A modular and hierarchically structured techno-economic model for FTTH deployments

Comparison of technology and equipment placement as function of population density and number of flexibility points

Marlies Van der Wee(1), Koen Casier(1), Karel Bauters(2), Sofie Verbrugge(1), Didier Colle(1), Mario Pickavet(1)

Dept. of Information Technology (INTEC)
Ghent University - IBBT
Ghent, Belgium
Marlies.VanderWee, Koen.Casier, Sofie.Verbrugge,
Didier.Colle, Mario.Pickavet@intec.ugent.be

Dept. of Industrial Engineering
Ghent University
Zwijnaarde (Ghent), Belgium
Karel.Bauters@ugent.be

Telecommunications is a domain that is characterized by a constant and rapid evolution. The available bandwidth keeps on increasing as the amount and quality of the offered services grows almost continuously, and it is generally accepted that upgrades towards Fiber-to-the-Home (FTTH) are necessary. FTTH comes in a plentitude of variations, mainly differing between Point-to-Point and Point-to-Multipoint solutions. Several techno-economic calculations comparing these options are available in literature today, but they lack a generic structured calculation and never focus on the impact of the size of the area and population density on the cost of deployment and operations of an FTTH network. This paper will present a flexible, generic model for techno-economic evaluation of an FTTH network that compares different solutions considering equipment type and placement for a broad range of population densities. The outcome of the simulations proofs the versatility of the generic techno-economic calculation approach and show the impact of the tradeoff in equipment placement and distance to the central office.

Keywords- Fiber-to-the-Home, techno-economic evaluation, flexibility points, population density, PON, HRN, ASN

I. INTRODUCTION AND MOTIVATION

Ever more bandwidth hungry applications and higher network and service penetration lead to a request - or at least a clearly perceived benefit as seen from the customer - for higher bandwidth network connections. For providing much higher bandwidths, optical fiber networks are certainly superior to copper or coaxial based networks. However, installing a new underground infrastructure (reflecting common practice in Europe) brings a lot of road works and tremendous costs.

According to [1] and [2] the trenching constitutes by far the largest cost (~70%) in an FTTH network and several approaches focus on bringing this cost down, either by improving the physical installation or by optimizing the installation path. The size and impact of the remainder of the costs (~30%) will be technology dependent, where current literature makes the main distinction between passive optical networks (PON) and active optical networks (AON).

Within the active optical networks, a further distinction can be made based on the location of the active equipment: in the street cabinet (Active Star Networks - ASN) or centralized in the Central Office (Home Run Networks - HRN). Note that this split could in theory also be made for a PON network, but this will typically not be the case (at least not for the current GPON solutions) and is not considered in this paper. A high level overview of the considered architectures is shown in Figure 1.

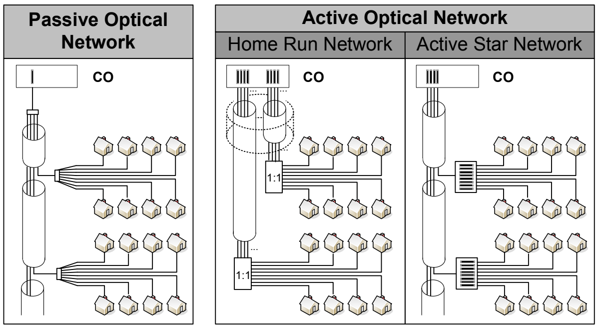

Figure 1: High level overview of the three considered FTTH architectures

Clearly the comparison of FTTH technologies should involve the placement of equipment and the granularity of the equipment (e.g. how many ports does a line card have in all solutions). Solutions with aggregation of traffic closer to the field will clearly benefit from saving fibers at the expense of the distributed and possibly partially unfilled equipment. As such the actual placement of the equipment together with the cost and granularity of this equipment will be essential to make a fair comparison of the costs of the different solutions. This paper builds an abstracted logical model for equipment, areas and installation. It is capable of calculating all costs for an FTTH network depending on coupled areas of aggregation and comparing differences in placement of the equipment (by varying the number of flexibility points). In this manner it is easily possible to model an HRN with equipment in the central office and patch cabinets, or an ASN with active street cabinets aggregating traffic of about 200, 400 or more customers, or a PON with a 1:32 split centralized or distributed and see the impact on the different cost components. This allows seeing the impact of port count, fan-out, equipment location, distance to central office, number of aggregation points, etc.

