Economics of Residential Broadband Access: Network Technologies and Strategies

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Abstract

This article presents a techno-economic assessment of the evolution of the access network segment toward broadband data service delivery, including in-depth sensitivity analysis of key issues faced by the infrastructure providers. The line costs and payback periods of different access network technologies for infrastructure broadband upgrades are examined, subject to variation in parameters like the existing infrastructure, the broadband take rate, civil work costs, revenues, and rollout year. The work should enable establishment of guidelines for broadband infrastructure upgrade strategies.

On the threshold of wide-scale implementation of the "information superhighways," the residential access network infrastructure remains one of the major obstacles to the deployment of a broadband[1] telecommunications network. At present the residential broadband market is characterized by high uncertainty, rapidly increasing competitiveness with operators positioning for the residential broadband service battle, and corresponding high risks associated with upgrading the very cost-sensitive access network segment [1, 2]. Nevertheless, a wide range of infrastructure upgrade technologies are readily available [3]. Services like fast Internet access are emerging as likely broadband market drivers, and enhanced copper technologies and coaxial cable modems are enabling early entry for many of the operators [4]. However, the operators are perfectly aware of the risks associated with too-early entry into this uncertain market [5]. The market challenge is two-fold: to reap the revenue potential of broadband delivery, and to secure market shares in the existing narrowband market.

The access network operators face several issues in preparing for a migration from narrowband to broadband connectivity [6,7]. The new broadband infrastructure will most likely be based on upgrading the existing access network, and hence the utilization of the vast amount of capital invested in the current infrastructure. An access network infrastructure must be established for delivery of a complex mix of broadband services like fast Internet access, telecommuting, and video on demand in a market of great demographic diversity. The main challenge will probably be to find the appropriate combination of the relevant technologies to deliver a versatile and scalable multiservice solution for delivery of broadband data services, and hence build a so-called full service access network [8].

The above advocates for a techno-economic analysis of residential broadband access network upgrade projects in order to gain an improved understanding of the business opportunities of broadband access delivery, and hence derive suitable minimum-risk introduction strategies. The major contribution of this article is an in-depth sensitivity analysis of some of the key aspects and underlying strategic issues of upgrading the existing access network infrastructure to residential broadband services. The methodology and tool developed within the project RACE (Research in Advanced Communications in Europe) 2087/TITAN (Tool for Introduction Strategies and Techno-Economic Evaluation of Access Networks) has been used to evaluate the most relevant upgrade options, with respect to both transmission medium and system technology. These alternatives include asynchronous transfer mode (ATM)-based broadband passive optical network (BPON), hybrid fiber coax (HFC), and digital subscriber line (DSL) alternatives [9–11]. The work should enable development of guidelines for broadband upgrade strategies [12–14].

The Broadband Market

Forecasting new broadband services with respect to both application type and demand is very difficult, mainly due to the lack of historical data [1]. Despite recent field trials and market surveys, the new broadband residential and small business customer applications remain to be well defined. Nevertheless, some trends can be recognized:

[1] *Broadband: Capacity per customer ≥ 2 Mb/s.*

- The integration of telecommunications and information processing is escalating.
- The use of interactive video services, such as videoconferencing, is growing.
- Entertainment services are increasingly important.

New services forecasts and demand projections have recently been reported, derived from current spending patterns of households or from market surveys [15]. A Delphi survey on broadband demand, carried out by TITAN in 10 European countries, established forecasts for wideband[2] and broadband services [16]. In this article both symmetric switched broadband (SSB) and asymmetric switched broadband (ASB) services have been examined. The latter is particularly in focus in this study, mainly since emerging residential broadband services like fast Internet access are widely expected to be asymmetric in nature. 2 Mb/s capacity per subscriber in the downstream direction is taken as the reference connection. The study presents a comprehensive analysis of the impact of variations in take rates for the same access network architectures, as opposed to some recent papers in which the emphasis was on in-depth studies of the effect of specific service penetration scenarios [12, 17, 18].

