Impact of protection strategies on the cost of Next Generation Hybrid PON access networks

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Abstract—**Network operators are evaluating different alternatives to increase the capacity of their access networks as well as increasing reach and fanout. Hybrid Passive Optical Networks (HPONs) have been depicted as one of the best solutions in terms of cost and migration effort. The foreseen combination of homogeneous terminals (e.g. home users, base stations) requires also offering protection in access networks. This paper compares different protection strategies of HPONs and the impact they have on the total cost.**

Keywords—resilience, next generation optical access networks, network planning

I. INTRODUCTION

The huge increase of demands for broadband services (eightfold as claimed by Cisco [1]) and the expected increase of bandwidth required (more than 250 Mbps by residential users in 2015 [2]) require a fast upgrade of existing access networks. Today's operators in the telecommunications industry invest on optical access networks to offer broadband services and applications to users. The investment targets to offer Fiber to the Home (FTTH) using Passive Optical Networks (PONs) in most of the cases. A PON is a point-to-multipoint based network that interconnects the central office (CO) with all the Optical Network Units (ONUs) through a passive splitter. Hence, the most important advantages of PONs is the reduction of fibers (because the point-to-multipoint topology) and the avoidance of complexities involved in keeping outdoors active equipment.

Actual PON solutions are rather limited in terms of reach (max 20 km), client count and offered bandwidth. These limitations fade when targeting Next Generation Optical Access (NGOA) networks. The requirements for the NGOA network systems are longer reach (40 km for the working path and 90 km extended reach option for the protection path), larger client count (1024 ONUs/customers per feeder fiber), and higher bandwidth per user (128 Gbps to 500 Gbps aggregate capacity per feeder fiber)[3].

However, the new requirements have an impact on the network dimensioning since the clustering of users to access nodes change due to the new client count, reach distance, etc. Furthermore, operators are looking into the possibility to reduce the number of central offices to decrease the operational cost of their networks, thanks to the longer reach distance. In general, NGOA could allow the reduction of access nodes and keep only the 13% of traditional access nodes as metro access nodes (i.e. access nodes for NGOA networks). This scenario is referred in this paper as "node consolidation" scenario in contrast to the traditional access scenario referred as "non-node consolidation".

Hybrid PON networks have been presented as one of the best candidates to cope with the NGOA requirements since they have long transmission reach, can reuse existing optical distribution networks (ODN), e.g. from traditional GPONs, take advantage of WDM to deliver high bandwidth to users, have passive equipment in the field, etc. For these reasons, this work is focused on this new architecture.

In order to study the deployment of a NGOA system for a real-life network scenario, a real topological data stemming from Geographical Information Systems (GIS) has been used. In that manner, data from the OpenStreetMap project [4] were used, from which geographic information such as buildings and street data were extracted, and converted to network information so as to construct a real-life network model. To make use of this information, a software application named "PON Planner" was developed [5]. This tool is able to dimension an access network with one or two splitting points so that all users are connected to the central office and the duct sharing is maximized (in order to minimize the trenching costs and link failure management). This tool has been used to plan Hybrid PON solutions in different types of areas. Furthermore, the planning tool is able to find optimal unprotected and protected layouts.

This paper is structured as follows: Section II presents the Hybrid PON architecture as well as the most important parameter and characteristics. Section III introduces three different protection strategies that an operator could consider. Section IV proposes the cost model for unprotected and protected HPON architectures. The complete cost analysis is given in Section V and Section VI concludes the paper.

II. HYBRID PON NGOA

The passive Hybrid PON considered in this study is shown in Figure 1. It consists of two splitting points: a power splitter and a wavelength splitter (Array Waveguide: AWG). Wavelengths are first routed through a cyclic AWG (at first Remote Node RN1) and then power splitted in a second Remote Node (RN2). In the OLT, we considered burst-mode transceiver (TRX) arrays with 10 x 10 Gbit/s capacity. Regarding the ONUs, they are equipped with tunable 10 Gbit/s APD transceivers.

The downstream signal is a WDM signal that gets demultiplexed at RN1. At RN1, each wavelength is sent through a different port and reaches a different RN2. A wavelength reaching RN2 is shared by all users connected to RN2 and hence, TDM is used to share the wavelength capacity.

Two different splitting ratios have been considered:

- "HPON40": considers an AWG with 40 channels, and a 1:32 power splitter.
- "HPON80" considers an AWG with 80 channels and a 1:16 power splitter.