This paper will continue in section II with a thorough description of the different logical calculation modules and how they combine in a hierarchical techno-economic model. Section III completes this model with the input for the different technologies and gives a summary of the parameters used. Running extensive calculations for different equipment placements (different number of flexibility points) and customer densities followed by an analysis of the most striking results will be presented in section IV. Section V concludes the paper and gives some directions for future research.

II. Hierarchical Techno-Economic Model

We developed a modular in-house calculation toolset for performing techno-economic analysis. The calculation chain used throughout this paper consists of three chained modules as shown in Figure 2.

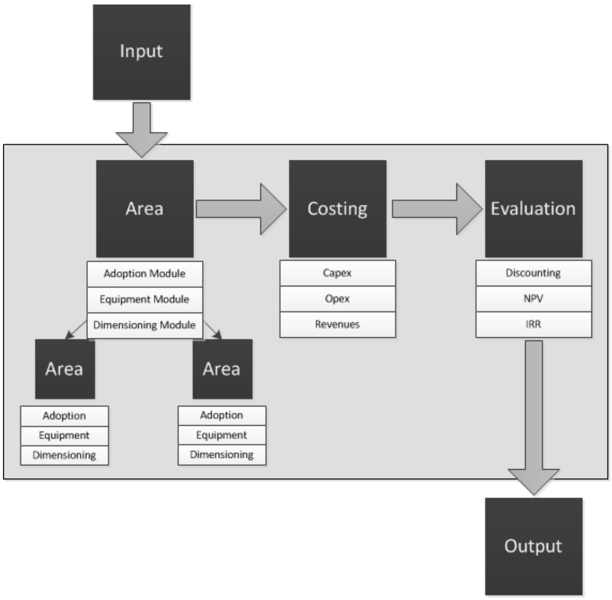

Figure 2: The calculation tool chain used in this paper

1. Area: a hierarchical structure which will calculate based on the sub-areas and own information. Each area or sub area consists of three smaller calculation modules: the adoption module, the dimensioning module and the equipment tree module.
2. Cost: the results of the area calculations are then used as an input for the costing module, which calculates the costs for the infrastructure as well as the operations
3. Evaluation: The third and final building module, the evaluation module, allows to automatically combine all previously calculated results and determine final results like Net Present Value (NPV), Internal Rate of Return (IRR), etc.

A. The Area: an hierarchical structure

The basis of the model is the area, which is built up as a hierarchical structure that contains several sub-areas. The structure and functionality of these subareas are identical to the structure of the area itself. Splitting up the main area in subareas allows to subdivide the problem, for instance in smaller geographical regions that each have their own street cabinet.

Each area consists of three primary calculation modules, which will be shortly explained below.

1. Adoption module: this module is responsible for forecasting the number of subscribers the network will have every year. Many theoretic adoption curves are described in literature, but for this paper, the authors chose to implement the Bass adoption model [2] with parameters (innovation-parameter: 0.01, imitation-parameter: 0.38) [5].
2. Dimensioning module: the second module in Area calculates the amount of fiber and trenching needed to deploy the access network. The calculations are based on analytical models, as described in [3]. We chose to use a street based estimation of the trenching and cabling length.
3. Equipment module: this module consists of a hierarchical structure that allows determining the amount of equipment needed to connect the subscribed customers. By installing only the equipment that is needed to serve the subscribed customers, the costs of equipment are spread out and the operator receives a direct payoff that can be used to pay back the investment in equipment.

