Broadband Access Networks

Optical Networks

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Technologies and Deployments

Springer

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Preface

At present, there is a strong worldwide push toward bringing fiber closer to individual homes and businesses. Fiber-to-the-Home/Business (FTTH/B) or close to it networks are poised to become the next major success story for optical fiber communications. In fact, FTTH connections are currently experiencing double-digit or even higher growth rates, e.g., in the United States the annual growth rate was 112% between September 2006 and September 2007, and their presence can add value of U.S. $4,000–15,000 to the selling price of a home. FTTH networks have to unleash their economic potential and societal benefits by opening up the first/last mile bandwidth bottleneck, thereby strengthening our information society while avoiding its digital divide. FTTH networks hold great promise to enable the support of a wide range of new and emerging services and applications, such as triple play, video on demand, videoconferencing, peer-to-peer (P2P) audio/video file sharing, multichannel high-definition television (HDTV), multimedia/multiparty online gaming, telemedicine, telecommuting, and surveillance.

Wireless technologies, on the other hand, have seen tremendous success over the years and wireless networks have now become increasingly popular due to their fast and inexpensive deployment and their capabilities of providing flexible and ubiquitous Internet access. In particular, currently next-generation fixed wireless broadband networks (deployed as wireless mesh networks, WMNs) are motivated by several applications including broadband home networking, community and neighborhood networking, enterprise networking, and so on. The aggregate capacity and performance of these WMNs can be increased through either the use of multiple channels or through the adoption of high capacity wireless links, e.g., WiMAX. A WMN consists of stationary wireless mesh routers, forming a wireless backbone; these routers serve as access points for mobile devices and they aggregate and forward data to gateways connected to the Internet through a wired infrastructure, which is typically realized by means of a broadband optical access network.

The Broadband Access Networks: Technologies and Deployments book condenses the relentless research, design, and deployment experience of state-of-the-art access networks. The material presented here is intended: (1) to consolidate and disseminate the latest developments and advances in the area of broadband access network technologies and architectures; (2) to combine and share the emergent technologies developed and devised in the last few years; (3) to share the many experiences and lessons learned from the deployments of field/testing trials of these technologies; (4) to model and analyze the broadband access technologies in a comprehensive and detailed manner so it can be used as a supplement textbook for a graduate course on optical networks or advanced topics on computer communications, as well as for graduate students and other researchers working in this area.

The book consists of the following five parts:

- Introduction and Enabling Technologies.
- Copper and Wireless Access Networks.
- Optical Access Networks.
- Optical-Wireless Access Networks.
- Deployments.

Each part consists of 2–6 chapters dealing with the topic, the book contains a total of 17 chapters. The book shares the critical steps and details of the developments and deployment of emergent access network technologies, which is very crucial particularly as telecommunications vendors and carriers are looking for cost-effective broadband "last-mile" access solutions to stay competitive.

Internationally recognized skilled researchers and key talented industrial players have contributed the 17 chapters of the book; they deserve our immense gratitude for their support and professional cooperation. In addition, it has been a pleasure working with Prof. Biswanath Mukherjee and we thank him for his valuable feedback and suggestions.

Finally, it is a pleasure to acknowledge our family and students, as well as Ms. Katelyn Stanne of Springer Press, who commissioned this text.

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Part I
Introduction and Enabling Technologies

Chapter 1
The Anatomy of an Access Network

Nicholas Gagnon

Abstract This chapter will review the different access network technologies that promise to support multi-stream video service deliveries. Technologies such as ADSL2+/VDSL2 copper, fiber to the home/building, hybrid fiber coax, and wireless architectures will be analyzed, pinpointing the pros and cons of each of these alternatives, in context of the increasing popularity and customer demand of high-definition video services delivery over access network architectures. All these technologies have particularities and operators establishing their technology roadmaps and their business cases need definitely to have a look at the global picture before taking any specific decisions.

1.1 The Evolution Path of Typical Access Networks

Long gone are the days where access network was built only with copper cables and was hardly allowing a data transmission at 56 Kbps (kilobits per second) in the best of the cases! Nowadays, copper cables remain present in the access networks because new technologies and compression techniques allow the operators to leverage these existing assets and provide broadband services over them. So much copper loop plants are in place that operators have second thoughts about replacing them, especially when they analyze the business case of fiber-to-the-home (FTTH) projects. Copper loop plant remains important asset for the operators. ADSL2+/VDSL2 technology can be used to transmit 24–30 Mbps (megabits per second), over a typical 1–1.5 km copper loop plant. This level of bandwidth performance is interesting for many broadband applications and certain network operators consider this sufficient to deliver broadband services.