Both architectures have the same client count but HPON80 offers higher bandwidth than HPON40. This HPON scheme offers advantages (over splitters only) due to the significant reduction of insertion loss, and also provides security against potentially malicious ONUs.

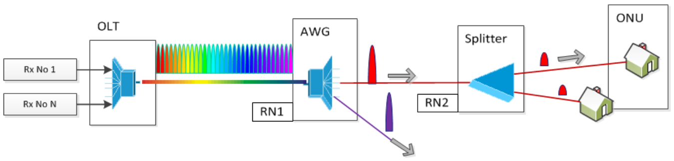


Figure 1 Hybrid PON architecture with two remotes nodes (RN): RN1 with wavelength splitter and RN2 with power splitter.

III. NGOA PROTECTION SCHEMES

Protection in access networks has been relegated from the first priority tasks since the associated costs have been claimed to be too high. Furthermore, in PON solutions, only the protection of the feeder fiber is foreseen since it is the only one that increases the connection availability [6]. In this study we consider the possibility to include feeder fiber protection, which should be disjoint from its working feeder fiber, in four different approaches:

A. *Scheme 1: Greenfield – shared (GF_SH)*

In greenfield scenarios, operators can include the protection planning in their network dimensioning studies, so that the infrastructure is designed to have both working and protection feeder fibers. In this way, protection feeder fibers share as many ducts with working fibers as possible and hence, minimize the trenching costs, which have been identified as key cost driver. This scheme has been depicted in Figure 2.1 where green are working feeder fibers and red are protection feeder fibers. Dashed lines show where trenching costs are avoided.

B. *Scheme 2: Brownfield –Long (BF_LO)*

In brownfield scenarios, operators have designed their unprotected access network without considering any future protection. One alternative to plan the protected feeder network is to select the disjoint path that shares as much path with the working fibers as possible. This alternative would simplify the maintenance required for the infrastructure since the duct layout will be reduced. This scheme has been depicted in Figure 2.2.

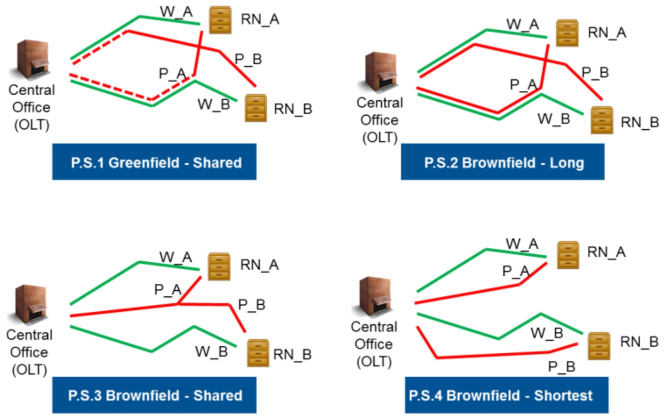


Figure 2 Different protection approaches: the green line shows the working feeder fiber, whereas the red line shows the protection feeder fiber (straight line when trenching is required, and dashed line when trenching is not required).

C. *Scheme 3: Brownfield -Shared(BF_SH)*

Assuming a brownfield scenario, operators may prefer to minimize the required trenching for the protected feeder fiber and hence find the paths that share as much protection duct as possible. Hence, the protection fibers share trenching costs, as depicted in Figure 2.3.

D. *Scheme 4: Brownfield -Shortest(BF_ST)*

Considering a brownfield scenario, another alternative to offer protection would be to find the shortest disjoint path for every feeder fiber as shown in Figure 2.4.

This work aims at comparing in terms of costs and type of area, the different protection alternatives.

IV. COST MODELING

The Hybrid PON cost has been modeled as the sum of Capital and Operational Expenditures (CAPEX and OPEX respectively). CAPEX includes the equipment and infrastructure costs, whereas OPEX includes the power consumption and the maintenance. CAPEX is a onetime investment, whereas OPEX is a cost per year of network operation. All costs are given in cost units (CU) which are relative to the cost of a GPON ONU [7].

