order to calculate a retail price, it is necessary to add the cost of the aggregation or backhaul network, the core network, the sales and marketing costs, et cetera, to the access network cost derived in this study.

There are cost differences between the single-fibre and multi-fibre schemes. For the multi-fibre scheme, it was considered that a different type of cable that contains more fibre should be deployed, leading to a higher value of the fibre cable. For example, more fibres are needed in the feeder segment for the GPON and XG-PON architectures. Moreover, depending on the number of alternative operators that share the network, more splitters in the street cabinet and in the basement of the building are necessary. It was assumed that the street cabinets are big enough so that they can be shared by distinct operators.

4. Economic Aspects of a Co-investment Model

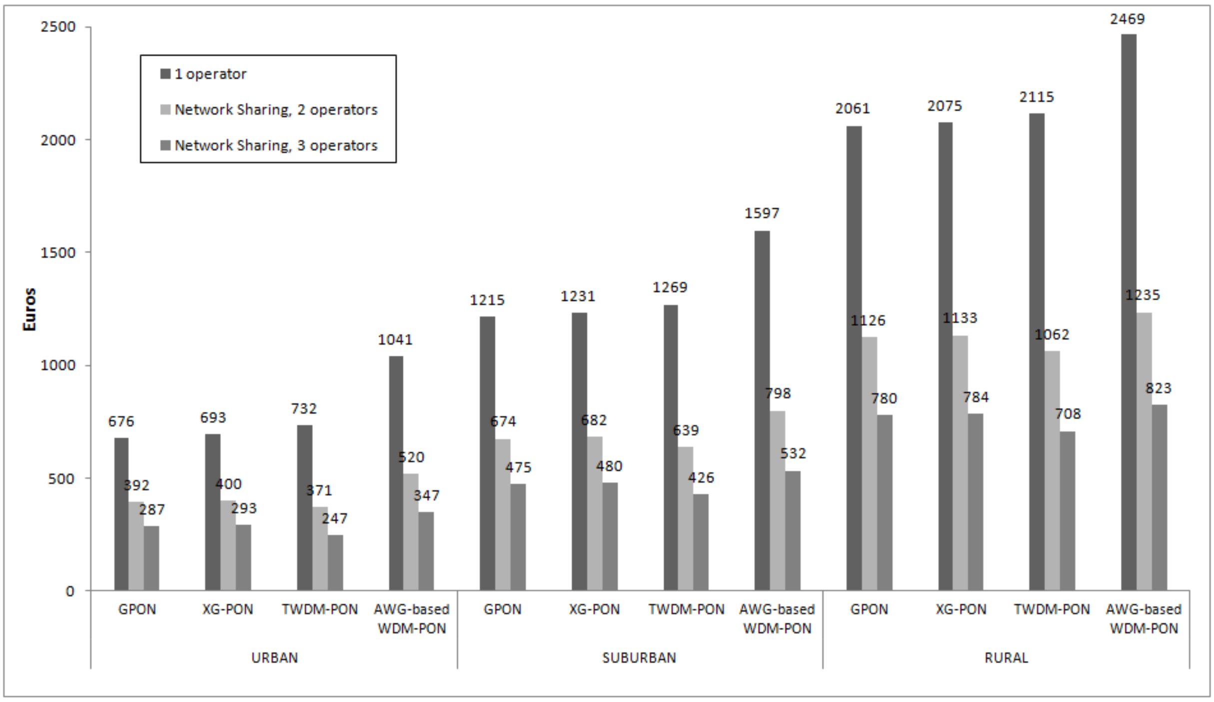
This section describes the investment per home passed, the investment per home connected, the effect of market share on the cost per home connected, and the lessons that can be learned from the analysis of the results.

4.1 Investment per Home Passed

In order to assess the necessary investment to deploy a network in a region, an operator usually calculates the investment per home passed, which depends on all the potential households that can be connected (100% market share). This section first explains the cost reductions achieved by using the network sharing scheme and, second, the differences in costs between the different PON architectures. Fig. 2 depicts the investment per home passed for the three geotypes and the four PON network architectures considered in the study.