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1.2 The Future Is Bright for IP Video

Operators may become aware they have much greater opportunities than offering 24–30 Mbps of broadband services, especially if they adapt their transport network to deliver converged IP (Internet protocol) services. Converged IP services are made possible when operators choose to use IP technology to transmit high speed Internet (HSI) data services, voice service (VoIP) and IP Video, including IPTV (Internet protocol television), video on demand (VoD), and streaming video on the Internet. Offering all these IP-based services simultaneously to the subscriber may require more than 24–30 Mbps, especially when subscribers want to view different video services on more than one television sets in the same house simultaneously and particularly when the video services are in high definition television (HDTV). Table 1.1 presents the different bandwidth requirements for different IP converged services delivered to subscribers over the access network.

Table 1.1 Bandwidth requirement for IP services

IP services	Standard definition	High definition
Windows Media or H.264 streams	1–1.5 Mbps	7–8 Mbps (1080p)
Hulu.com (Streaming Video)	1 Mbps (480p)	2.5 Mbps (720p)
MPEG-2 streams (IPTV or VoD)	3.5 Mbps	18–20 Mbps
MPEG-4 AVC streams (IPTV or VoD)	1.5 Mbps	9 Mbps
VoIP call (full-duplex)	128 Kbps	
Internet on-line gaming	10 Mbps	
Peer-to-peer file sharing on the Internet	As much bandwidth in upload/download allowed by the ISP	

The bandwidth requirement for IP video services (IPTV, VoD, or Streaming video on the Internet) depends of the video codec (compression/decompression algorithm) used. MPEG-4 AVC is now deployed massively in the industry and its bandwidth consumption advantage requires about half the bandwidth than MPEG-2-encoded content.

1.3 Not All the Access Network Connection Are Created Equal

Having listed the different bandwidth requirements for broadband IP services, the interesting question to ask is “How much bandwidth to the home a typical subscriber may require to satisfy his/her broadband IP services needs?” The answer to this question will vary a lot depending on the region of the world, the number of television and computer sets owned and the number of family members living in the household of this subscriber and ultimately on the discretionary budget for broadband services entertainment this subscriber may have. All the preceding factors will of course influence the number of streams that may be demanded simultaneously by all the users living in the household of the subscriber.

All these users requiring simultaneous streams (VoIP, IPTV, VoD, streaming video), peer-to-peer file sharing and Internet on-line gaming will be using the access network connection fixed bandwidth; therefore, a limited number of streams will be available simultaneously. In a not so far future, it is very realistic to envision a critical mass of subscribers requiring access network connection allowing over 40 Mbps downstream (from the network to the home) and at least 20 Mbps upstream (from the home to the network). Figure 1.1 presents a realistic breakdown of downstream and upstream bandwidth requirement separated in services.

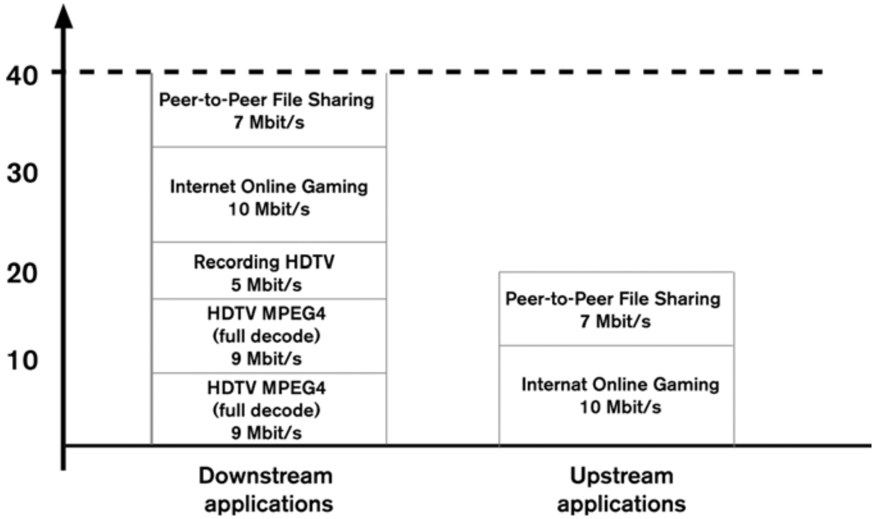

Fig. 1.1 Realistic access network bandwidth requirement for broadband IP connections

