University of Macedonia
Master Information Systems
Networking Technologies Professors: A.A. Economides
A. Pomportsis

Fiber Optics In The Local Loop

Student: Gkatzelidis Panagiotis M 08/05

Thessaloniki 2005

Πανεπιστήμιο Μακεδονίας
Πληροφοριακά Συστήματα
Τεχνολογίες Τηλεπικοινωνιών & Δικτύων
Καθηγητές: Α.Α. Οικονομίδης
Α. Πομπόρτσης

Θέμα : Οπτικές Ίνες στον Τοπικό Βρόγχο

Φοιτητής : Γκατζελίδης Παναγιώτης Μ 08/05

Θεσσαλονίκη 2005

Contents

Περιεχόμενα

Abstract

The use of fiber optics in the construction of residential networks is an essential factor for the quality of the provided services to the end users, since fiber optics is the only long-term solution that can provide the bandwidth required for multimedia and interactive applications. The two dominant architectures, which service providers use in order to offer these solution are the hybrid fiber coaxial (HFC) networks and the “Fiber to the Home” architecture. A hybrid fiber coaxial (HFC) network is a telecommunication technology in which optical fiber cable and coaxial cable are used in different portions of a network to carry broadband content. Using HFC, a telecommunication company, installs fiber optic cable head-end (distribution center) to serving nodes located close to businesses and residential users and from these nodes uses coaxial cable to individual businesses and homes. Fiber to the home (FTTH) is the ideal fiber-optics architecture. In this architecture, fiber deployment is carried all the way to the customer’s home (premises). The advantage of these architectures is that some of the characteristics of fiber optic cable (high bandwidth and low noise) can be brought close to the end user.

Περίληψη

Η χρήση των οπτικών ινών στην κατασκευή δικτύων σε περιοχές κατοικιών είναι βασικός παράγοντας για την ποιότητα των υπηρεσιών που προσφέρονται στους τελικούς χρήστες, αφού οι οπτικές ίνες είναι η μόνη μακροπρόθεσμη λύση που μπορεί να παρέχει το απαιτούμενο εύρος ζώνης για πολυμεσικές και αλληλεπιδραστικές εφαρμογές. Οι δύο κύριες αρχιτεκτονικές, που χρησιμοποιούνται από τους παροχείς δικτυακών υπηρεσιών για αυτό το σκοπό είναι τα υβριδικά δίκτυα οπτικών ινών και ομοαξονικού καλωδίου (HFC) και η αρχιτεκτονική «Οπτική ίνα ως τις κτιριακές εγκαταστάσεις του συνδρομητή» (FTTH). Ένα υβριδικό δίκτυο οπτικών ινών και ομοαξονικού καλωδίου (HFC) είναι μια τηλεπικοινωνιακή τεχνολογία στην οποία χρησιμοποιούνται οπτικές ίνες και ομοαξονικό καλώδιο σε διαφορετικά τμήματα του δικτύου για να μεταφέρουν ευρυζωνικό περιεχόμενο. Χρησιμοποιώντας την τεχνολογία HFC, μια εταιρία τηλεπικοινωνιών, εγκαθιστά οπτικές ίνες από το κέντρο παροχής δικτυακών υπηρεσιών ως τους κόμβους εξυπηρέτησης, που τοποθετούνται κοντά σε επιχειρήσεις και συνδρομητές, και από τους κόμβους αυτούς χρησιμοποιείται ομοαξονικό καλώδιο ως τις κτιριακές εγκαταστάσεις των επιχειρήσεων και των συνδρομητών. Η αρχιτεκτονική “Οπτική Ίνα ως τις κτιριακές εγκαταστάσεις του συνδρομητή» (FTTH), είναι μια ιδανική τεχνολογία οπτικών ινών, στην οποία η χρήση της οπτικής ίνας γίνεται από το κέντρο παροχής δικτυακών υπηρεσιών ως την κατοικία του συνδρομητή. Το πλεονέκτημα αυτών των αρχιτεκτονικών είναι ότι μερικά από τα χαρακτηριστικά των οπτικών ινών υψηλό εύρος ζώνης, χαμηλός θόρυβος) μπορούν να προσφερθούν στον τελικό χρήστη.

1.Introduction

The local loop is going through its most fundamental transformation in this century. New technologies, wireline as well as wireless, are at the source of this change. The impact on industry, however, represents much more than a technological transformation. It affects not only the core of the telephony market structure but also the whole world of telecommunications where wireline telephony is converging with wireless services and cable television. As a result, it is not surprising that the local loop is increasingly becoming the focus of the government policy debate.

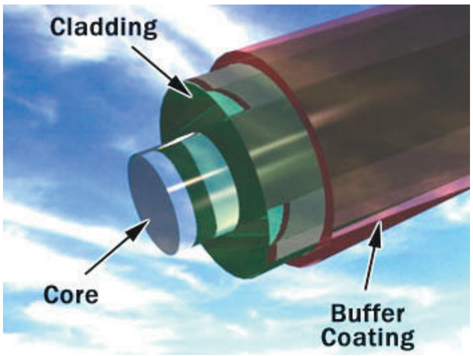
For over half a century, the local loop was conceived as the heart of the bottleneck monopoly. This was the main argument to defend the PTTs monopoly. However, it was also the very premise upon which the divestiture of the Bell System was argued. Other segments that were considered to be competitive had to be separated from the bottleneck local loop. Only recently, new models were formulated which look at the local loop not as a bottleneck but as competitive.

This paper suggests that the absence of scale economies in the local loop may extend beyond wireless technologies to new local loop wireline architecture such as the hybrid fiber/coax (HFC), fiber to the curb (FTTC) and, eventually, to future fiber to the home/ building (FTTH/B). These technologies tend to have production and economic cost characteristics that are fundamentally different from the traditional twisted pair copper distribution networks. Their scale economies tend to be lower. There are also strong indications that these new architectures can achieve significant economies of scope that were not available to either telephone or cable television networks in the past .

The growing ability of wireless technologies to be cost competitive with the existing twisted copper pair telephony in the provision of narrowband service (up to ISDN) enables wireless providers to expand the range of service they offer to tetherless and even fixed local access in direct competition with the existing telephone networks. Moreover, the narrowband constraint of today's wireless distribution network is expected to give way soon to competitive wide and broadband access capabilities. In the meantime, wireline technologies like FTTC or HFC can be used to offer PCS services. Wireless networks are not the only source of economies of scope in telecommunications. The convergence of telephony, wireless, and CATV enables multimedia services to be developed using combined elements of these various access technologies. Economies of scope mean that customers will be increasingly able to satisfy multimedia needs through any of a number of suppliers from formerly distinct industries.

2.Basic Definitions

Optical Fiber



Optical fiber (or fiber optic) refers to the medium and the technology associated with the transmission of information as light pulses along a glass or plastic wire or fiber. Optical fiber carries much more information than conventional copper wire and is in general not subject to electromagnetic interference and the need to retransmit signals. Most telephone company long-distance lines are now of optical fiber.

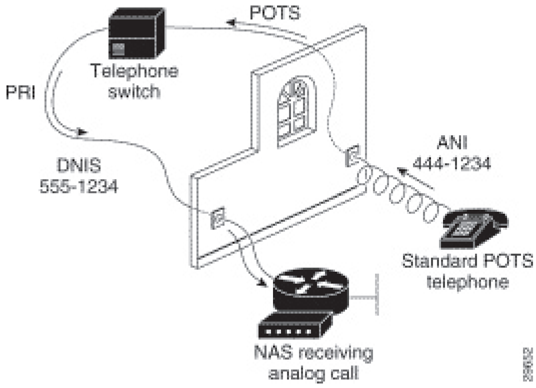
Transmission on optical fiber wire requires repeaters at distance intervals. The glass fiber requires more protection within an outer cable than copper. For these reasons and because the installation of any new wiring is labor-intensive, few communities yet have optical fiber wires or cables from the phone company's branch office to local customers (known as local loops)

A type of fiber known as single mode fiber is used for longer distances – multimode fiber is used for shorter distances.

Local Loop

In telephony, a local loop is the wired connection from a telephone company's central office in a locality to its customers' telephones at homes and businesses. This connection is usually on a pair of copper wires called twisted pair. The system was originally designed for voice transmission only using analogue transmission technology on a single voice channel. Today, your computer's modem makes the conversion between analogue signals and digital signals. With Integrated Services Digital Network (ISDN) or Digital Subscriber Line (DSL), the local loop can carry digital signals directly and at a much higher bandwidth than they do for voice only.

