# Economics of Fixed Broadband Access Network Strategies

*Thomas Monath, T-Systems Nova GmbH*
*Nils Kristian Elnegaard, Telenor*
*Philippe Cadro, France Telecom*
*Dimitris Katsianis and Dimitris Varoutas, University of Athens*

## ABSTRACT

This article presents a comprehensive techno-economic evaluation of two upgrade strategy cases for broadband IP services for residential and business customers, and illustrates their respective merits and pitfalls, allowing the definition of a reasonable investment policy. The work should enable establishment of guidelines for broadband infrastructure upgrade strategies from the incumbent operator's view. Following the definition of appropriate service sets, and taking into account demand scenarios established within the project, this work has been focused on developing a techno-economic model, based on the TONIC tool [1]. Tariff structures have been applied to compute the key economic indicators, net present value, internal rate of return, and payback period. This investment analysis was carried using the tool, which was developed by IST-TONIC [1]. The results show that the choice of technology (Ethernet or ATM) has almost no effect on the cost level and profitability of the cases. For the suburban area, a fiber to the cabinet solution is too expensive due to heavy infrastructure investments; for dense urban and urban areas the FTTC solution is worth the investments. The FTTH/office deployment scenario is only profitable in dense urban areas (> 5000 potential customers/km$^2$) and already highly risky in the urban area.

## INTRODUCTION

In the context of growing demands for new broadband services, network operators are facing increasing bandwidth requirements. New infrastructure and equipment is required in order to deliver multimedia services in the megabit-per-second range to end customers. Ten years ago most experts expected an evolution toward fiber to the home (FTTH). However, economic analyses indicated that such solutions, if planned on larger scales, would bear excessive costs. Fiber-to-the-cabinet (FTTC) solutions and FTTH (particularly as a first step fiber to the office, FTTO) nonetheless appear to be the best choice in specific areas with the right conditions (high availability of ducts, high density of potential customers, etc.).

This article is based on work within the IST project Techno-Economics of IP Optimized Networks and Services (TONIC). The project examines various scenarios for phasing in new network technologies, replacing older technologies, from a techno-economic point of view. The European Union (EU) IST TONIC [1] project is a precursor in the investigation of the economic side of such deployments; consequently, this work is the first step in assessing the market conditions, architectures, and potential for a profitable business case of a telecom operator.

This article investigates hybrid fiber/copper-based access architectures (FTTx) applied in different urban areas. The focus within this study is the comparison of different network technologies under common business case assumptions (framework). Several competitive technologies could be an option for operators (e.g., cable modems or WLANs), and their presence might affect the overall broadband map [2]. This article analyzes how close to the customer fiber can be profitably deployed and how important the actual choice of technology (Ethernet or ATM) is from the incumbent operator's point of view since this option is most likely within the next eight years to enable the advancement of broadband services.

The scope of this article is to:

- Identify the network infrastructure, service and traffic characteristics for different urban access areas
- Analyze two replacement scenarios from an economical perspective:
  - –FTTC in combination with very high rate digital subscriber line (VDSL): Gigabit Ethernet and Ethernet over VDSL (EoVDSL) and comparable ATM-based architecture
  - –FTTH/O in the ATM architecture with a passive optical network (PON) and with optical point-to-point connections for the Ethernet-based access network

The article will describe the main assumptions


0163-6804/03/$17.00 © 2003 IEEE

regarding the model that has been developed, the scenarios under study, and the results of the business case. The breakdown of the main investments as well as economic parameters such as net present value (NPV), internal rate of return (IRR), and IFC will be shown. We will discuss the achievable results with a comparison of the scenarios.

## FRAMEWORK

The techno-economic modeling was carried out using the TONIC tool, which is an implementation of the methodology developed by a series of EU cooperation projects in the field. The tool has been extensively used for several techno-economic studies [2, 3] among major European telecom organizations and academic institutes.

The base of the model's operation is a database where the cost figures of the various network components are deposited. These figures are constantly updated with data gathered from the biggest European telecommunication companies. The database outputs the cost evolution of the components over time. A geometrical model is used to calculate the number of network elements as well as their cost, for the set of services and the network architectures defined. The cable infrastructure costs of the network are calculated using the geometric model, which involves parameters such as subscriber density, duct availability, and type of civil works as inputs.

Finally, the future market penetration of these services and the tariffs associated with them, calculated through market forecasts and benchmarking, are inserted into the tool. All these data are forwarded into the financial model of the tool that calculates revenues, investments, cash flows, and other financial results for the network architectures for each year of the study period. An analytical description of the methodology and the tool can be found in [3, 4].

## ASSUMPTIONS AND MODEL DESCRIPTION

The study period assumed for all scenarios is eight years, from 2003 to 2010. The discount ratio is 10 percent for all scenarios, and taxes have not been considered at all.

### AREA DESCRIPTION

The description and characterization of the network areas considered in this article with respect to subscriber density, loop lengths, and geographical and market characteristics will follow. Similar areas can be found in many countries of the world, according to the operator statistics in our consortium.

