Technoeconomic Analysis of a VDSL2/G.fast Vectoring Network: a case study from Greece

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Abstract

Following the increasing need for higher broadband speeds, the European Commission (EC) has set specific goals to all member states regarding the development of new generation networks. Due to the high deployment cost, many countries have adopted only a partial transition to a purely optical fiber network. Fiber-to-the-Cabinet (FttC) architecture combined with very-high-bit-rate digital subscriber line 2 (VDSL2) and vectoring noise cancellation techniques may provide a more viable short-term solution. Technoeconomic analysis is vital at the initial development stages of a telecom network, which usually require large investments in infrastructure. This analysis addresses the viability of the project from a financial perspective. In this paper, we present a technoeconomic framework for the analysis of VDSL2 vectoring technology with its subsequent G.fast upgrade and illustrate its applicability in a particular suburb of the city of Athens, Greece. A number of different scenarios are evaluated predicting profits even from the first quarters. The analysis includes estimation of the degree of market penetration, analytical cost calculations for the implementation and operation of the network leading to the evaluation of financial indicators regarding the prospects of the investment in vectoring services. The overall framework can be applied in similar evaluations, regarding the deployment of telecommunication access networks.

Keywords: Broadband, Telecommunications, VDSL 2, Vectoring, Technoeconomic Analysis, FTTC.

1. Introduction

According to the data published in 2017 [1], the European Union (EU) is one of the biggest broadband markets and more than 176 million households have broadband connections delivered by next generation access (NGA) networks. In order to meet the deadlines for the deployment of higher broadband speeds and to avoid the high deployment cost many countries have adopted a partial transition to optical fiber network with Fiber-to-the-Cabinet (FttC) architecture.

In areas where fiber to the home is not cost effective, vectored DSL is a cost-effective solution for achieving downstream data rates of 100 Mb/s over 500 m by leveraging the existing copper infrastructure [2]. If vectoring is applied on a FttB architecture (100m from the customers premises), the downstream bitrate can exceed 200Mbps using VDSL2 35b profile [3]. However, the large number of lines (up to a few hundred) that coexist in the same cable results far-end crosstalk (FEXT), limiting the performance of VDSL2. Reducing interference with noise cancellation techniques, enables the delivery of higher data rates which are closer to the theoretical maximum capacity of the line [4]. In order to apply the vectoring technology, an anti-signal is generated to cancel the crosstalk [5]. Although vectoring gives the ability to harvest the existing infrastructure to a greater extent reducing the cost, it relies on measurements from all the lines for obtaining the best performance [2]. Migration to vectoring involves all lines in the same cable to be controlled by a single service provider [6]. However, this restriction is contrary to the current regulatory framework which aims at promoting infrastructure competition. To solve this problem, fixed access network sharing (FANS) [7] and the single-operator vectoring (SOV) can be used. In Greece, the National Regulatory Authority, decided to adopt the SOV implementation model [8]. Following all these, a new technology known as G.fast [9] brings user data rates up to 1 Gbps over copper twisted pairs implemented with fiber-to-the distribution point architecture (FTTdp). FTTdp comprises a distribution point unit (DPU) connected to the central office by fiber while DPUs are installed closer to the customer premises (typically in mini cabinets or curb boxes) enabling bit rates of 500Mbps over 250m. Near-end crosstalk (NEXT) is avoided by using synchronized time-division duplexing, while FEXT is canceled using vectoring [6]. The deployment of this comprises a technological migration and G.fast will share the access network with existing DSL systems, particularly with vectored VDSL2. So, coexistence of G.fast with legacy VDSL2 is a key to success of the new technology. In [10] after analyzing the coexistence of G.fast and vectored VDSL2 services in a distribution point deployment, it is shown that the deployment of spectral-compatible band plans is an effective means to improve vectored VDSL2 performance with tolerable impact on G.fast. Moreover, authors in [11] investigates the performance of G.fast coexisting with VDSL2 and present a scenario where FttC locations can be upgraded to serve G.fast. Higher data rates are available for subscribers located close to the cabinet, while subscribers with longer lines or with legacy equipment are served with the legacy service. Finally, authors at [12] conclude that G.fast brings DSL technology to a new level, comparable to the FttH grade of service. It allows operators to offer a total aggregated bit rate up to 1 Gb/s and low propagation delay.

In September 2017, British Telecom in an effort to upgrade its services announced a limited deployment pilot of G.fast across the UK [13] and the service is delivered over the existing access infrastructure (FttC). Taking into consideration the common elements between the English and the Greek access network, namely the FttC architecture and the length of the copper cables which is shorter than 300m in both cases (allowing G.fast upgrade), we conclude that G.fast is probably the best option for upgrading VDSL2 vectoring technology. For all these reasons mentioned before we decided to apply this framework in a particular suburb of the city of Athens and discuss the financial aspects of these technologies.