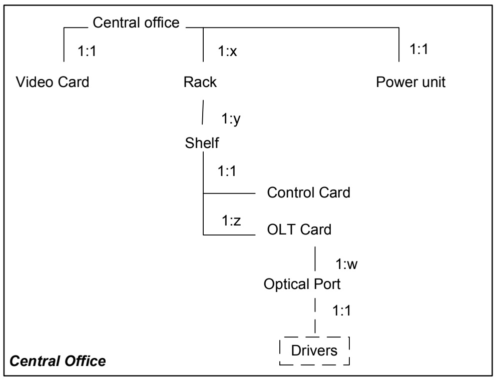

Figure 3: Example of the tree structure of the equipment model

Figure 3 gives an example of an equipment tree structure. The relationship between the different levels in this tree is defined by a granularity factor. The lowest level equipment is coupled to drivers (e.g. amount of customers to be connected) that allow for a full calculation of the entire equipment tree from a bottom-up approach, which means that the equipment tree receives input at its 'leaves' (e.g. a number of subscribers) that allows to calculate the number of optical ports needed. This number of optical ports then determines the number of OLT cards and so on, until the 'root' of the tree (in this case the number of central offices to be installed) is reached. The actual models used to obtain the results of this paper, are described in section III.

B. The costing module links equipment and manpower to costs

The output of the area module serves as an input for the costing module, which links the unit costs to the amount of equipment, fiber, trenching and customers calculated in the Area module. A distinction is made between Capital Expenditures (upfront cost for the infrastructure) and Operational Expenditures (costs to keep the network up and running). Capital Expenditures include installation and re-installation (after its end-of life) of the equipment and the costs for deploying the fibers (making the trenches, installing the ducts and blowing the fibers). The Operational Expenditures on the other hand consists of costs for maintenance and repair, connection and service provisioning of the customers, and daily operational costs like floor space and power consumption. The costing module also allows calculating revenues, but since the revenues will not differ much in between the different topologies, they are not taken into account in this paper.

C. The evaluation module translates into economic indicators

The third and final building module in the tool chain is the evaluation module, which automatically discounts and sums all costs over a specified period of time. This module receives input from the costing module under the form of different cost divisions (e.g. CAPEX needed for blowing the fibers specified for every year), which it can then process into a number of predefined economic calculations like NPV, IRR, etc.

III. HIERARCHICAL EQUIPMENT MODELS FOR THE CONSIDERED TECHNOLOGIES

As mentioned the aim of this study is to look into tradeoffs between different technologies, notably the difference between shared vs. non-shared optical medium between the customer and the active switching and/or routing equipment and the impact of the population density and the distance to this active equipment on the costs of the network. Clearly this can be mapped on the tradeoff between current Time Division Multiplexing Passive Optical Networks (TDM-PON), Active Star Networks (ASN) in which the active switching equipment is placed in some kind of cabinet between the central office and the customer and Home Run fiber Networks (HRN) in which the active equipment is placed in the central office.

A. Network Structures

The following figures give an overview of the network details for the three considered architectures.

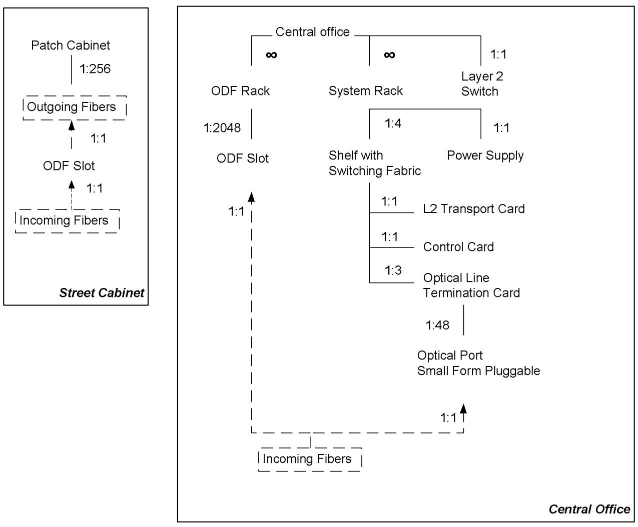

Figure 4: Equipment tree for HRN (both SC and CO)

Figure 4 shows the two equipment structures for an HRN (SC: street cabinet and CO: central office). For smaller areas, a patch panel is not a necessity, but most typically it will be included in all constellations in order to introduce a point for easier flexibility and to be used in case of trouble shooting.