Plain old telephone service (POTS)



POTS are the services available from analogue telephones prior to the introduction of electronic telephone exchanges into the public switched telephone network. These services had been available almost since the introduction of the telephone system in the late 19th century. POTS is a term sometimes used in discussion of new telephone technologies in which the question of whether and how existing voice transmission for ordinary phone communication can be accommodated. For example, Asymmetric Digital Subscriber Line and Integrated Services Digital Network connections provide some part of their channels for "plain old telephone service" while providing most of their bandwidth for digital data transmission.

Fiber in the Loop (FITL)

FITL is a system implementing or upgrading portions of the POTS local loop with fiber optic technology from the central office of a telephone carrier to a remote Serving Area Interface (SAI) located in a neighbourhood or to an Optical Network Unit (ONU) located at the customer premises (residential and/or business). Generally, fiber is used in either all or part of the local loop distribution network. FITL includes various architectures, such as fiber to the curb (FTTC), fiber to the home (FTTH) and fiber to the premises (FTTP).

A similar network called a hybrid fibre coaxial (HFC) network is used by cable television operators but is usually not synonymous with "fiber In the loop", although similar advanced services are provided by the HFC network.

3.Hybrid Fiber Coaxial (HFC)

3.1 General

A hybrid fiber coaxial (HFC) network is a telecommunication technology in which optical fiber cable and coaxial cable are used in different portions of a network to carry broadband content (such as video, data, and voice). Using HFC, a local CATV company installs fiber optic cable from the cable head-end (distribution center) to serving nodes located close to business and residential users and from these nodes uses coaxial cable to individual businesses and homes. An advantage of HFC is that some of the characteristics of fiber optic cable (high bandwidth and low noise and interference susceptibility) can be brought close to the user without having to replace the existing coaxial cable that is installed all the way to the home and business. Both cable TV and telephone companies are using HFC in new and upgraded networks and, in some cases, sharing the same infrastructure to carry both video and voice conversations in the same system. Scientific Atlanta lists four reasons why cable TV and telephone companies are upgrading facilities to HFC:

1) The use of fiber optic cable for the backbone paths allows more data to be carried than coaxial cable alone.
2) The higher bandwidth supports reverse paths for interactive data flowing back from the user.
3) That portion of the infrastructure with fiber optic cable is more reliable than coaxial cable. Reliability is perceived as more important in an interactive environment.
4) Fiber optic cable is more efficient for interconnecting cable TV or phone companies that are consolidating with geographically adjacent companies

3.2 Hybrid fiber-coaxial (HFC) architecture

A number of optic fiber cable-based architectures have been deployed by different Telecom and cable operators around the world. However, the network architectures originating from different starting points have resulted in a large variety of similar HFC structures, but with quite different costs and topology. The following HFC architecture reflects the possible implementation in three stages of a full service network in a country, on the base of the existing installed network:

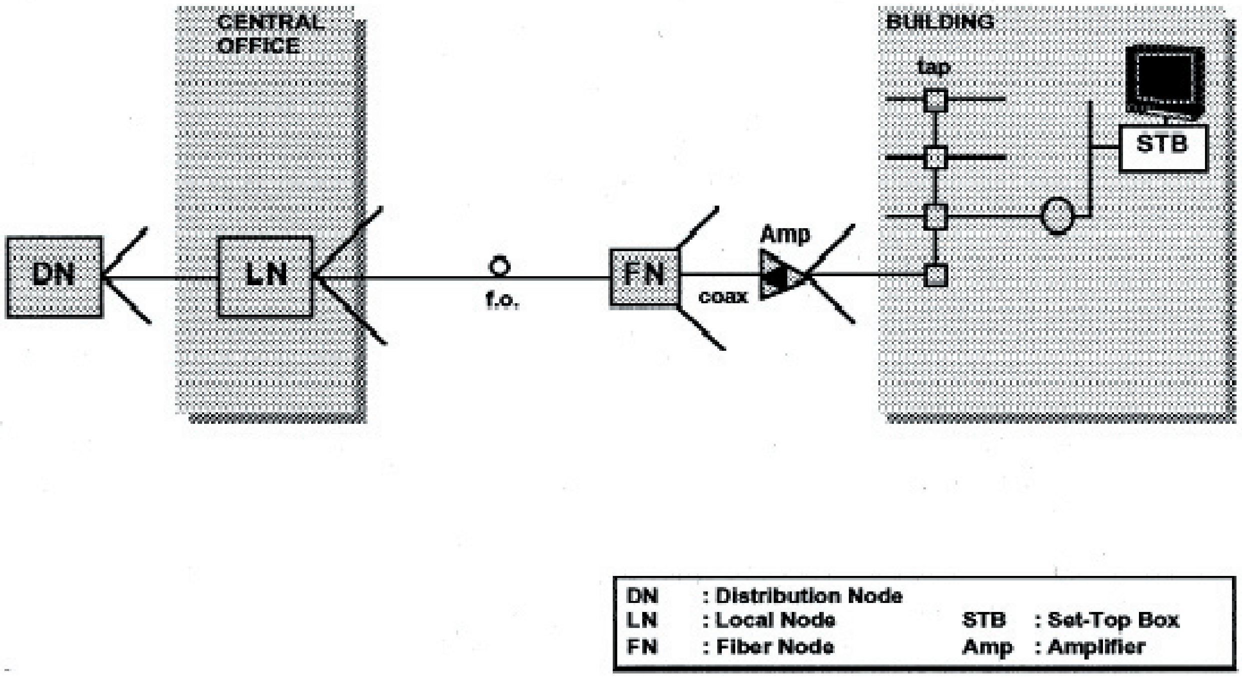
1.The first step is distributive video services
2. The second step is IMM and on-line services introduction
3. The last step is the integration of the POTS service over the HFC network.

There is a common consensus that these HFC networks provide the potential for upgrading to interactive digital networked services. Fig. 1 shows the likely architecture of a HFC system and its key components. A HFC network is potentially able to support the following services:

1. Analogue distributive (Pay TV) services
2. Digital distributive services (including hundreds of MPEG compressed video Channels)
3. Digital interactive services
4. PSTN services.

A HFC network employs fiber and coaxial cable to reach the customer's premises. The key technical feature of a HFC network is that all the information delivered over the network reaches all the network users. This resource sharing has some security implications (e.g. potential limitation for the security of the high quality communication services).

Analogue (PAL 8 MHz) and digital (MPEG2 6 Mbit/ s) video channels will be deployed in the downstream bandwidth (54–862 MHz). The allocation of frequencies to provide broadcast, interactive and PSTN services is:



1. 54–470 MHz broadcast (analogue and digital);
2. 470–862 MHz (downstream for interactive services).

The bandwidth 5–30 MHz is available for signalling in the starting phase of the materialization and will be used for upstream channels and POTS services in the following years.