2. Related Work

The continuous technological innovations and a large variety of access network technologies and architectures, in combination with the constant effort to reduce implementation costs and operational expenses, have raised new and complex problems concerning the planning of telecommunications networks. Regarding the evolution paths towards a wide range of new services many frameworks have been published presenting hybrid optical/wireless networks as the cost-effective solution for bringing broadband services to the less populated areas. In [14] the author focusing to find which hybrid optical/wireless architecture poses as cost effective concept for providing broadband services to the rural areas with small number of inhabitants per km^2. In the techno-economic analysis of the hybrid architecture, network costs are divided in two segments: optical segment where the costs are simulated as if the FttH network was deployed and the wireless segment where cost models for LTE and WLAN networks are presented. As a result of the comparison between FttC and hybrid alternatives, total fibre lengths for both cases are used as a border at which FttC concept is more or less cost-effective compared with the two possible hybrid network solutions. The authors in [15] proposes a methodology for analyzing the total cost of ownership (TCO) of a number of backhaul options based on fiber, microwave, and copper technologies. The study included both outdoor and indoor users, and was employed in a Greenfield scenario to compare the TCO values of four backhaul network architectures and in a Brownfield scenario to compare the TCO values of six backhaul network migration options.

Authors in [16] presents a techno-economic framework able to assess not only the TCO but also the business viability of a HetNet deployment. In the evaluation work two technology options for the transport network are considered (i.e., microwave and fiber) assuming both a homogeneous (i.e., macrocells only) and a HetNet deployment. The results show a considerable increase of the backhaul TCO in the heterogeneous deployment compared to the homogeneous scenario and that fiber is the most cost-efficient and profitable backhaul technology for heterogeneous wireless deployments in areas with high density of users. According to the papers general conclusions a low TCO does not always lead to high profits and secondly, in order to have a profitable solution, it is recommended to choose the technology or the deployment option that does not require a large upfront investment and starts generating income as early as possible.

In scenarios where last mile access based on wired technologies is not economically viable authors in [17] proposed a generalized optimization framework that can be used to cost-optimally plan 5G fixed wireless access and its optical x-haul network. It is analysed the optimal deployment cost performance of the framework under various network conditions and deployment scenarios in order to demonstrate how versatile the proposed framework is in identifying, in each case, the best x-haul option among the ones under consideration.Finally, authors in [18] identifies all essential elements of a general framework for the economic analysis of different access network technologies and architectures, as well as describes some specific issues/problems related to the techno-economic evaluation of next generation access networks.

Most of the papers mentioned above focused on hybrid optical/wireless networks and present alternative technologies that can be used as a last mile solution to provide cost effective high-speed broadband access to areas where fixed broadband is limited. In our framework we decided to focus in areas with high population density that copper network infrastructure already exists. Taking into consideration the best way to use the legacy network and avoiding a large upfront investment due to an unstable and difficult economic period, we concluded that a two phase migration path would be the best solution. Authors in [19] shown that in order to find the best migration path, a techno-economic study is fulfilled in terms of technologies, time dependent CAPEX, OPEX, revenue, and time period. For the migration to FttH, several fixed access technologies are taken as multiple intermediate steps. According to these in the first phase FttC architecture with vectored VDSL2 is implemented and in the second phase a migration/ upgrade to G.fast technology is taking place. This will result in a fast FttC deployment, meeting the demanding deadlines, with the minimum CAPEX investment and with a generating income as early as possible. Our framework, is differentiated from other related works, as except from the CAPEX and OPEX analysis, we evaluate the total investment in term of income and revenue. In order to achieve more realistic results extensive demand forecasting is applied based on historical data from previous technologies. Moreover, different priced services are available for customers to choose, while the prices are defined accordingly based on a correlation in pricing policy followed by the local providers of the market we are addressing.

3. Technoeconomic Analysis

A typical technoeconomic analysis, as the one adopted in this paper consists of the following steps [20]:

- The development of the scenarios to be evaluated, based on the network topology, the technologies, etc.
- Demand forecasting for the deployed services.
- Modelling costs and revenues and transforming them into annual cash flows and discounted cash flows, for the selected time horizon.
- Investment analysis by calculating the crucial financial indices, like payback period, NPV, return on investment (RoI) and IRR, for each scenario.
- Sensitivity analysis in order to identify the impact of input parameters over the project performance.

The technoeconomic approach described above can be applied to potentially all technology market projects, with small modifications customized to each case.

3.1. Demand Forecasting

A major component to the evaluation of the project, is the estimated demand for the offered services. Diffusion models are mathematical functions of time, used to estimate the parameters of the diffusion process of a product or service life-cycle. They produce S-shaped curves corresponding to future demand at an aggregate level, rather than at the individual user level. The main advantage of aggregate diffusion models is that they are able to provide accurate forecasts without relying on the underlying specific parameters that drive the process. Diffusion models have been successfully used to forecast telecommunications services [21].

The aggregated S-type diffusion models can be derived from a differential equation (1):

$$\frac{dY(t)}{dt} = r \times Y(t) \times \left[S - Y(t)\right] \tag{1}$$

Where Y (t) represents the total penetration at time t, S is the saturation level of the specific technology (the maximum expected adoption level) and r is the coefficient of diffusion which describes the diffusion speed and correlates the diffusion rate with the actual and the maximum penetration. As observed in equation (1), the diffusion speed is proportional to both the population that has already adopted the service, denoted by Y (t), and the remaining market potential, represented by the quantity S -Y (t).

