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Cost Analysis of Network Sharing in FTTH/PONs

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ABSTRACT

This article examines the cost implications of a network-sharing scheme for different fiber to the home/passive optical network (FTTH/PON) architectures. Varied metrics are employed to understand the effect of a network-sharing arrangement on costs. The results show that for the majority of cases studied the cost per home connected and the payback period increase when employing a network-sharing scheme, but the initial investment is strongly reduced. The reuse of existing passive infrastructure does not bring any cost advantage in comparison to the stand-alone scenario, but it helps to reduce the total cost per home connected.

***Keywords**:* cost, network-sharing, FTTH, PON

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

INTRODUCTION

The improvement of broadband access capacity is on the agenda of many operators and regional and national administrations worldwide. Potential investors are undertaking techno-economic evaluations to determine advantages and disadvantages of the different networks available in the market. Fiber to the home (FTTH) is a future-proof fixed-access network that provides a much higher transmission capacity than cable- or copper-based networks. However, a challenge associated with FTTH deployment is the high cost of the passive infrastructure; and in particular, of the civil works, which correspond to the majority of the whole investment. This fact, together with the uncertain number of subscribers that can be reached in competitive markets or in markets where users have limitations in terms of broadband affordability, increases the investment risk [1]. One way in which operators could possibly reduce the amount of investment required to deploy fiber-access networks is to share the network infrastructure, thereby reducing the investment needed to deploy and operate the FTTH network.

Several operators have already deployed or selected FTTH/passive optical networks (PONs) as the access network. Operators that already own or are planning to invest in PONs have been examining the broadband transmission capacity that can be achieved over the next years with current and future versions of PONs. The improvement of the transmission capacity and other features of PONs have been included in the standardization process. The pre-standards forum full service access network (FSAN) has been actively involved in the definition of next-generation (NG) PONs, which are referred to as NG-PON1 and NG-PON2. Among other topics, the standardization groups have discussed the type of wavelength-division multiplexing (WDM) that should be used. WDM improves transmission capacity by utilizing different wavelengths on the same fiber [2]. New standardized versions of PON architectures will likely be deployed over the coming years.

Given that a network-sharing (NS) approach might offer a way of overcoming the financial limitations of operators interested in deploying FTTH/PONs, the cost implications of sharing these networks dictate investigation. A few studies have addressed the cost implications of various features of PONs [3-5]. Some have compared the cost of deploying different fiber-based access networks [6, 7]. Others have examined the regulatory implications of co-investing in next-generation access (NGA) networks [8, 9]. The economic effects of co-investing in PONs for a few scenarios have been addressed in [10].

However, there are still several aspects of network sharing that have not been addressed in the above mentioned studies. The purpose of this article is to contribute to the clarification of the cost implications of sharing different types of FTTH/PONs. The following research question is addressed: *What are the economic implications of a network-sharing scheme for operators that decide to make a joint investment in FTTH/PONs?*

We tackle this question by utilizing a cost model to derive the deployment cost of FTTH/PON architectures shared by several operators. Standardized networks and networks that are in the standardization process have been used in the study: 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. Urban, suburban, and rural geotypes based on average values of select European countries were employed.

The rest of the article is organized as follows: In the next section, we describe the FTTH/PONs used for the analysis and the technical ways in which distinct operators can share them. We then describe the network scenarios and the costing methodology employed. We present the results of the cost assessment, which are based on the analysis of the following four metrics: the required initial investment, the cost per home connected, the payback period, and the effect of the existing passive infrastructure on the total cost. Finally, the conclusions are provided.

PON ARCHITECTURES

The four PON architectures described in this article are currently under consideration for deployment by different operators in Europe and other regions around the world. The XG-PON and the TWDM-PON have been studied initially in the FSAN. The FSAN specifications are submitted to the International Telecommunication Union –

Telecommunication Standardization Sector (ITU-T) in order to proceed with standardization. The standards related to GPON and the XG-PON have been developed by the subgroup referred to as Question 2 (Q2) of the ITU-T Study Group 15 (SG15), which deals with optical access networks. This subgroup has also been addressing the standardization task related to TWDM-PONs. The subgroup Question 6 (Q6) of the ITU-T SG15 works on the standards related to metro WDM technologies. The AWG-based WDM-PON architecture described in this article is based on the Recommendation G.698.3, which was approved by the subgroup Q6 [11]. This network was approved as a metro network and a few operators are evaluating the possibility of using it in the access network.

GPON is commercially available and has been deployed by several operators in different countries. The downlink and uplink capacities are 2.5 Gbps and 1.2 Gbps, respectively. The splitting factor can, in theory, be up to 128. However, in practice, operators employ a value of 64 or lower. Different operators cannot physically share a fiber because all the signals work with the same wavelength pairs. Operators need multi-fiber deployment in order to physically share the GPON architecture.

The XG-PON was defined as part of the NG-PON1 standardization path. The ITU-T G.987 recommendation describes the features of XG-PONs [12]. The downlink capacity is 10 Gbps, whereas the uplink capacity is 2.5 Gbps. In practice, it is expected that operators will employ a splitting factor of up to 128. Different signals use the same wavelength pairs. Therefore, physical sharing of the same fiber is not possible, and operators need to utilize multi-fiber deployment to share the XG-PON. With XG-PON, the same passive infrastructure used for GPONs (i.e., splitters and fiber cables) can be employed in the XG-PON architecture.