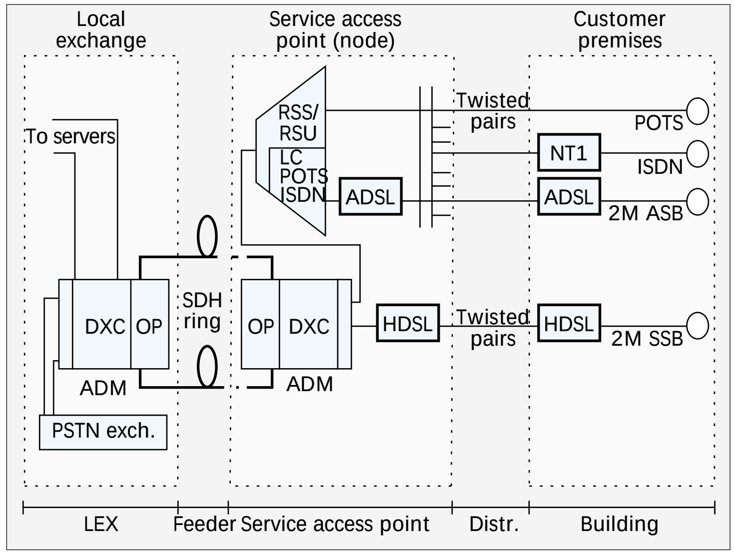


Figure 1. *The enhanced copper upgrade option with ADSL for 2 Mb/s asymmetric demand and HDSL for 2 Mb/s symmetric demand.*

Broadband Upgrade Options

Today there is a wide range of alternatives for upgrading the physical layer of the access network to broadband, in selection of both transmission medium and system technology. At present no single technology or network architectures seems the obvious choice. Instead, boundary conditions given by the existing infrastructure and customer segment characteristics will probably require simultaneous rollout of several technology alternatives. In this study we have considered the options likely to be relevant toward the turn of the century. Twisted copper pairs, coaxial cable, and optical fiber are the relevant wireline transmission media. The broadband radio alternatives of MMDS (multichannel multipoint distribution service) and LMDS (local multipoint distribution service) are not studied here; nor are the satellite-based Iridium and Direct-PC alternatives.

Enhanced Copper, DSL Technologies

The enhanced copper or DSL system technologies include asymmetric DSL (ADSL), very-high-speed DSL (VDSL), and high-bit-rate DSL (HDSL). In general, for the DSL options there is a trade-off between distance and capacity. ADSL uses one twisted copper pair for transmission of between 2 Mb/s (4 km) and 8 Mb/s (2 km) downstream and 176 kb/s and 1 Mb/s upstream. HDSL requires two or three pairs for symmetric 2 Mb/s transmission over 2.5 km. VDSL provides both asymmetric and symmetric transmission, with asymmetric capacities as high as 26 Mb/s (1 km). In the short term the main advantages of copper is a variable cost option, alleviating the need for high and risky upfront investments. In addition, the installed base of 800 million copper lines worldwide constitutes an immediate advantage [10]. Figure 1 shows a detailed sketch of the enhanced copper architectures analyzed here. Architectures with and without synchronous digital hierarchy (SDH) rings between the local exchange (LEX) and service access point[3] (SAP) have been studied. The infrastructure for the narrowband services, plain old telephone service (POTS) and narrowband integrated services digital network (N-ISDN), are included in all architecture figures for clarity, even if the analysis of these were outside the scope of this work.

Coaxial Cable Upgrades

The HFC technology for coaxial cable networks allows provision of return capacity in the coaxial cable distribution networks [11]. Both dedicated channel systems for asymmetric and symmetric broadband transmission and shared capacity systems (cable modems) have been proposed. An HFC upgrade implies splitting the coaxial network into smaller coaxial segments in order to achieve the required return path capacity. In the case of each subscriber being fitted with a 10 Mb/s cable modem, typically 5–600 subscribers share 50–60 Mb/s upstream capacity. Figure 2 depicts the HFC upgrade option with cable modems as analyzed here. The existing coaxial cable infrastructure between the access node serving 1000 subscribers and the homes is upgraded to a bidirectional network with a return path. Cable modems are installed at the customer premises.

Fiber Alternatives

Second-generation fiber in the loop (FITL) systems will provide broadband capacity. The concept of BPON is already well known as systems that typically offer 622 Mb/s or 155 Mb/s downstream capacity and 155 Mb/s upstream capacity [3]. The access is shared between 16 or 32 ONUs (optical network units) with an inherent statistical multiplexing capability. However, it is expected that it will be years before fiber deployment for broadband reaches economically justifiable levels. We have examined when and at which take rate level that might occur. Several network architectures like FTTB (fiber to the building), FTTC (fiber to the curb), and FTTN (fiber to the node) are commonly proposed, depending on the local network area conditions. The BPON architecture (FTTB) examined is shown in Fig. 3. Architectures with ONUs serving 8 (BPON-8), 32 (BPON-32), 64 (BPON-64), or 128 (BPON-128) potential subscribers have been studied.