Fig. 2

Investment per Home Passed.



The reduction in the investment per home passed when a co-investment scheme is used can be observed in Fig. 2. For the case of two alternative operators, the investment for each operator in relation to the incumbent's investment ranges from 50.0% for AWG-based WDM-PON to 58.0% for GPON in urban areas. When three alternative operators share the network, the investment for each operator relative to the investment for the incumbent ranges from 33.3% to 42.5%. In comparison with the scenario with one operator, the total investment reduction for the 12 cases presented is 46.9% on average when two alternative operators share the network, and 63.4% when three alternative operators share. In every case and for all the geotypes analysed, the investment needed by each alternative operator that co-invests in the network is lower than the investment needed by the incumbent operator.

The cost reduction is achieved through sharing the passive infrastructure, a cost which is equivalent to the majority of the whole investment. Table 3 shows the cost composition of the urban scenarios presented in Fig. 2. The cost percentage of the in-house segment shown in Table 3 refers to the infrastructure in the basement of the building, and not the cost of the in-house cabling and the ONT. Table 3 indicates that the cost percentage of the feeder segment ranges from 14% to 21%, whereas the cost percentage of the distribution segment ranges from 42% to 61%. For the case of GPON, XG-PON and TWDM-PON, the cost percentage of the feeder and distribution segments is reduced when two or three alternative operators co-invest in the network architecture. For example, for XG-PON, the cost percentage of the feeder segment is 21%, 19%, and 17%, when one, two, and three operators use the network, respectively.

Table 3

Cost Composition of PON Architectures, Homes Passed, Urban Area.

	GPON			XG-PON			TWDM-PON			AWG-based WDM-PON		
	1 op	**2 op**	**3 op**	**1 op**	**2 op**	**3 op**	**1 op**	**2 op**	**3 op**	**1 op**	**2 op**	**3 op**
Central office	5%	5%	4%	7%	6%	6%	11%	13%	13%	42%	42%	42%
Feeder segment	21%	19%	17%	21%	19%	17%	20%	19%	19%	14%	14%	14%
Street cabinet	3%	4%	6%	3%	4%	6%	3%	3%	3%	1%	1%	1%
Distribution segment	61%	56%	51%	60%	55%	50%	57%	56%	56%	42%	42%	42%
In-house segment	10%	16%	22%	9%	16%	21%	9%	9%	9%	1%	1%	1%

A comparison of average costs of the three geotypes shows that the investments for XG-GPON and TWDM-PON when one operator deploys the network are 1.5% and 5.1% higher than GPON, respectively. The active network element of XG-PON, the OLT in the central office, has a higher cost than the cost of the active network element of the GPON architecture, but the passive network infrastructure (feeder and distribution segments and splitters in the street cabinet and in the basement of the building) 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 investment needed to deploy TWDM-PON for the three geotypes is on average 5.1% lower than the investment required to deploy XG-PON. When comparing the deployment cost of one operator, the cost of deploying the TWDM-PON infrastructure is on average 3.5% higher than that of XG-PON. When comparing the scenarios where two or three alternative operators share the network, the TWDM-PON cost is 6.6% and 12.2% lower than that of XG-PON, respectively. 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 fibre in the feeder and distribution segments to several operators, which reduces the costs of the passive infrastructure.

The investment needed to deploy AWG-based WDM-PON is on average 23.8% higher than for the other technologies. In AWG-based WDM-PON architectures, there are no splitters and there is a single fibre in the feeder segment; however, in the distribution segment, there is one fibre 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 3 shows that the cost percentage of the central office, where the OLT is located, is 42% with the AWG-based WDM-PON architecture. For the other three PON architectures, this value ranges from 4% to 13%.