The TWDM-PON is the primary solution in the NG-PON2 standardization path. With TWDM, it will be possible to stack at least four 10 Gbps signals instead of one 40 Gbps signal, and potentially as many as eight or more. The downlink capacity of a port is 40 Gbps (4*10 Gbps), and the uplink capacity is 10 Gbps (4*2.5 Gbps). The splitting factor will be at least 256 [13]. Physical unbundling of a fiber is possible because operators can employ different wavelengths. A WDM mux, which is used to combine signals from different operators, can support up to four or eight XG-PON lines (ports). The same passive infrastructure (i.e., fiber cables and splitters) employed for GPONs and XG-PONs can be reused for TWDM-PON deployment.

In AWG-based WDM-PON architectures the downlink and uplink transmission capacity per subscriber is 1.25 Gbps, and a fiber has a total transmission capacity of 40 Gbps (32*1.25 Gbps). It has yet to be defined whether there will be 16, 32, or 48 wavelengths per fiber. One advantage of the AWG-based WDM-PON is the minimum capacity that can be assigned to one user. TWDM-PONs can have the same transmission capacity as AWG-based WDM-PONs. However, if the TWDM-PON architecture employs a higher splitting factor—such as 64 or 128—then the guaranteed transmission capacity per user will be lower.

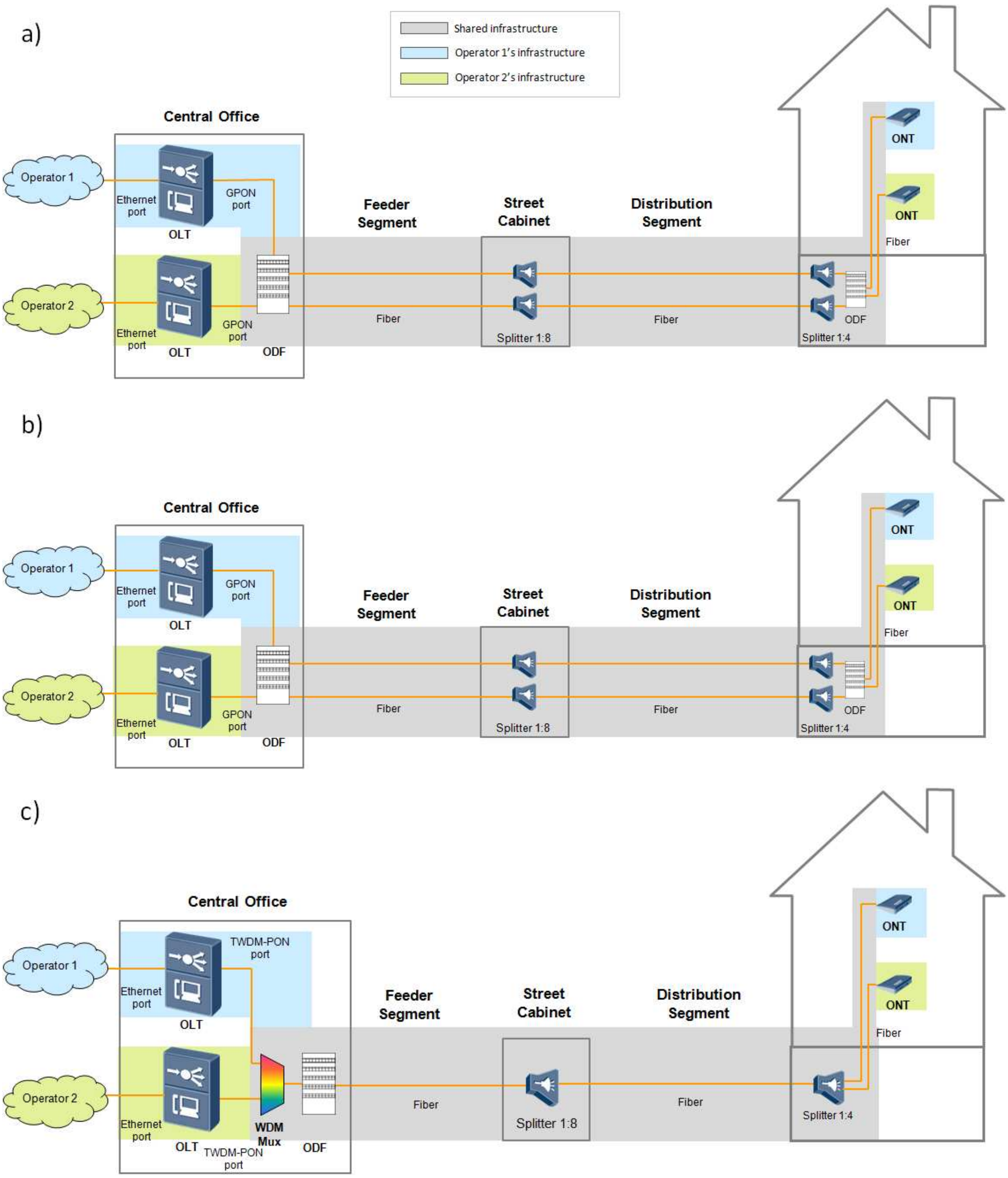
IMPLEMENTATION OF THE COST MODEL

Network Architectures

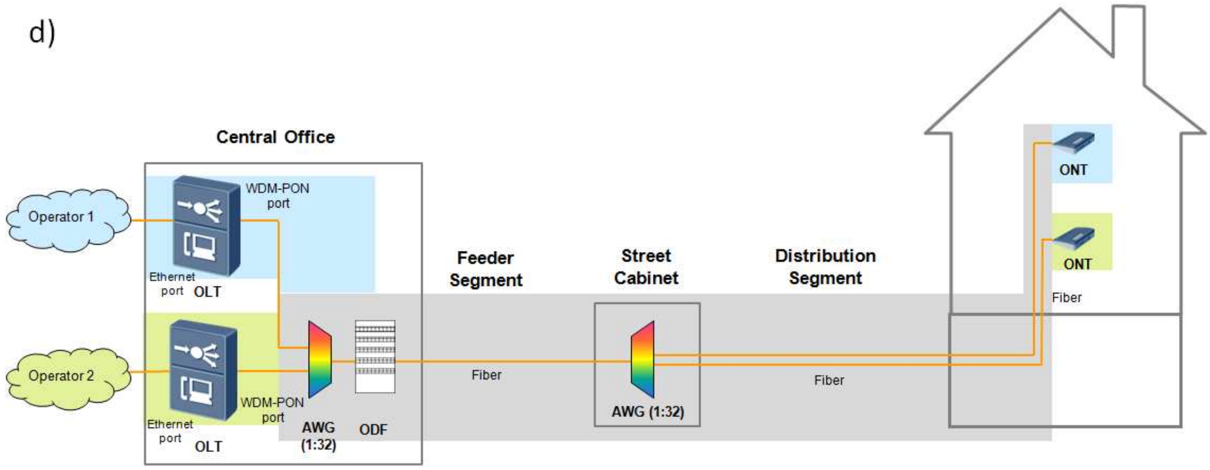
In the approach adopted in this study, it is assumed that the operators that make the initial co-investment create a special purpose entity (SPE), which will deploy and maintain the passive infrastructure and will be in charge of providing the owners of the SPE with a dark fiber service. Each operator is in charge of deploying and maintaining its own active infrastructure. Each operator can provide voice, video or data services or sell wholesale access to the active and passive infrastructure to a service provider. In other words, each operator has the possibility of reselling a high-speed access link to a third party in a bitstream mode. Figure 1 shows the principal components of the passive infrastructure used in the four PON architectures: the in-house cabling, the splitters and optical distribution frames (ODFs) located in the building for the case of a few PONs, the distribution segment, the street cabinet, the feeder segment, and the ODF in the central office. The active elements, which are also depicted in Figure 1, include the optical network terminal (ONT) in the user's home and the optical line terminal (OLT), with the PON and upstream Ethernet ports in the central office. The network architectures depicted in Figure 1 are similar to the networks described in [10]. The SPE should ensure that there are no interoperability problems between the active equipment employed by the different operators. For example, the operators will have to buy ONTs that are pre-approved by the SPE and which also enable various service providers to offer different services.