A. *Network model*

The Hybrid PON has been modeled as eight segments as shown in Figure 3:

- Central Office is where the OLT is located. The OLT consists of Line cards, Booster and preamplifiers, diplexers, switch and the necessary shelves and racks to contain them.
- Feeder Fiber is the fiber placed between OLT and the wavelength splitter. The feeder fiber layout is defined to minimize the trenching cost is a given area [5].
- The first remote node consists of a wavelength splitter, which is an Array Waveguide (AWG) of 40 or 80 channels. In case the distance to the users is larger than the reach, a reach extender is co-located to guarantee the signal quality at the user.
- The distribution fiber has been defined in two segments: Distribution Fiber 1 interconnects the AWG with the power splitter, and the Distribution Fiber 2 interconnects the power splitter with the customer.
- The second remote node is a power splitter with splitting ratios of 16 and 32.
- The ONU is placed at the customer location.

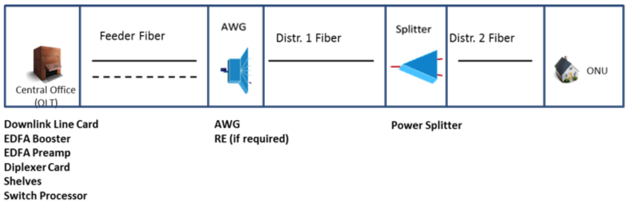


Figure 3 Network model segments of a HPON architecture

The elements at each segment will be dimensioned based on the area and the considered splitting ratios of AWGs and power splitters.

B. *CAPEX*

CAPEX includes the costs of equipment and infrastructure:

- Equipment costs are the costs of the necessary equipment including the OLT, AWG, Power Splitters, Reach extenders and ONUs. OLTs are dimensioned based on the required components such as Downlink Line Cards, EDFA Booster, EDFA Preamplifier, Diplexer Card, Shelves and Switch Processors.
- Infrastructure costs refer to the optical fiber cables and trenching costs that interconnects any network equipment. These costs are presented separately to see the impact of Greenfield versus brownfield.

C. *OPEX*

The operational aspects evaluated in this study are:

- Power consumption associated to the active equipment. The OLT and reach extenders consume power associated to the operator, whereas the ONU power consumption is associated to the user.
- Network maintenance is an operational cost which depends on the network size. In this work, the cost has been considered proportional to the number of OLT cards and the number of reach extenders. Passive equipment needs significantly less maintenance than active components.

V. COST ASSESSMENT

A. *Considered Scenarios*

In order to reach realistic outcomes, real geographic data is used in this techno-economic study. The real locations of buildings and the distribution of streets connecting these buildings are retrieved from OpenStreetMap, which is a free and open source worldwide map database [4]. The proposed HPON solutions are dimensioned over the geographic data retrieved from OpenStreetMap by using the database functions enabled by PostGIS, which adds support for geographic objects on the PostgreSQL object-relational database and routing functions enabled by PgRouting [8]. The proposed tool [5] is able to dimension the HPON over a selected area so that the duct lengths are minimized. This tool has been extended to evaluate different protection approaches on different areas.

The network dimensioning is done as follows: First the clients are grouped into clusters of size the client count of the considered architecture (1032 clients/OLT port in our case).

For each cluster, the users are grouped into smaller clusters of size the splitting ratio of the AWG in RN1.

In this study dense urban (DU) and rural (R) areas have been compared with and without node consolidation (an example is shown in Figure 4. Node consolidation reduces the number of central offices so that costs are expected to decrease (less floor space, lower power consumption) but technologies allowing higher client count and longer transmission reach should be used (e.g. HPON). Node consolidation is achieved by merging existing (i.e. no consolidated) areas.

TABLE I. CONSIDERED AREAS: DENSE URBAN (DU) AND RURAL (R) WITH AND WITHOUT NODE CONSOLIDATION IN TERMS OF HOUSHOLDS (HH) AND BUILDINGS (BB).

Area Type	Area	Surface (km^2)	# of HH	Density (HH/ km^2)	# of BB	Density (BB/ km^2)
no node consolidation DU	**Darmstadt, DE**	4,8	19026	4000	3171	660
no node consolidation R	**Garching, DE**	56	3610	65	1805	32
Node consolidation DU	**Kirchheim FR**	16	65448	4090	10908	680
Node consolidation R	**Trento, IT**	480	48080	100	24040	50

The areas used in this study have been summarized in Table I. The difference between DU and R areas is the user density: more than 500 buildings (BB) per square kilometer in DU areas, whereas R areas have few tens of BB per square kilometer. Furthermore, the number of households (HH) per BB also depends on the area (6 HH/BB in DU areas and 2 HH/BB in R areas). Regarding node consolidation, a consolidation degree of 87.5% has been considered, which implies merging around 3 no-node consolidated DU areas into a node consolidated DU area, and 10 no-node consolidated R areas into a node consolidated R area.