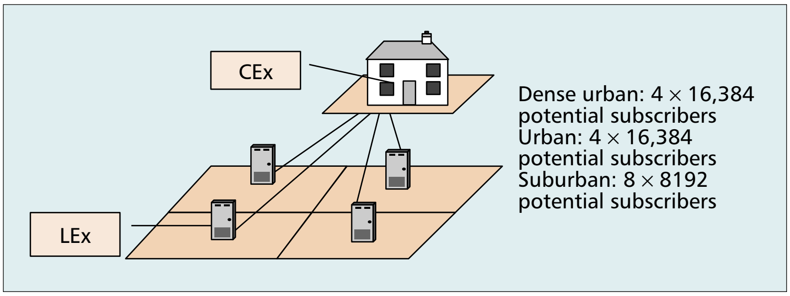


**Figure 1.** *Example: central exchange segmentation.*

The network model for the selected case study regarding urban areas is based on the metropolitan area network (MAN), starting from the central exchange (CEx) and comprising the whole access network all the way to the customers. The model has been developed as a total of eight flexibility points (FPs) and seven link levels (LLs). It is assumed that the CEx area encompasses and concentrates four dense urban, four urban, or eight suburban service access areas (Fig. 1). The dense urban and urban service access areas under study serve 16,384 customer units, suburban 8192. For each service access area all customers are connected to the same local exchange (LEx). The total number of customer units connected via plain old telephone service (POTS) lines to one CEx is thus to 65,536 for all scenarios, which is the same derived by multiplying the number of buildings by the number of subscribers per building. This is the maximum number of potential customers the operator can serve offering broadband connections (Table 1).

Within a given FP layer, a uniform distribution of the total number of FPs has been assumed. The LEx is assumed to be located in the middle of each service access area. The location of the CEx has been defined by its distance (cable length has been calculated) to each LEx in the areas under study as described in Table 1.

Assuming a uniform distribution of all customers within the area, a geographic model developed in the TITAN project [4] has been applied.

The main broadband network of an operator could be divided into three main areas, taking into account the geographical distribution of the possible consumers. These three types of areas are described below.

The **dense urban area** has been modeled as an area of 3 km$^2$ with an average copper loop length of 1400 m. The mean subscriber density corresponding to 16,384 subscribers/service access area of 3 km$^2$ is then 5461 subscribers/km$^2$. The subscribers are located in buildings with 64 apartments distributed over 16 floors.

| Area | Average cable length, customer–LEx (m) | Subscribers/km$^2$ | Number of buildings | Subscribers/building |
|---|---|---|---|---|
| Dense urban | 1400 | 5461 | 1024 | 64 |
| Urban | 2200 | 2048 | 2048 | 32 |
| Suburban | 3400 | 410 | 16,384 | 4 |

**Table 1.** *Area structure.*

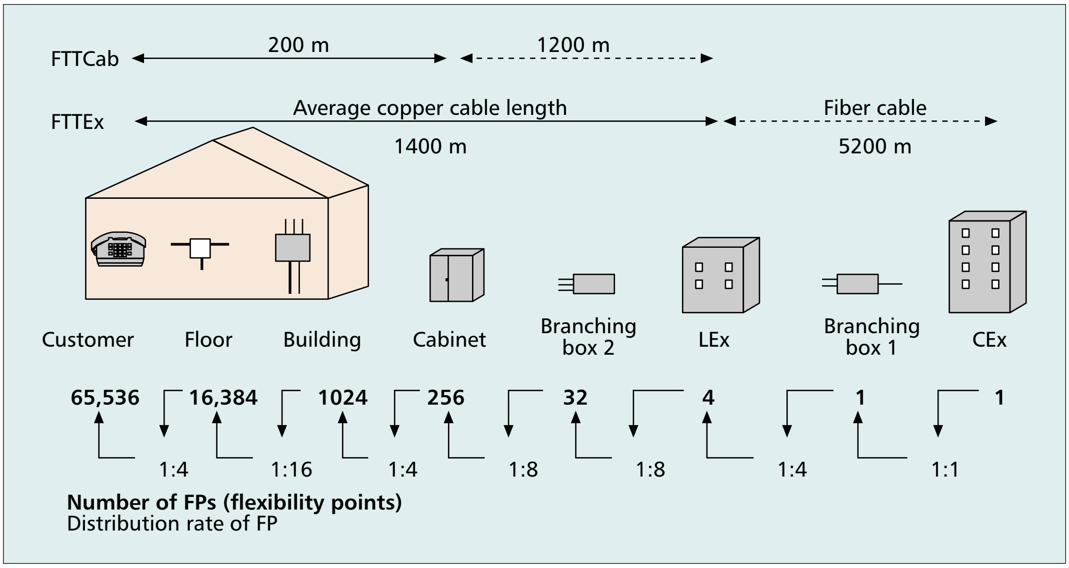


**Figure 2.** *Distribution structure and geographic model of the dense urban area.*

| Market potential | Dense urban | Urban | Suburban |
|---|---|---|---|
| Customer units total | 16,384 | 16,384 | 8192 |
| Households/access area | 14,746 | 15,237 | 7700 |
| Business/access area | 1638 | 1147 | 492 |
| Percentage business | 10% | 7% | 6% |

**Table 2.** *Definition of market potential.*

These customers could be any mix of residential or small and medium enterprises (SMEs). An analytical description is illustrated in Fig. 2.