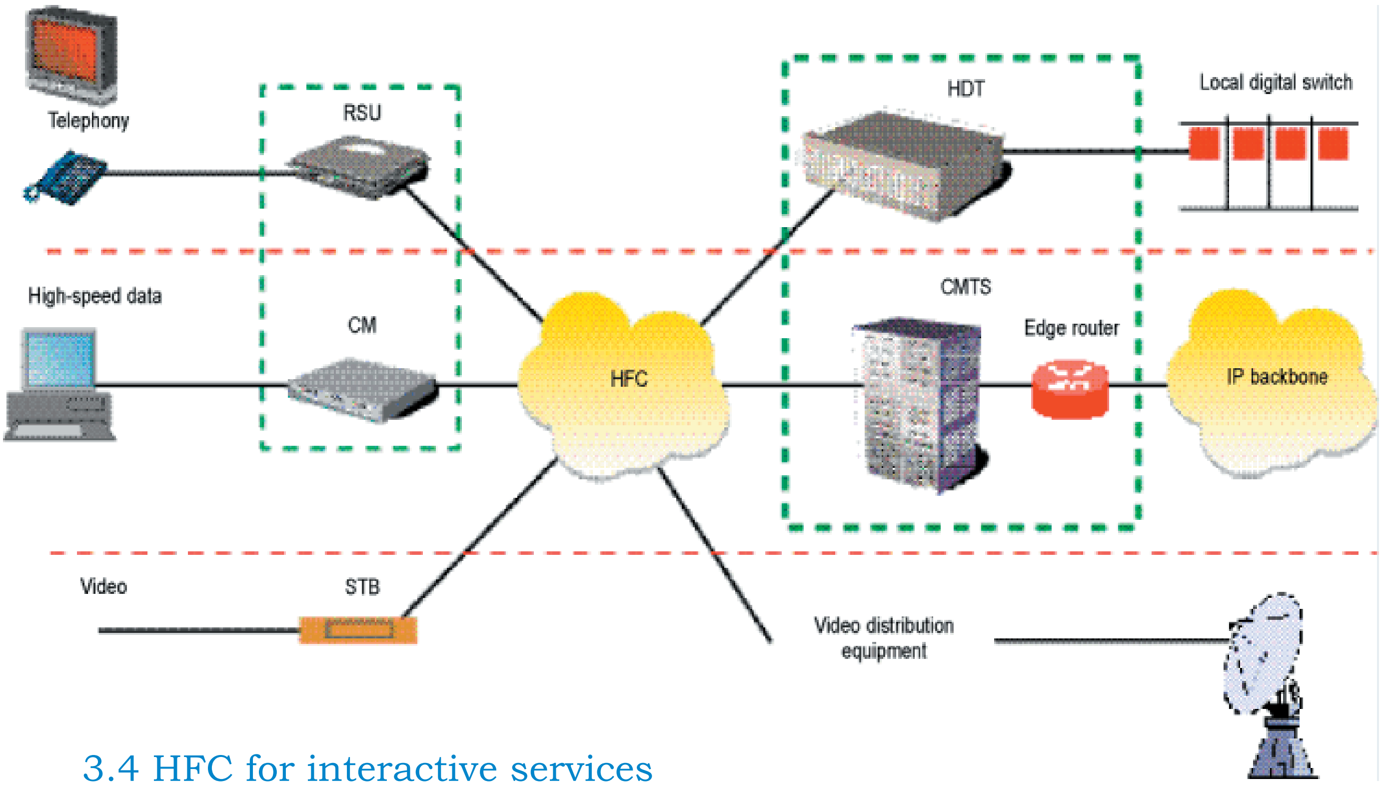
3.3 HFC for distributive services

With the initial configuration the main service to be provided will be analogue and digital video channels. These will be sent from the head-end throughout the network via a distribution node (DN). A DN is the first topological element of the network for broadcast services. DNs will receive all the broadcast signals from the head ends (HE) of the service providers.

All these channels will be distributed over local nodes (LN). The LN will receive the signals from DN and retransmit these signals to the fiber node (FN) located in the coverage area.

With an analogue PAL TV channel requiring 8 MHz, this means that, in practice, up to 50 channels could be provided in the bandwidth 54–470. A key feature of the architecture is the provision of a backchannel of about 50 MHz. This is likely to be used for responses from the set-top-box. Furthermore, it might allow a menu driven system for ordering ‘pay per view’ movies or other distributive services. The back channel can also be used to enable the headend to ‘poll’ the stored set-top units for data that relate, for instance, to ordering ‘pay-per-view’ movies.

The system employs a ‘bus’ architecture. That is to say that each household does not have a dedicated cable but shares the bandwidth — a very large one (862 MHz) — on the cable with other households. This type of network is similar to that employed in cable TV systems and is used widely by cable operators with considerable operational experience. The video signals then pass to the home where they are received and processed by a set-top-box. Initially, up to about 400 homes could be serviced on each fiber node, but as the network is upgraded to provide interactive services, more cable FNs could be introduced to provide more bandwidth per household. For broadcast TV, where every household receives the same signals, there are enough available channels. However, where customers need a dedicated channel, there will be a limit to the number of dedicated channels in the 470–862 bandwidth. Thus, the number of FNs will increase from 1 per 400 houses to 1 to 300–350 homes.



3.4 HFC for interactive services

Upgrading the system to provide interactive services involves the use of the 50 MHz backchannel at the local node. The sizing of the network presents some problems, since the capacity and reliability requirements of future services are still not well understood. At present, there is no standard model for such networks. However, an assumption of 25% simultaneous access for IMM services at the peak hour was made.

3.5 HFC integration of telephony and broadband services

One possible scenario for the final upgrade of the HFC network is its full integration into a broadband PSTN. However, although some examples (e.g. Scientific Atlanta) are available at the moment, the technical and economic effectiveness of such integration are still to be demonstrated (at least in the long term).

4. Fiber to the Home (FTTH)

4.1 General

Fiber to the Home (FTTH) refers to a broadband telecommunications system based on fiber-optic cables and associated optical electronics for delivery of multiple advanced services such as the triple play of telephone, broadband Internet and television to homes and businesses. FTTH has been developed in response to several residential access market drivers, including the following:

- The Internet explosion, second line growth, the desire for higher speeds, alternative strategies such as voice over DSL (VoDSL), voice over IP (VoIP), voice over ATM (VoATM), and cable modems
- The increased competition in the market due to the growing number of competitive local-exchange carriers (CLECs), an increase in services offered by application service providers (ASPs), and deregulation and pending Federal Communications Commission (FCC) rulings
- Turn-up complexities that affect ease of deployment and maintenance
- The declining costs of optical equipment
- Technology life cycles that dictate a need to deploy the right technology at the right time and to future-proof existing networks

4.2 Technologies

There are two competing FTTP technologies : Active FTTP and PON (Passive Optical Network) architectures.

Active FTTP networks utilize equipment in neighborhoods (usually 1 equipment cabinet for every 400-500 subscribers). This neighborhood equipment performs layer 2/layer 3 switching and routing, offloading full layer 3 routing to the carrier's central office. The IEEE 802.3ah standard enables service providers to deliver 100 Mbit/s full-duplex over a single singlemode fiber to the premise.PON FTTP networks on the other hand avoid the placement of electronics in the field.

PON networks use passive splitters to distribute fiber to individual homes. One fiber is optically split into 16, 32, or 64 fibers (depending on the manufacturer) which are then distributed to residential or business subscribers. In PON architectures, the switching and routing is done at the carrier's central office. Service providers using PON include Verizon (FiOS) and several greenfield development networks.

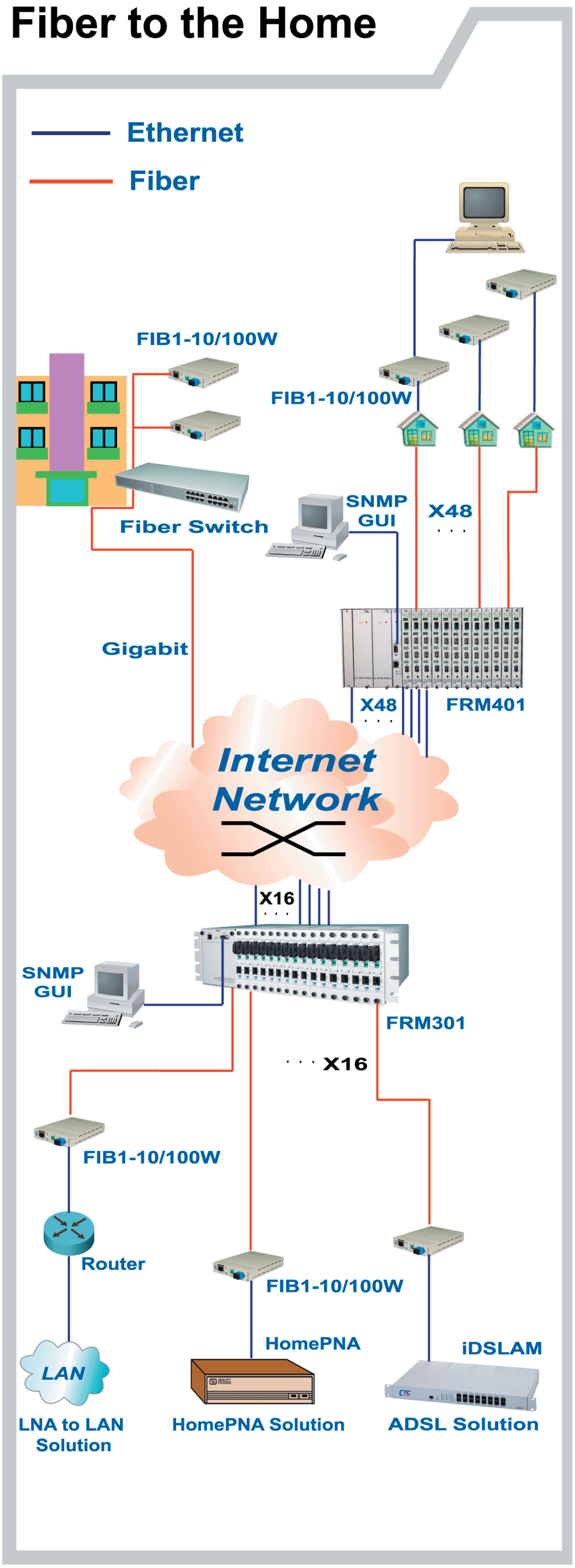
4.3 Evolution of FTTH

Fiber-based networks in general evolved in response to consumer demand for a vast assortment of multimedia services and applications. In order to meet this demand, service providers need a robust, broadband networking solution such as fiber technology, which offers unlimited bandwidth and the flexibility to meet customer demand for two-way, interactive, video-based services.