Among the most popular models are the linear logistic [22] and the Gompertz models [23].

The former is described by the following equation,

$$Y(t) = \frac{S}{1 + e^{-a-bt}} \tag{2}$$

while the latter by,

$$Y(t) = S \times e^{-e^{-a-bt}} \tag{3}$$

The next step in the forecasting process is to determine the values of parameters, that best describe the specific dataset. This is achieved by employing historical data describing the diffusion of the specific or similar technologies and use them as an input to a statistical software able to perform nonlinear least squares (NLS) regression. The result of this process will provide the values of the parameters of the evaluated model and provide corresponding forecasts. Not all the aggregate models are able to accurately describe all historical datasets, since the latter are a result of the specific social and economic characteristics of the considered market. For this reason, forecasting should be based on the application of more than one diffusion model, in order to provide a range, within which diffusion is expected to lie.

Forecasts for the diffusion of the vectoring network can be based on the assumption that since vectoring technology is the evolution of VDSL, demand can be based on historical data available from non-vectored VDSL which currently upgrades legacy ADSL service. Analysis of market penetration for the years 2005 to 2012 [24] for ADSL and 2012 to 2017 [25] for VDSL in Greece, leads to some insights regarding the expected adoption scheme: during the first year that both ADSL and VDSL were commercially introduced, only a small percentage of subscribers adopted the new service, the second year saw a significant growth, while the third year tripling the number of subscribers, followed by a steady annual increase observed in the year to come. We assume that the demand for vectoring will proceed in the same manner. Figure 1, shows the demand forecasting from the year 2020, when vectoring will be introduced based on the previous VDSL penetration available data from 2012 to 2016. According to the original data the percentage of ADSL subscribers that adopted VDSL was 4.07% in 2012, 6.92% in 2013, 10.4% in 2014, 14.2% in 2015 and 18% in 2016. Assuming that the same penetration is expected for vectoring these values used as input in NLS to obtain the penetration from 2024 onwards.

The figure also shows the penetration for G.fast introduced in the year 2024, i.e. four years after the introduction of vectoring. By the year 2020, the total number of subscribers available in the study area is 2.800 and an annual increase of 5% subscribers is calculated matching the broadband annual subscription growth [26]. The time of G.fast introduction was taken to coincide with the break-even point of vectoring calculated in our subsequent analysis (see Section 3.3). For G.fast, we use the same values with VDSL2 vectoring shifted ahead in 2024, since we expect that the user tendency to adopt new technologies will not vary significantly over time. For our investment project, we take into account the worst-case scenario that G.fast users are all originating from vectoring users and not legacy VDSL users, i.e. user technology adoption does not skip a generation. Figure 1, shows the gradual increase of VDSL2 vectoring and G.fast subscribers for both logistic and Gompetz models. The red and blue vectoring curves correspond to the forecast for vectoring, without taking into account the introduction of G.fast. From year 2024 onwards, where G.fast is introduced, the number of VDSL vectoring subscribers is calculated by subtracting the subscriber number obtained from these curves and the corresponding G.fast penetration curves. The figure also illustrates the different results obtained by the two models which originates in the assumptions used for their construction. Application of more than one diffusion model, in the context of a technoeconomic analysis, is a common approach and results in a range of values within which the diffusion is expected to lie. This range can also serve as an input for the sensitivity analysis of the technoeconomic valuation of the project, since the number of subscribers are the most important input parameter.

3.2. Billing

The vectoring broadband bundles provide faster internet access to the customers with downstream speeds up to 100Mbps and 10Mbps upstream data rates. These bundles are combined various options for domestic and mobile calls [25] resulting in three different bundles for access technologies:

- *Economy* (E), which provides only unlimited broadband services.

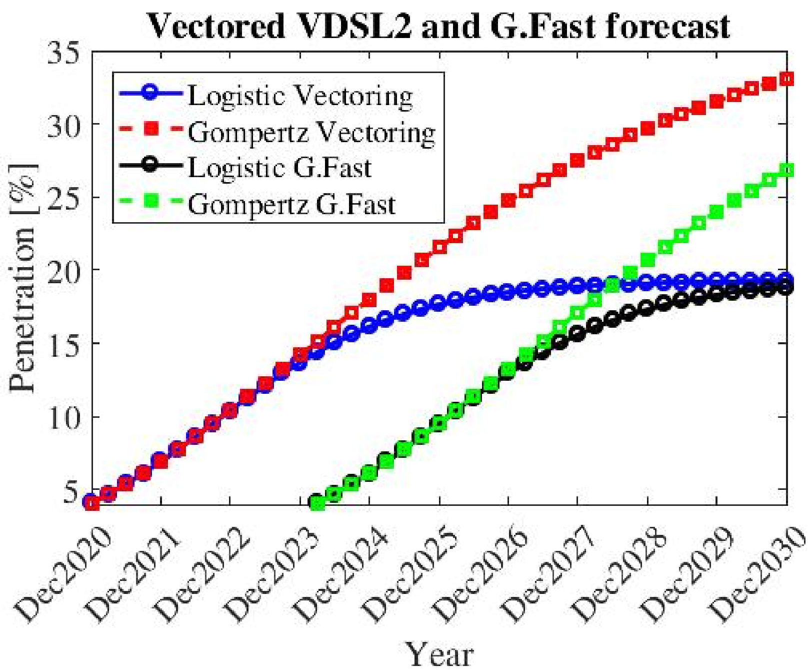


Figure 1: Forecast for vectored VDSL2 and G.fast penetration.

