Technoeconomic analysis of Next Generation Networks

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Abstract. In this thesis a methodological framework for the technoeconomic analysis of telecommunication networks is presented and then used in order to address problems concerning the deployment of Next Generation access Networks (NGN). Issues concerning the technoeconomic evaluation are presented such as economic indexes for the evaluation of investments, discounted cash flow analysis, real option analysis and risk analysis. The methodology is used in order to address several case studies for NGN deployments using both wired (FTTx) and wireless (FSO) architectures. In order to clarify the uncertainty real option analysis is used along with risk and sensitivity analysis.

1 Introduction

Telecom operators are skeptic in introducing fiber to the home (FTTH), due to the high investment costs associated with civil works, especially in urban and rural areas. Therefore, their current strategy is to exploit at the highest possible level their existing copper-based networks as long as possible. This strategy leads to fiber to the cabinet (FTTC) and fiber to the node (FTTN) deployments with VDSL access at last mile. A number of research and policy questions have arisen as different architectures and technologies are discussed, such as the upgrade possibilities from FTTC to FTTH. During recent years, an increasing number of research papers besides the consultancy reports, have been developed within national and international collaborative projects appeared aiming to contribute to this broadband debate. Most of these works deal with the installation first cost (IFC).

However, a complete analysis related to the FTTH deployment scenarios aiming to offer quantitative results and to analyze the associated attitude from incumbent and greenfield operators is still absent. This dissertation aims to offer these quantitative results by incorporating both "traditional" Discounted Cash Flows (DCF) analysis and Real Options Analysis (ROA).

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1.1 The TONIC-ECOSYS methodology and tool

The technoeconomic methodology adopted for the evaluation of NGA deployments is based on the ECOSYS tool developed within the IST-TONIC [1] and the CELTIC-ECOSYS [2] European projects. The ECOSYS tool and its antecedent, the TONIC tool have been used for several studies among European telecom operators and universities for many years.

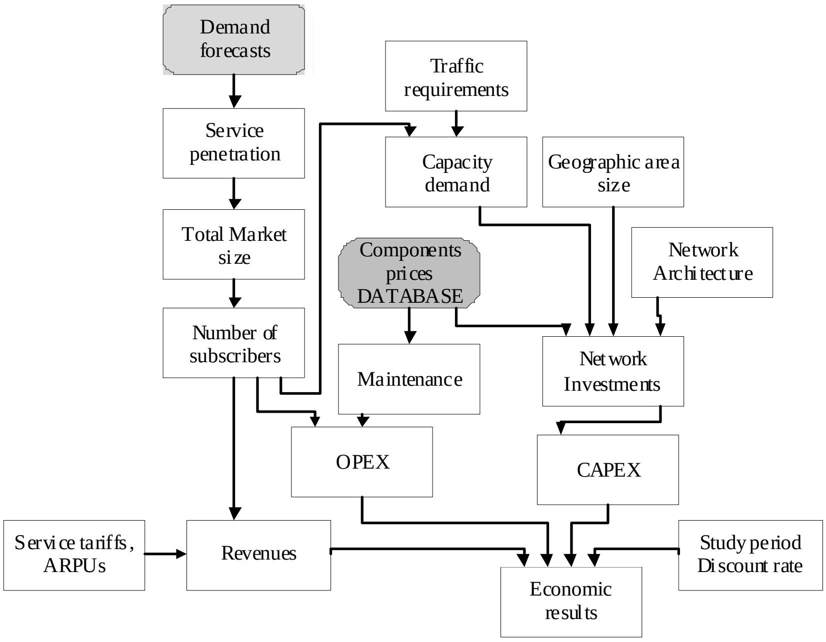

Fig. 1: Techno-economic methodology and tool

The model's operation (fig. 1) is based on its database, where the cost figures of the various network components are kept and updated from data gathered from the biggest European telecommunication companies and vendors as well as from telecom market.

The study period is best adapted to the case at hand. For a fixed network deployment case an eight to ten-year period is reasonable, considering the time a fixed network or service takes to reach market maturity and to payback the investments. The services offered are specified as well as their market penetration over the study period. In addition, the service tariffs are defined taking into account both econometric and price forecasts models and the part of the tariff that is attributed to each network under study can also be modeled. From the combination of yearly market penetration and tariff evolution, with the ECOSYS tool the revenue side of network deployments for each year given the selected service set can be calculated.