For estimation of infrastructure costs it is important to define the duct availability, which is set to 90 percent for the network parts between the LEx and the cabinets, and to 50 percent between the cabinets and the customers' buildings. This factor is an important parameter. It has a strong influence on the economics of the various scenarios due to the high investment costs of ducting systems related to civil works.

The **urban area** has been modeled as an area of 8 km$^2$ with an average copper loop length of 2200 m. The mean subscriber density corresponding to 16,384 subscribers/service access of 8 km$^2$ is then 2048 subscribers/km$^2$. The subscribers are located in buildings with 32 apartments distributed over eight floors. Again, these customers could be a mix of residential and SMEs. The duct availability rate is set to 60 percent for the network parts between the LEx and the cabinets, and to 40 percent between the cabinets and the buildings.

One **suburban area** is 20 km$^2$ with an average copper loop length of 3400 m. The mean subscriber density related to 8192 subscribers/service access area considering 20 km$^2$ is derived to be 410 subscribers/km$^2$. The subscribers are located in buildings with either four apartments distributed over two floors or corresponding numbers of SMEs. The duct availability rate is fixed at 25 percent between the LEx and the cabinet, and 0 percent between the cabinet and the building.

## Services and Demand

The services to be considered depend on the customer profile. Customers are classified as *residential* and *business* customers [5], which in turn include SMEs and small office/home office (SOHO) customers, including teleworkers. Key network require-

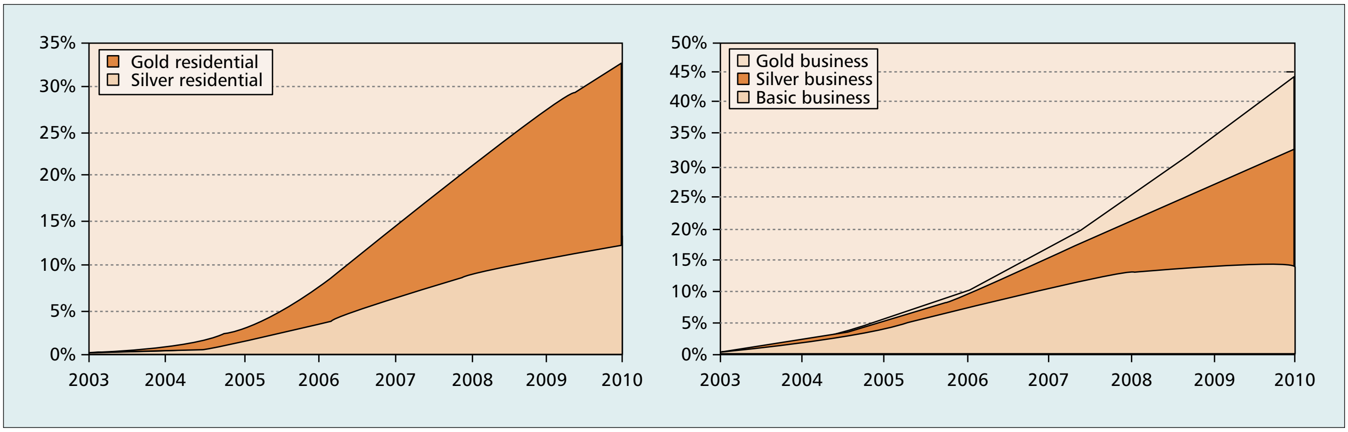


**Figure 3.** *Application of the broadband forecast model for the urban service access area.*

| Service classes | Maximum downstream (kb/s) | Maximum upstream (kb/s) | Examples of interface type | Traffic concentration (start value) | Mean source traffic (kb/s) |
|---|---|---|---|---|---|
| Silver-residential | 6,144 | 640 | 10BaseT | 0.05 | 307 |
| Gold-residential | 23,168 | 4,096 | 10/100BaseT | 0.05 | 1,158 |
| Basic-business | 6,400 | 6,400 | 10/100BaseT 3xE1 | 0.2 | 1,280 |
| Silver-business | 8,576 | 8,576 | 10/100BaseT 4xE1 | 0.2 | 1,715 |
| Gold-business | 23,168 | 23,168 | 10/100BaseT E3/ATM25.6 | 0.2 | 4,634 |

**Table 3.** *Definition of service classes and traffic assumptions.*

ments for business customers are scalability, security, flexibility, and differentiated QoS.

The **broadband access forecasts** for both the business and the residential users (Fig. 3) have been applied according to the methodology from [6] and [7]. The market share of the incumbent operator has been assumed to be 60 percent in the dense urban area.

The range of services required by business customers is also wider than for residential customers: file transfer within an intranet, which means burst traffic and highly variable bit rates, high-bit-rate access to the Internet, and videoconferencing with strong real-time constraints [5, 8]. In most cases, these services require higher bit rates than typical residential services. Table 2 shows the total market potential assumed and the percentage of business customers in all studied areas.

The **common framework** about the areas studied includes a basket of **common service classes** to be offered and a **traffic model** (Table 3). The table shows the maximum bit rates of each service, examples of customer interfaces, and the mean source traffic.

For each service class, we have considered the mean source traffic to dimension the network, which equals the maximum bit rate multiplied by a traffic concentration factor. The first year, this factor is set to 5 percent for all residential and 20 percent for all business service classes. Then we take into account the increase in bandwidth requirement and assume that the mean bit rate grows by 5 percent each year.