TABLE II. INFRASTRUCTURE COST VALUES

	Fiber		Duct	
	Type	Cost [CU/km]	Type	Cost [CU/km]
Feeder	8x	16	Big trench	1000
Distribution	4x	12	Microtrench	400

All costs are given normalized with respect the cost of a GPON ONT and they are referred as cost units (CU). The infrastructure costs considered in this study are summarized in Table II.

Figure 4 Examples of DU (left) and R (right) areas for no-node consolidation scenarios

B. *Hybrid PON cost analysis*

In this first study, the HPON cost is compared for the different areas presented in Table I.

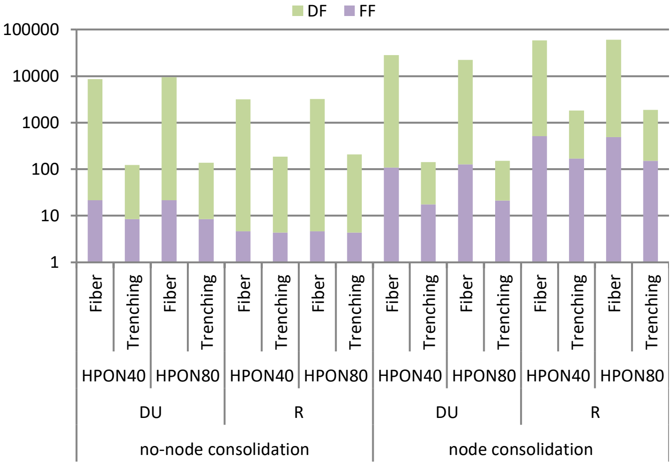
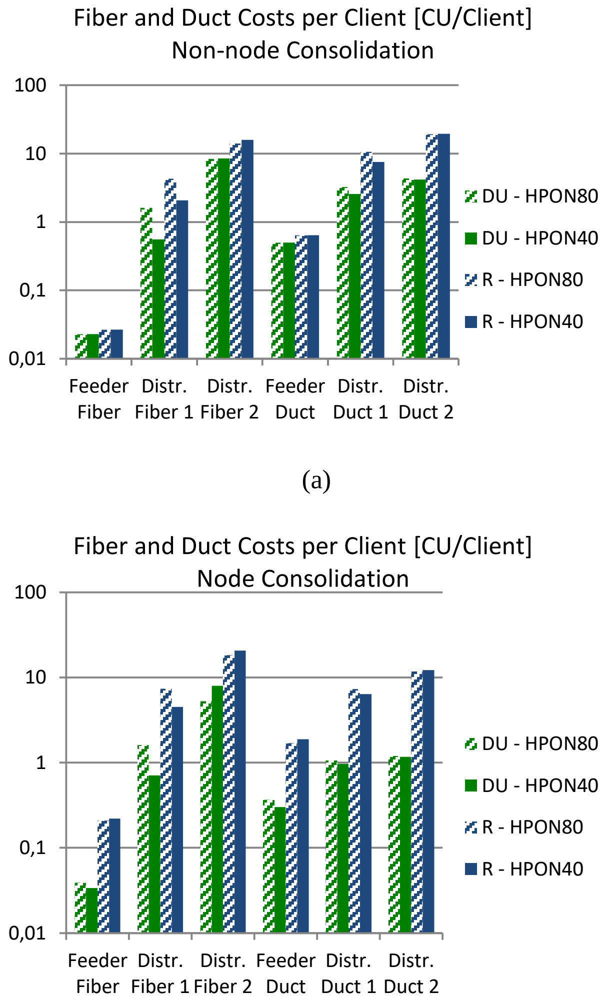


Figure 5 FF and DF fiber and trenching length [km] for for non-node and node consolidation scenarios in DU and R areas for HPON40 and HPON80 architectures

First, the length of the required fiber and trenching (depicted in Figure 5) are computed for HPON80 and HPON40. It can be observed, that fiber length is much longer than trenching due to the sharing of trenching by several fibers. Furthermore, DF is always much longer than the FF due to higher number of households compared with the number of AWGs in the field. This figure also shows the length increase due to node consolidation, since the area they should cover is much larger. In rural areas the increase is significant, especially on FF because of the spread AWGs. However, DU areas keep the trenching limited due to the higher sharing among fibers. The most dominant fiber section is the distribution fiber 2 which interconnects the power splitter to the user, since it is the fiber which is dedicated per user.