For the expenditures side, the architecture scenarios that provide the selected service set are selected from the candidate ones. This kind of modeling needs network planning expertise and is mostly outside of the framework of the ECOSYS methodology. However many network architectures can be accounted for such as tree, mesh or ring architectures, incorporated within the tool, which includes a set of geometric models that assist in the network planning by automatically calculating lengths for cables and ducting. These geometric models are optional parts of the methodology and the ECOSYS tool can be used without them, as in the technoeconomic case of radio access technologies. Network data from other planning tools can also be used. The output of the architecture scenario definition is the so-called shopping list, which is calculated for each year of the study period and shows the volumes of all network cost elements (equipment, cables, cabinets, ducting, installation etc.) and the distribution of these network components over different network levels and layers.

In order to estimate the number of network components required throughout the study period, the necessary forecasts (both demand and price forecast) are carried out according to existing methodologies or market studies and incorporated in the technoeconomic model. The Operation Administration and Maintenance (OA&M) cost for each network element is estimated from the price of each of its constitutive parts. For example, in the case of an Ethernet switch, the model includes the switch basic equipment (switching fabric, power supply, rack and line interface cards) taking into account list price information of several vendors. The price evolution of the network components is estimated using the extended learning curve model. As far as the cost of repair parts is concerned, it is calculated by the model as a fixed percentage of the total investments in network elements while the cost of repair work is calculated based on Mean-Time-Between-Failure (MTBF) and the Mean-Time-To-Repair (MTTR).

By combining the revenues and expenditures sides, namely service revenues, investments, operating costs and general economic inputs (e.g. discount rate, tax rate), the tool calculates the results necessary for DCF analysis such as cash flows, Net Present Values (NPV), Internal Rate of Return (IRR), payback period and other economic figure of merits.

1.2 Area charactersitics

The FTTH and FTTC architectures with a combination of Gigabit Ethernet and Ethernet over VDSL for the last mile are investigated, under the incumbent operators' point of view. Two area types in an average European country, namely Dense Urban (DU) and Urban (U) are under study. These areas share the same network topology but differ in several characteristics such as area dimension, population density, average cable and duct lengths, these characteristics are presented at Table 1. One common assumption is that one Central Exchange (CEx) is connected to four Local Exchanges (LEx) serves each area. Furthermore each LEx is located in the center of the service area and has a number of Cabinets connected to it. Finally all the customers are connected through their nearest cabinet (Fig 2). The fiber lengths have been calculated with the use of a geometric model. In order to model an entire European-type city, the appropriate number and pattern of dense urban and urban areas matching the city's characteristics should be assembled and added accordingly.

Table 1 Area characteristics

Area type	**Dense Urban**	**Urban**
Number of Central Exchanges (CEx)	1	1
Number of Local Exchanges (LEx)	4	4
Cabinets	256	256
Number of buildings	1024	2048
Subscribers per building	64	32
Total population per area	65536	65536
Total Service area (km^2)	12	32
Density (Houses/Km^2)	5641	2048

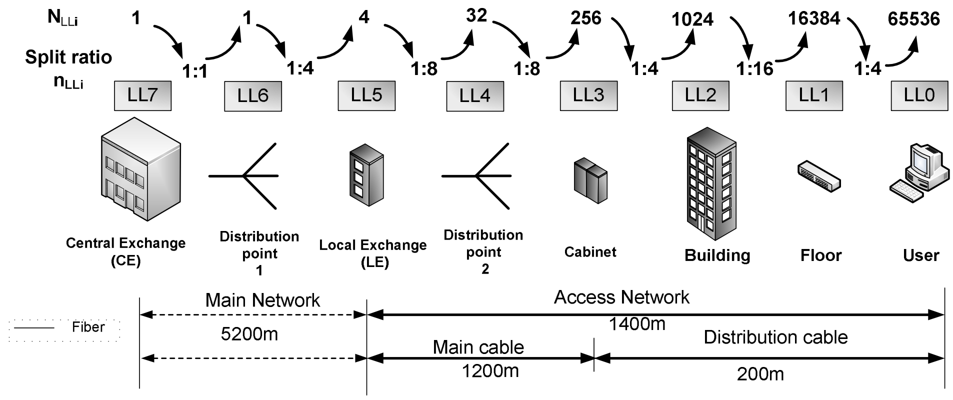

Fig. 2. Dense Urban area architecture and calculated lengths

1.3 Demand model

In the analysis, a logistic model is used to perform the demand forecasts for the selected services. This model is recommended for long-term forecasts and for new services both for fixed and mobile networks. To achieve a good fit, a four- parameter model including the saturation level is used. The model is defined by the following expression:

$$Y_t = \frac{M}{\left(1 + e^{a+bt}\right)^c} \qquad (1)$$

where the variables are as follows:
Y_t : is the demand actual or forecasted at time t as a population percentage
M: is the demand saturation level as a population percentage
t : is time in years and
a,b,c: are the diffusion parameters which can be estimated based on existing market data, related to broadband penetration across Europe.

2 Results and discussion

In the second part of the thesis the developed methodology was applied in selected case studies for both wireline (FTTx) and wireless (FSO) access networks.

2.1 Technoeconomic evaluation of FTTC and FTTH deployment scenarios using DCF and Real options valuation

For the case of FTTC, the incumbent operator makes a strategic decision at the first year of the project (in this model year 2009 has been used as the first year) to invest on a VDSL upgrade on the network in the dense urban areas. Part of these results was published in [3]. On the other hand, if the FTTH scenario is chosen all the copper lines are replaced with fiber ones reaching the customer premises. The decision that should be taken by an incumbent operator is whether or not should invest also to the urban areas and if yes when in the following years is the optimum time to do it. In order to answer these questions, initially the case of building these new networks simultaneously at both dense urban and urban areas was examined and then the impact of the delay of expanding the network to the urban areas as a function of time (e.g. if operator delays the expansion at urban areas for T=1,…,6 years after the initial deployment at dense urban areas at T=0) was studied. The analysis was performed both with the traditional DCF analysis but also with the application of Real Options analysis.

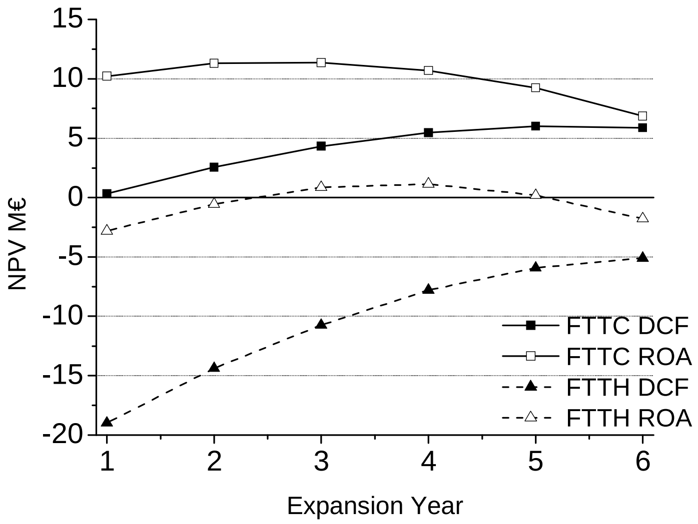

Fig. 3. ROA and DCF analysis results

At Fig.3, the NPVs for both scenarios for all the possible year of expansion with both DCF and ROA methods are presented. It can be observed that the difference in the calculations are significant for the first years and then both methods seem to converge as the years pass, which can be expected as any option value decreases as the time reach the expiration date. However, an important finding of the ROA is that in the case of investment subsidization, the option value to expand in a later phase can significantly improve the financials of the business cases and this additional value should be taken into account The results are financially improved and there are cases that the NPV turns positive. According to ROA the optimal strategy is to wait for four years, but the difference between the NPV values between the 2nd and the 4th year are marginal and thus, if the decision is made one or two years sooner it can be justified. This is mainly the explanation of the incumbent's current attitude, especially in Europe. Most of the incumbent operators did not invest in FTTH in urban areas and wait for either state-aid subsidizations via national funds or significant economic developments. For both cases the incumbent before making the decision must also take account the presence of the competitors in these areas, and can further benefit from an earlier investment by taking over the potential market share and have accessional economical advantages which have not been captured in the analysis made.