We assume that, in general, low-bit-rate services are provided with existing asynchronous DSL (ADSL) technology, which is beyond the scope of this study. These services will gradually migrate to higher bit rates during the study period. The study does not take into account high-bit-rate service classes above 23 Mb/s symmetric since the penetration of these services will be limited, and these services are out of our focus.

For each area we have defined the market share of the incumbent operator. As illustrated in Table 4, competition between operators is different depending on the area and the market. We notice that there is no competition in the suburban area, and assume that the business market is the most competitive market.

Figure 3 shows the penetration forecasts [9] applied for both business and residential services considering the market share of an incumbent operator.

The **broadband tariff structure** is rather complex. Important tariffs are the connection tariff, access tariff, service provider tariff, traffic tariff, transaction tariff, and charge for content (i.e., pay per view).

| | Dense urban | Urban | Suburban |
|---|---|---|---|
| Residential market share | 90% | 95% | 100% |
| Business market share | 60% | 80% | 95% |

**Table 4.** *Market share of an incumbent operator.*

| Tariff parameters | Parameter value |
|---|---|
| Share of the value chain for the network operator | 60% |
| Tariff increase for each capacity doubling for residential customers | 17% |
| Tariff increase for each capacity doubling for business customers | 30% |

**Table 5.** *Tariff parameters for an access network operator.*

The tariff model ([6, 7, 9]) is constructed in the following way. Basically it sets a reference tariff (derived from a survey conducted by a number of large operators in Europe) of 720 /year in 2001 for 512 kbs asymmetrical services dedicated residential customers and another reference tariff of €5280/year in 2001 for 512 kb/s symmetrical services dedicated to business customers. In addition, the model assumes an increase of 17 percent (Table 5) for each doubling of asymmetric downstream capacities and 30 percent for each doubling of symmetric downstream capacities in 2002. Yearly price erosion of 10 percent is applied in addition to the above mentioned tariff increase for transfer rate doubling (Fig. 4).

The studied business model assumes that 100 percent of the tariff is collected by the ISP, which cedes back 60 percent to the broadband access network operator.

### Network Element Cost Model

The *network element cost model* (Fig. 5) was built based on a switch model containing the parts found in switches of different vendors. The model takes into account list price information of several vendors and volume production effects. Input information from different vendors has been used to build an average cost model [10]. The maximum number of interface cards is necessary to dimension the network elements. In

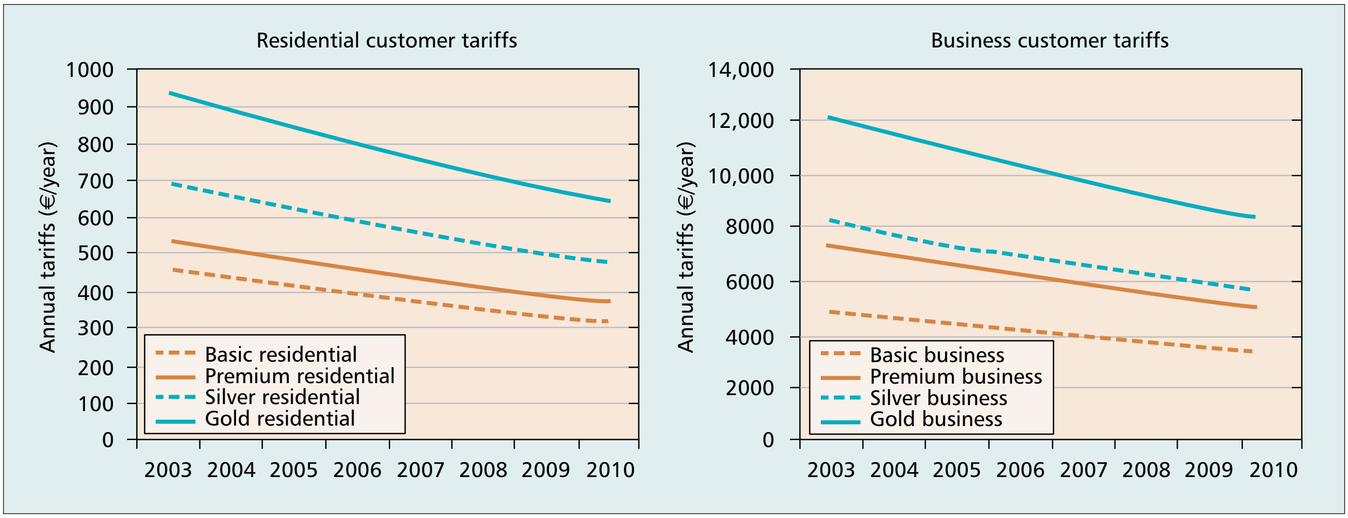


**Figure 4.** *Tariffs for residential and business customers.*

general, medium-length interface cards have been applied within the scenarios.

## SCENARIOS

Figure 6 shows the different network solutions in order to figure out the comparison architecture explicitly. Different network locations are equipped with switches, and the customer's gateway is considered as well in the investment model.