FTTH enables service providers to offer a variety of communications and entertainment services, including carrier-class telephony, high-speed Internet access, broadcast cable television, direct broadcast satellite (DBS) television, and interactive, two-way video-based services. All of these services are provided over a passive optical distribution network via a single optical fiber to the home. In addition, an FTTH solution based on wavelength division multiplexing (WDM), or a λ-based architecture, allows for additional flexibility and adaptability to support future services.

The full-service access network (FSAN) initiative, whose objective is to obtain cost-effective solutions to accelerate the introduction of broadband services into the public network, is also testing asynchronous transfer mode (ATM).passive optical network (PON) technology for FTTH, which transports network services in ATM cells on a PON. This mode of transport provides key service features, such as multiple quality-of-service (QoS) guarantees, which enables the successful transmission of integrated voice, video, and data services by prioritizing traffic. It also permits statistical multiplexing for bursty traffic, such as Internet access and data transfers.

4.4 How FTTH works



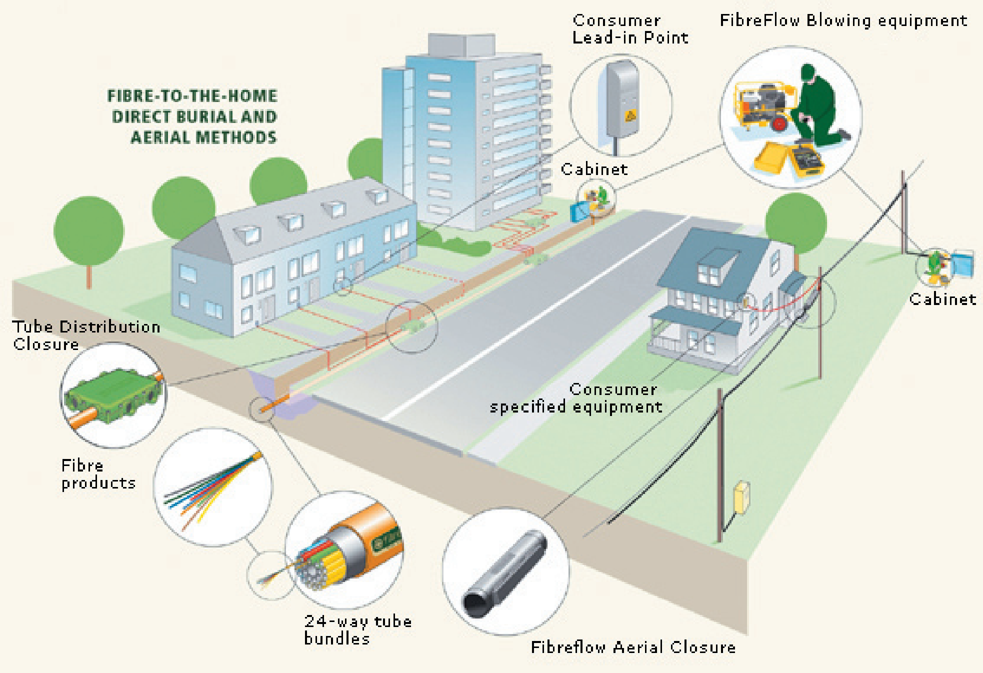
In an FTTH system, equipment at the head end or CO is interfaced into the public switched telephone network (PSTN) using DS.1s and is connected to ATM or Ethernet interfaces. Video services enter the system from the cable television (CATV) head end or from a satellite feed.

All of these signals are then combined onto a single fiber using WDM techniques and transmitted to the end user via a passive optical splitter. The splitter is typically placed approximately 30,000 feet from the central office (CO). The split ratio may range from 2 to 32 users and is done without using any active components in the network. The signal is then delivered another 3,000 feet to the home over a single fiber. An ideal FTTH system would have the ability to provide all of the services users are currently paying for, such as circuit-switched telephony, high-speed data, and broadcast video services.

At the home, the optical signal is converted into an electrical signal using an optical electrical converter (OEC). The OEC then splits the signal into the services required by the end user. Ideally, the OEC will have standard user interfaces so that special set-top boxes are not needed to provide service. These interfaces would include RJ11 jacks for telephony, RJ45 jacks to high-speed data, and 75 ohm coax ports for CATV and DBS service.

4.5 The Future of FTTH

With consumer demand for high-speed bundled services, FTTH has been recognized as the ultimate solution for providing these services to the end user. Twisted pair, coax, and hybrid fiber/coax (HFC) networks are not as robust or future-proof as FTTH architecture. And with the continued declining costs of optical equipment, FTTH has proven to be a technology to watch as it gains



the interest of service providers. Today, FTTH is just beginning to penetrate the market with numerous service providers starting to deploy small networks.

The desire for two-way, video-based services such as interactive television, distance learning, motion picture quality videoconferencing, and videophones is expected to continuously increase. In fact, some observers believe that there is already a worldwide demand for these futuristic services today. The capability to meet this demand and continuously add new services at mouse-click speed is creating enormous competitive pressures.

Such capability also offers tremendous revenue potential. Service providers who are able to offer these services to an ever-growing customer base can double or even triple their revenue in a short period of time. As a result, demands for fiber technologies such as FTTH are on the rise. Technology advancements in the area of WDM are expected to further refine and enhance the technology, enabling more service providers to justify the investment in FTTH.

5. Fiber to the curb (FTTC)

5.1 General

"Fiber to the curb" (FTTC) refers to the installation and use of optical fiber cable directly to the curbs near homes or any business environment as a replacement for "plain old telephone service" (POTS). Think of removing all the telephone lines you see in your neighbourhood and replacing them with optical fiber lines. Such wiring would give us extremely high bandwidth and make possible movies-on-demand and online multimedia presentations arriving without noticeable delay.

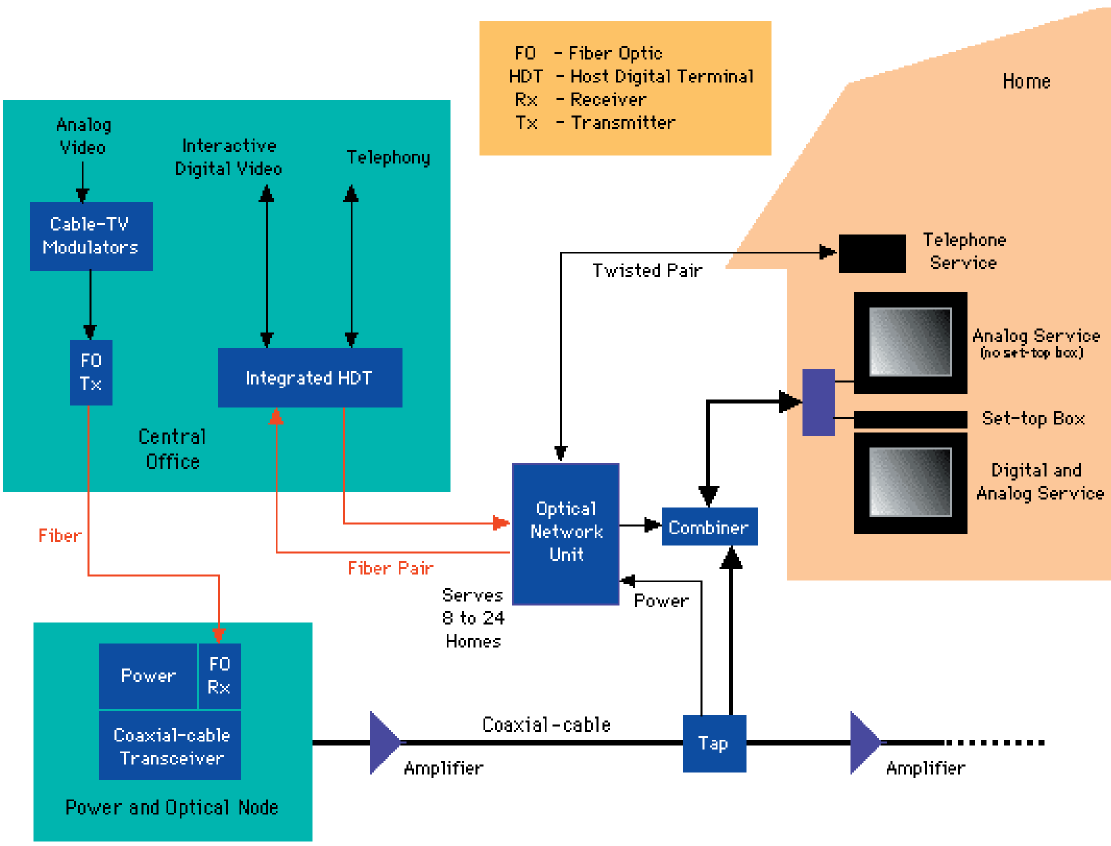
The term "fiber to the curb" recognizes that optical fiber is already used for most of the long-distance part of your telephone calls and Internet use. Unfortunately, the last part - installing fiber to the curb - is the most expensive. For this reason, fiber to the curb is proceeding very slowly. Meanwhile, other less costly alternatives, such as Asymmetric Digital Subscriber Line on regular phone lines and satellite delivery, are likely to arrive much sooner in most homes.