In our example, there are two splitting levels in the GPON, XG-PON, and TWDM-PON architectures: 1:8 in the street cabinet and 1:4 in the basement of the building, which gives a total splitting factor of 1:32 per PON port. The WDM mux used in the TWDM-PON architecture is located in the central office; it combines the signals that arrive from the OLTs of the operators and transmits these through a single fiber. By using a splitting factor of 32, the average downlink transmission capacity per user in the GPON, XG-PON, and TWDM-PON architectures is 78 Mbps, 312 Mbps, and 1.25 Gbps, respectively. These average values were derived by dividing the capacity of one PON port by the splitting factor. In fact, the real transmission capacity of each PON user will depend on the broadband consumption of all the users in the access segment that are transmitting and receiving simultaneously. The downlink capacity of one user of the AWG-based WDM-PON is 1.25 Gbps. For comparison purposes, the AWG in the AWG-based WDM-PON architecture supports up to 32 users. As depicted in Figure 1, in this study, the AWG-based WDM-PON architecture includes an AWG located in the street cabinet. Therefore, there must be at least one fiber per end-user in the distribution segment. There is no sharing of fiber in the distribution segment. It can be seen that there is a point-to-point (P2P) link between the ONT and the AWG located in the street cabinet.

Figure 1. *FTTH/PON architectures: a) GPON, b) XG-PON, c) TWDM-PON, d) AWG-based WDM-PON.*



d)



Three scenarios were considered in the study. In the first scenario, only one operator invests in the fiber access network, and the passive infrastructure is deployed in single-fiber mode. The second and the third co-investment scenarios use a network-sharing scheme, which consists of the deployment of enough passive infrastructure for up to four operators in the feeder and the distribution segments. In the second and third scenarios, two and three operators share the network, respectively.

Three geotypes were modeled: urban, suburban, and rural. Usually these geotypes are employed in cost studies of FTTH deployments to simplify the different scenarios that are possible within a country [14, 15]. The geotypes are based on average values of three European countries: France, Germany, and the United Kingdom. The main differences between these geotypes are the size of the distribution and the feeder segments and the number of central offices, street cabinets, and subscribers. In the urban geotype, the density of users is high, and the size of the feeder and the distribution segments is relatively short. In the rural geotype, the subscriber density is low, and the size of the feeder and the distribution segments is large. The suburban geotype has intermediate values. The values of the segment lengths and of the prices of the passive network components and network deployment were collected through interviews with multiple companies that deploy passive infrastructure in the above-mentioned countries. The length of the feeder segment in the urban, suburban and rural areas is 850m, 1200m, and 2500m, respectively, whereas the length of the distribution segment in the same areas is 80m, 145m, and 220m, respectively. The cost of digging and preparing the trench for urban, suburban and rural areas is 120

US$/m, 100 US$/m, and 88 US$/m, respectively. The cost of the network elements that still are not commercially available at the moment of writing this article, such as the ONTs and the PON line cards of the TWDM-PON architecture, were derived by using current market costs of the components of the products and by considering, based on trends of previous years, that the cost will decrease with a sales volume increase.