### FIBER TO THE CABINET

This scenario (Fig. 6) has been analyzed with Gigabit Ethernet based point-to-point and ATM based point-to-multipoint (PON) technology applied to the access area to offer the service set described earlier. The complete service set is offered using VDSL modem technology between the cabinet location and the subscriber. This gives an incumbent telecom operator the advantage of connecting customers via the old copper cable infrastructure within the first mile. It has been assumed that the part between the cabinet and the LEx will be replaced with a fiber infrastructure. This also includes replacing the old passive cabinets with new climatic conditioned cabinets, including power access. In most of the European countries the duct infrastructure between the LEx and the CEx already exists. Within this area the cost of fiber cable, branching boxes including installation cost, and pulling costs into the ducts have been estimated. Within a total copper length of 750 m all customers are connected via VDSL directly from the LEx. Only customers with higher connection length are connected via new fiber nodes.

Several flexibility points have been equipped with Ethernet or ATM switches. The access lines are terminated with network terminations (NTs). The dimensioning of the elements is based on the effective source traffic and the number of interfaces needed.

### FIBER TO THE HOME/OFFICE

All customers have been connected via fiber lines directly to the local exchange. This scenario is using two different strategies, which are applied

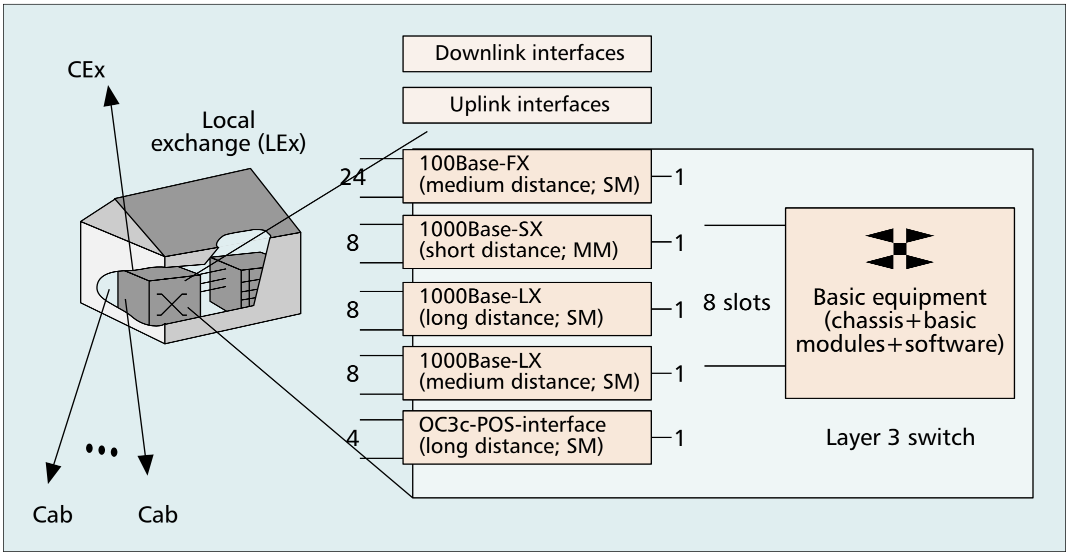


**Figure 5.** *Example: a model of Gigabit Ethernet local exchange switch architecture.*

within the access network configuration. FTTH/O in case of the ATM architecture is using a broadband PON (BPON) structure between the LEx and the customers. This BPON system has been defined within the full service access network (FSAN) initiative and is standardized in International Telecommunication Union (ITU) Recommendation G.983. In Ethernet an optical point-to-point architecture is used to connect all customers to the broadband IP network. Each customer has been connected with two fibers to the LEx. That leads to an enormous fiber rollout and equivalent 100 base fiber exchange interfaces at the LEx location. Using a simple rollout model 30 percent of all buildings within each service access area are connected within the first year of the study period. After seven years, 90 percent of all buildings within the access areas are connected with fiber cables.

## Results and Discussion

The two scenarios under comparable business case conditions have been investigated. The evaluation of the results shows that for both scenarios the differences in the economics between the areas studied are mainly due to:

- Revenues associated to customer profile (Business revenues > Residential revenues)
- Interface granularity and fiber consumption
- Infrastructure, in particular duct length and duct availability

Table 6 summarizes the main economic results of the study.

FTTC solutions for the dense urban and the urban areas result in a positive business case (positive NPV) with a payback period between approximately four and six years. The positive result for dense urban and urban areas is mainly driven by the existing infrastructure in terms of ducting systems, the short total connection distance to the customers, and the housing structure as well. The most important variables influencing the business case are tariffs, customer penetration, the network operations costs, and the access equipment costs. The total investments for point-to-point Ethernet compared to point-to-multipoint ATM FTTC architectures focusing on both business and residential market are, in general, on the same order (Fig. 7). The point-to-point Ethernet FTTC architectures serving both business and residential market segments seems to be a plausible solution as a first migration step after ADSL for both dense,

| Net present value (NPV) | | | | |
|---|---|---|---|---|
| | Fiber to the cabinet | | Fiber to the home/office | |
| Area | ATM | Ethernet | ATM | Ethernet |
| Dense urban | €29.45 mill | €29.40 mill | €18.31 mill | €7.47 mill |
| Urban | €18.13 mill | €18.06 mill | €–9.11 mill | €–22.30 mill |
| Suburban | €–34.42 mill | €–38.21 mill | €–279.49 mill | €–295.32 mill |
| **Internal rate of return (IRR)** | | | | |
| | FTTC | | FTTH/O | |
| Area | ATM | Ethernet | ATM | Ethernet |
| Dense urban | 66.8% | 56.2% | 46.1% | 21.5% |
| Urban | 30.8% | 29.7% | No return | No return |
| Suburban | No return | No return | No return | No return |
| **Payback period (years)** | | | | |
| | FTTC | | FTTH/O | |
| Area | ATM | Ethernet | ATM | Ethernet |
| Dense urban | 3.8 | 4.3 | 5.5 | 7.5 |
| Urban | 5.3 | 5.7 | No return | No return |
| Suburban | No return | No return | No return | No return |