Fiber to the curb implies that coaxial cable or another medium might carry the signals the very short distance between the curb and the user inside the home or business. "Fiber to the building" (FTTB) refers to installing optical fiber from the telephone company central office to a specific building such as a business or apartment house. "Fiber to the neighbourhood" (FTTN) refers to installing it generally to all curbs or buildings in a neighbourhood. Hybrid Fiber Coax (HFC) is an example of a distribution concept in which optical fiber is used as the backbone medium in a given environment and coaxial cable is used between the backbone and individual users (such as those in a small corporation or a college environment).

5.2 FTTC Architecture

From the architectural point of view, the last 200 m, from the curb to the building, will be covered using copper pairs and VDSL modems (51 Mbit/ s), downstream.
The basic philosophy of this architecture is that all the signals (broadcasting or interactive) will be collected at an LN level that corresponds ideally to a local switch of the PSTN. To evaluate the viability of this kind of architecture for both broadcasting and IMM services, the impact that the signalling traffic generated by broadcasting services (e.g. zapping) may have, still remains to be analyzed in further detail.
However, to finalize the economic evaluation, some assumptions on the network size and its costs were made.
The FTTC architecture is able to support the following services:

1. Digital video channels (with selection at network level);
2. On-line services;
3. Interactive video services;
4. bi-directional symmetrical services (including POTS).



6. History and recent developments in FttH and FttC

In many cases the operators' access networks, the local loop or last mile, have fallen behind in their development towards higher speeds and possibilities compared with backbone networks, even if they are positioned as broadband networks (ADSL and cable). In today's (marketing driven) popular speech broadband means 128 Kbit/s (ISDN A+B) up to 1.5 Mbit/s (ADSL). Real broadband networks provide the user with 10 Mbit/s, and even more in the future. FttC and FttH are essential for these speeds.

Of late there have been initiatives from user communities to arrive at fast local infrastructures. Examples in the Netherlands are Almere, and Kenniswijk in Eindhoven and Helmond. In Europe the projects of Bredbandsbolaget, the Swedish company, are of interest. These first mile projects require different organisational and financial methods, and are usually based on fibre-optics.

Modern access networks have a number of characteristics. They have relatively short spans; 20 km is the norm. Their traffic is strongly distributive and aggregative in character and they nearly always contain a reduction stage, as not all users are active at any given moment. Their installation is laborious, and investments in the last/first mile are done with the long term in mind. Maintenance should be minimal. The load strongly differs in time and per user type. Small business users have different requirements from private persons or those working at home. Due to its present large capacity, expected to last far into the future, fibre-optics are well-suited for the last/first mile, meeting requirements for a longer period of time. Moreover (especially in the US) the costs of maintenance are expected to be lower for a fibre-optic infrastructure than for a copper infrastructure. Fibre-optics therefore offer a safe basis for the relatively high investment costs for a new or renewed access network.

The technology for fibre-optics in access networks is relatively young and is still being amply developed. Despite this there is great interest in FttC and FttH, especially in the US. The US often lack cable networks and there is strong competition between telecom operators and cable companies. This makes it efficient to combine a network for video distribution and fast Internet with multiple telephony lines. In July 2001 the FTTH Council was founded in the US, in which especially equipment manufacturers and integrators have united. In Europe the predominant stimuli at present are the first mile projects.

At the end of the eighties, when the FttH ideas began to be developed, a practical problem emerged: the patch cabinets in the local exchanges would become huge if the same method as with the copper local loop was applied. This would especially be the case with further concentration, made possible by less attenuation in optical fibre. Patch cabinets with a very high density for example can have 2000 fibres fitted on them. A single fibre solution in a city of 100,000 houses and corporate housing (125,000 connections) would then require 100 patch cabinets, with the necessary fall back. The typical dimensions of a patch cabinet are 90X60X220 cm. This requires much more space than the termination of copper.

Moreover the optical transceivers (two per connection) constitute a major part of the costs, and the costs of installation are strongly influenced by the number of fibres to be terminated. The application of splitters in street cabinets is therefore an attractive option. This part is called the outside plant in the US. These splitters can either be based on active (electronic) circuits or on passive splitting. Chapter 3 elaborates on the passive optical networks (PONs). There are estimates that the installation of a PON-based network costs 50 0.000000e+000ss than a network based on a direct fibre to the user. Present day LANs are based on active splitters.

The current CATV networks are also splitter-based. The mini-star concept commonly used in the Netherlands in combination with the Hybrid Fibre Coax networks are fundamentally examples of FttC with active components.

FttC can be considered a less expensive solution than FttH, if the user's bandwidth requirements can be met through the speeds reached over twisted pair copper (or coaxial cable) over short spans. xDSL (especially VDSL) seems a good technology for twisted pair, but Ethernet over copper is also suitable.

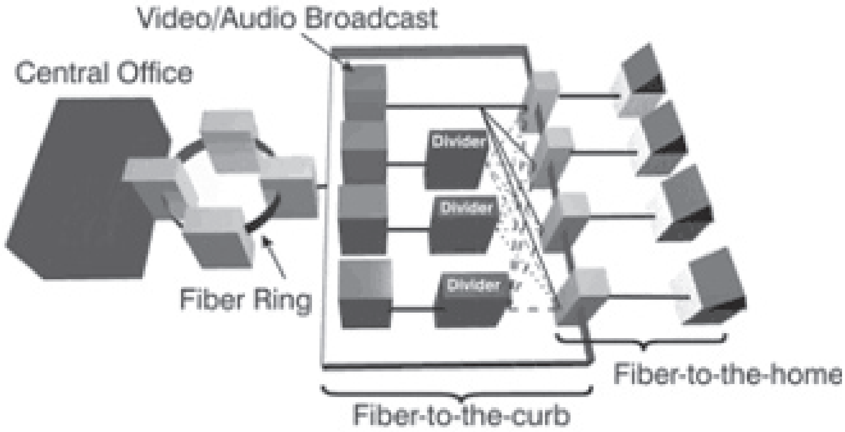
At first the interest in FttH and FttC came from the operators who wished to provide a range of services using fast multi-service access networks. Video-on-demand proved an important motive. Operators have set up trial projects in different places in the world for this purpose.

A good example is the Amsterdam-Sloten project, run by PTT Telecom, as it was known then. It involved the installation of a fibre-optic infrastructure for telephone and CATV services in a new housing estate. This project yielded know-how, but did not lead to any further developments. The costs were high and the package of services, telephony and cable TV, did not offer anything other than the existing (less expensive) networks.

Development in the US came later. Several telephone carriers seriously considered switching to the HFC-networks like those rolled out by cable companies. In the US FttH/C is now being implemented on a large scale, for example by SBC Communications Inc. in its ADSL Pronto project.

The current development of FttH/C is mainly aimed at the improved optical technologies and improvements in the installation techniques for fibre-optics and the consequently improved price-performance ratio.

The possibility of providing broadband Internet is an important stimulus at this moment. ADSL services are provided in many places to satisfy the call for faster Internet. The roll-out of ADSL is not always successful. This is mainly to do with MDF access and crosstalk problems between wire pairs. These problems encourage interest in FttH/C. FttC technologies can be used in the backbone networks for xDSL, Wireless Local Loop (WLL), CATV and mobile networks. Especially VDSL offers a possibility of making optimum use of the last stretch of copper. VDSL is currently not yet fully standardised. The feeder networks for 3G mobile networks will require a larger capacity and density. A fibre-optic infrastructure can provide this.