Figure 5 shows the splitter cabinet and central office in case of a 1:32 TDM PON. The equipment model for the central office is similar to the model for the HRN, apart from different granularities (typically in the OLT port count).

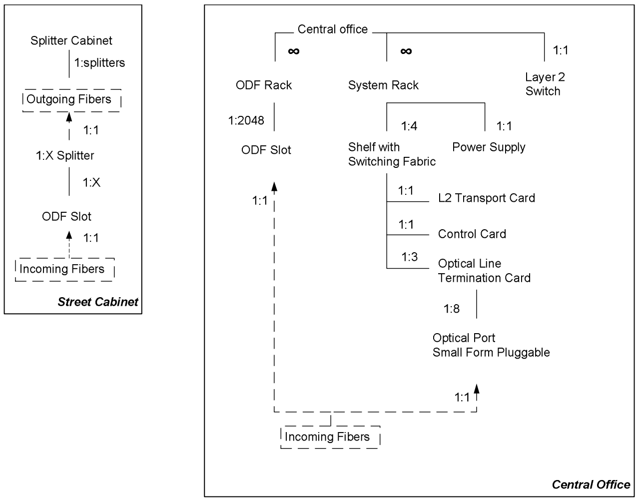

Figure 5: Equipment tree for 1:32 TDM PON (SC)

Figure 6 shows the active cabinet and the central office equipment model in case of an ASN. Here we see that the transport and switching/routing happens at the street cabinet and as such an additional switching/routing is installed in the central office.

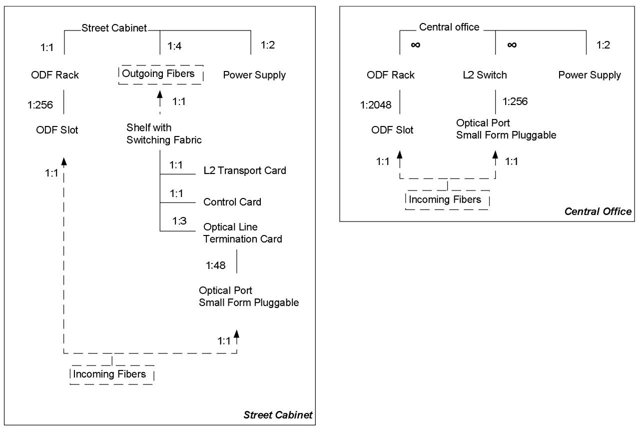

Figure 6: Equipment tree for ASN (both SC and CO)

B. Infrastructure, Operational and Equipment Parameters

The logical structures of the central offices, street cabinets and the modular building blocks for connecting the equipment modules to the areas, dimensioning, costing and evaluation allows to quickly run a batch of calculations and find out the impact of a network architecture and population density on the costs. Table 1 below shows the data set we used for calculating through the simulations. The price for the CO is not taken into account directly, but calculated based on the floor space for the

System and ODF (Optical Distribution Frame) Racks (1). The costs for the Control Card and the Layer 2 Transport Card are not considered separately, but included in the price of the Shelf (as there is a one-on-one relationship between these types of equipment) (2). A price for a street cabinet for PON is not included (since in a PON topology, there is no SC containing active equipment, only a patch cabinet with splitters). The same reasoning holds for the Splitter (3).

Table 1: Overview of the prices for the equipment

Equipment	price AON (€)	price PON (€)
Central Office	- (1)	- (1)
ODF rack	800	800
ODF slot	20	20
System rack	600	600
Shelf with switching fabric	5900	5375
Optical Line Termination Card	600	2000
Control Card	- (2)	- (2)
Layer 2 Transport Card	- (2)	- (2)
Optical Port Small Pluggable	15	15
Layer 2 Switch	650	650
Street Cabinet	6000	- (3)
Patch Cabinet	1500	1500
1:32 Splitter	- (3)	500
Power supply	700	700

Furthermore, some input data is needed for the calculation of the different cost components. The unit costs are summarized in Table 2. Reference costs for all equipment and operational actions are based on [6], [7] and [8]. It is to be noted that these parameters depend on market characteristics of offer and demand and are therefore possible to change over time. The effect of changes in these values can also be investigated, but this falls beyond the scope of this paper.