Cost Model

The cost model is essentially based on a greenfield deployment, i.e., all the network components that appear in Figure 1 should be installed. However, at the end of the article we will also analyze cases in which ducts in the feeder and distribution segments are already available, corresponding to a brownfield deployment.

The cost of a home connected includes all the access network elements, from the Ethernet upstream port in the OLT to the ONT in the user's premises. The value derived for the cost of a home passed does not include the cost of the in-house cable or the cost of the ONT. The total cost of ownership (TCO) includes capital expenditures (CAPEX) and operational expenditures (OPEX). The calculations of the cost per home connected and per home passed consider a timeframe of 15 years. The OPEX values of the network elements were derived by employing mark-up values: 4% for the active infrastructure and 1% for the passive infrastructure. The OPEX values include, among other items, the cost to repair or replace the network components when they stop working. In the central office, the OPEX also include the costs of the energy consumption of the active elements and the costs of the floor space rental. The lifetime of the passive infrastructure is 30 years. The lifetime of the active equipment is at most 10 years. In particular, it was assumed that the lifetimes of the OLT and ONT are 10 and 6 years, respectively.

Figure 1 shows the network elements in the central office and in-house segment that are shared. The entire infrastructure in the feeder and distribution segments and street cabinet is shared when using the network-sharing scheme. The cost of the feeder and distribution segments includes the cost of digging and preparing the trench, manholes, and the cost of deploying the fiber. The street cabinet includes the cabinet, the splitters or AWG, and the cost of splicing the fibers.

The values of the cost per home passed and cost per home connected were derived by using the cumulative present value (CPV) formula with a discount rate of 9%. In this study, only the cost of the fiber-based access network was taken into account. The cost of the core and metro aggregation networks, the marketing and sales costs, the cost of the systems required to manage and provision a shared access, administrative costs of the special purpose entity that manages the passive infrastructure, the cost of the necessary permits to deploy the infrastructure, the cost of engineering drawings, as well as the cost of providing services such as telephony, video, or broadband, were not included in the cost model.

In the cost model, the network was deployed in equal proportions over the first four years. For the calculation of the cost per home connected, it is necessary to know the number of subscribers that each operator owns. Therefore, a target market share was employed. It was assumed that an operator reached 22.5%, 45.0%, 67.5%, and 90.0% of the target market share over the first, second, third, and fourth years, respectively. Afterwards, the take-up rate is 0.96%, which enables the operator to reach 100% of the target market share in 15 years.

COST ASSESSMENT

Initial Investment

To calculate the initial investment needed to roll out a network in a region, operators usually calculate the cost per home passed. This cost corresponds to the required CAPEX and depends on all of the potential subscribers or households that can be connected (i.e., 100% market share). Table 1 shows the cost per home passed for the three deployment scenarios. There are strong differences between the costs per home passed for the urban, suburban, and rural geotypes.

Table 1. *Investment per home passed per operator (US$), CAPEX.*

	URBAN				SUBURBAN				RURAL			
	GPON	**XG-PON**	**TWDM-PON**	**AWG-based WDM-PON**	**GPON**	**XG-PON**	**TWDM-PON**	**AWG-based WDM-PON**	**GPON**	**XG-PON**	**TWDM-PON**	**AWG-based WDM-PON**
1 op	892	907	949	1,332	1,558	1,573	1,613	2,020	2,602	2,615	2,657	3,096
NS, 2 op	532	539	480	666	881	888	812	1,010	1,440	1,446	1,334	1,548
NS, 3 op	399	404	320	444	630	634	541	673	1,008	1,013	889	1,032

According to the numbers in Table 1, the cost for operators on shared networks is lower than the cost of one operator deploying the network alone; and this is true regardless of which network architecture or geotype is analyzed. In the scenario where two operators share the network, the cost of each operator in comparison to the cost of an operator that deploys the network alone ranges from 50% for the AWG-based WDM-PON architecture to 60% for the GPON architecture. When three operators share the network, the cost of each operator in comparison with the cost of one operator that deploys the network alone ranges from 33% to 45%.

In comparison with the stand-alone scenario, operators engaged in the co-investment model that employs GPON, XG-PON, or TWDM-PON must add additional infrastructure in order to share the network. For the TWDM-PON architecture, it is necessary to employ the WDM mux in the Central Office, which results in slight increases of the total cost: up to 0.6% and 0.7% more for the scenarios with two and three operators, respectively. For the cases including GPON and XG-PON architectures, different network elements must be added to share the network. Figure 2a shows the composition of the total cost required by all the operators to deploy the XG-PON in an urban area. By dividing the total costs that appear in Figure 2a (907 US$, 1,078 US$, and 1,211 US$) by the number of operators that use the network, it is possible to obtain the values shown in Table 1: 907 US$, 539 US$ and 404 US$ for one, two, and three operators, respectively.