- *Unlimited* (U), which combines unlimited broadband services and unlimited domestic calls to Greek landlines.
- *Unlimited Plus* (U+), which is similar to U, including 360 minutes calls to mobile phones.

Pricing is one of the most important factors about the final demand a service will have and for this reason we try to understand how Greek market works and follow the same pricing policy for the new offered bundles. By this way, minimize the chance to impact penetration and the analysis is going to lead us to the most realistic result possible.

In 2016, pricing for the corresponding legacy VDSL economy (E), double play (U) and double play (U+) at 30Mbps were 33.2€/month, 36.2€/month and 40.2€/month respectively (service prices without taxes 24%). For VDSL at 50Mbps the pricing was 40.2€/month and 44.2€/month for the U and U+ bundles, while no E option was offered for this access rate which represent the flagship of the operator. Furthermore, comparing the prices of VDSL2 bundles when firstly appeared a correlation emerges in pricing policy. Particularly, the economic bundle of a service has similar price with the U+ bundle of a slower speed service, while the price difference between U and U+ of the same speed service usually defined at 4 to 5 €. Based on these figures, we have assumed a pricing of 45€/month and 49€/month for the U and U+ 100Mbps VDSL vectoring bundles in 2020. The pricing for vectoring starting from 2020 is estimated based on the similar billing policies of the legacy ADSL and VDSL packages during the time period from 2012 to 2017. The actual price variations in the service bundles depend on the specific strategy of each operator and can vary from year to year. In our case, we have assumed that the price reduction follows a simple geometric distribution $P(n) = P(1)(1-k)^{(n-1)}$, where the index k is the average reduction rate for each year. The value of k for VDSL vectoring can be inferred from the price evolution of similar technologies, in our case legacy VDSL. Based on available pricing data for the corresponding bundles in legacy VDSL in Greece, we have found that prices within 2012 and 2017 correspond to an average annual reduction k of 3.77% and 3.43% for U and U+, respectively. Applying the geometric formula, we can ascertain that the price reduction of U and U+ at the end of the 10 year period will be $\cong$ 30% and $\cong$ 27% respectively.

Following the bundle policy of British Telecom, we introduce two different G.fast packages with 400Mbps/50Mbps and 200Mbps/30Mbps for downstream and upstream data rates respectively. When G.fast becomes available at 2024, the prices of the VDSL2 vectoring packages would be reduced by $\cong$5€. Furthermore, G.fast would replace VDSL2 U+ vectoring as the most expensive package. In order to maintain the price difference, G.fast pricing policy is estimated to follow the diminishing value of VDSL2 vectoring, incremented steadily by 6€ and 10€ for the 2 available G.fast packages respectively (G.fast 200 and G.fast 400).

As it was mentioned before the Greek national authorities decided to adopt the SOV implementation model. In this model, each provider is responsible for implementing the FttC architecture in a specific demarcated area. The CAPEX and OPEX of the network implementation and operation may vary depending on the chosen equipment and the suppliers but in general there are no major deviations as there have been set specifications for the chosen equipment by national network authority. The bundles and their price depend exclusively on each provider with the condition that the price will remain the same regardless of whether you are in their region or not. By this way, competition is applied in national level. In order to demonstrate SOV in the techno-economic analysis, we assume that the incumbent provider would have the 55% of the total subscribers of the area while the remaining 45% will be owned to the other alternative providers and they would be served as wholesale subscribers. According to the Greek market, the wholesale prices are varied depending on the speed of the broadband service and are the same for all providers. So for the existing available services the prices are 10.84€ for the 100Mbps, 13.29€ for the 200Mbps and 17.88€ for the 400Mbps (the prices are without taxes 24%). These mentioned prices are for the first year and it is estimated to also follow the diminishing value of VDSL2 vectoring. The following example illustrates how SOV model works. If alternative provider X offers vectoring 100Mbps at the price of 45€and a subscriber of X is located in the area serviced by Z provider, then 10.84€will be paid to the area incumbent provider Z, for renting the line and the rest 34.16€will be the actual earning for X. So, for provider X the 10.84€are considered as OPEX and in contrast for provider Z are considered as income.

3.3. Implementation Cost

The investments required for the development of an NGA network based on the FTTC architecture are divided in CAPEX and OPEX. CAPEX refer to the funds used to acquire or upgrade physical assets such as property, buildings and equipment, as well as the installation cost. OPEX are the expenses that a business incurs through its usual business operations, including rent, equipment, inventory costs, marketing, payroll, electrical consumption and maintenance of the infrastructure. The calculation of the cost is based on the actual region of Egaleo (a suburb of Athens, Greece), which was chosen for our technoeconomic analysis. The complicated town planning and the local grove largely affect the optical fiber route (see Figure 2). As a result, a detour needs to be made for the connection between the cabinets and the distribution center, which increases the final distance of the optical fiber network by several hundred meters. This is a useful case study, being one of the worst case scenarios, as it will raise the implementation cost and that's why this specific region was preferred. The particular examined area is 188,000m^2 and there are 9 cabinets. In the map presented in Figure 2, the exact location of the nine cabinets is marked along with the route of the optical fiber network from the distribution center to the cabinets and the overall covered area inside the blue lines.