Based on this infrastructure layout, the cost per user can be obtained. Figure 6 shows the fiber and duct cost per user in the non-node consolidation (a) and in the node consolidation scenarios (b). It can be observed that the duct cost per user is significantly higher in rural areas due to the lower number of users sharing the duct cost, especially the distribution 1 section. Furthermore it can be observed that when moving towards the user, the cost difference between duct and fiber decreases due to the fact that the distribution duct is shared by different buildings (and the microduct has lower cost than feeder duct) and so users, whereas the fiber is dedicated per user.

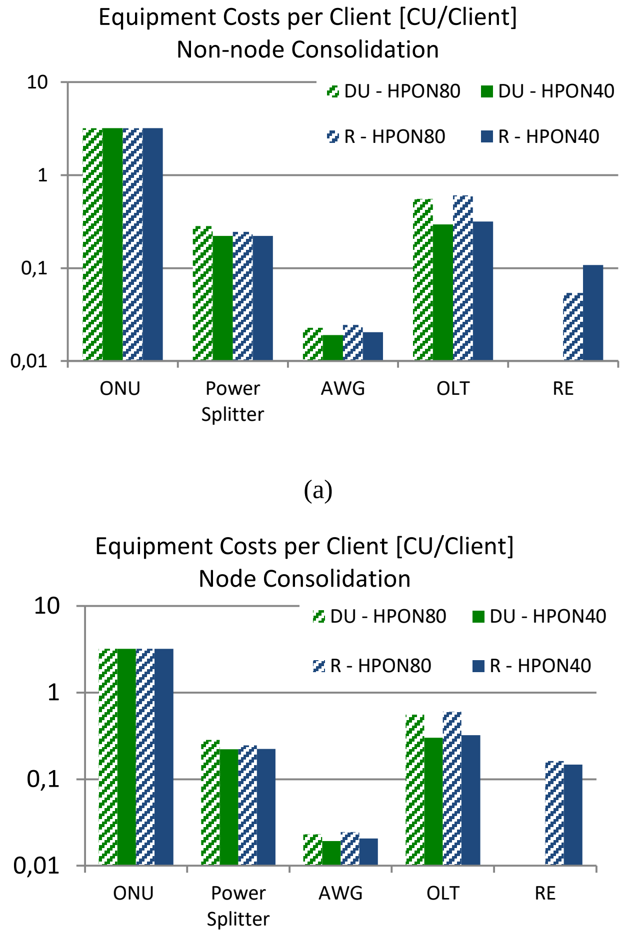


(a)

(b)

Figure 6 Fiber and duct cost per user in (a) non-node consolidation and (b) node consolidation scenario

Based on the optimal network dimensioning of HPON40 and HPON80 on the different areas (DU and R), the equipment cost distribution has been compared in Figure 7 (a) and (b) for the non- and the aggressive node consolidation scenarios respectively. The cost comparison is given as cost per user in terms of cost units per user [CU/user]. It can be observed that the ONU is the most costly equipment due to the fact that the ONU cost is not shared by users. The HPON needs a highly more expensive ONU than traditional GPON PON. The second costly component is the OLT, since it is the one coping with all cards, switching components, etc. It can be observed that HPON40 has lower OLT cost than HPON80 due to the fact that needs half the cards need less transmitters than in HPON40. It can be also observed that only in rural areas, reach extenders are required, and their cost is rather low due to the fact that they are shared by all users connected to this remote node 1. The cost distribution is not dependent on the consolidation degree.