2.2 On the economics of Time and Wavelength Domain Multiplexed Passive Optical Networks

In the analysis made in [4], we discuss how the technoeconomic framework developed in the European project ECOSYS, can be applied to study and compare the business prospects of TDM/PON and WDM/PON architectures and provide support to the decision making process regarding access network installations.

Using the model described in the previous sections, the two PON scenarios were evaluated in the case of a greenfield telecom operator, where the PON main and access network must be build from scratch (i.e. no fiber ducts are available from any previous deployments), in the dense urban area case. The Net Present Value (NPV) was calculated for a study period of eight years starting at 2010 and is shown in Table 2. According to these results, the TDM/PON scenario appears better compared to the WDM/PON one.

Table 2 Greenfield operator results

Scenario	NPV (M€) (base case)
TDM/PON	-8,5
WDM/PON	-14,5

In order to gain a further understanding on these results and consider the uncertainties involved, a sensitivity analysis is performed for both PON architectures. Sensitivity analysis consists of the study of the impact of changes in a single parameter while all other parameters are kept constant. The parameters chosen for the sensitivity analysis were customer tariffs, service penetration, optoelectronic component prices, calculated duct length, the household density and the duct availability. All the parameters (except the duct availability that was studied separately in a later section) were varied within an interval of ±50% of their initially assumed values (figures 4 and 5). In both scenarios, the most crucial parameter affecting the NPV is the customer's tariff price. In the case of TDM/PON, a 50% increase in the monthly rates (e.g. bringing it to 51€/month in the case of a silver residential subscriber) results in a positive NPV, while in the case of WDM/PON, it can improve its NPV by as much as 10M€. On the other hand, if the value is reduced by 50% (e.g. 17€/month in the case of a silver residential subscriber), the investment projects attain an NPV about two times less than the base case. It should be pointed out that, although the dependency on tariff pricing is strong, no major variations in these prices are expected due to the competition from other operators.

The next crucial parameter under consideration is the duct length that the operator has to dig in order to deploy the network and connect the customers. For the TDM/PON, if the duct length drops by half, then the project has an NPV of -0,3M€ while if it increases by 50%, then the NPV becomes twice as low (-16,6M€). The total duct length used in these calculations was estimated using an accurate geometric model and so no major variation in the initial value is expected.