Table 2: Overview of the cost parameters

Cost Component	Unit Cost (€)
Trenching (per km)	50000
Fiber (per km)	200
Duct (per km)	1000
Power (per OLT Card/y)	255
Connection (per customer)	500
Fiber cut (fixed)	60
Fiber cut (extra per fiber)	2
Floor space (per m^2/y)	150

Table 3 additionally details the ranges we used for the set of simulations in order to find the impact of the tradeoffs. In this case we varied all of those parameters for a discrete amount of intermediate values. The customer density (CD) ranges from 50 households per km^2 (HH/km^2), which matches with a rural region, over 1500 HH/km^2 (urban region), to 3000 HH/km^2 (dense urban region). The number of flexibility points (FPs) equals the number of subareas (in the hierarchical structure of the model) and ranges between 1 and 400. Unless indicated differently the middle of the predefined variation range is used as the default value for each parameter in the analysis. The size of the area is kept fixed at 150 km^2 (reference surface of Ghent, Belgium).

Table 3: Parameter ranges for simulation

Parameter	Minimum	Standard	Maximum
Customer density (HH/ km^2)	50	1500	3000
flexibility points (sub areas)	1	200	400

IV. COMPARISON OF PON, HRN AND ASN ON EQUIPMENT PLACEMENT AND CUSTOMER DENSITY

This section will describe the most important results from comparing ASN, HRN and PON for different customer densities and varying number of flexibility points.

A. Comparing total costs for Passive versus Active Optical Networks

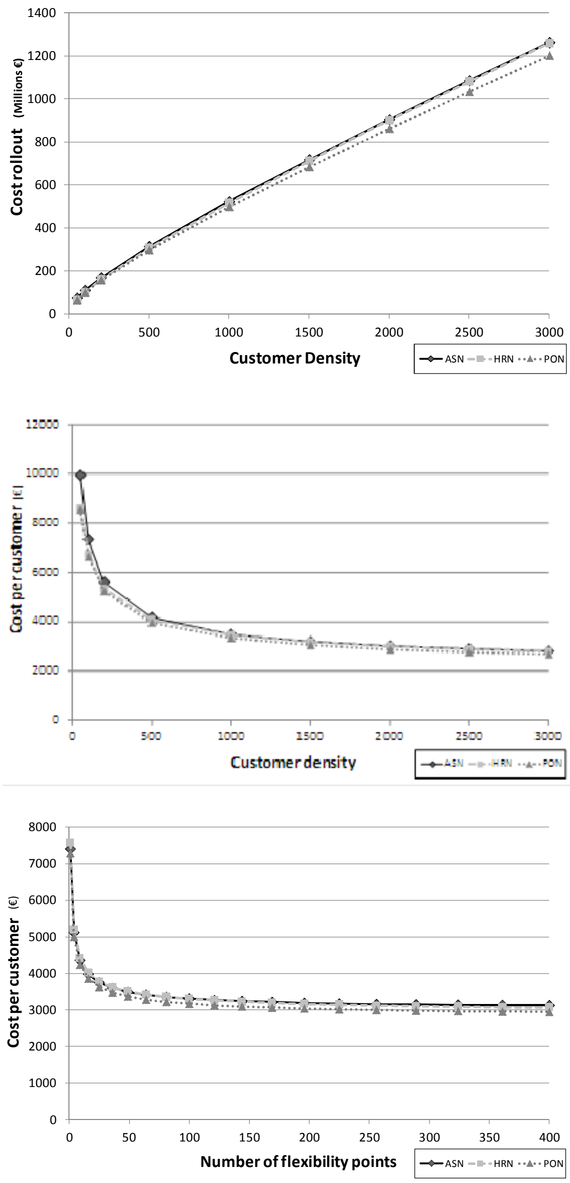

Figure 7: Comparison of cumulative costs (over 20 years) for HRN, ASN and PON
(a) full cost as a function of customer density (FPs = 200)
(b) per customer cost as a function of customer density (FPs = 200)
(c) per customer cost as a function of flexibility points (CD = 1500)