Table 1: Cost Calculation (CAPEX)

CAPEX						
Equipment	Units		Cost / Unit (€)		Total Cost (€)	
	VDSL v.	G.Fast	VDSL v.	G.Fast	VDSL v.	G.Fast
Duct and fiber	2,105(m)	-	30	-	66,075	-
Cabinets	9	-	1,500	-	13,500	-
DSLAM & control boards	9	9	3,650	5,000	32,850	45,000
Service boards	54	54	450	650	24,300	35,100
SFP	18	54	100	100	1,800	5,400
Fiber patch cord	18	54	5	5	90	270
ODF	9	-	30	-	270	-
Filter reglet	135	90	25	25	3,375	2,250
Batteries	36	-	100	-	3,600	-
Cabin installation	9	9	7,100	3,000	63,900	27,000
Power supply	9	-	350	-	3,150	-
Technical design	9	-	688	-	6,192	-
OLT	1	1	4,000	9,500	4,000	9,500
Switch	1	1	5,200	5,200	5,200	5,200
OCR	1	-	500	-	500	-
DC patch-cord	18	54	5	5	90	270
Air condition	1	-	1,150	-	1,150	-
DC installation	1	1	4,100	3,000	4,100	3,000
Subscriber router	300	450	25	40	7,500	18,000
Cumulative cost					**241,642**	**150,990**

Table 2: Cost Calculation (OPEX)

<table>
<tr><th colspan="7">OPEX</th></tr>
<tr><td colspan="3" rowspan="2">Equipment</td><td colspan="4">Annual operation cost (€)</td></tr>
<tr><td colspan="2">VDSL v.</td><td colspan="2">G.Fast</td></tr>
<tr><td colspan="3">Cabinets</td><td colspan="2">13,230</td><td colspan="2">6,930</td></tr>
<tr><td colspan="3">Distribution Center</td><td colspan="2">5,145</td><td colspan="2">2,364</td></tr>
<tr><th colspan="7">Maintenance cost</th></tr>
<tr><td>Year</td><td>Existing Copper cable (€)</td><td>Duct and fiber (€)</td><td>Cabinets (€)</td><td>DSLAM equipment* (€)</td><td>Distribution center**(€)</td><td>Batteries, cooling system (€)</td></tr>
<tr><td>2020</td><td>872.87</td><td>365.19</td><td>533.71</td><td>1,116.25</td><td>485.73</td><td>-</td></tr>
<tr><td>2021</td><td>872.87</td><td>709.29</td><td>1,040.01</td><td>2,065.10</td><td>935.71</td><td>-</td></tr>
<tr><td>2022</td><td>872.87</td><td>689.68</td><td>1,013.64</td><td>1,921.43</td><td>904.95</td><td>4,250</td></tr>
<tr><td>2023</td><td>872.87</td><td>671.49</td><td>988.37</td><td>1,798.33</td><td>878.47</td><td>-</td></tr>
<tr><td>2024</td><td>872.87</td><td>654.72</td><td>964.27</td><td>2,853.52</td><td>1,227.77</td><td>4,250</td></tr>
<tr><td>2025</td><td>872.87</td><td>639.35</td><td>941.46</td><td>3,687.11</td><td>1,542.09</td><td>-</td></tr>
<tr><td>2026</td><td>872.87</td><td>625.42</td><td>920.13</td><td>3,406.61</td><td>1,492.61</td><td>4,250</td></tr>
<tr><td>2027</td><td>872.87</td><td>6612.98</td><td>900.50</td><td>3,166.94</td><td>1,450.40</td><td>-</td></tr>
<tr><td>2028</td><td>872.87</td><td>602.10</td><td>882.85</td><td>2,963.53</td><td>1,414.65</td><td>4,250</td></tr>
<tr><td>2029</td><td>872.87</td><td>592.85</td><td>867.44</td><td>2,792.46</td><td>1,384.69</td><td>-</td></tr>
<tr><td>2030</td><td>872.87</td><td>585.24</td><td>854.47</td><td>2,650.28</td><td>1,359.90</td><td>4,250</td></tr>
<tr><td colspan="7">DC=distribution center, OCR=optical consolitation rack, ODF=optical distribution frame, OLT=optical line termination, SFP=small form-factor pluggable</td></tr>
<tr><td colspan="7">*(including DSLAM, control-service board,fiber patch cord, SFP, ODF, filtered reglets)</td></tr>
<tr><td colspan="7">**(including OCR rack, OLT, OLT cards, switch, patch-cord)</td></tr>
</table>