The Case Study

Some of the key issues of broadband access delivery have been addressed through a case study in which a network evolution over a 10-year period from 1996 to 2005 has been examined. One of the most competitive market segments is

[2] *Wideband: capacity per customer < 2 Mb/s.*

[3] *The SAP, as used in this study, refers to the localization of the concentrator and/or add and drop multiplexers in the network, as commonly used in European countries with advanced access network infrastructures.*

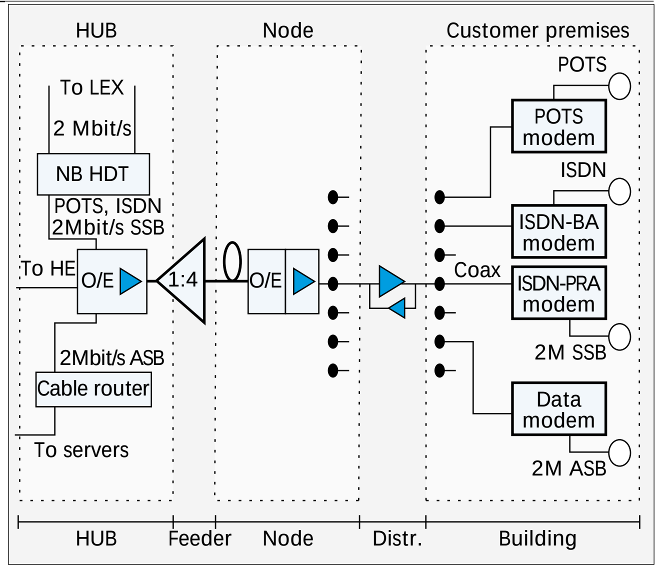
analyzed: an urban residential and small business area with customers living in apartment blocks with an average of 32 dwellings/block. The average outdoor loop length from the network concentrator location to the buildings is 400 m. Network architectures based on twisted pairs and a 450 MHz distribution coax network have already been established in the area. The existing network includes optical access network nodes serving approximately 1000 subscribers. All the existing infrastructures have been fully amortized.

The assessment of the upgrade alternatives is based on several key assumptions, summarized in Table 1. The potential users are assumed to be uniformly distributed over the access area. Only the part of the network between the LEX and the customer premises is taken into account. The SAP in our study has a capacity of 1024 users. Civil works costs may contribute significantly to the overall costs and are therefore of paramount importance when considering access network upgrades. Civil works, as used here, encompass digging, ducting, and surface reinstatement. The cost per unit length depends on area type, distance from the exchange, and technology used. For conventional ducting in the distribution part of the network US$30/m is taken as an average figure. This figure is then multiplied by duct availability. All feeder- and distribution cables for all services are installed at the start of the study period; service-specific equipment for the initially selected architecture is carried out during the project period at the time of connection of new service subscribers. For the BPON and cable modem alternatives, a concentration factor of 10 is assumed in dimensioning the network.

The Methodology

The methodology developed by the RACE 2087/TITAN project has been applied to evaluate the broadband upgrade case [9]. The ability to combine low-level, detailed network parameters of significant strategic relevance with high-level, overall strategic parameters is a key feature of this methodology and tool as compared to other similar assessment methods and tools recently reported [19].

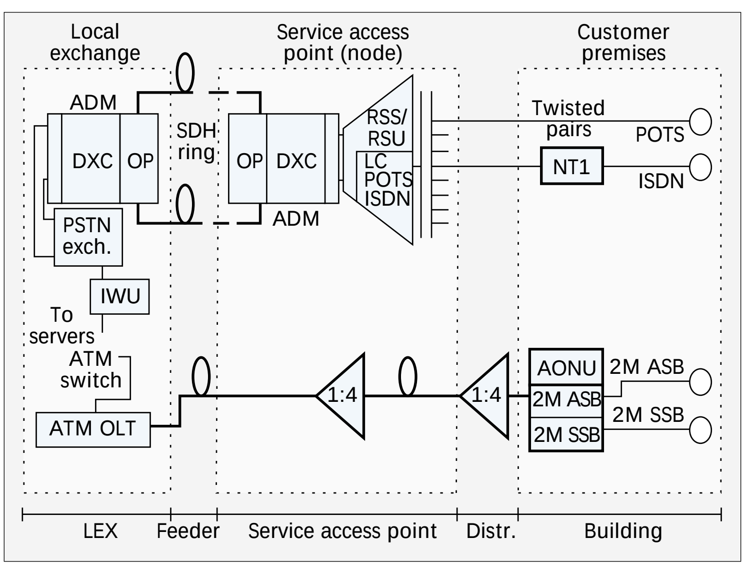
In TITAN the network costs are calculated taking the evolution of component costs into account. The cost trends of the various network elements are derived from initial cost, appropriate learning curve coefficients, and network penetration assessment over the study period considered. A database including costs at a given reference year for components, installation, civil works, and operations and maintenance (OAM) has been developed within the TITAN project. The database contains data gathered from many European sources and includes so-called European average costs. The cable infrastructure costs of the network are calculated using a geometric model which involves parameters such as subscriber density, duct availability, and type of civil works as inputs. At first the discounted system cost is derived; then OAM costs are calculated using inputs from the cost database, yielding life-cycle costs. Finally, the overall financial budget is calculated for the various projects by incorporating revenue estimates from demand and tariff inputs.