When comparing the three technologies, varying both customer density and number of flexibility points, we see a lower total cost for PON in all cases, although the difference is not very big. Figure 7 shows the total cumulative cost and cost per customer after 20 years for the three technologies for a range of customer densities (a) & (b) and flexibility points (c). The relation between the number of customers and the total cost is less than linear (a), which indicates that the cost per customer in dense urban areas is less than in rural areas, which is also clear from (b). An increase in the amount of flexibility points (c) in the median case also leads to a sharp decrease of the cost per customer (at least initially) and flattens afterwards.

Clearly the differences are small for the different solutions in this median case. Comparing the costs of all solutions to the lowest cost solution shows how PON is in all cases most cost efficient and that the maximal difference is only 6% as is shown in Figure 8. The same figure also points out how placing the active equipment in the central office is the cheapest solution when increasing the amount of flexibility points and distributing the equipment is (slightly) more cost efficient in the case of a choice for a low amount of flexibility points – which was already demonstrated to be an unfavourable action. The largest difference in costs between Active and Passive Optical Networks is found in areas with high customer densities and number of flexibility points. This can be explained by the higher number of fibres needed in an active network. There is however one exception: for ASN, an even high difference with PON is found in areas with a very high number of FPs, but a very low customer density. This is due to the upfront cost of installing a street cabinet, which then will not be used to its maximum capacity. Since the costs for a patch cabinet for HRN and a splitter cabinet for PON are much lower, we don't see this big cost difference in between those topologies.

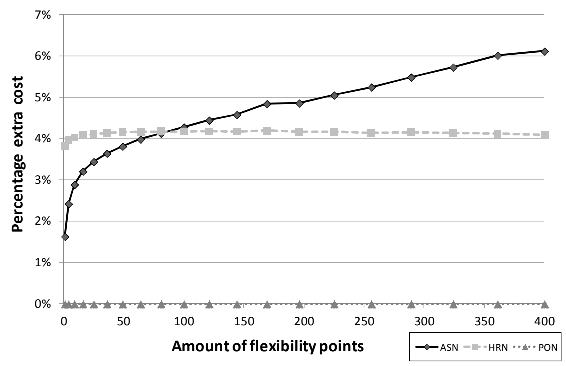

Figure 8: Extra percentage on top of the lowest cost for HRN, ASN and PON as a function of the number of subareas (CD = 1500)

When choosing for ASN, HRN or PON, operators should make the trade-off between an extra cost of a few percent and the degree of flexibility. Since HRN and ASN both offer P2P connections, they are more easily adapted to new technological requirements.

Furthermore, this extra cost percentage is mainly due to the upfront investment, when comparing the yearly cost per customer in year 20 (presumed to be steady-state), differences in between the three topologies are less than €3 on a per-year basis (ranging from €67.5 to €70 per customer per year) as is shown in Figure 9. This figure contains very sharp differences which are caused by uncertain and incomparable equipment replacements and granularities for the different cases.

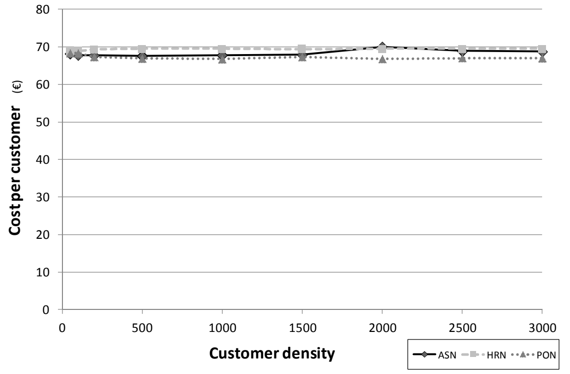

Figure 9: cost in year 20 for HRN, ASN and PON as a function of the number of the customer density (FP = 200)

B. *Variations in cost per customer for Active Optical Networks: HRN versus ASN*

Figure 10 shows a more detailed comparison of ASN and HRN for all calculated customer densities and amounts of flexibility points.