**Table 6.** *Major economic results.*

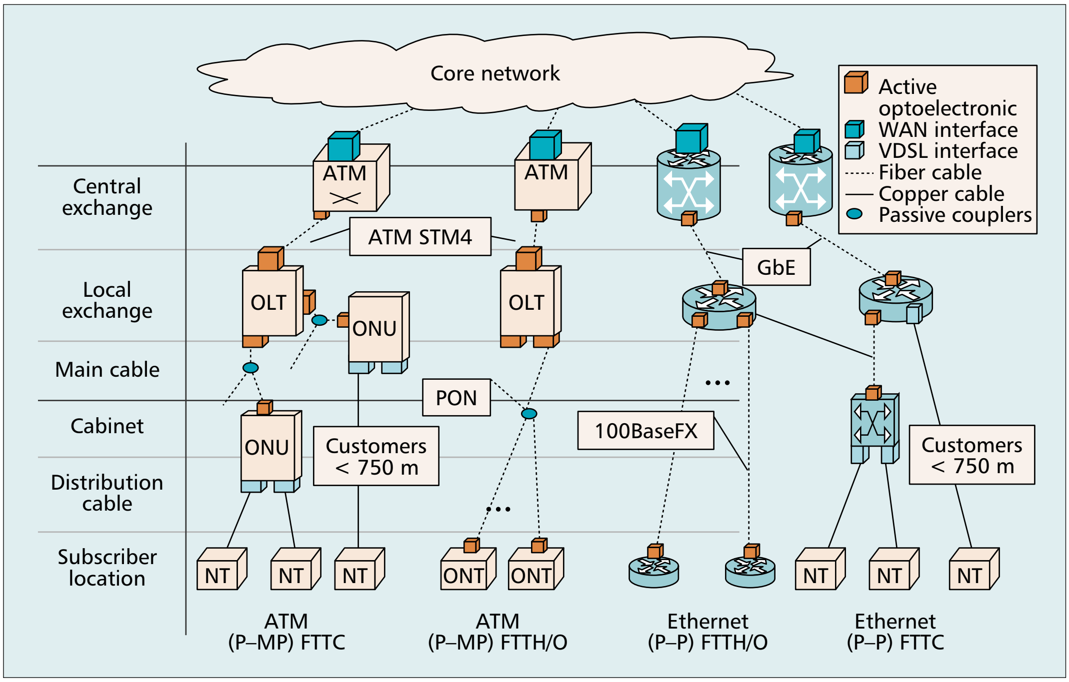


**Figure 6.** *Generic comparison architectures.*

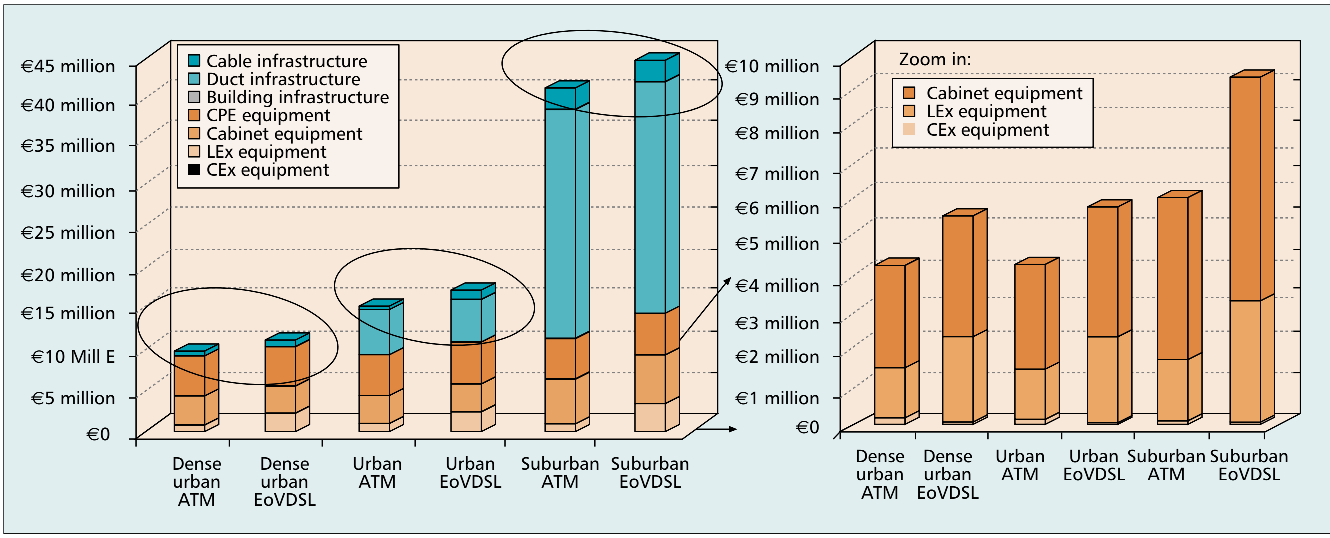


**Figure 7.** *Investment breakdown for FTTC deployment by area and technology.*

urban, and suburban areas. From this step it is easy to step further to the FTTH/O architecture in the future if the market became mature enough for such high-speed data transfer rates.