■ Figure 2. *The HFC upgrade option with cable modems.*

Results and Discussion

The analysis results include line costs and payback periods of different access network technologies for broadband upgrades, subject to variation in parameters like the existing infrastructure, broadband take rate, optical node size, revenues, and civil work costs. The issue of symmetric and asymmetric upgrades has been studied, with emphasis on asymmetric alternatives. The short- and long-term perspectives have been addressed through in-depth studies of the effect of rollout timing. Payback periods are calculated as a function of service penetration and expected average annual revenues per connection. These results include OAM costs and expected revenue streams in addition to the investments. All results shown, except in Fig. 7, are for a linear upgrade project from 1996 to 2005. It is assumed that the service penetration increases linearly during the 10-year period. The penetrations indicated in the figures are saturation levels in the final year. Hence, the line costs shown are average costs, significantly lower than the costs for a rapid rollout within the next few years. This is due to the combined effect of component cost reduction over time and discounting. The line costs shown are at a level comparable to the expected line cost in the middle of the upgrade period.



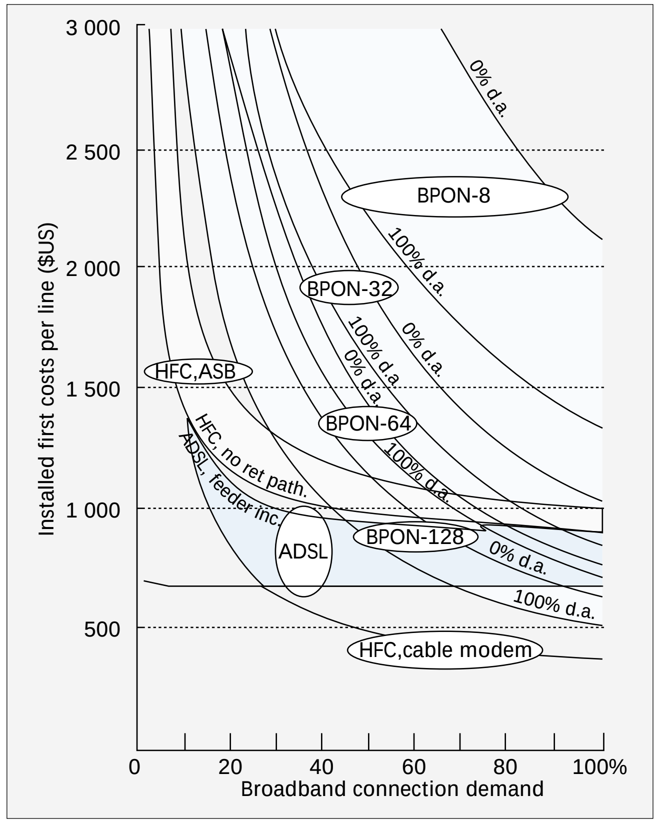
■ Figure 3. *The broadband PON upgrade option based on an ATM PON in an FTTB configuration.*

Line Costs and Average Capacity Demand

Figure 4 shows the installed first costs (IFC) per 2 Mb/s access line as a function of penetration in 2005 for the main alternatives studied. The IFC for BPON

General assumptions	
Number of households in area	1024
Number of buildings in an area	32
Number of households per building	32
Duct availability, feeder	100%
Duct availability distribution, fiber	0–100%
Duct availability distribution, coaxial cable	0–100%
Civil works cost per meter	US$30
Global cable length, distribution network	7.46 km
Distance, SAP–building	400 m
Global cable length, indoor drop network	20.5 km
Average cable length, drop network	20m
Discount rate	7.5%
Tax rate	30%