Other access network architecture can deliver greater bandwidth performance than what ADSL2+/VDSL2 copper access network architecture can deliver. Fiber to the home is one candidate, with a solid capital expenditure (CAPEX) tag associated with this option, particularly associated with the construction of the fiber-optic network. Hybrid fiber coax (HFC) used by multi-service operators (MSO) delivering community access television (CATV) is another option, particularly when leveraging the DOCSIS 3.0 technology. HFC networks are not perfect; important operation expenditures (OPEX) are associated with this technology. Wireless is also an option (WiMAX, long-term evolution or LTE) evolving very rapidly, but it is still to demonstrate if this option can support solid competitive performance for video services. This is not the case right now, particularly for multi-streams video transmission.

There is no clear winner or champion yet among all the access network architectures; each one has its pros and cons. In the following pages, we will review all these access network architectures and try to objectively compare them against the others and analyze in greater details their main particularities.

1.4 Broadband Copper Access Network Using ADSL2+/VDSL2 Technology

The bandwidth performance delivered at the home of a subscriber by a copper-based access network using ADSL2+/VDSL2 technology depends on the length of the copper loop. Typically, it is possible to achieve 24–30 Mbps over a 1–1.5 km copper loop plant. This network architecture is commonly used by numerous network operators around the world. This option is attractive for the operators because they can re-use the existing last section of the copper loop plant already installed. Doing so, the operators are leveraging an important asset they already own. They need to push the fiber-optic technology deeper in the access network to connect a remote ADSL2+/VDSL2 digital subscriber line access multiplexer (DSLAM), but this investment is less important than if they would decide to go with the fiber optic all the way to the home.

It is interesting to compare the typical 24–30 Mbps bandwidth performance (downstream) and 1Mbps (upstream) over a reasonable distance of 1–1.5 km copper loop plant using ADSL2+/VDSL2 technology with the realistic access network bandwidth requirement for broadband IP connections scenario presented in Fig. 1.1. In this previous scenario, three simultaneous MPEG-4 AVC-encoded IP video streams (IPTV or VoD) are downloaded, corresponding to a bandwidth requirement of 23 Mbps, two viewed streams, fully decoded, 9 Mbps each streams, and one stream digitally recorded on a personal video recorder (PVR) at 5 Mbps. The network will require an extra 2–3 Mbps of bandwidth for buffering, leaving very little bandwidth extra for Internet on-line gaming and peer-to-peer file sharing on the total capacity of 25–30 Mbps. If this scenario seems realistic to the reader, he must come to the conclusion that an access network architecture using ADSL2+/VDSL2 technology has very little margin for error when multi-streams high definition IP video is highly considered by the subscribers.

Broadband copper access network using ADSL2+/VDSL2 technology remains a technology of choice to deliver simultaneously one high-definition IP video stream with one or two standard definition IP video streams, high speed Internet services and VoIP calls (Fig. 1.2).

VDSL2 technology has been used a lot for inside the building copper-based network in Multi-dwelling units (MDU). In MDU situations, where copper loop plant distances are typically smaller than 500–600 m, VDSL2 technology can deliver over

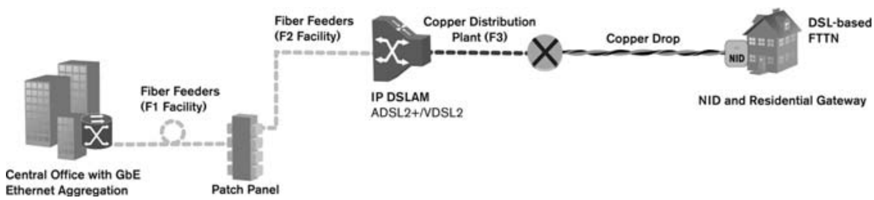

Fig. 1.2 ADSL2+/VDSL2 broadband copper access network representation

60 Mbps of bandwidth (40 Mbps downstream and 20 Mbps upstream). VDSL2 technology deployment inside MDU has been adopted as a mainstream trend for economic and ease of installation reasons.