Figure 2: Map of the Egaleo area

3.3.1. CAPEX estimation

CAPEX accounts for the cost for equipment purchase and the installation cost and are summarized in Table 1. The installation of the fiber optic network is estimated at 30€/meter. For the successful interconnection between the distribution center and the nine cabinets (the area is served by nine old copper cabinets, which will be replaced by an equivalent number of new optical cabinets) the total cost is 66,075€ for a distance of about 2Km of optical fiber. In addition, the calculated cost for the purchase and the installation of the nine cabinets is 152,127€ including all the necessary equipment inside the cabinet, like DSLAM, batteries, optical distribution frame (ODF), copper line termination and cooling system. In the distribution center, the equipment cost is estimated at 15,940€, including the cost of telecom equipment, such as the optical consolidation rack, the optical line termination, switches and the cooling system. Finally, the operator will provide the subscribers with vectoring routers and this leads to an extra cost of 7,500€, in order to meet the estimated demand for the first two years. By the third year, depending on the demand, a new router batch purchase will be required. Taking into consideration the aforementioned analysis, the total cost for the deployment of the NGA network is 241,642€. When calculating costs, wherever technical work is required such as installing the fiber optic network and installing cabinets, prices also include the labor cost. Regarding the CAPEX of G.fast implementation there is an additional cost for purchasing and installing the new equipment. The advantage of the FTTC architecture is that the new equipment will be placed inside the cabinet and there is already available fiber optic network to support it. The implementation cost of active G.fast equipment (DSLAM, service boards, SFP) for the 9 cabinets, the distribution center and the G.fast routers is calculated at 150,990€ including the labor cost when needed and is going to be installed during the 4th year of the VDSL2 vectoring operation. The calculations are summarized in Table 1,2 and Figure 3. Regarding the product lifetime there is variation between the useful lives of different network equipment. Table 3 shows the asset lifetimes of the network elements needed for the implementation of both the VDSL vectoring model and the upgraded technology of G.fast according to [27].

3.3.2. OPEX

For a FTTC network, the OPEX mostly depends on the electrical consumption and the maintenance of basic equipment and more specifically, DSLAMs, batteries and cooling system for the cabinets as well as optical line termination (OLT) equipment, switch and air conditioner for the distribution center. For a realistic estimation of the electrical consumption, the cooling system is considered to work at the maximum level during summer period, at 70% during spring, at its 50% for three months during autumn and at 20% during the winter. In a similar way, the DSLAM and other devices consumption is estimated, assuming they work for six hours per day at maximum consumption, ten hours approximately at 50% and 30% for the rest of the day. As a result, the annual operational cost for the nine cabinets is expected to reach 13,230€ and the OPEX for the central office 5,145€. An average cost of 0.16€ for 1kWh is assumed. On a daily basis, the cooling system of a single cabinet is expected to operate for 5 hours during winter, 12 hours during autumn, 17 hours in the spring and 24 hours at summer period.

Table 3: **Asset Lifetimes by Equipment Type**

Equipment Type	**Asset Lifetimes (Years)**
Ducts and dark fiber	40
Street Cabinet	20
Electronic equipment *	5
ODF	10
Batteries	2
Reglet	20
Rack and Frames	10
Air condition	10
Subscriber router	10
Optical fiber interconnections	5
*including DSLAM, control boards, service boards, SFP, OLT, Switch	

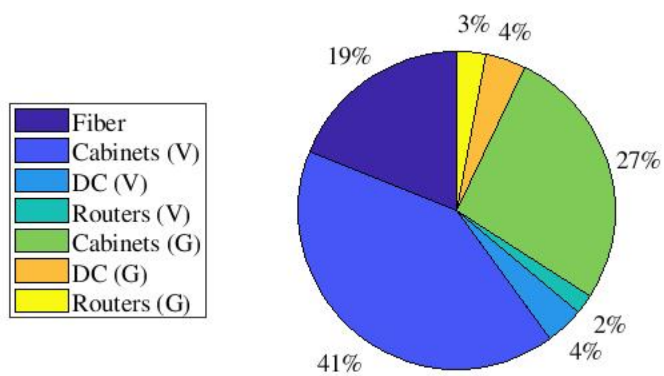


Figure 3: CAPEX Individual Costs including fiber installation, cabinets (equipment & installation), subscriber routers and distribution center costs for VDSL vectoring (V) and G.fast (G)

With an average power consumption of 0.800kW the total daily consumption is 4kWh, 9.6kWh, 13.6kWh and 19.2kWh, respectively for the four different seasons while the daily cost is 0.64€, 1.53€, 2.17€ and 3.07€. Summing up, for total cost for the winter period the cost is expected to be 58€, 138€ in autumn, 195€ in the spring and 276€ in the summer. The annual cooling cost for a single cabinet is therefore calculated at 667€. In the same way, the annual energy consumption of the DSLAM and the power supply for the nine cabinets in addition to the OLT, switch and air conditioner for the distribution center are estimated. In the distribution center, there is also a monthly additional rental cost of 47€ per rack and two of them are required for vectoring needs. When G.fast equipment is installed in all cabinets and the distribution center the OPEX are expected to be increased. The energy consumption of the new equipment will be added to the existing one. The energy consumption of G.fast equipment is calculated with the same methodology and as a result the annual cost is expected to reach 770€ per cabinet. In the distribution center the annual energy consumption cost is calculated at 1,800€ for the OLT and the switch while it will be used one more rack for the G.fast equipment with annual rental cost of 564€ as shown in Table 2.