■ Table 1. *General assumptions.*



■ Figure 4. *The cost per line for the main alternatives examined as a function of broadband connection demand (d.a.: duct availability).*

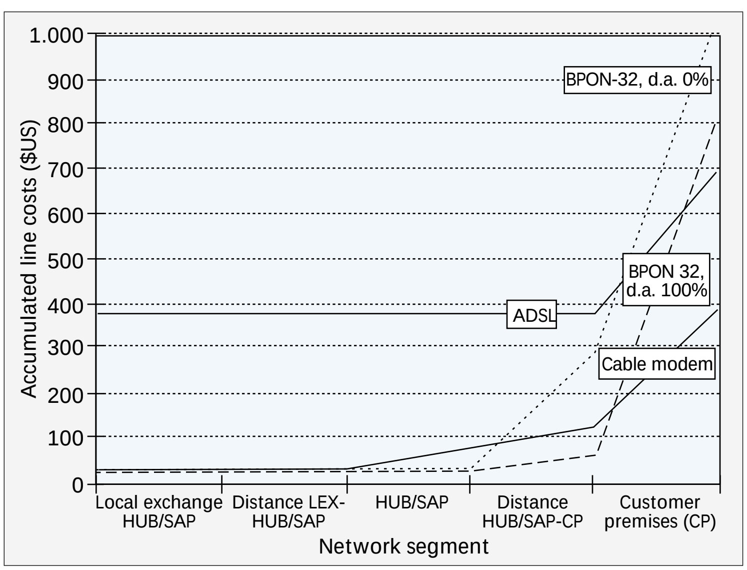
in the FTTB configuration are included for two degrees of duct availability, 0 and 100 percent. The FTTB costs are plotted for each ONU serving 8 (BPON-8), 32 (BPON-32), 64 (BPON-64), or 128 (BPON-128) potential customers.

The results show that, in general, for the fiber solutions and dedicated channel HFC upgrade (HFC ASB or SSB), the operator will have to rely on take rates of 50 percent or higher in order to reach line cost levels below US$1000. ADSL or cable modem upgrades are the only alternatives with prospects of line costs close to US$500 for moderate take rates. The costs per line of upgrading existing twisted pair networks and coaxial cable networks with, respectively, DSL and cable modem technologies are comparable for take rates up to 30 percent. For higher penetrations the cable modem technology seems to have a cost advantage but a limitation in traffic capacity compared to the DSL technologies.

Optical alternatives like BPONs will most likely have to rely on take rates in excess of 50 percent and more than 50 subscribers/optical node in order to be justifiable in pure economic terms. The results illustrate that the costs of civil works and ONUs remain major obstacles for extensive introduction of fiber in areas with an established access network of good quality. Fibering the upper part of the access network is already likely to be cost effective in some cases, as illustrated by the cost levels of the BPON-64 and BPON-128 alternatives. However, the lower part of the network is very sensitive to civil works costs. The fiber/copper crossover point's dependence on the amount of civil works required is clearly seen by the effect of duct availability on the upfront costs of the fiber alternatives. This illustrates that fiber deployment beyond the main flexibility point in the network increases the overall costs significantly if available ducts are scarce.

Figure 5 depicts the accumulated costs per 2 Mb/s line as a function of network segment for some selected architectures. The costs are shown for a 100 percent 2 Mb/s ASB take rate in 2005. The results clearly indicate that in moving from the LEX toward the customer premises (CP), the distribution part of the network (distance from HUB/SAP to CP) is the cost driving network part in addition to the CP equipment. This holds true for all solutions, even if the fiber alternatives have a larger portion of the overall upgrade costs associated with these network levels.

In urban areas the cost per new switched service connection (POTS and N-ISDN) in the existing access network is typically in the range of US$500–800. The costs of a broadband upgrade varies from just below US$400 to more than US$3000 per connection, depending on factors like take rate, technology choice, dwelling distribution, and civil



■ Figure 5. *Accumulated line costs per 2 Mb/s for a ten-year linear upgrade project 1996–2005 with 100 percent 2 Mb/s asymmetric switched broadband take rate in 2005.*

works. Hence, a further upgrade of the access network will probably require huge investments for any technology selected. The operators are then likely to face investment projects of similar or even higher financial burdens than those of establishing the narrowband access networks of today.

Figure 6 depicts the discounted total upgrade project cost for the 2 Mb/s upgrade options examined in an area with 1024 potential customers. Both ASB and SSB upgrade project costs are shown. The costs are depicted as a function of saturation penetration in 2006.