The results for FTTC show that the choice of technology (Ethernet or ATM) has almost no effect on the cost level and profitability of the cases (pointed areas of Fig. 7). For the suburban area, an FTTC solution is too expensive due to heavy infrastructure investments.

The investment breakdown figures show just a small difference between the different technologies. Even if we zoom in on the different equipment more deeply (on the right), the differences in dense urban and urban areas are small. It has been observed that the differences have nothing to do with the protocol architecture, but rather with interface granularity and fiber consumption. These are mainly caused by:

- The influence of the PON compared to the point-to-point system in terms of interface savings (less ATM OLT at the LEx compared to the Ethernet switches)
- The higher granularity in terms of interfaces, which can be allocated to the ATM optical network unit assumed to be 144 compared to 24 in the Ethernet case.

Only the dense urban area case is profitable for both FTTH/O architectures and technologies, with payback periods of 5.5 years for the ATM PON solution and around seven years in the Ethernet point-to-point solution. For the Ethernet FTTH/O architecture the positive NPV is mainly driven by the rest value, which is €18 million. The IRR of 21.5 percent in the pure point-to-point Ethernet FTTH/O architecture, taking into account the 10 percent discount ratio, gives 11.5 percent return on investment per year for the dense urban area. For the urban and of course even more so for the suburban area, an FTTH/O solution is too expensive, so other access technologies should be considered. This is again due to the high level of infrastructure investment caused by the high level of new ducting required. Thus, FTTH/O migration is for the time being still too costly in urban and suburban areas. Other access technologies like wireless solutions should be used in such areas in order to reduce the investment cost [2], but not for such high-speed broadband services.

Due to the uncertainty of the assumptions made, an extensive risk assessment has been performed on the different fixed network scenario and business cases based on Monte Carlo simulation. In Fig. 8 the probability of a negative NPV has been calculated. The FTTC deployment scenarios have small risk for the urban and dense urban areas. The FTTH/O deployment scenario is highly risky especially in the urban area; this is the most critical issue for decision makers. If the market is not mature enough for broadband connection to the home/office, operators should wait, since the risk is high and the probability of profit very small.

## Concluding Remarks

The issue of broadband access network upgrade remains a major challenge for operators due to the high cost sensitivity of this network segment and the high uncertainty of future service take-up. This study has highlighted some of the key issues of broadband access upgrade and their possible impact. For all examined alternatives the broadband upgrade costs are comparable to and in some cases even several times higher than the overall costs of establishing the existing network. Hence, access network upgrading is likely to turn out to be a long term project.

This article shows the economical impact of Ethernet technology compared to ATM-based technology applied to provisioning broadband IP services from the viewpoint of an incumbent network operator. Two urban scenarios applying different architectures (FTTC, FTTH/O, and combinations) have been studied. The comparison of the scenarios under investigation gives one indicator of the conclusion that the equipment investments of ATM or Ethernet based network architectures under comparable conditions are in the same range.

The general conclusion is that this application seems to be worth the investment, especially in dense urban areas. Both scenarios are economical for dense areas, but in typical urban areas only the FTTC scenario is truly positive. Particularly in the FTTH/O scenario within an urban area, neither the Ethernet point-to-point architecture nor the ATM PON leads to a payback within the study period. Considering that the assumed services cannot be accepted by an operator today, especially considering the risk environment, a payback period of five years roughly represents the economical limit under the assumptions that have been made.

On the other hand, even if operators invest in building out a new infrastructure based on fiber within the access area, a longer payback period should be accepted. Both the revenues of new broadband services in combination with operational cost savings over SDH-based services, and the creativity of the service provider and retailer are able to create new value chains for incumbent operators.

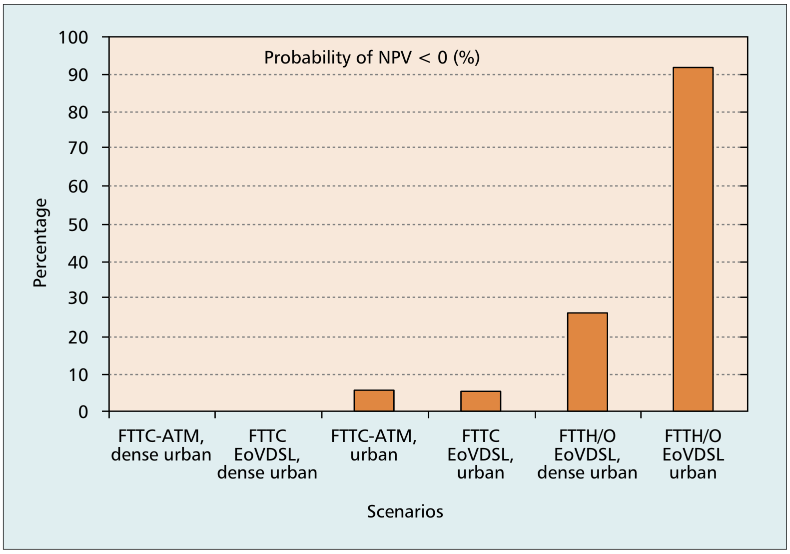


**Figure 8.** *Risk profiles by probability of NPV < 0.*


## Acknowledgments

This work has been performed in the framework of the IST project IST-2000-25172 TONIC, which is partly funded by the European Union. The authors would like to acknowledge the contributions of their colleagues from Nokia Corporation, Telenor AS Research and Development, France Télécom Research and Development, National and Kapodistrian University of Athens, ATLANTIDE, Swisscom AG, Universidade de Aveiro, and T-Systems Nova GmbH.