Broadband Internet as a stimulus for FttH has also increased interest in IP-networks. An increasing number of backbone networks is already IP-based for efficiency reasons, and IP appears attractive also for local infrastructures. IP can be used for Internet traffic as well as for transmission of telephone and video (CATV) traffic in digital form.

People are beginning to realise that Ethernet can be an efficient basis for local networks. Ethernet was originally set up for bus topology LANs of limited spans, but has developed into a technology that can span up to 100 km, and appears interesting for FttH/C as well. Ethernet is a relatively simple technology, very cost-effective, suitable for high speeds (10 Gbit/s is being developed) and suitable for streaming traffic. Also telecommunications backbone architectures and the networks on the premises are increasingly Ethernet-based.

Every public network infrastructure requires a clear interface between the infrastructure and the user's own facilities. This is an argument for placing a Network Termination Unit (NTU) within the user's home, to be managed from the infrastructure. The ISDN NT1 is a good example. For multi-service FttH/C infrastructures providing multiple telephony lines, Internet and video services the NTU will have to offer several connections, such as analogue telephony, RJ45 for Ethernet and coaxial cable for CATV.

7. Economic models

This section presents the methodology and the specific assumptions made to evaluate the cost comparisons and the economics of the previously presented network architectures when they are deployed to carry broadcasting, interactive and on-line services and telephony. The aim of this description is to highlight all the key elements at the basis of economic evaluation.

The approach of this paper involves the costs estimation of each architecture's various components. The cost per connected home is considered as a standardized unit of analysis for cost comparison. This cost was calculated as follows:

Investment per home connected (1)
$$\frac{\sum_{i=1}^{t} \frac{I_i}{(1+w)^i}}{\sum_{i=1}^{t} \frac{C_i}{(1+w)^i}}$$

where I is the specific and common investments per year, C is the connected I homes per year, w is the W.A.C.C. (weighted average cost of capital), and t is the business plan period.

Estimates were made of the likely changes in cost components over time and between different geographic areas. Assuming that the cabling will start in high density areas before low density and rural areas, cost estimates for all the households in different geographic areas were assessed on the basis of a spreadsheet model.

The expression (1) is a more effective way of evaluating the economics and making comparisons than the use of the standard cost per 'home passed', since this concept is not objective and depends on several factors: technology, time to 'upgrade' a passed home to a connected home, etc.

Moreover, the expression (1) considers the actual network revenue streams independently from the technology.

Finally, the mentioned expression takes into account not a single year, but all the business plan period and emphasizes the financial effect in the calculation of the cost per 'home connected'.

The cost estimates were calculated as an average of confidential sources (Vendors) and official sources such as media reports and catalog studies. Caution should be exercised in using the estimates presented. Furthermore, it should be noted that all the cost comparisons were developed considering a fixed HOME PASSED profile and varying the percentage of connected homes.

As for the services' availability over the different platforms, it should be noted that since the performance of the system is expected to be largely different, all the dimensioning (number of transmitters, number of customers per fiber node, etc.) was made to minimize such differences. In other terms, the actual differences due to different technologies in the services offered were compensated in part by an appropriate dimensioning of the networks (in order to have a certain block probability for concurrent access to the same content in a HFC network, the number of customers per FN has been reduced from 800 to 300–400).

The cost comparison for both IMM and broadcasting services is assessed on the basis of different penetration scenarios. The economic evaluation for broadcasting and IMM services is made on the basis of the architecture to deploy broadcasting services only and the additional costs to extend such networks for IMM services. The allocation of the common costs between IMM and broadcasting services is based on homes connected per service.

For IMM services subscribers, the dimensioning of the devices is calculated under the assumption that 25% of subscribers seek simultaneous and concurrent access to the video or IP server in the peak hour (as already specified).

Specific assumptions for each architecture

Firstly, it must be stressed that 100% of wire line and cable plant is underground.

HFC

For this architecture the following cost elements are considered for broadcasting services.

Distribution node (DN)

DN is the first topological element of the network for broadcast services:

1. Analogue matrix;
2. Combiner;
3. Monitoring and control;
4. AM modulators;
5. 64QAM modulators;
6. Splitters.

All the installation charges and other civil costs are considered.

Links DN–LN

Each DN will be linked with up to 32 LN. Each link length varies from 15 to 40 km, depending on the level of density of the area to be covered. For each fiber link between DN and LN the following costs are taken into account:

1. Civil engineering costs;
2. Percentage of reuse of the infrastructure (only ducts);
3. Installation of the fiber inside the ducts;
4. Percentage of reuse of fibers;
5. Percentage of the total length used for multiple fibers;
6. The average number of fibers for each duct.

Connectors, etc.

The values of all these parameters depend on the density of the area and the level of reuse of existing infrastructures.

Local node

As shown in Fig. 1, the LN will receive the signals from DN and re-transmit these signals to the FN (fiber node) located in the coverage area. In terms of costs the following items are considered at LN level:

1. Receivers from DN;
2. Optical receiver from FN (for up-stream channels);
3. Transmitters;
4. Passive splitters;
5. Passive optical devices;
6. Others.

Additional common costs and installation charges are included in the cost evaluation.

IMM

The interactive and POTS services will be inserted at the local node level. Other specific costs were included for the network upgrading for IMM services: a simultaneous 64QAM modulator for each 16 VOD channels, connection management controller (to handle all the signals from QPSK modulators), ATM matrix interfaces, splitters, receivers, QPSK modulators, combiner system, etc.

POTS

To provide POTS services, other specific costs are included in the calculation (optical transmitters, one for each FN, QPSK modulators, etc.).

Link LN–FN

Up to four FN will be connected on each optical loop. The specified parameters are the same as the above mentioned ones for the link DN–LN.

Fiber node

The FN receives the optical signal from the LN and performs the opticalelectronic conversion. Up to 300–350 users will be connected at each FN, depending on the density of the area. The FN will be installed in the center of the serving area. To estimate the FN costs, a total bundled cost provided by the suppliers was considered. It includes electronic devices (e.g. launch amplifier) and passive devices. Also, civil engineering and installation costs were added.

Link FN–TAP

Each FN will be connected with up to 16 TAP (average), one amplifier and related container were considered for each coaxial link. The length of this link varies from 200 to 250 m.

TAP

This is the last topological element and is located at the building basement. The TAPs are completely passive for broadcasting provisioning services, while active electronics (NIU, containing QPSK modem, etc.) were considered for IMM and POTS services.

Vertical links

A star topology was assumed to link the TAP to the customer premises with coaxial links.

Common costs:

For HFC architecture, the vertical link (MDU) was split with 50% for broadcasting services and the remaining 50% for IMM services, including also the specific costs.

FTTH

The most significant elements of the cost model are:
1. Additional OLT-ONU in the local node, 1 for FN;
2. Additional splitters and combiners in the FN (to reuse the existing fibers in the link LN–FN);
3. Installation of additional fibers between FN and TAP;
4. Installation of ATM-ONU (including specific cards for IMM and POTS users) at the TAP level.

Specific interfaces must be considered for the interconnection with the existing PSTN.

As will be examined further on, in the cost comparison section, it is evident that the electronics costs (cards, ONU, etc) per user are now substantially increased in comparison to HFC: this increase confirms the increasing role the variable costs are playing in the new local loop architectures, thus, reducing the scale economies of the traditional local loop.

For FTTH, no cost allocation for vertical link was made, since two separate supports were used for IMM and broadcasting services.

FTTC

To finalize the economic evaluation of the FTTC solution, only digital video channels were considered with the exclusion of all the analogue chains in the HFTTC network and the inclusion of the switched digital video electronics. In particular, on the basis of the topology described for the FTTH (LN–FN), the link costs are the same as for the parallel PON of FHHT, with the exclusion of the last 200 m from FN to the home. The use of the VDSL cards at the FN level (here FN is only a topological reference, since the FN functionalities were implemented using FN cards at the ONU level) results in a larger investment in distributed electronics.

The increments in the maintenance cost related to this kind of architecture were
also considered.

The specific electronics are the following:
1. Video switch at LN level;
2. ATM-ONU at FN level;
3. PSTN, ISDN, VOD, FN (for broadcasting channels) cards;
4. VDSL cards;
5. Others (rack, box, etc.).