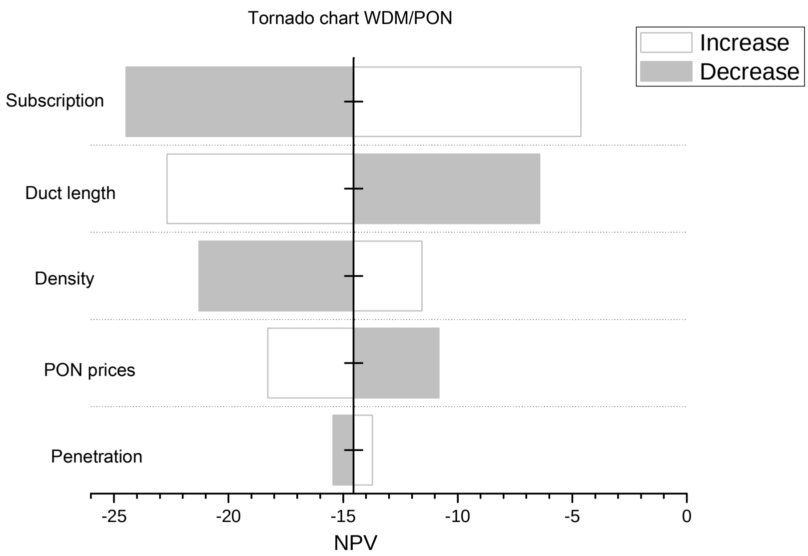

Fig. 4. Tornado chart for WDM/PON

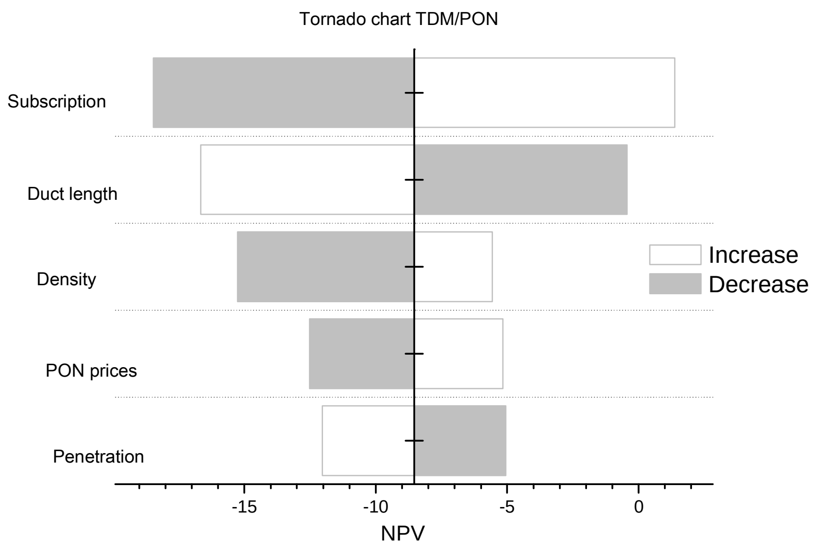

Fig. 5. Tornado chart for TDM/PON

In order to identify the most critical cost components, figures 6 and 7 illustrate the distribution of the capital investments (sum all over the study period) for WDM/PON and TDM/PON architectures respectively, for the case of a Greenfield operator. The largest part of the total costs for both examined architectures is the infrastructure expenses (digging trenches, installing cables and fibers). The cost of the optoelectronic components includes the necessary network equipment need to be installed in the OLT premises (transceivers, switches, etc) and the RN (AWGs, splitters, etc) and is more expensive for the WDM/PON than the TDM/PON. The ONT includes all equipment installed in the user premises (ONT, indoor fibers, transceivers, etc.). In the case of WDM/PON, the ONT is more expensive because of the more advanced optical components that must be installed and is almost 12% of the total investments compared to 5% in the TDM/PON case. This difference can be explained due to the higher prices of optoelectronic components used at the ONTs.

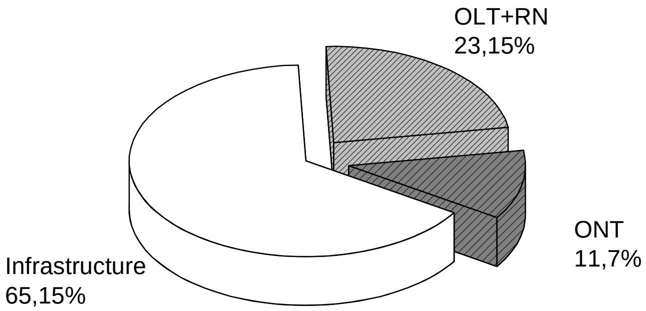

Fig. 6. Capex for TDM/PON

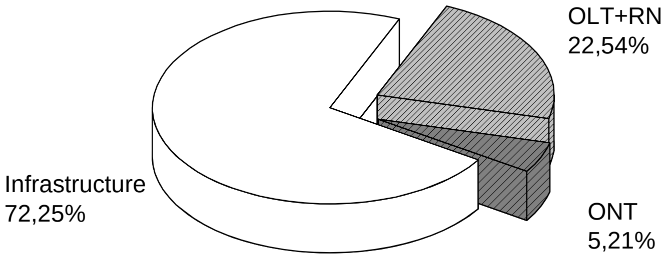

Fig. 7. Capex for WDM/PON

2.3 Business Prospects of Free Space Optics (FSO) in Dense Urban Areas

To investigate the business prospects of FSO technology for wide spread deployment in the access network, three alternative scenarios are considered [5]. In the FSO Lex-Cabinet scenario, a number of relatively Long Range (LR) Gigabit FSO links (GigFSOLR) with Automatic Gain Control (AGC) for increased reliability are deployed to connect the LEx and the Cabinet. Similar to the FTTC scenario, the users are connected through VDSL modems using the existing copper infrastructure. In the FSO1 Lex-Building scenario, GigFSOLR are used to provide wireless Gigabit connections between the buildings and the cabinet. Alternatively, in the FSO2 Lex-Buiding scenario, the Cabinet/customer connections have been established using less expensive, Shorter Range (SR) Gigabit FSO links (GigFSOSR) without AGC.