The capital expenditure (CAPEX) of building a broadband copper access network using ADSL2+/VDSL2 technology is definitely lower than a fiber-to-the-home project. The saving associated with the re-use of the last copper loop plant is significant, when a distance of 1–1.5 km is kept. The trade-offs for the operator are not trivial, the bandwidth performance will be limited and the operation expenditure (OPEX) to maintain the copper loop plant will be greater, compared to bandwidth performance and OPEX for the maintenance of a FTTH network.

1.5 Fiber-to-the-Home/Building (FTTH/B) Access Network

It is common knowledge that fiber-optic technology has no bandwidth limit. The usual limitation is not the physical medium, it is the budget allowed to connect electro-optical equipment at both ends that will normally determine the transmission speed running on the fiber optic itself. Transmission equipment makers have developed different types of electro-optical equipments creating different types of fiber-to-the-home/building (FTTH/B) access network architectures that have been already deployed in many regions of the world. The three main FTTH/B network architectures existing today are point-to-point Ethernet FTTH (or home-run fiber to the home), passive optical network (PON) FTTH, and Wavelength Division Multiplexing (WDM) PON FTTH.

1.5.1 Point-to-Point Ethernet FTTH (Home-Run FTTH)

This architecture is created by connecting a subscriber with a dedicated connection between the subscriber's location and the central office (CO) of the operators. In some region of the world this architecture has been deployed and financed by community, the subscriber being the owner of its access network connection. One other interesting particularity of this architecture is the fact that it can support 1 Gbps (Gigabit per second) rate by installing the right transmission equipments at both ends. For residential purposes 100 Mbps rate are more popular. Transmission rates are always symmetrical in the case of point-to-point Ethernet FTTH .

One downside of this network architecture is the quantity of fiber in the access network is more important than other FTTH architectures. This architecture does not use passive splitter to combine the traffic of many subscribers on a portion of the fiber plant; each subscriber has its own dedicated strand of fiber optic all the way from the CO to the subscribers' home (home-run). The distance between the CO and the subscriber location will depend on the quality and power of the laser included in the electro-optical transmission installed at both ends of the fiber-optic link. Typical distance of 40 km can be reached with good quality 1550 nm optical transceivers, and 20 km can be reached with 1310 nm optical transceivers.

1.5.2 Passive Optical Network (PON) FTTH

On the passive optical network (PON) side, two protocols are offered to organize the service layer transmission. Ethernet is one, developed around the specifications of the IEEE 802.3ah and Gigabit Encapsulation Method, or GEM protocol, developed around the ITU-T G.984 recommendation, the higher bit rate successor of broadband PON (BPON).

The PON architecture uses passive splitter components in the FTTH access network to allow multiple users, typically a group of 4, 8, 16 or 32 users, to share a distribution fiber transporting typically 2.5 Gbps of traffic for GPON. The PON FTTH architecture uses significantly less fiber miles in the access network than point-to-point Ethernet FTTH.

A PON access network uses at least two wavelengths, one wavelength downstream, typically 1490 nm, and one wavelength upstream, typically 1310 nm. A second downstream lambda can also be used for RF video overlay, typically 1550 nm. Even if the RF overlay wavelength usage was more popular when BPON network was deployed, the BPON transmission rate was limited at 622 Mbps per wavelength; hence, the separation of video on a second BPON card was the norm, the RF overlay wavelength can be used on GPON system.

The typical distance of a PON FTTH access network is 20 km. The typical downstream bandwidth a PON FTTH connection provides, per subscriber, is 80 Mbps for a gigabit passive optical network (GPON), or 2.5 Gbps with 32 splits. The upstream bandwidth, per subscriber, is typically 40 Mbps, or 1.25 Gbps with 32 splits.

Passive optical network PON architectures require important capital expense (CAPEX) investment, particularly when fiber optic is not already installed in the access network. According to Alcatel-Lucent, construction or labor costs of all the segments of the access network, from the Central Office (CO) to the home of the subscribers, are the most important (digging, trenching, installation of ducts, laying the fiber optic in ducts or aerial installation of fiber optic using poles), and account for nearly 60% of the total estimated charges of around $1250 for Greenfield situation or $1600 for overbuild situation. Equipment CAPEX (fiber, splitter, drop cable, electro-optical transmission equipments) follows, accounting for about 40% of the total estimated charges [1] (Fig. 1.3).