In this case, a typical fixed cost (the coaxial cable) was eliminated and more variable costs (cards, video switch, etc.) were introduced. For FTTC, the copper 2 re-use of the existing plant was considered at no cost.

8. Economics of local loop architectures

This section will assess the current economics of local loop transformations. It is based on the results of the economic models evaluating different network architectures and broadband network plan investments and on the comparison of the different average cost functions calculated using expression (1).

As mentioned above, the following curves highlight the cost trend in the case of a fixed similar 'home passed profile' with variation of the connected homes percentage. Due to the confidentiality of the sources employed for the estimation, only relative cost could be presented in the paper. The investment axis indicates an index not usable as an absolute value.

Fig. 5, Fig. 6, Fig. 7 and Fig. 8 show different average cost functions for different network architectures and services. Starting from Fig. 5 showing the investments per home connected for broadcasting services, it is clear that while the average cost function for copper plant is strictly decreasing, thus, showing economies of scale over all of the possible output range, all the other cost functions exhibit different slopes and different degrees of scale economies. More precisely, the more we move towards architectures with a higher percentage of electronics (FTTC, Radio LMDS) the lower are the economies of scale.

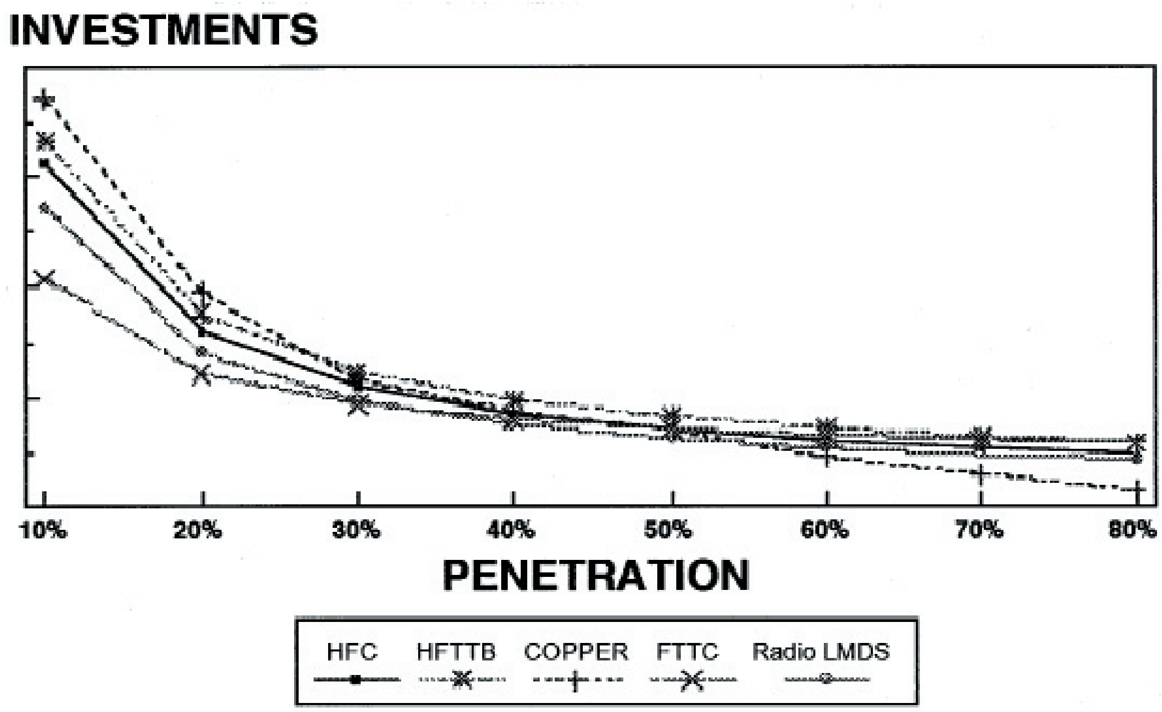


Fig. 5. Investments per home connected (broadcasting services). Comparison with copper plant for POTS only.

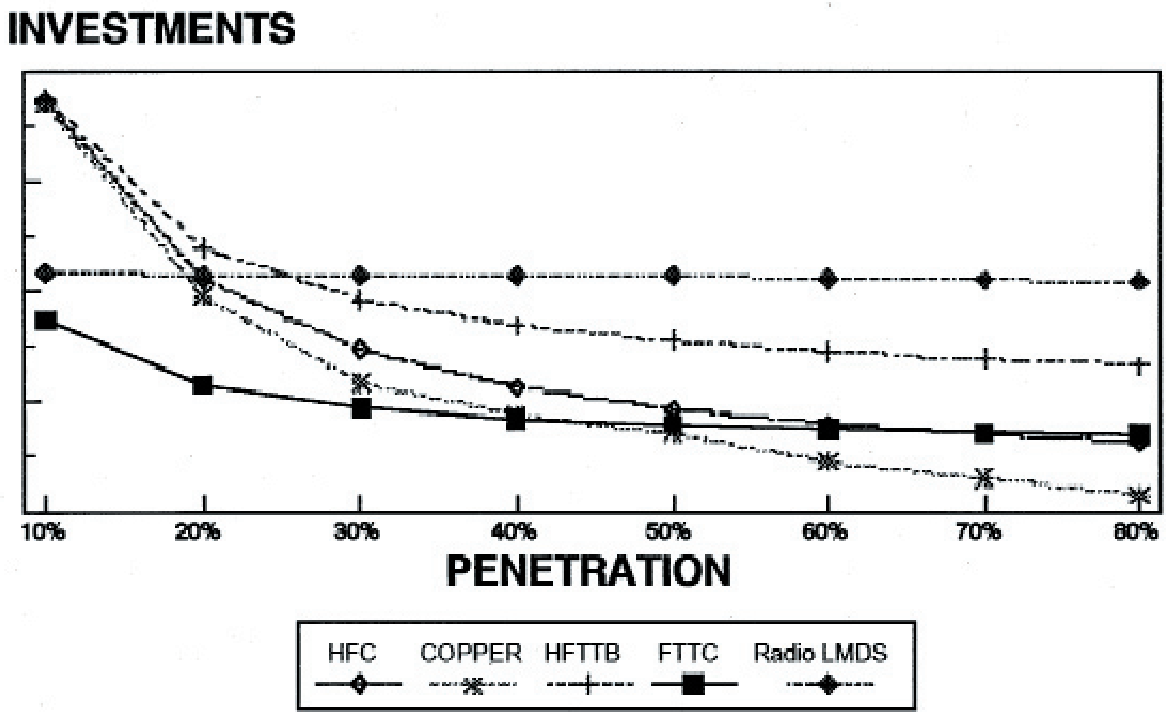


Fig. 6. Investments per home connected (IMM services). Comparison with copper plant for POTS only.

This pattern is clearer, if we look at Fig. 6, which shows investments per home connected for IMM services, and Fig. 7, which presents the investments in civil engineering per home connected. While the first one demonstrates the major role played—as demand varies in this type of services offering—by variable costs (electronics and optronics) and points

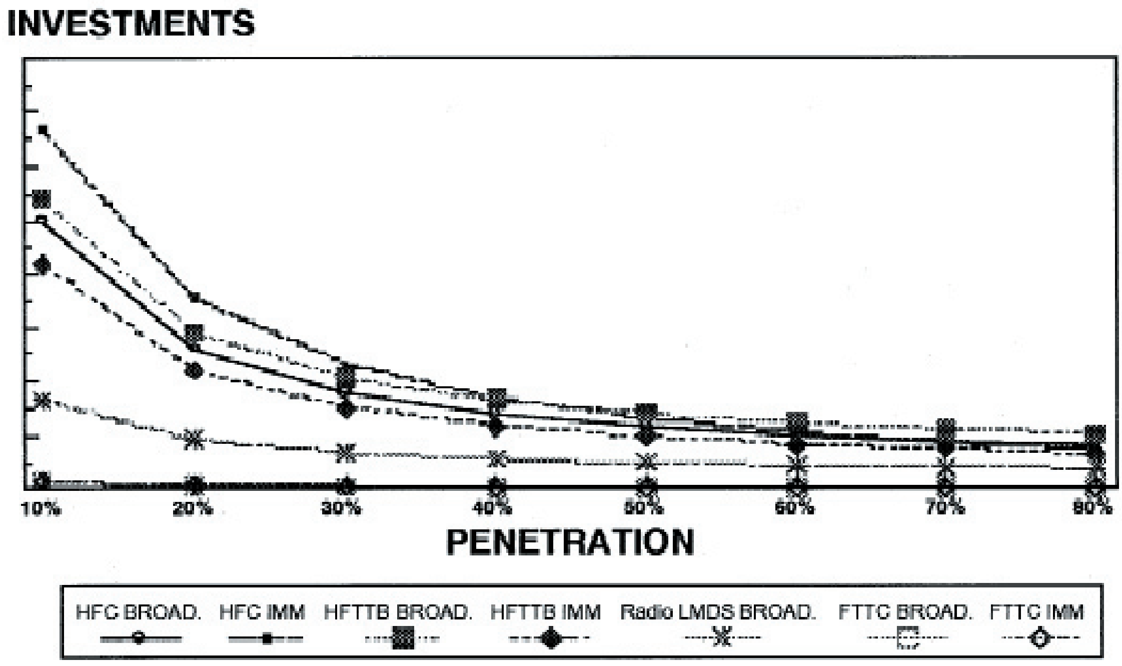


Fig. 7. Investment in civil engineering per home connected.