Over time, network equipment maintenance costs will typically decrease as shown in Table 2. In order to evaluate the annual equipment maintenance costs, we first estimate the decreasing equipment value, for each year after purchase [20]. Using these values, the annual maintenance cost of every equipment can be calculated [28], excluding the maintenance cost of the batteries and the cooling system. A precautionary maintenance cost is considered for the latter, after the third year and subsequently every two years, with a total cost of 4,250€.

3.3.3. Investment Analysis

In Figures 4a and 4b, a comparison between the CAPEX, OPEX and revenues is presented for the Gompertz and logistic models respectively. In this point, it should be mentioned that the number of subscribers who choose VDSL2 vectoring is equally divided between the 2 available bundles U and U+. By the same way, the subscriptions of G.fast are split for G.fast 200 and G.fast 400 services. By the end of 2023 (before the G.fast introduction), the number of VDSL2 vectoring subscribers is estimated to reach its top value with 449 subscriptions for logistic model and 466 for Gompertz model. Correspondingly, by the end of 2030 the total G.fast subscriptions is estimated at

776 for logistic and 948 for Gompertz model. Both figures clearly illustrate that the venture can quickly outweigh its expenses, indicating a favorable investment opportunity.

Based on these values, measurements of investment profitability, such as the NPV and the IRR can be calculated. By setting the annual discount rate to 5%, the calculated NPV for the first ten years of operation is:

- 287,824.93€, for the logistic model.
- 480.786,78€, for the Gompertz model.

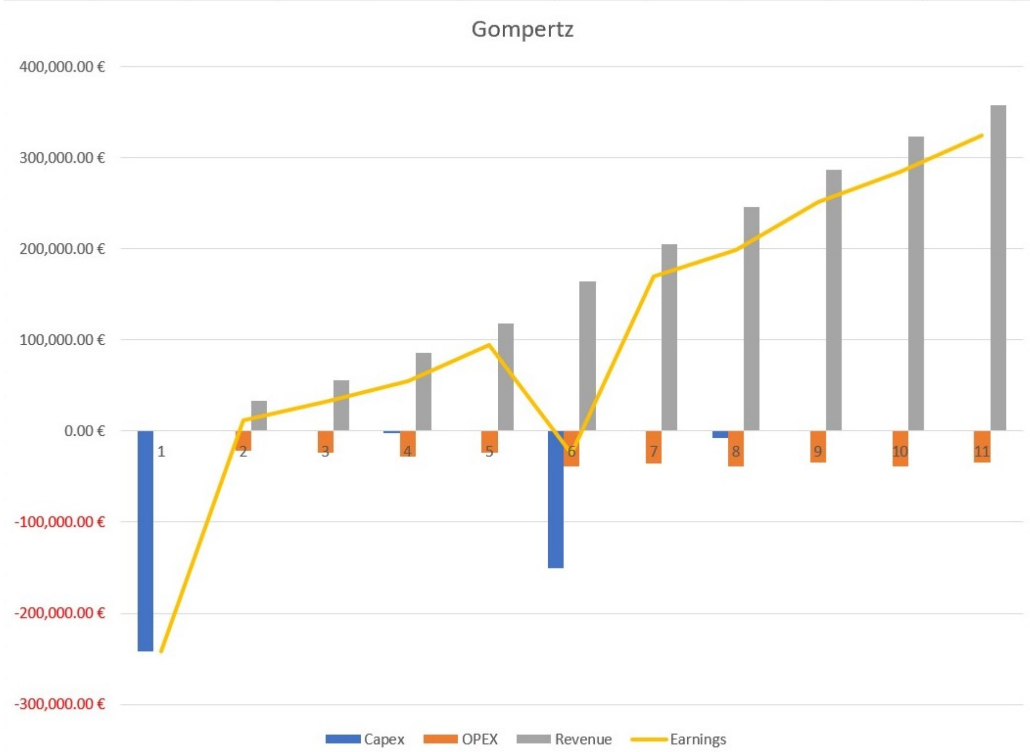
while the IRR for the same period is:

- 17.8%, for the logistic model.
- 22.7%, for the Gompertz model.