The steep slope of the HFC SSB upgrade is caused by the limited return path capacity in HFC systems, and illustrates the trade-off between capacity and node size of such architectures. For large capacities the coaxial networks must be segmented, thus increasing the civil works involved and reducing the optical node size to a level at which the cost advantage vanishes.

The figure illustrates that low demand for broadband services favors copper-based solutions, while high capacity demand favors more aggressive fiber-based access network solutions. The upfront costs are lower for the copper-based solutions, but the marginal costs of providing more capacity are lower for the fiber-based solutions. The break-even point in the figure indicates the capacity limit beyond which the demand can justify the deployment of optical solutions in pure economic terms. In general, if the demand is high enough the fiber-based solutions will be the most cost-effective.

Given the intention of an FITL upgrade, the establishment of the fiber infrastructure is in itself probably strategically more important than the choice of system technology, provided a system-independent infrastructure is rolled out. The reason behind this is twofold: the facts that the fiber infrastructure costs are likely to be significant and quite similar for all kinds of fiber systems, and that the difference in system costs can be rather marginal between different technological options. Second, the expected technical lifetime of the fiber infrastructure is long compared to the lifetime of the equipment.

An ADSL upgrade consists of modem installation at the central office (CO) and CP. It may also include the installation of ADSL multiplexers at the CO, and as such only require marginal upfront investments. The ADSL upgrade costs will therefore be sensitive to variations in broadband demand only to a very limited degree. A cable modem line seems to have lower cost than an ADSL line; however, significant initial investments at the exchange side and in the distribution network for return path capacity leads to a requirement of at least 20 percent take rate in order for the cable modem upgrade to reach a cost advantage with respect to the ADSL line.

In the short term, 10 Mb/s cable modems for upgrade of existing coaxial cable networks and ADSL modems for upgrade of the twisted pair base seem to be the preferred alternatives for residential broadband data services delivery.

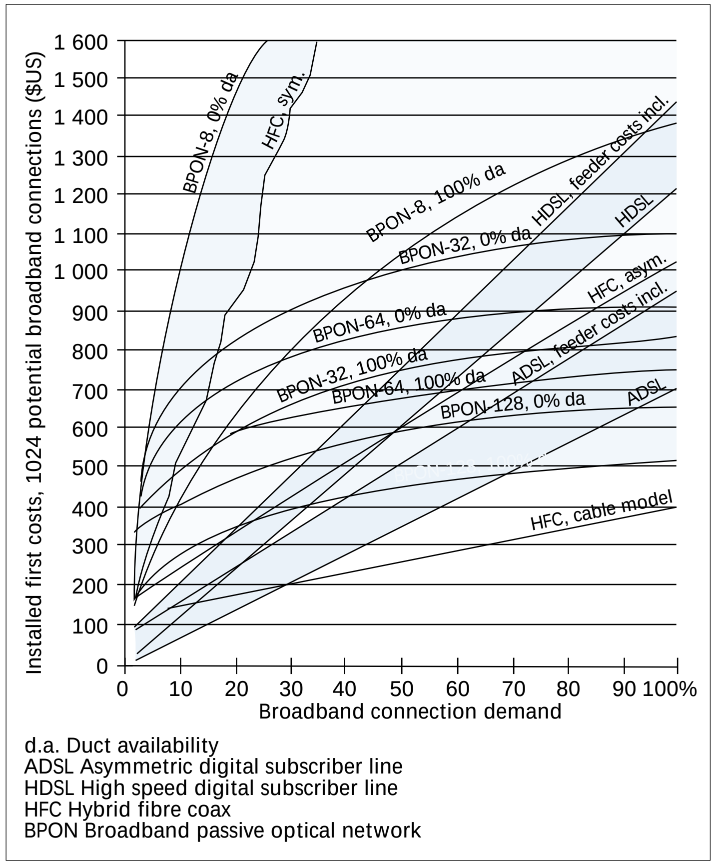


Figure 6. *The discounted upgrade project cost for the 2Mb/s upgrade options examined in an area with 1024 potential customers as a function of broadband connection demand (d.a.: duct availability).*