On the other side, PON architecture is envisioned as bringing important advantages relative to operation expense (OPEX). According to IP Business News, the operation expense (OPEX) or annual maintenance charge for a mile of FTTH PON

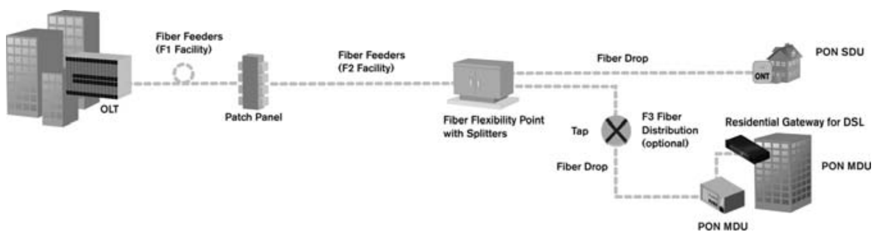

Fig. 1.3 Representation of a PON FTTH architecture

plant is about one-tenth of the ones to maintain hybrid fiber coax infrastructure [2]. Verizon FiOS experience briefing supports this statement in presenting the total field dispatches and OSP-related dispatches are showing solid decline from fiber-to-the-node to fiber-to-the-home maintenance process, with 80% reduction [3]. These economies alone would be important enough to justify the investment in PON FTTH and obtain a return on the investment (ROI) in 10–15 years.

Standard organizations (ITU and IEEE) and operators organizations like full service access network (FSAN) are discussing the next 10 Gbps standard for PON. Some additional works at the ITU are also made to extend the reach of GPON access network to 60 km of distance.

1.5.3 Wavelength Division Multiplexing (WDM) PON FTTH

WDM PON is using the same passive optical network architecture with passive optical splitter component. The wavelength division multiplexing (WDM) difference is that this system is using several wavelengths, one wavelength per subscriber. An array wave guide (AWG) splitting each wavelength to one specific route to feed one subscriber is used as a passive splitter.

The commercial WDM PON available in the market at this time are providing a typical 100 Mbps per wavelength to the subscriber, but developments are in the work to increase this transmission rate at 1 Gbps per wavelength and planning activities to bring the transmission rate to 10 Gbps per wavelength are active.

1.6 Hybrid Fiber Coax Running DOCSIS Protocol

The hybrid fiber coax network architecture has proven to be flexible and rugged in the last 10 years, since the multi-service operators (MSO) have decided to provide first high speed Internet (HSI) service, followed by digital phone or voice over IP (VoIP) service and more recently digital high definition (HD) video, either broadcast or video on demand (VoD), on this network architecture previously used to radio frequency (RF) broadcast video. MSO's networks have evolved in this period of time; higher bit rate and wavelength division multiplexing (WDM) have been installed in the transport ring of the network, typically the same improvement that all network providers offering broadband services have realized in this same segment of their network (Fig. 1.4).

The hybrid fiber coax access network portion begin at the distribution hub; from this point a variable length of fiber optic will feed an optical node where the optical-electrical conversion of the signal is realized to adapt the signal for the coaxial portion of the network. The coaxial portion of the HFC network has evolved with the installation of bi-directional and more powerful amplifiers, allowing broadband services transmission. The coaxial sections, trunk and line, can reach typical distance greater than 8 km, leveraging the use of the amplifiers.

The transmission of broadband services over HFC network has been greatly eased by the development of the data over cable service interface specifications