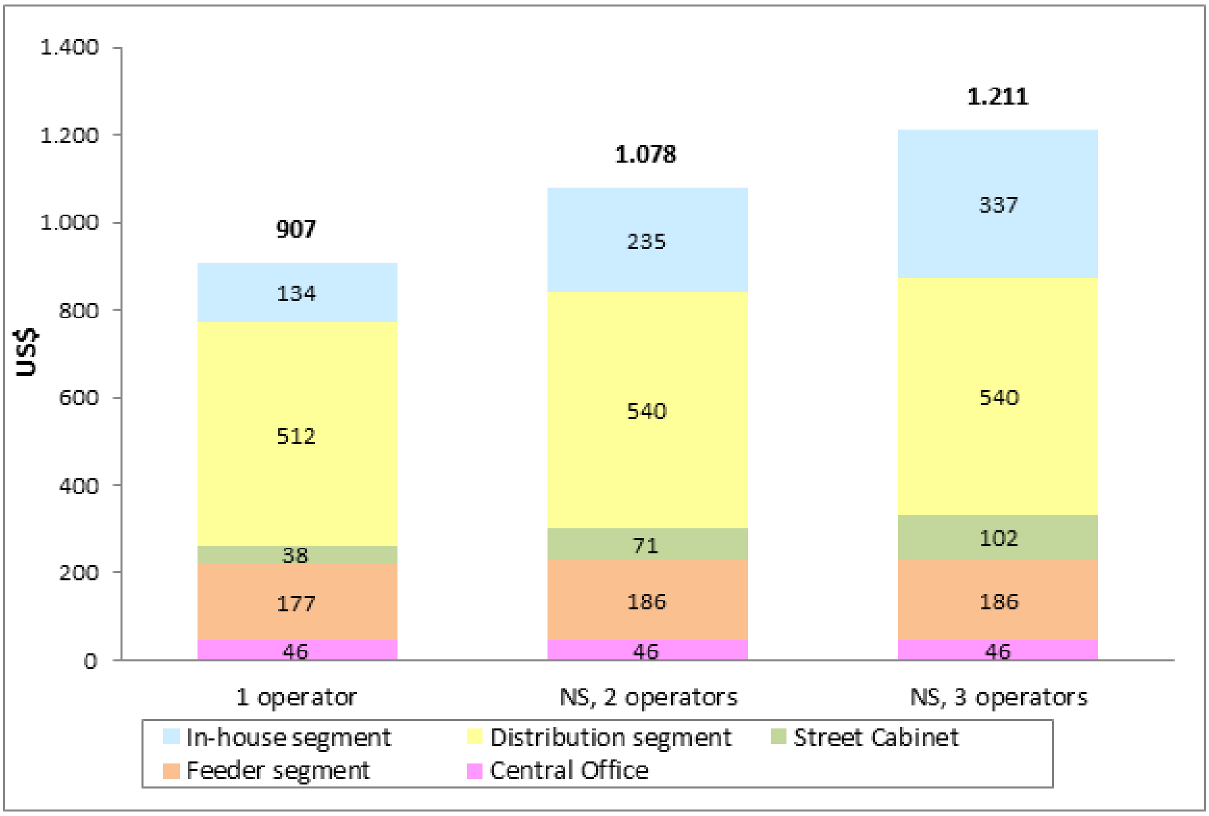
In Figure 2a, the costs per home passed for the central office are identical: 46 US$. In the cost model, it was assumed for the three scenarios that there exists a 10% spare capacity for the components located in the central office. The cost of the feeder segment for the two network-sharing scenarios, 186 US$, is higher than the cost for the stand-alone scenario, 177 US$. An identical situation appears in the distribution segment where 540 US$ and 512 US$ are required for the network-sharing and stand-alone scenarios, respectively. For the XG-PON architecture, a multi-fiber deployment is necessary for network sharing, which requires the deployment of enough infrastructure to support additional fibers in the feeder and distribution segments. This leads to an increase of the cost of these segments.

Figure 2b shows the cost components of the street cabinet (38 US$, 71 US$ and 102 US$) and in-house segments (134 US$, 235 US$ and 337 US$). These values correspond to the examples shown in Figure 2a. More splitters and additional splicing efforts are required in the street cabinet. Moreover, a larger street cabinet is needed for the network-sharing scenarios in order to support more splitters. In the in-house segment, the splitters will be located in a Fiber Access Terminal (FAT) and every operator will have allocated a FAT with the corresponding splitters. The total costs of the following network components located in the basement will increase when using the network-sharing scheme: FAT, splitters, ODF, patch cable, splicing works, and the corresponding installation works.

As is depicted in Figure 2a for the case with one operator, the cost percentage of the feeder and the distribution segments, which are the sections of the access network that require more investment, adds up to 19% and 56%, respectively. Even though additional infrastructure is needed in almost all sections of the XG-PON to enable a network-sharing scheme—particularly in the street cabinet and in-house segment—sharing the access network strongly reduces the total cost per home passed per operator.