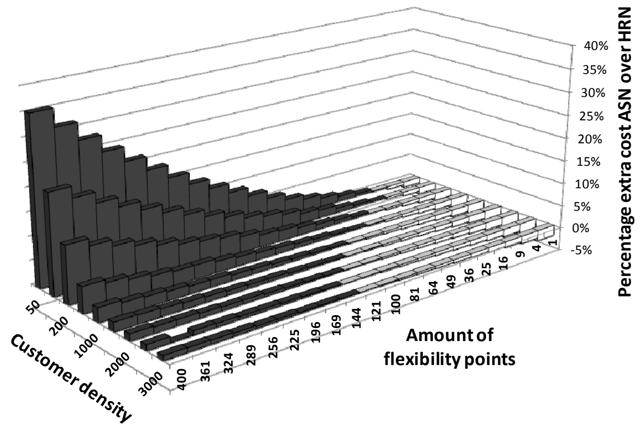

Figure 10: Comparison of ASN and HRN
percentage higher cost of ASN is indicated in black
percentage lower cost ASN is indicated in white

It is clear that ASN is the preferable topology (lowest cost per customer) when opting for a lower amount of flexibility points, but that HRN becomes cheaper with increasing number of flexibility points. Clearly this advantage becomes less for higher customer densities and in dense urban areas, there are hardly any possibilities to make ASN as cheap as HRN.

C. *Impact of the number of flexibility points on the cost per customer for ASN*

As can be seen from Figure 7, the impact of the number of flexibility points is the greatest for ASN. Investigating this impact on the cost per customer, leads to interesting conclusions: there exists an optimal number of street cabinets for each customer density, and this optimal number decreases with decreasing customer densities. In Figure 11 the case in which this effect is the highest, when the customer density is the lowest, is shown.

Clearly this is linked to the fact that there are large equipment preparations – street cabinet, powering, etc. – for each street cabinet in ASN which are hardly filled for low customer densities. This effect can clearly be seen from Figure 12), which shows the cost breakdown (infrastructure, equipment and operational expenditures) for ASN. The higher equipment costs, as well as the costs for re-installation of equipment (part of the operational expenditures) are clearly visualized here. This trend is not observed in HRN and PON simulations, since there, the cost for a patch cabinet is much lower (and thus of less influence) than the cost of a street cabinet in ASN.

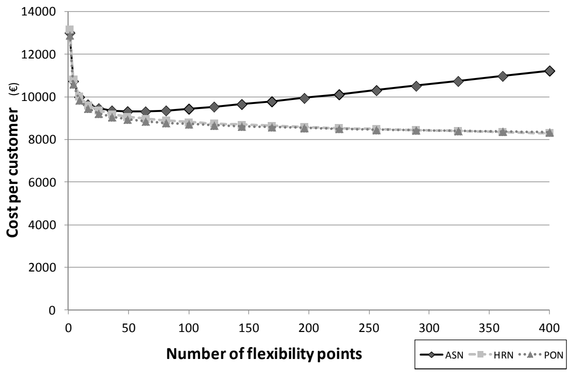

Figure 11: Cost per customer for ASN is initially decreasing, but increases for a further increase of the flexibility points. (CD = 50)