(a)

(b)

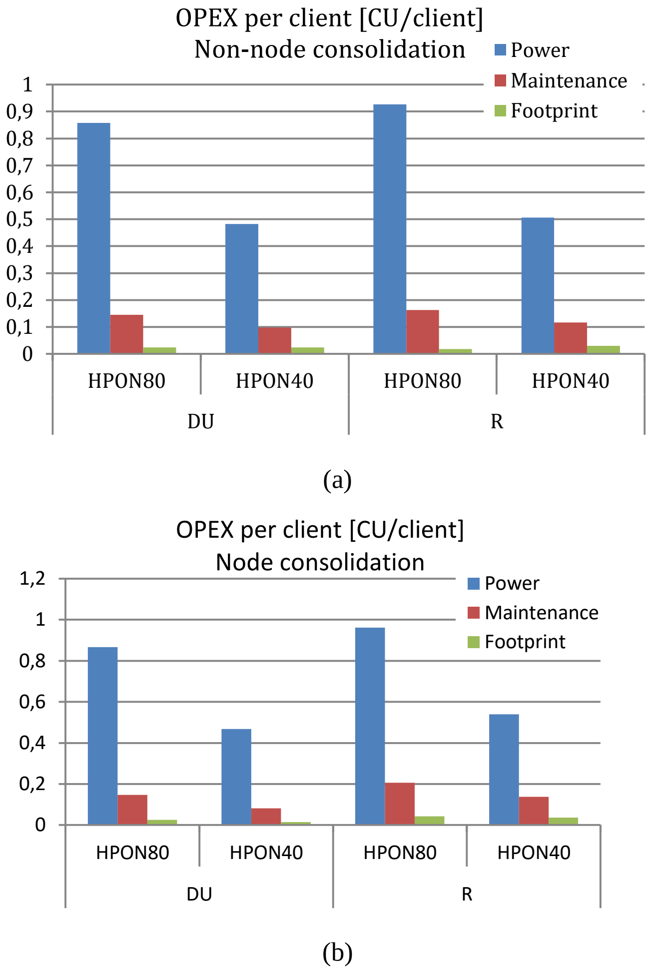
Figure 7 Equipment cost distribution per user for (a) non-node consolidation and (b) node consolidation scenarios

The cost assessment also includes the comparison of some operational aspects such as power, maintenance and floor space (i.e. footprint of the OLT equipment at the central office or any active component in the field). The cost comparison of these parameters for the non- and the aggressive node consolidation scenarios have been shown in Figure 8 (a) and (b) respectively. Both node consolidation scenarios present similar cost per user. Power consumption is the predominant cost key factor, especially for the HPON80 solution that requires more transmission cards. It is also important to mention that although in rural areas, less equipment is needed, and hence, less maintenance and power consumption are associated, the cost per user is higher due to the lower number of users in the area and the required reach extenders.

Based on the network planning of each case study, the CapEx and Opex of each case has been evaluated for a network timelife of 10 and 15 years to see the impact that it could have on the TCO. Figure 9 (a) depicts the CapEx and OpEx per user with (a) no-node consolidation and (b) node consolidation. It can be observed that CapEx is higher than OpEx, especially in rural areas where users are so sparse. Although the total infrastructure cost is higher in dense urban areas, the cost per user is much lower because of the higher density of users.

As previously mentioned, the OpEx of HPON40 is significantly lower than for HPON80 due to the reduced number of LT cards and smaller OLT size to cover the same number of users. This reduction of equipment implies less maintenance, power consumption and required floor space.

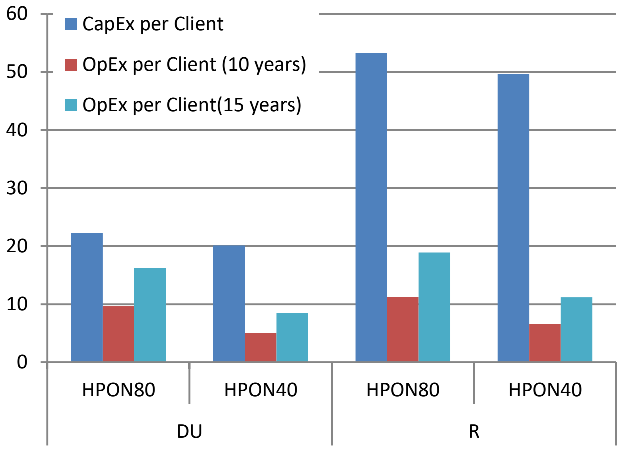
In Figure 9 (b), the CapEx and OpEx per user for a network life timeframe of 10 and 15 years with node consolidation scenario is shown. It can be observed that CapEx is always higher than OpEx except for the HPON80 in the DU scenario with 15 network lifetime: high number of users, require large number of LT cards at OLT, increasing the power consumption and floor space compared with the HPON40 case or any other scenario