Figure 2. *Investment per home passed, CAPEX, XG-PON, urban area, a) Cost composition of all the network elements, b) Cost composition of network elements in the street cabinet and in-house segment.*

a)



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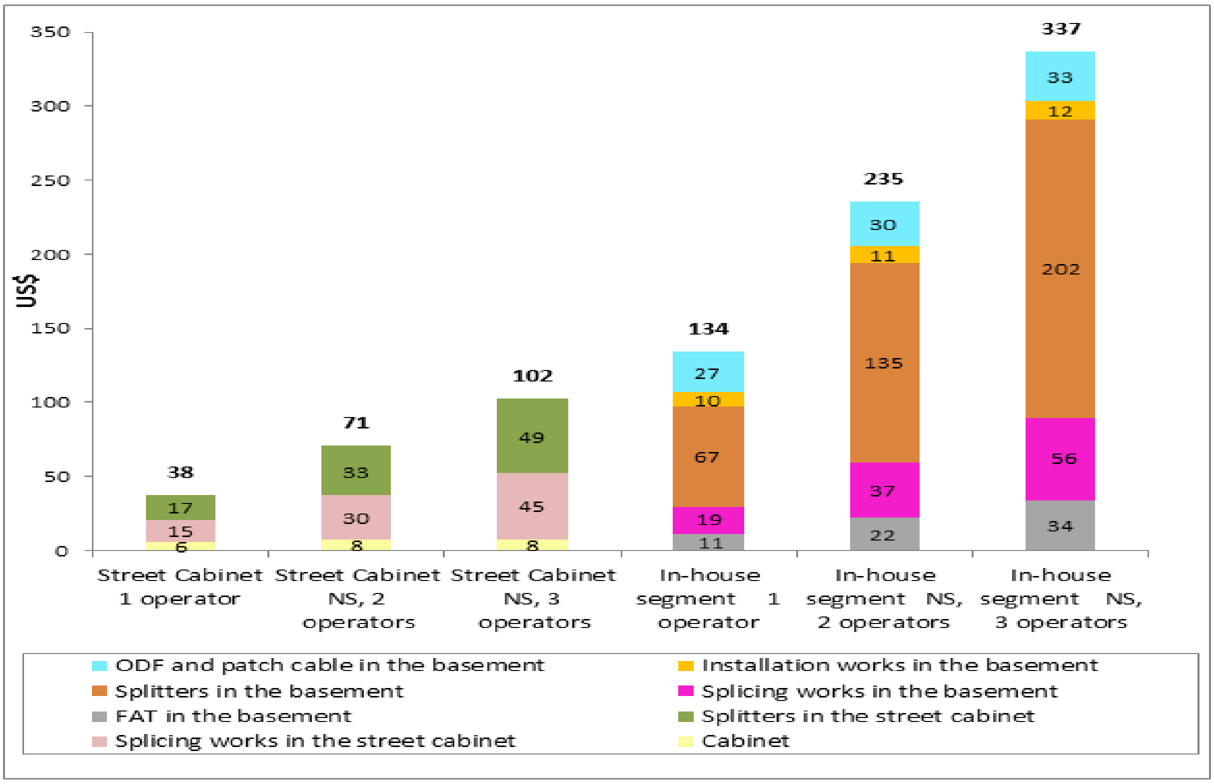
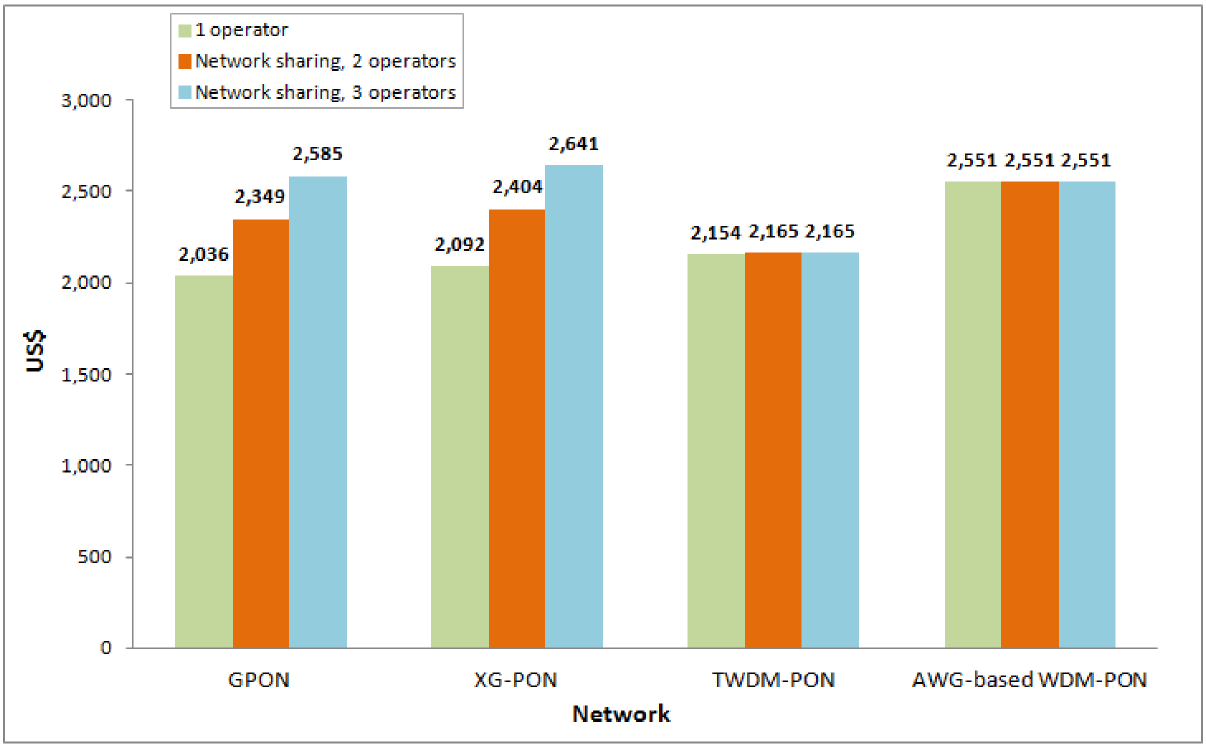