4.2 Investment per Home Connected

The investment per home connected depends on the market share and refers to the investment needed for every active user. Table 4 shows the investment per home connected derived from the deployment of the four PON architectures in urban, suburban and rural areas when the market share of all operators adds up to 50%. When two or three operators share the network, the market share of every alternative operator is 25% and 16.6%, respectively.

The cost of the GPON deployment shown in Table 4, €1,575 per home connected when the network is deployed by one operator with a 50% market share in an urban area, is in the order of magnitude of a fibre deployment in urban areas in a few European countries. Elixmann et al. (2008) have shown that the cost of a home connected with FTTH/PON in urban areas in some European countries ranges from €1,110 (Italy) to €2,039 (Germany), with a 50% market share. Analysys Mason (2008) found that the cost of a home connected with FTTH/GPON in urban areas in the United Kingdom was approximately €1,450, with a 50% market share.

Table 4

Investment per Home Connected, 50% Total Market Share.

	GPON			XG-PON			TWDM-PON			AWG-based WDM-PON		
	1 op (50%)	2 op (25%)	3 op (16.6%)	1 op (50%)	2 op (25%)	3 op (16.6%)	1 op (50%)	2 op (25%)	3 op (16.6%)	1 op (50%)	2 op (25%)	3 op (16.6%)
Urban	€1,575	€1,776	€1,918	€1,633	€1,835	€1,977	€1,720	€1,730	€1,730	€2,046	€2,046	€2,046
Suburban	€2,651	€2,904	€3,040	€2,710	€2,963	€3,098	€2,796	€2,806	€2,806	€3,182	€3,182	€3,182
Rural	€4,342	€4,709	€4,868	€4,398	€4,764	€4,924	€4,486	€4,496	€4,496	€4,924	€4,924	€4,924

When using the XG-PON architecture in an urban region, the investment per home connected for the incumbent operator is €1,633, with a 50% market share. If two or three operators share the network, the investment per home connected is €1,835 and €1,977, respectively. These values show how the investment per home connected changes when sharing the investment. For suburban areas, the investment per home connected ranges from €2,710 to €3,098, whereas for rural areas, the investment per home connected is between €4,398 and €4,924. For the GPON, XG-PON and TWDM-PON architectures, the average cost increase between the scenario with two operators and the scenario with one operator is 8.6%, 6.4% and 5.7% for the urban, suburban and rural geotypes, respectively. This gives an average increase of 6.9% for the three geotypes. The average increase between the scenario with three operators and the scenario with one operator for the three geotypes and these three network architectures is 10.8%. Ilic, Neumann and Plückebaum (2009a) show that the total investment cost increases by 10% to 30% when a multi-fibre model is used for FTTH deployments.

The increase of the investment per home connected between the network sharing scenarios and the standalone scenario is due to two factors. First, for the GPON, XG-PON and TWDM-PON architectures, alternative operators need more infrastructures in comparison with the incumbent operator. As is explained below, this will lead to an increased total investment of the necessary infrastructure. Second, as is shown in equation (2), the total investment cost is divided by the number of subscribers connected by every operator. As there will be several alternative operators sharing the network, the number of subscribers per operator will decrease.

The reason for this increase in the total investment when using the co-investment scheme can be explained by analysing the cost structure of each scenario (see Table 5). In GPON and XG-PON architectures, a multi-fibre scheme requires more investment in the feeder and distribution segments. Therefore, in comparison with the scenario with one operator, these costs are higher in the co-investment model. Moreover, in a network-sharing scheme, the number and total cost of the splitters in the street cabinet and in the basement of the building depends on the number of operators that share the network. Each alternative operator needs to deploy enough resources to cover every area, even though in the co-investment scenarios shown in this analysis, they will reach a market share of only 25% or 16.6%. These differences explain the different results per geotype shown in Table 4. With regard to the TWDM-PON architecture, the slight difference in cost between the co-investment scenarios and the standalone scenario is due to the use of the WDM mux in the central office to combine the signals provided by every alternative operator. When only one operator uses the TWDM-PON, the WDM mux is an option, but it is not mandatory. For this study, it was assumed that for a standalone scenario, the WDM mux was not necessary. With AWG-based WDM-PON, the costs are the same for the standalone and network sharing scenarios because the required network elements are the same.