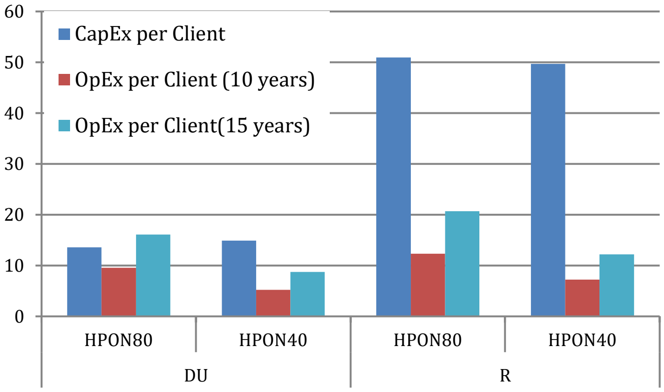
(a)

(b)

Figure 8 OPEX per client for (a) non-node consolidation and (b) node consolidation scenario



(a)



(b)

Figure 9 CapEx and OpEx [CU/user] user for a network life timeframe of 10 and 15 years with (a) non-node consolidation and (b) node consolidation scenario

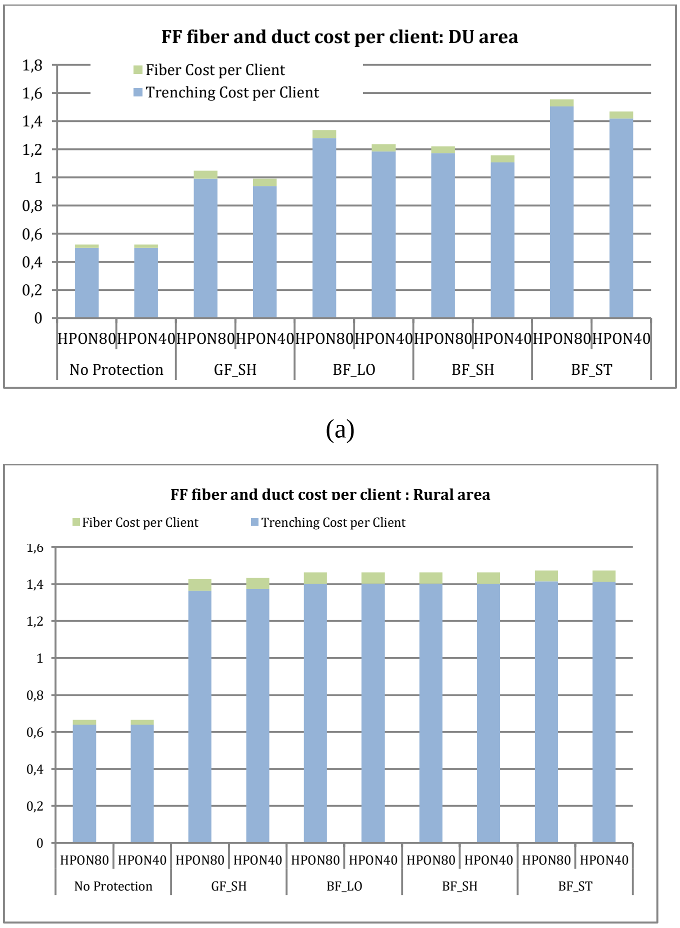
Comparing both figures it can be observed that the cost per user is comparable in both alternatives for consolidation. Although the total cost is significantly higher with node consolidation (due to larger covered area and higher number of users), the cost per user remains the same.

However, the expected savings of node aggregation is the reduction of aggregation costs, which have not been included in this study. This aggregation cost per user is higher with non-node consolidation and hence, it will incur so important savings when implementing node consolidation.

C. Protection assessment

This section focuses on the cost assessment of the different proposed protection strategies for the feeder fiber section.

The cost comparison of the FF fiber and duct required for each scheme has been shown in Figure 10. It can be observed that the FF cost increased at least 88%. It can be perceived that the most expensive alternative is the Brownfield –Shortest alternative, which does not look to maximize any sharing but finds the shortest disjoint path. The more cost efficient solution is the Greenfield sharing which looks to maximize the duct sharing with working paths and therefore, recurs to a minimization of required trenching. The second best solution is the Brownfield –Shared which maximizes duct sharing among protection fibers, which may be a good solution for operators that have now pre-planned the protection of their networks. The graph also shows that the most expensive solution BF_ST incurs to more than 60% cost than the GF_SH alternative, which encourages operators to do their planning considering any future protection of their network. However, in rural areas, the savings is rather small due to the fact that ducts are more spread and duct sharing is more difficult to be achieved.