Cost Per Home Connected

The cost per home connected is a value that includes CAPEX and OPEX and which depends on the market share; it reflects the amount of capital necessary to connect one subscriber to the network over a certain period. A comparison of the cost per home connected for the four PON architectures in an urban area when the total market share of all operators adds up to 50% is shown in Figure 3. A penetration rate of 50% for the PONs was taken into account because it was assumed that fiber-based access networks will compete with wireless networks and cable- and copper-based access networks. Furthermore, possibly not all households will have a broadband subscription. Three scenarios were considered for each network architecture: in the first scenario, one operator deploys the network alone, reaching 50% market share; in the second scenario, two operators share the network, and each operator reaches 25% market share; in the third scenario, three operators share the network, with each reaching 16.6% market share.

Figure 3. *Cost per home connected in an urban area, with 50% market share in total.*



For the GPON, XG-PON, and TWDM-PON architectures, the cost of the home connected utilizing a network-sharing scheme is higher than that of a stand-alone scenario. For the scenario with 2 operators, there is an increase of 15%, 15%, and 0.5% for the GPON, XG-PON, and TWDM-PON architectures, respectively. For the scenario with three operators, the increase is 27%, 26%, and 0.5% for the GPON, XG-PON, and TWDM-PON architectures, respectively. For the AWG-based WDM-PON there is no cost difference between the network-sharing and stand-alone scenarios. The cost increase can be explained by two factors: 1) the additional number of network elements needed to share the network, as explained above for case of the cost per home passed; and 2) the lower number of subscribers achieved by each operator in a network-sharing scheme. To obtain the cost per home connected, the total cost per operator should be divided by the number of subscribers of each operator.

The average costs of the three scenarios with the XG-PON are 2% higher than with the GPON. The ONTs and the OLTs, the active network elements of the XG-PON architecture, have a higher cost than those of the GPON architecture. However, the impact of the cost of the active network elements in the GPON and the XG-PON on the total cost is low because more than 90% of total costs correspond to the passive network infrastructure.

The deployment cost of the TWDM-PON for the three scenarios is, on average, 9% lower than that of the XG-PON. Although the active network elements of the TWDM-PON have a higher cost than those of the XG-PON, the TWDM-PON allows several operators to share a fiber in the distribution and feeder segments, thereby reducing the cost of the passive infrastructure. The cost of the TWDM-PON is 14% lower than the cost of the XG-PON when comparing the scenarios in which two or three operators share the network.

The AWG-based WDM-PON is, on average, 12% more expensive than the GPON, the XG-PON, and the TWDM-PON. The AWG-based WDM-PON architecture does not have splitters, and there is a single fiber in the feeder segment. In the distribution segment, there is one fiber allocated to every user. However, the active network elements of the AWG-based WDM-PON architecture are more expensive than those of the other three PONs.

Payback Period

The payback period is one metric employed to understand the outcome of the business case. Table 2 shows the payback period of the PON architectures for different case scenarios. The cost per home connected was employed to derive the payback period. A monthly price of 30 US$ per subscriber for the access network was used to derive the revenues in the cost calculations. The total market share for the three scenarios is 66%.

In the urban geotype, the payback period ranges from 9 to 13 years; in the suburban geotype it ranges from 14 to 19 years; and in the rural geotype it ranges from 22 to 29 years. The long payback periods that can be found in suburban and rural areas explain why operators usually prefer to invest initially in FTTH deployments in urban areas. As the payback period depends on the total cost per operator and the number of subscribers achieved by every operator, there is an increase in the number of years for some PON architectures. For the three geotypes, there are differences in the payback period of the GPON and the XG-PON architectures between the scenario where an operator makes the investment alone and the scenarios where two or three operators invest. For example, when 3 operators use the XG-PON architecture the increase ranges from 2 years for urban areas to 4 years for rural areas. Table 2 shows increases in the payback period for the GPON and XG-PON architectures. This is because the GPON and the XG-PON use multi-fiber deployment, and because every operator involved in sharing the network has to deploy additional infrastructure (e.g., splitters in the basement and the street cabinet). As the cost per home connected is slightly increased when using the network-sharing with TWDM-PON, there is only a slight increase in the payback period. However, this is an increase of a few months and cannot be appreciated in Table 2. For the case of AWG-based WDM-PON there is no increase in the payback period.