When operators co-invest and deploy a network in a region, they will be competing against each other. This will lead to a reduced market share per operator and, therefore, to less revenues. Furthermore, alternative operators will need to invest more in marketing and sales in order to acquire users. This effect can also reduce the profits per user.

Table 5

Cost Composition of PON Architectures, Homes Connected, Suburban Area, 50% Market Share.

	GPON			XG-PON			TWDM-PON			AWG-based WDM-PON		
	1 op	2 op	3 op	1 op	2 op	3 op	1 op	2 op	3 op	1 op	2 op	3 op
Central office	2%	1%	1%	2%	2%	2%	4%	4%	4%	15%	15%	15%
Feeder segment	19%	18%	18%	19%	18%	17%	18%	18%	18%	16%	16%	16%
Street cabinet	1%	2%	2%	1%	1%	2%	1%	1%	1%	1%	1%	1%
Distribution segment	63%	61%	58%	62%	60%	57%	60%	60%	60%	56%	56%	56%
In-house segment	12%	15%	18%	12%	15%	18%	11%	11%	11%	7%	7%	7%
ONT	3%	3%	3%	4%	4%	4%	6%	6%	6%	6%	6%	6%

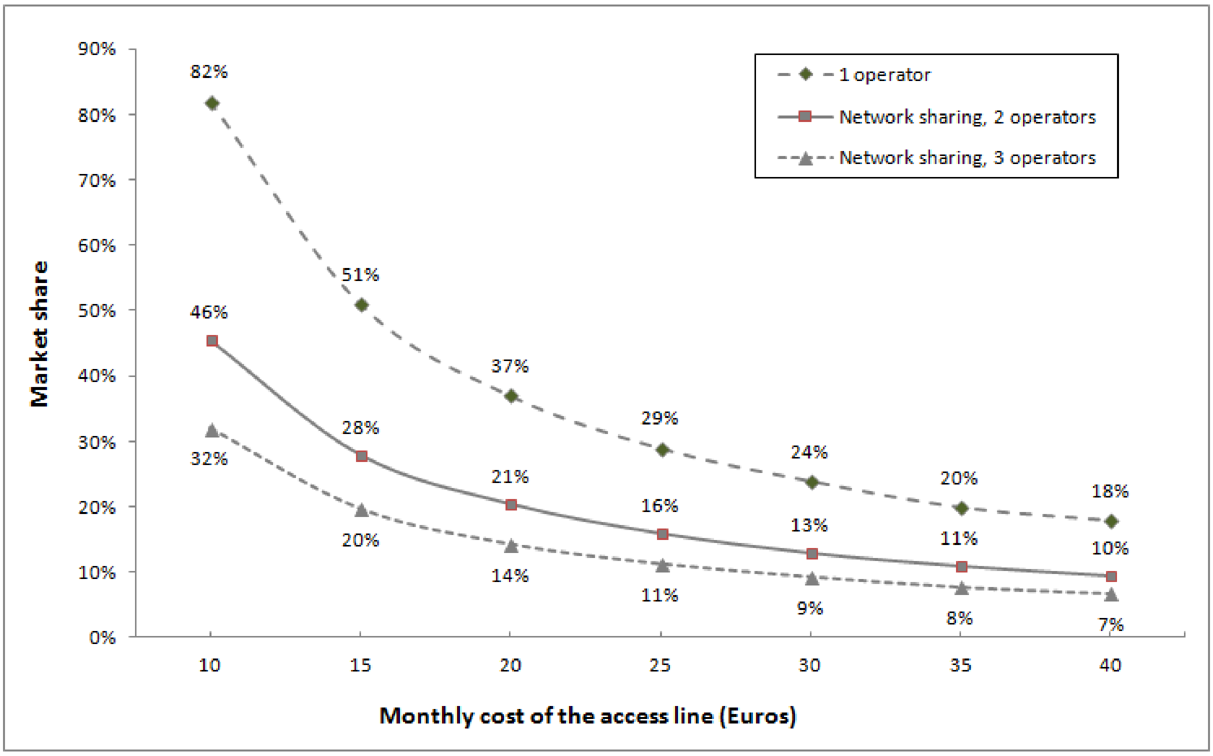
4.3 Relationship between Market Share and the Cost per Home Connected