(a)

(b)

Figure 10 FF Fiber and duct cost per client for the different protection alternatives in Dense urban (a) and rural (b) areas in non-node consolidation scenario.

Furthermore, in order to see the impact of this investment on the connection availability, the Mean Down Time Comparison has been performed for the different schemes. The connection availability is twofold: from the customer perspective the service quality is mainly determined by the failure probability and the mean down time of individual services. From a network operator's economic point of view the impact of a failure terms of the number of customers being simultaneously affected by a failure, called failure penetration range, is also very important. The Mean Down Time (MDT) per client can be calculated using the formula MDT=Ux365x24x60 where U is the unavailability. Figure 11 shows as example the impact of the different protection alternatives of the MDT in Dense Urban areas. The unprotected solution has high MDT that refers to the right y-axis, whereas the protected solutions have a MDT referring to the left y-axis.

It can be observed that the MDT is reduced by 83% when offering any type of protection (all schemes offer comparable MDT since it only differs on the FF length of each scheme).

Figure 12 shows the MDT for rural areas. It can be observed that the MDT in no consolidation is quite similar with the dense urban case, the with aggressive node consolidation, the MDT increases more than two minutes, due to the longer distances. For protected solutions, the difference is even lower, in the order to seconds.

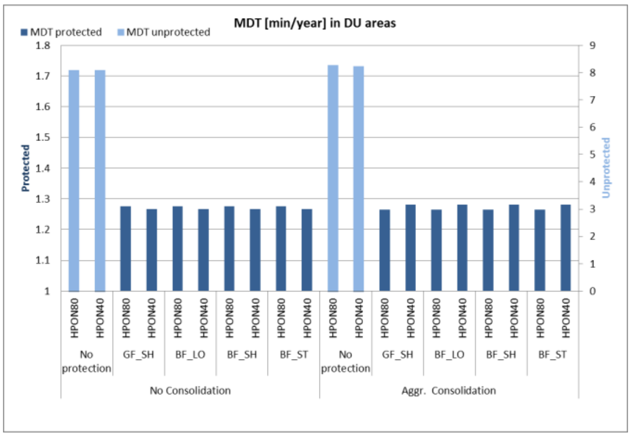


Figure 11 Mean Down Time for DU areas

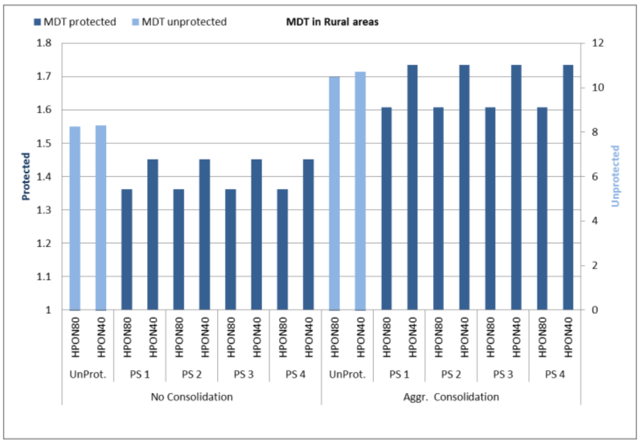


Figure 12 Mean Down Time for Rural areas

VI. CONCLUSION

This paper has presented a cost assessment of Hybrid PON for different areas and node consolidation. It has been shown that the HPON splitting ratios do not impact significantly the cost since both architectures have the same fanout. It has been also shown that node consolidation incurs to higher fiber and trenching lengths. However, the trenching costs per user are lower in the node consolidation scenario due to the higher duct sharing. Furthermore, the cost key drivers have been identified which are the infrastructure and the ONU cost, followed by the OLT cost. It has been also observed, that the main difference between HPON40 and HPON80 is the power consumed, which is higher for the HPON80 due to the higher number of cards at the OLT. The second part of the paper has presented and analyzed four alternatives to offer FF protection. It has been shown that although the reduction of MDT is few minutes per year, the cost savings when doing a network panning foreseen protection can achieve 60% savings on the network protection.

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