Table 3 compares the NPV for eight year study period for the two fiber-based and the three FSO-based scenarios assuming a dense urban area and d_a=0 (corresponding to limited past investments) or d_a=70% (corresponding to increased past investments). The FSO Lex-Cabinet scenario is better than FTTC and both FSO Lex-Building scenarios resulting in greater NPVs than FTTH/O in the case of no duct availability (d_a=0). Note also that the FSO1 Lex-Building scenario, results in a marginally positive NPV value. Based on the above remarks, it can be deduced that FSO technology can lead to more favourable business opportunities compared to its fiber counterpart, especially if no trenches for fiber ducts have been digged up. However, the fiber-based scenarios are better than their FSO alternatives if $d_a \geq 70\%$.

Table 3. NPV Comparison of scenarios

Scenario Type	NPV (M€)
FTTC (d_a=0)	+15,08
FTTC (d_a=70%)	+25,0
FSO Lex-Cabinet	+19,95

FTTH/O (d_a=0%)	−8,86
FTTH/O (d_a=70%)	+4,97
FSO1 Lex-Building	−3,67
FSO2 Lex-Buiding	+1,14

3 Conclusions

In the thesis the alternatives of FTTC/VDSL and FTTH roll-outs in dense urban and urban areas from an incumbent's point of view have been investigated. The analyzed business cases are reflecting the current stance of incumbent telecom operators regarding their decision to upgrade their infrastructure towards FTTH architecture.

Both classical DCF analysis and ROA have been used in order to evaluate the options that the incumbent has. ROA seems more suitable for capturing these effects comparing to DCF analysis. These results reveal that for FTTC the expansion can be made even for one year after the deployment at Dense Urban areas while in the FTTH case after two years.

The technoeconomic analysis carried out in the thesis revealed that infrastructure installation remains the higher cost component. If these costs can be reduced, say by using existing duct availability, or reducing the cost of civil works, then the prospects of both FTTH deployment scenarios are improved significantly. The analysis also suggests that the optimal strategy would be first to commence the installation of TDM and implement the costly infrastructure civil works and later upgrade to WDM solution when the WDM components prices will probably fall. This upgrade will use the infrastructure already deployed and will upgrade the optoelectronic equipment (ONTs, OLTs etc).

Also a technoeconomic evaluation of the business prospects of wide-scale deployment scenarios of FSO technology in the access network was carried out. Using key economic figure of merits, it was shown that in areas with limited fiber duct availability, FSO can provide an interesting, economically viable broadband alternative to FTTH and FTTC, since FSO installation does not require any civil works, which are mainly time invariable costs. As FSO equipment is mainly installed in the beginning of the deployment project, larger productions volumes and therefore better performance and price reductions due to vendor-operators agreements can be expected, which will result in further improvement of their business prospects.

References

1. IST-TONIC, 2000 - 2004, "Techno-economics of IP Optimised Networks and Services", European Union, EU IST, IST-2000-27172, Project information available at: http://www-nrc-nokia.com/tonic/
2. CELTIC-ECOSYS, 2002 - 2006, "techno-ECOnomics of integrated communication SYStems and services", CELTIC, Project information available at: http://www.celtic-ecosys.org/

3. Th. Rokkas, D. Katsianis and D. Varoutas, “Techno-economic evaluation of FTTC/VDSL and FTTH roll-out scenarios: discounted cash flows and real option valuation” in IEEE/ Journal of Optical Communications and Networking, Vol. 2 Issue 9, pp.760-772 (2010)
4. Th. Rokkas, D. Katsianis, Th. Kamalakis and D. Varoutas, “On the economics of Time and Wavelength Domain Multiplexed Passive Optical Networks” in IEEE/OSA Journal of Optical Communications and Networking, Vol. 2 Issue 12, pp.1042-1051 (2010).
5. Th. Rokkas, Th. Kamalakis, D. Katsianis, D. Varoutas and Th. Sphicopoulos, “Business Prospects of Wide-Scale Deployment of Free Space Optical Technology as a Last-Mile Solution: A Techno-Economic Evaluation”, OSA Journal of Optical Networking Vol. 6, Iss. 7, pp. 860–870 (2007)