4.3.1 Effect of market share on cost

One of the questions that operators attempt to answer is the minimum market share necessary to recover the investment. Fig. 3 illustrates the relationship between the minimum value that should be assumed monthly for the fibre access line in order to recover the investment, plus the corresponding market share that should be achieved by each operator. This monthly cost is not the retail price; it is the cost of the fibre access network. Fig. 3 is based on the roll-out of an XG-PON in a suburban area, and shows that if the market share of one operator increases, the monthly cost per user is subsequently reduced. This is because with more subscribers, the investment in infrastructure per user is reduced. For any specific value of the cost of the access line, it is possible to obtain lower market share values with the co-investment scenarios than with the scenario where one operator deploys the network alone. For example, for a monthly cost of €15 per home connected, the market share that one operator should achieve is 51%. When two alternative operators co-invest in the network infrastructure, every operator should achieve a market share of 28%. In the case of three alternative operators, every operator should achieve a market share of 20%.

Fig. 3

Market Share of Each Operator vs. Monthly Cost per Line, Suburban Area, XG-PON.



4.3.2 Impact of different market share distributions on the costs

In order to determine the possible advantages that a co-investment scheme could have for alternative operators in comparison with the possible deployment of a similar architecture made by the incumbent operator, three network sharing distributions are depicted in Table 6. It was assumed that the incumbent operator will deploy the network in a standalone mode without sharing it. For Case 1, the incumbent operator has a 70% market share, whereas the alternative operators have a 30% market share in total. For Case 2, the incumbent operator has a 50% market share, and the alternative operators have a 50% market share in total. In Case 3, the incumbent operator and the alternative operators have 30% and 70% market shares, respectively, in total. In practice, it will be difficult for the incumbent and the co-investors to reach these market share distributions due to the presence of alternative broadband service providers that use different access networks.

In Case 1, for the two alternative operators who share the network and have a 15% market share, each has an investment per home connected of, at most, 136.9% higher than that of the incumbent, which is the case for a rural area. When three alternative operators share a network, the investment for each of the three operators is, at most, 144.9% higher than the incumbent's investment. For Case 2, two alternative operators that share the network have an investment of, at most, 12.4% higher than the investment of the incumbent operator, whereas three alternative operators have an investment of, at most, 21.1% higher than the incumbent's investment. In Case 3, each of the two alternative operators that share the network has an investment value of, at most, 57.0% of the incumbent's investment, whereas each of the three alternative operators has an investment value of, at most, 61.2% of the incumbent's investment. When the total market share of all the alternative operators is lower than or equal to the incumbent operator's market share, the cost per home connected for an alternative operator is higher than that for the incumbent operator.

Table 6

Investment per Home Connected, XG-PON.