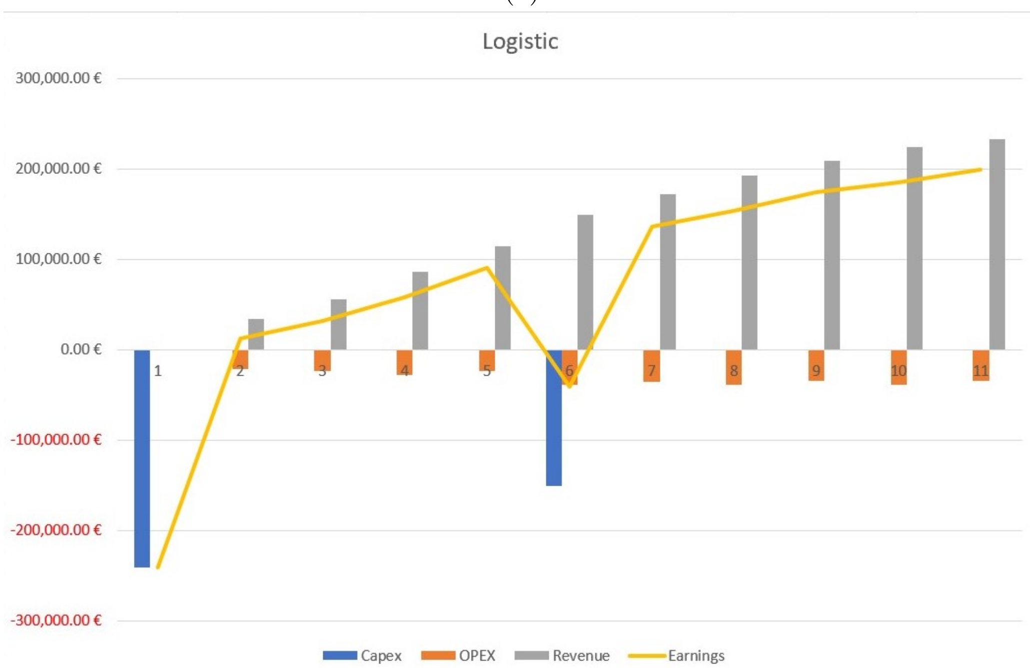
In both scenarios, the break-even point calculated in figure 5 is expected to occur in the middle of the fourth operational year. As expected, during the first two years the balance is negative due to the slow diffusion, while during the third year, where a larger increase of subscribers is expected, the investment will start showing signs of profitability. Following this, the investment is largely attributable during the fourth year and the profit level is half the initial invested capital. In the coming years the investment continues to generate revenues and finally, during the last year of the analysis, the total recorded profit is expected to be 757,546€ and 1,156,923€ for both scenarios. Based on the fact that both NPV and IRR are positive for both scenarios, the investment is considered highly profitable. The presented indicators show that from the fourth year of operation the telecom provider will record steadily rising profits.

4. Conclusions

In this paper, we have presented a technoeconomic evaluation of a VDSL vectoring scenario followed by a switch to G.fast technology. The framework in question was applied for a specific area of Athens, Greece. The framework entailed a detailed demand forecasting for both technologies in question, estimation of CAPEX, OPEX as well as revenues based on specific tariff policies. It can be used to estimate several key economic figures such as the NPV, IRR and the payback period. Results show that investments in



(a)



(b)

Figure 4: OPEX, CAPEX, revenues and earnings for a) the Gompertz and b) Logistic scenarios over the first 10 years of the investment.

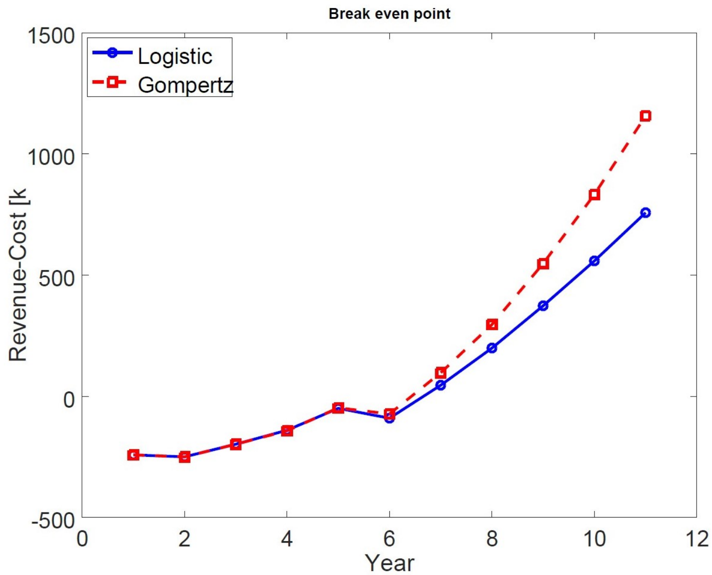


Figure 5: Break Even Point

VDSL/G.fast vectoring networks can be quite profitable at the initial stages and even if a pessimistic (logistic) demand model and a less favorable area is assumed.

Competition among telecom providers, which drives demand and pricing schemes as well as quality of services, constitutes directions for future work. Intense competition between providers, clearly benefits the consumers in terms of service improvement and lower prices. It is now an ideal time to invest funds for the development of fiber optical networks, since there is more installation experience compared to previous years. The case study incorporates how the particularities of the area can change the route of the fiber optical network, affecting the total cost and the return on investments. However this a vital step towards the evolution of telecom networks and services.

As far as VDSL2 vectoring with subsequent upgrade to G.fast is concerned, the time the service will be commercially available is imminent. With the vectoring solution, telecom providers bring new value to existing copper and manage to reach tomorrows speeds to todays networks. However, with the high annual growth rate in demand for speed, the question of "what is going to be the next step?" still remains. Many telecom analysts claim that FTTH networks will replace FTTC networks, but in uncertain economic times this evolution seems impossible. Currently, most service providers cannot afford the implementation cost of FTTH networks. To this extent, the most advantageous solution in terms of low cost investment and spectacular growth in data rates seems to be G.fast with speeds up to 1Gbps. It remains to be seen in the years to come, whether G.fast will deliver on its promise. This is a topic that requires further research both on a technical and an economic level.

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