## References


[1] http://www-nrc.nokia.com/tonic/

[2] D. Varoutas *et al.*, "Business Opportunities for UMTS-WLAN Networks," *Annals Telecommun.*, vol. 58, no. 3–4, Mar.-Apr. 2003.

[3] D. Katsianis *et al.*, "The Financial Perspective of the Mobile Networks in Europe," *IEEE Pers. Commun.*, Dec. 2001, vol. 8, no. 6, pp. 58–64.

[4] L. A. Ims, Ed., *Broadband Access Networks Introduction Strategies and Techno-economic Evaluation, Telecommunications Technology And Applications Series*, Chapman & Hall, 1998.

[5] K. Stordahl, L. Rand, "Long Term Forecasts for Broadband Demand," *Telektronikk*, vol. 95, no. 2/3, 1999.

[6] K. Stordahl, L. A. Ims, and M. Moe, "Broadband Market — The Driver for Network Evolution," *Proc Networks 2000*, Toronto, Canada, Sept. 10–16, 2000.

[7] K. Stordahl *et al.*, "Broadband Access Network Competition — Analysis of Technology and Market Risks," *Proc. GLOBECOM '98*, Sydney, Australia, Nov 8–12, 1998.

[8] F. J. Velez and L. M. Correla, "Mobile Broadband Services: Classification, Characterization, and Deployment Scenarios," *IEEE Commun. Mag.*, vol. 40, no. 4, Apr. 2002, pp. 142–50.

[9] Deliverable 8, "Market Models for IP Services," IST-2000-25172 TONIC, May 2002

[10] T. Monath *et al.*, "Economics of Ethernet Based Access Networks for Broadband IP Services," *XIV Int'l. Symp. Services and Local Access*, Seoul, Korea, Apr. 14–18, 2002.


## Biographies

THOMAS MONATH (thomas.monath@t-systems.com) worked as a telecommunication specialist after finishing his vocational training. IHe received his Dipl.-Ing. degree in communication engineering at the University of Rostock in 1997. He joined the Technology Center of Deutsche Telekom in 1997. His current position is senior expert, R&D of T-Systems Nova. He is responsible as project manager for DTAG-internal techno-economic evaluation studies of various wired as well as wireless technologies and system applications, ranging from access network to backbone solutions. He was also involved in European ACTS project AC364 TERA and IST-2000-25172 TONIC, where he was responsible for the FTTx business case evaluation.

NILS KRISTIAN ELNEGAARD received his M. Sc. degree in electronics engineering at the Technical University of Denmark in 1993. For the last five years he has been working on broadband access networks and strategies. The main activities are in techno-economics and risk analysis of broadband rollout strategies. He has participated in several European projects within ACTS, IST, and Eurescom. He joined Telenor R&D in Aug. 2000.

PHILIPPE CADRO received his Ph.D. in computer science from Rennes University, France, in 1998. He was involved in the performance evaluation of an optical packet switch within the European ACTS project Keys for Optical Packet Switch (KEOPS). In 1998 he joined France Telecom R&D (formerly France Telecom CNET), where he has been working on techno-economic studies for access networks. His main research interest is the techno-economic evaluation of optical technologies to provide innovative services to business customers. Since 2001 he has contributed to IST project TONIC.

DIMITRIS KATSIANIS (d.katsianis@di.uoa.gr) received an informatics degree and an M.Sc. in signal processing and computational systems from the University of Athens, Department of Informatics and Telecommunications. He is a research fellow with the Optical Communications Group, University of Athens, participating in several European R&D projects. He has worked as an expert scientific advisor for OTE S.A. (Hellenic Telecom) on networking aspects concerning simulation of ATM networks, management in an optical network, and telecommunication investment analysis, participating in several Eurescom projects. He is also a consulting partner with several firms in the field of techno-economic and network design studies, participating in ACTS projects AC226 OPTIMUM and AC364 TERA as well as IST 25172-TONIC. His research interests are broadband communications and methodology of network design with techno-economic aspects.

DIMITRIS VAROUTAS [M] (arkas@di.uoa.gr) studied physics, electronics, and radio communications at the University of Athens. He is a research fellow with the Optical Communications Group, University of Athens, as well as an adjunct lecturer in the Department of Informatics and Telecommunications of the university and in the Department of Telecommunications at the University of Peloponnese. He is an advisor in several organizations including EETT (Greek NRA for telecommunications) and Greek telecom companies in the fields of licensing, spectrum pricing, and legislation. His current research interests include optical and wireless communications and techno-economic evaluation and design of network architectures and services.