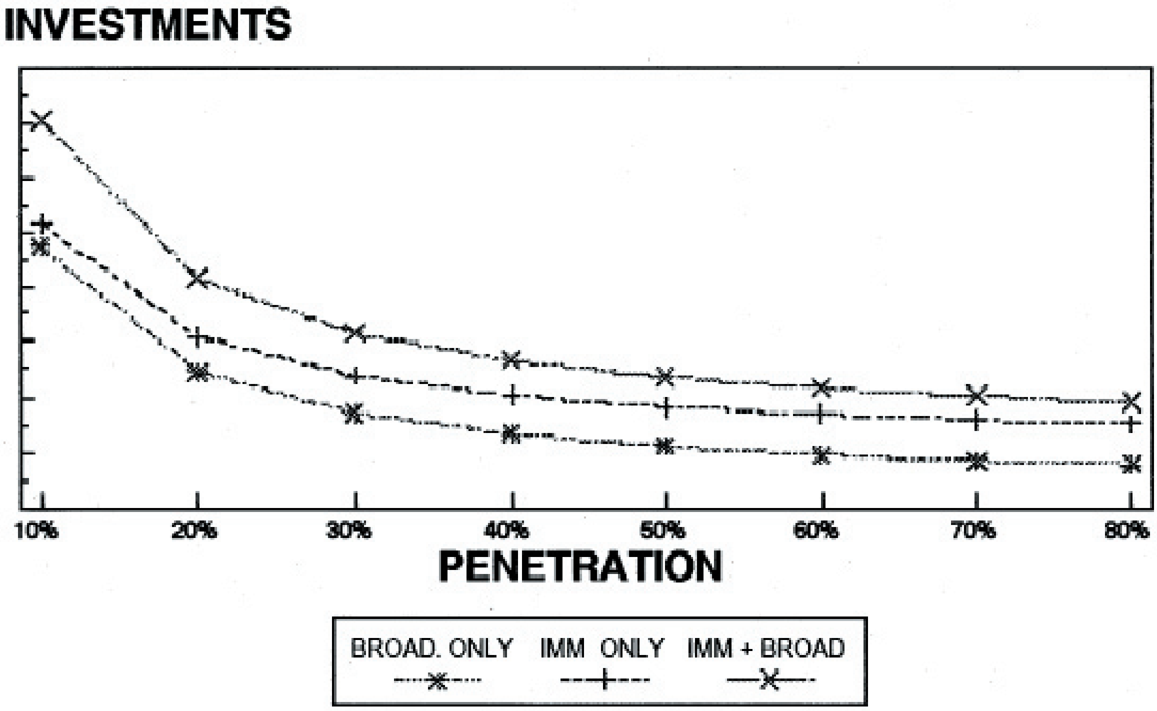


Fig. 8. Scope economies: investments per home connected (HFTTB).

out the increase in the spread of the average functions, the reduction of scale economies for the FTTC type of architecture and the elimination of this effect for the LMDS solution, the second one shows that scale economies in the local loop remain in the civil engineering costs, especially for some network architectures like HFC.

The most significant impact of the new economics of the local loop is outlined in Fig. 8 that shows how, for a HFTTB network, the cost of a joint offer of broadcasting and interactive services on the same network is lower than the costs of offering each service on a separate network (economies of scope). In addition, in our modeling, it appears that there may be also economies in the maintenance costs of one network instead of two.

9. Summary and conclusions

The results of this analysis clearly illustrate the transformations going on in the new local loop architectures for multimedia services. New technologies, wireline as well as wireless, are the source of this change. While for over half a century, the local loop was conceived as the heart of the bottleneck monopoly the new local loop architectures such as the hybrid fiber/coax (HFC), fiber to the curb (FTTC) and, eventually, future fiber to the home/ building (FTTH/B) tend to have production and economic cost characteristics that are fundamentally different from the traditional twisted pair copper distribution networks. Their scale economies tend to be lower because of the new role played by variable costs (electronics and optronics). There are also strong indications that these new architectures can achieve significant economies of scope that were not available to either telephone or cable television networks of the past.

These results have interesting policy implications that are easily summed up in two main issues. Firstly, it is very unlikely that, in today's competitive environment, a single uniform architecture will prevail in the way twisted copper pair dominated the telephone network and coax cable dominated cable television over the past century. The local loop of the future is more likely to be characterized by heterogeneous technologies. As a result, the inevitable competition will lead the successful operators to adopt most, if not all, of the forthcoming access technologies. Secondly, increased competition in the local loop will be the biggest policy implication because of low probability of effective entry pre-emption. On the one hand, the decrease in economies of scale facilitates entry; on the other hand, the increase in economies of scope creates incentives to offer a new range of services through which entrants can differentiate themselves from dominant operators.

Βιβλιογραφία

Ed Perry, Srinivas Ramanathan, **Experiences from Monitoring a Hybrid Fiber- Coaxial Broadband Access Network, Internet Systems & Applications Labatory**, HPL-98-67, April 1998, (Hewlett-Packard Company 1998).

David P. Reed. **Residential Fiber Optic Networks. An Engineering and Economic Analysis**, 1992 Artech House, Inc.,London

Samir Chatterjee & Suzanne Pawlowski. **Enlightening the effects and implications of nearly infinite bandwidth.** Communications of the ACM. June 1999/Vol.42 No.6, 75-83

Paul F. Gagen & William E.Pugh. **Hybrid Fiber-Coax Access Networks**. Bell Labs Technical Journal, Summer 1996, 28-35

Stephen A. Grzelak, Harrison Miles, Jr., Edward S. Szurkowski, William P.Weber,Jr. **Residential Data Services via Hybrid Fiber-Coax Local Access Networks**. Bell Labs Technical Journal, Summer 1996, 88-99

Michael J. Riezenman. Beneath the Internet: **Explosive Growth Drives Improvements to the Infrastructure**. IEEE Spectrum, January 2001, 54-56

Πηγές στο Διαδίκτυο

http://www.iec.org
Το site αυτό είναι το “International Engineering Consortium” και συγκεκριμένα στα links του site για online εκπαίδευση βρίσκεται πολύ υλικό για τις οπτικές ίνες και πως μπορούνε να χρησιμοποιηθούν σε διάφορες υλοποιήσεις δικτύων.

http://www.heal-link.org
Είναι η Ένωση Βιβλιοθηκών Ελλάδος με πολλά άρθρα γύρω από τα οπτικά δίκτυα

http://www.auranetic.com/Optic-Fiber.html
Το site αυτό είναι της “METRObility optical systems” και περιέχει μια σύντομη και περιεκτική παρουσίαση των οπτικών ινών και βασικά της χρήσης τους σε συνδυασμό με νέες τεχνολογίες για την παροχή μεγάλου εύρους ζώνης.

http://www.sciam.com/1999/1099issue/1099shumate.html
Το site αυτό είναι της Scientific America. Περιέχει ένα άρθρο του Paul W. Shumate, Jr. με τίτλο “The Broadest Broadband. A Less Expensive Way to Bring Fiber to the Home” και διαπραγματεύεται με σύντομο τρόπο τεχνο-οικονομικά την αρχιτεκτονική “Fiber to the Home”.

http://users.otenet.gr/~mlazos/opticalfiber.htm
Στη σελίδα αυτή υπάρχει μια εκτενής σύγκριση μεταξύ των οπτικών ινών και των χάλκινων μέσων μετάδοσης.

http://www.ftthcouncil.org/
http://www.ftthblog.com/
http://kmi.pennnet.com/
http://conta.uom.gr
http://en.wikipedia.org
http://www.whatis.com
http://www.brodbandproperties.com