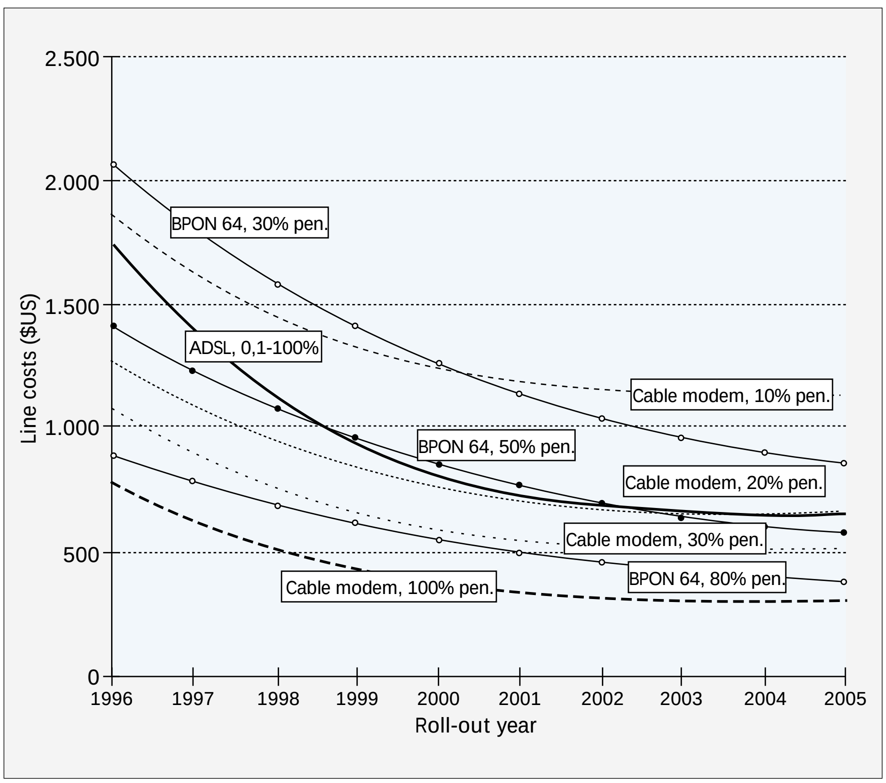


Figure 7. *Line cost as a function of roll-out year and penetration. It is assumed that the indicated penetration is obtained at time of roll-out. The BPON alternatives are calculated with 50% duct availability.*

This is due to both the expected commercial maturity and cost level. Our calculations show that broadband delivery systems may be implemented relatively soon (1997–1998) for line costs of approximately US$1200.

Deployment Time Scale

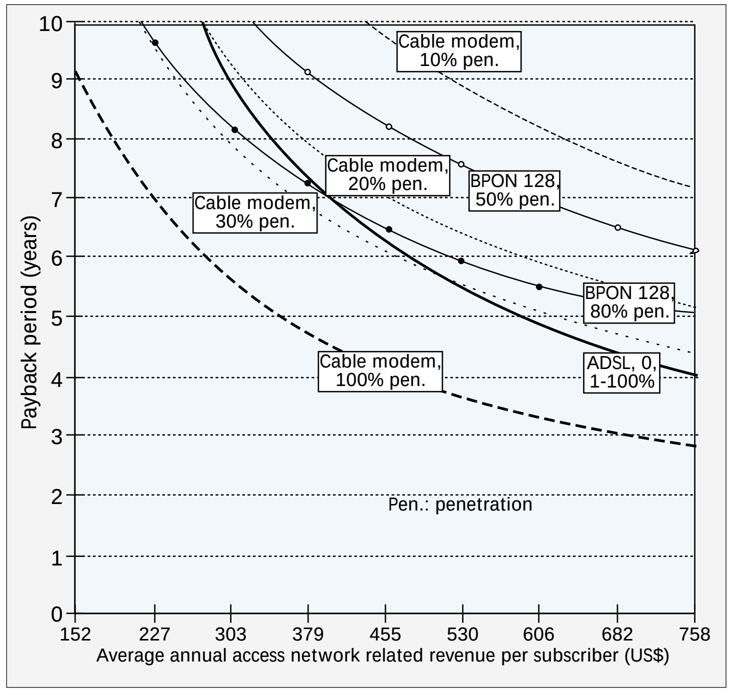
The appropriate timing of broadband upgrading is crucial, not least in order to reduce the investments. The costs of upgrade strategies involving mass deployment of residential access fiber is anticipated to become significantly lower if system introduction is delayed enough to benefit from component cost reductions. Figure 7 shows the broadband line cost as a function of rollout year and penetration for selected BPON, HFC, and ADSL alternatives. It is assumed that the indicated penetration is obtained at time of rollout. The figure illustrates the assumptions with respect to cost evolution embedded in the study results. The expected decrease in cost during the next years is clearly seen.