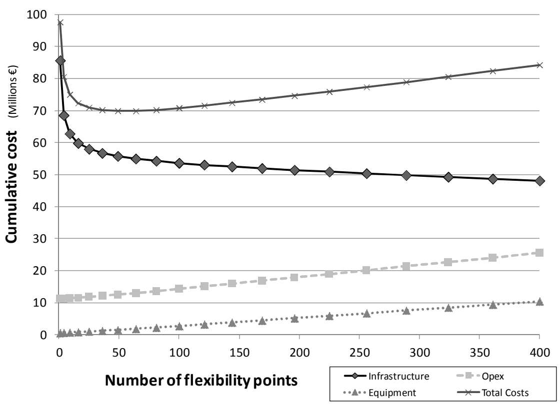

Figure 12: Cumulative cost after 20 years for Infrastructure, Equipment, Opex and Total for an ASN topology and varying number of flexibility points (CD=50)

V. GENERAL CONCLUSIONS AND FUTURE WORK

Because of ever increasing bandwidth demands, upgrades towards FTTH will be necessary in the near future. Different technological topologies for rolling out FTTH exist (PON, HRN and ASN) and the deployment costs depend on the choice of topology, but also on the number of customers that should be served (customer density) and the number of flexibility points (street cabinets, patch cabinets etc.). This paper presented a logical, modular model that allows for calculating the different parts of the cost (infrastructure, equipment, operational expenditures etc.) and investigating the impact of customer count, equipment specificities, distance to central office etc.

The results indicate that opting for a PON topology is always the cheapest option. An AON is more expensive, but the difference is relatively small and stays limited to a couple percents. The operator should make the trade-off between this small extra cost and a higher degree of flexibility when opting for an active optical network (be it ASN or HRN).

Installing more flexibility points will decrease the cost per customer for both HRN and PON. For ASN, however, the graph has a slight parabolic curve, leading to a minimum cost for limited number of street cabinets. This is due to the trade-off between installing extra street cabinets vs. a higher amount of fiber infrastructure. Comparing the two topologies for active optical networks, leads to a strong advantage for HRN for a high number of flexibility points. When opting for a low number of flexibility points, ASN gives the cheapest option, but the advantage is limited.

The gain in using a modular tool chain and a hierarchical calculation of areas as well as equipment allows to easily plug-in alternative architectures and equipment modules. Clearly, this tool chain will be used in the future to investigate tradeoffs between different – current and next generation – technology and equipment solutions and the impact of equipment and fiber pricing. Furthermore, a more extensive architecture set extending the current analysis in terms of layers (3 and more layers of flexibility points) and active equipment placement can be implemented. Finally, this model should be extended towards inclusion of the revenues, both direct and indirect.

ACKNOWLEDGMENTS

This research was partially carried out in the framework of the projects TERRAIN and OASE and co-funded by IBBT, IWT and EC (FP7/2007-2013) under grant agreement n° 249025. The first author is funded by an IWT grant.

REFERENCES

[1] K. Casier, S. Verbrugge, B. Lannoo, J. Van Ooteghem, P. Demeester, *Improving the FTTH Business Case - Benefits of an Holistic Approach*, The Journal of the Institute of Telecommunications Professionals, Vol 1. 2011.

[2] P. Fournier, *From FttH pilot to pre-rollout in France*, CAI Cheuvreux conference, http://www.francetelecom.com/en_EN/finance/invest-analysts/meetings-conferences/att00003205/20070626_FTTH.pdf June 26, 2007.

[3] F.M. Bass, *A new Product Growth for Model Consumer Durables*, Management Science, Vol. 15, no 5, pp. 215-227. 1969.

[4] K. Casier, *Techno-Economic Evaluation of a Next Generation Access Network Deployment in a Competitive Setting.* PhD degree at the Faculty of Engineering of the Ghent University. October 8th 2009.

[5] A. Mitcsenkov, M. Kantor, K. Casier, B. Lannoo, K. Wajda, J. Chen, L. Wosinska, *Geographic Model for Cost Estimation of FTTH Deployment: Overcoming Inaccuracy in Uneven-populated Areas*, ACP 2010, Shanghai, China. December 8-12, 2010.

[6] OASE, *Technical assessment of system concepts based on requirements*, Deliverable 4.2. 2011.

[7] Mouser Electronics – Electronic Component Distributor, http://www.mouser.com/.

[8] Farnell – Electronic Component Distributor, http://www.farnell.com/.