	Incumbent (One operator)	**Network sharing (Two operators)**		**Network sharing (Three operators)**	
Case 1: Incumbent 70% market share	70% market share	30% total market share 15% each operator		30% total market share 10% each operator	
	Investment	Investment	Difference	Investment	Difference
Urban	€1,266	€2,804	221.5%	€3,031	239.4%
Suburban	€2,040	€4,683	229.6%	€4,898	240.1%
Rural	€3,250	€7,700	236.9%	€7,959	244.9%
Case 2: Incumbent 50% market share	50% market share	50% total market share 25% each operator		50% total market share 16.6% each operator	
	Investment	Investment	Difference	Investment	Difference
Urban	€1,633	€1,835	112.4%	€1,977	121.1%
Suburban	€2,710	€2,963	109.3%	€3,098	114.3%
Rural	€4,398	€4,764	108.3%	€4,924	112.0%
Case 3: Incumbent 30% market share	30% market share	70% total market share 35% each operator		70% total market share 23.3% each operator	
	Investment	Investment	Difference	Investment	Difference
Urban	€2,479	€1,412	57.0%	€1,517	61.2%
Suburban	€4,271	€2,225	52.1%	€2,326	54.5%
Rural	€7,096	€3,517	49.6%	€3,636	51.2%

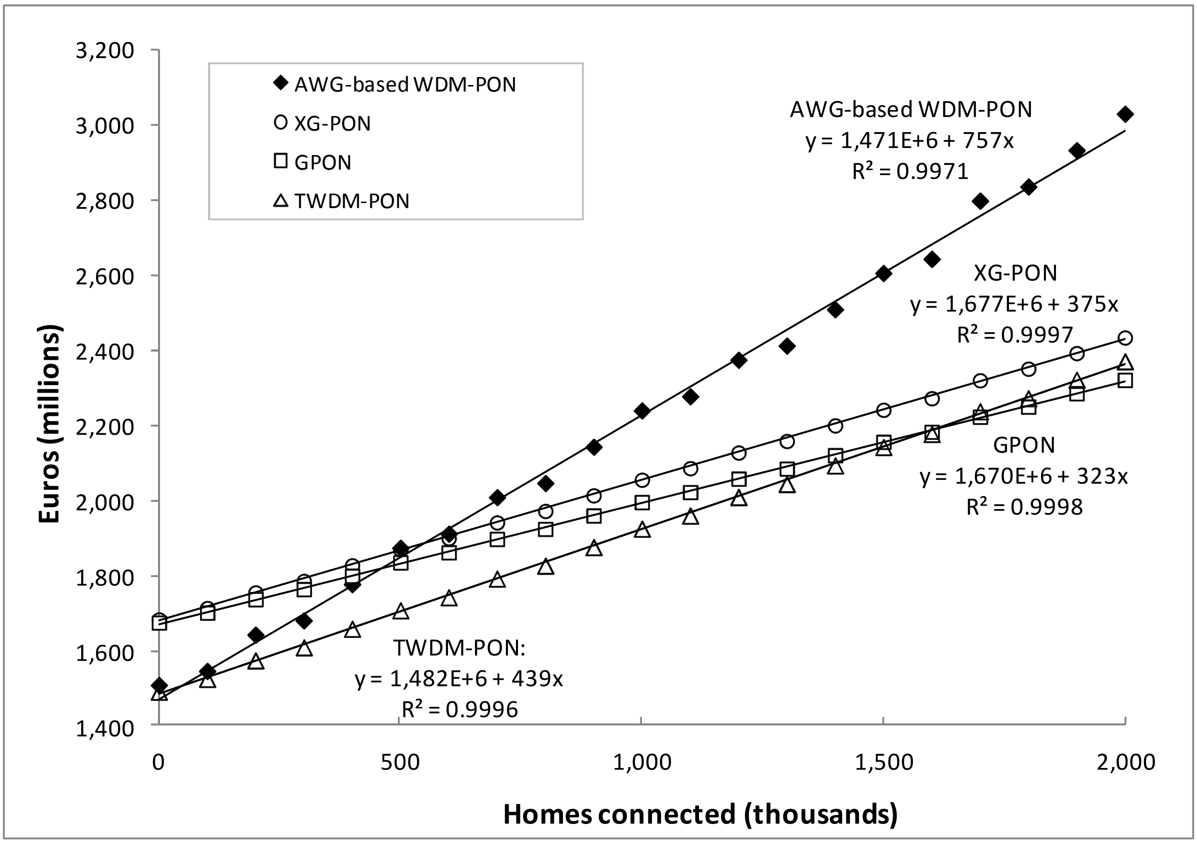
4.3.3 Total Investment and Number of Homes Connected