The equipment cost of the three upgrade alternatives will most likely have quite similar cost reduction potential, since they are all emerging technologies in this market. The total ADSL line costs are expected to be reduced by two-thirds of the 1996 cost level during the 10-year period, whereas the resulting fiber and coaxial cable upgrades are expected to experience a 50 percent cost reduction. The difference in cost reduction is attributed to the fact that the latter two upgrades involve civil works costs in addition to equipment costs.

In conclusion, postponing the fiber rollout may result in a cost advantage compared to the HFC and ADSL upgrades. In addition, prospects of future OAM savings might motivate extensive fiber deployment. So far, however, there is no clear evidence of decreased OAM costs to offset the huge investments required.

Figure 8 shows the payback period[4] as a function of average annual access-network-related revenue per line for a 10-year linear upgrade project. The indicated penetration is the saturation level of 2 Mb/s ASB service penetration in 2005.

The results indicate that the cost level of broadband Internet access is likely to be within the investment range in which payback periods on the order of five years may be expected with annual revenues per access line of US$450. However, it must be emphasized that these calculations are based on an early (1997), quite extensive rollout. A more gradual deployment, postponed in time, will require a lower turnover per access line in order to achieve acceptable payback periods.

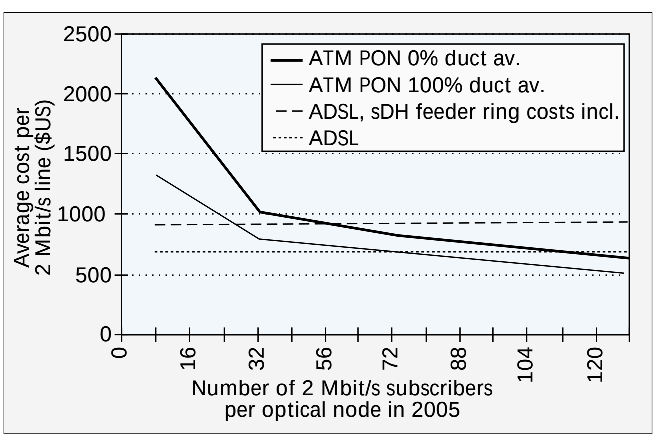


■ Figure 8. *Payback period as a function of average annual revenue per line for a 10-year linear upgrade project, 1996–2005. The indicated penetration is the saturation level of 2 Mb/s asymmetric switched broadband service penetration in 2005. The BPON alternatives are calculated with 50 percent duct availability.*

Optical Network Termination Sharing

Figure 9 shows the line costs as a function of optical node size (i.e., the number of 2 Mb/s subscribers per ONU). The costs are shown for a 10-year linear upgrade project during the period 1996–2005. The ADSL upgrade option is taken as a reference cost level. The figure depicts the influence on the overall costs of the sharing of network termination equipment in the BPON upgrade alternative.

The BPON solution benefits from cost reductions due to both reduced civil work costs and higher customer sharing of the ONUs if the ONUs are more centrally located. It is evident that around 50 subscribers/optical node is the critical size for which BPON can be justified in pure economic terms. This illustrates the great benefit with respect to IFC of sharing the ONU costs between a few tens of subscribers.



■ Figure 9. *Cost per 2 Mb/s line as a function of optical node size for a 10-year linear upgrade project 1996–2005 with 100 percent 2 Mb/s ASB take rate in 2005.*

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 uncertainties 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.

The results illustrate that the average capacity demand in

[4] *The payback period is defined as the period from the start of the project to the time when the cash balance (cumulative sum of the retained cash flows) turns positive.*

the access network is a very important parameter to take into account in strategic considerations, since the actual capacity provided is a differentiator between the different technology options and their associated overall investments. The costs per line of upgrading existing twisted pair networks and coaxial cable networks with, respectively, DSL and cable modem technologies are comparable for take rates up to 30 percent. For higher penetrations cable modem technology seems to have a cost advantage but a limitation in traffic capacity compared to the DSL technologies. Optical alternatives like BPONs will most likely have to rely on take rates in excess of 50 percent and more than 50 subscribers/optical node in order to be justifiable in pure economic terms.

Fiber rollout seems to be a key strategic decision since the costs of extensive fiber deployment are strongly related to civil works costs, and cost reduction relies heavily on optical network termination customer sharing.

In general, broadband residential access upgrades will have payback periods of at least between five and ten years, depending on the technology applied, the existing network, and the deployment time scale.

In general, broadband residential access upgrades will have payback periods of at least between five and ten years, depending on the technology applied, the existing network, and the deployment time scale.

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