Table 2. *Payback period (years), 66% market share in total; price of the access network: US$ 30.*

	GPON			XG-PON			TWDM-PON			AWG-based WDM-PON		
	Stand-alone investment	Network-sharing		Stand-alone investment	Network-sharing		Stand-alone investment	Network-sharing		Stand-alone investment	Network-sharing	
	1 op	**2op**	**3op**	**1 op**	**2op**	**3op**	**1 op**	**2op**	**3op**	**1 op**	**2op**	**3op**
Urban	9	10	11	9	11	11	10	10	10	13	13	13
Suburban	14	15	16	14	16	17	15	15	15	19	19	19
Rural	22	24	25	22	25	26	23	23	23	29	29	29

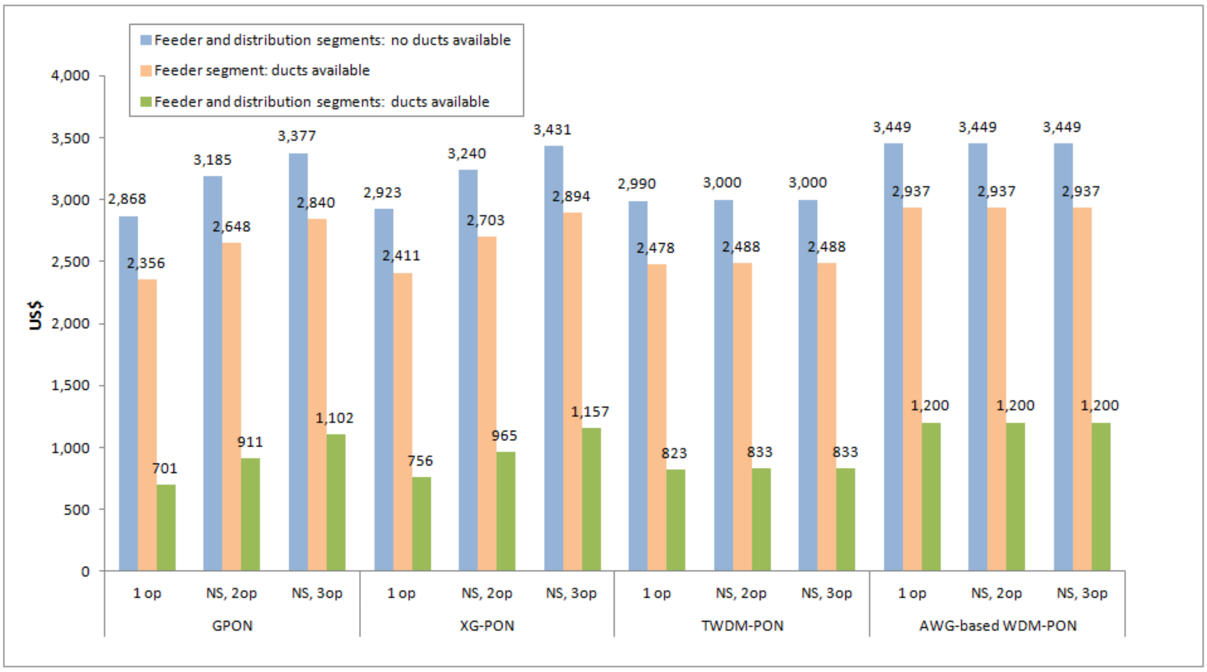
Effect of the Available Passive Infrastructure on the Cost

In a few regions it is feasible to reuse part of the existing available passive infrastructure to facilitate the rollout of a fiber-based access network. It is possible that a municipality or an operator has already installed the ducts and so fiber operators would only need to deploy the cables and active equipment; or a passive operator has already deployed the cables and the dark fiber is rented to operators that intend to provide the broadband service. For this study, we will consider two cases when the existing infrastructure is reused. In case 1 the ducts of the feeder segment are already available, which implies that an operator that rents the passive infrastructure incurs no initial investment for digging or for deploying manholes; but this operator needs to pay an annual fee for using the ducts and must deploy the fibers. In case 2, the ducts of the feeder and distribution segments are already available and the operator must pay an annual fee and deploy the fiber.

Figure 4 illustrates the reduction of the cost per home connected achieved when the available ducts in the feeder and distribution segments are used. For all the cases presented in Figure 4, there are important cost reductions achieved. When utilizing the available ducts in the feeder segment, the cost reduction ranges from 15% for AWG-based WDM-PON to 18% for a single operator with GPON. When using the available passive infrastructure in the feeder and distribution segments, the cost reduction ranges from 65% for AWG-based WDM-PON to 76% for a single operator with GPON.

When the passive infrastructure is reused, the cost per operator is reduced. However, a network-sharing scheme still leads to a higher cost for GPON, XG-PON and TWDM-PON than the stand-alone scenario. For example, when there is no available infrastructure, XG-PON costs increase for 2 and 3 operators by 11% and 17%, respectively. When the ducts in the feeder segment are available, the cost increases are 12% and 20%, and when both feeder ducts and distribution segments are present, the increases are 28% and 53%.

Figure 4. *Effect of the available passive infrastructure on the cost per home connected, 60% market share in total, suburban area.*



CONCLUSIONS

In this article we have employed different metrics to understand the possible effects of a network-sharing scheme for several FTTH/PON architectures. For the majority of cases described in this article, the cost per home connected and the payback period increase when employing a network-sharing scheme, but the initial investment is strongly reduced. The reuse of existing passive infrastructure does not bring any cost advantage in comparison with the stand-alone scenario, but it helps to reduce the total cost per home connected. In conclusion, a network-sharing scheme can be a solution for operators that cannot afford the initial investment on passive FTTH infrastructure. As the operators involved in the market-share arrangement will be competing for the same subscribers, the market share and the revenues that will be achieved by one operator will be lower than the ones that it could achieve if it deployed the network in stand-alone mode.

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