Fig. 4 depicts the relationship between the total investment and the number of homes connected for the four PON technologies described in the article. The values derived correspond to the case of two alternative operators that deploy a network in an urban area. The upper limit of the x axis, 2 million homes connected, corresponds to a market share of 86.9 %. Fig. 4 shows also the cost functions, which were obtained by using regression analysis. In all cases, a linear cost function was derived. The results show that, for values of homes connected located in the range 0.54 million (23.4% market share) - 1.62 million (70.4% market share), the four networks are arranged in decreasing order of total investment:

first, AWG-based WDM-PON; second, XG-PON; third, GPON; and fourth, TWDM-PON. This is consistent with the values shown in Section 4.2, which were derived for a market share of 50%.

Fig. 4

Total Investment vs. Number of Homes Connected and Cost Functions, 2 operators, Urban Area.



4.4 Assessment of the Investment per Home Passed and the Investment per Home Connected

The investment per home passed is a value that reflects the minimum investment needed per household to deploy an access network close to the subscriber's premises. To calculate the total investment needed in a region, the value of the investment per home passed should be multiplied by the total number of households in the region. As explained in Section 4.1, in all the cases studied, there are important economic benefits obtained when operators decide to share the network infrastructure. However, this metric does not reflect the effect of the following items: the cost of the in-house cabling and the ONT and the market share achieved by every operator. The investment per home connected includes these values. As described in Sections 4.2 and 4.3, the value of the market share that each alternative operator achieves will determine how cost competitive the investment of a home connected is. In summation, there are a few lessons that can be learned from the analysis of the investment per home passed and the investment per home connected:

- A network sharing scheme leads to a strong reduction in the total investment needed by an alternative operator to deploy an FTTH/PON network and to have all homes passed in a region. By analysing the values of the investment per home passed, it has been shown that there could be on average a cost reduction of 46.9% when two operators share the network, and 63.4% when three operators share. This cost reduction could be motivation for alternative operators when deciding to co-invest. Probably, without this cost reduction, an alternative operator would not be able to afford the whole investment on its own.
- For the GPON, XG-PON, and TWDM-PON architectures, when the total market share is the same, the average increase of the cost per home connected between the scenario with two operators and the scenario with one operator is 6.9%. The average increase between the scenario with three operators and the scenario with one operator is 10.8%.
- To be cost competitive with the incumbent operator, an alternative operator should achieve a market share that is much lower than that of the incumbent operator.

5. Conclusions

Operators in the process of determining the type of investment they will make to provide high-speed broadband services are pondering the financial implications of the deployment of different access networks. This article has examined the economic implications of co-investing in FTTH/PON architectures. Current and next-generation PON technologies have been investigated in the study. The cost differences between these PON architectures have been explained and the effect of the market share on the cost per home connected has been shown.

It has been shown that the investment per home passed for an alternative operator indicates important cost reductions when a co-investment scheme is used. On the other hand, the results illustrate that when the incumbent's market share is equal or higher than the total market share of all the alternative operators that share the network infrastructure, the investment per home connected for an alternative operator is higher than that for the incumbent operator. Furthermore, in order to be cost competitive with the incumbent operator, an alternative operator should achieve a market share that is much lower than that of the incumbent operator.

The two metrics used in this study, the investment per home passed and the investment per home connected, have provided relevant information regarding the cost implications of a co-investment scheme. Further research can provide insights into other aspects of a network sharing agreement. For example, the following aspects could be studied: the effect of a network sharing agreement on the total cost when available passive infrastructure in the distribution and feeder segments, such as ducts and fibre cables, is reused; a sensitivity analysis that describes the effect of the most relevant input parameters on the total cost; and the impact of the network sharing scheme on the payback period.

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