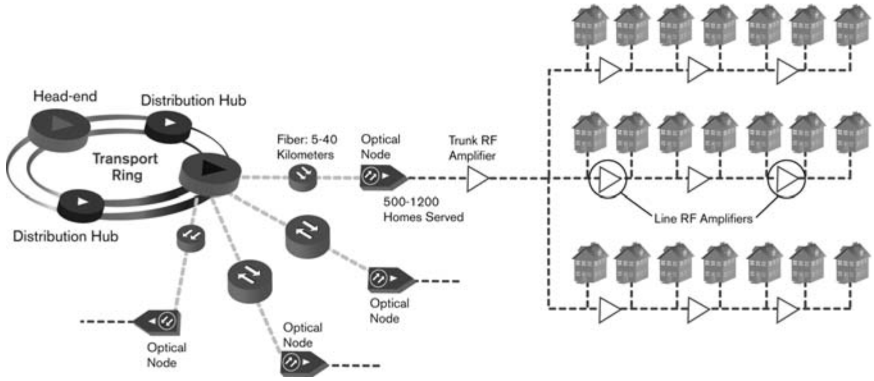

Fig. 1.4 Representation of a hybrid fiber coax network architecture

(DOCSIS) or CableLabs Certified Cable Modem project. Founded in 1988 by cable operating companies, Cable Television Laboratories, Inc. (CableLabs®) is a non-profit research and development consortium that is dedicated to pursuing new cable telecommunication technologies and to helping its cable operator members integrate those technical advancements into their business objectives.[1] DOCSIS is using channels of 6 MHz of RF spectrum on the coaxial medium to carry 38 Mbps of broadband services.

The first commercial application of the new DOCSIS 3.0 will allow channel bonding, upstream and downstream, to allow bi-directional transmissions up to 100 Mbps for each subscriber. This level of performance is definitely competitive with fiber-to-the-home services. The main disadvantage of the HFC network remains in the operation expense (OPEX) of maintaining these cascades of trunk and line RF amplifiers, this expenditure represents about $1,100 per mile of plant per year [2].

The HFC network architecture remains performant and flexible, even if the OPEX of the maintenance of the RF amplifiers is important. MSOs have the alternative to reduce this expenditure by investing in deeper fiber architecture to reduce the length of the coaxial loop plant in the HFC network, thereby reducing or eliminating the cascade of amplifiers and the OPEX for the maintenance of these amplifiers.

Another important consideration for the MSOs is to reduce to the minimum the back-office equipment modifications (cable modem termination system, CMTS, RF video equipments) at the distribution hub, as well as the cable modems and set-top boxes at the customer locations. Vendors are proposing to the MSOs a fiber-to-the-home network architecture using active optical node and amplifiers distributed in the access plant, feeding RF network interface unit at the customer location. In this case MSOs can leverage the bandwidth of FTTH without having to change back offices and customer premises equipments.[2]

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[1] CableLabs http://www.cablelabs.com/

[2] As an example of FTTH network architecture optimized for MSO, reader can refer to CommScope Bright-Path solution at http://bb.commscope.com/eng/solutions/fttx/index.html.

1.7 Wireless Access Network

Wireless access network architecture is used since many years to transmit voice over Internet protocol (VoIP) and high speed Internet (HSI) data. Pre-wiMAX technologies have demonstrated typical point-to-multipoint performance of 5–6 Mbps over a distance of 8–10 km. This network infrastructure has not demonstrated performance sufficiently reliable to be used to stream IP video, particularly for high definition signals or for multi-streams of standard definition video signals. The limitation of 5–6 Mbps says it all. Not enough to transmit HD content, too much at the limit to even transmit one stream of standard definition content.

WiMAX and long-term evolution (3GPP LTE) will provide technologies that will improve the performances stated above. These technologies are not deployed in the field yet, therefore, the exact specifications associated with these new technologies are not neither precise yet. About 20 Mbps downstream and 5 Mbps upstream over reasonable distance are proposed in point to multipoint. This could position wireless access network as an alternative for delivering video signals as well. This architecture should never be a candidate for multi-streams HD transmissions, but if it can transmit two video streams, one high definition and one standard definition, along with voice and HIS data, this might create an interesting alternative, particularly for rural areas where the cost of deploying wire line architecture is prohibitive.

1.8 Summary

We have seen in this chapter that many technologies can be used to connect the subscribers in the last portion of the network, the access network. All these technologies provide different levels of performance in terms of bandwidth or downstream line rate and upstream line rate. It is this bandwidth or these downstream and upstream line rates that will determine how many simultaneous services the customers will be able to consume.

The main driver that has pushed the operators to invest and improve their access networks in the last years has been the capacity to transmit video most effectively. The common denominator to all the network architecture presented is the fiber-optic infrastructure, or how deep or close this fiber-optic infrastructure is to the subscribers. Without a doubt, the deeper the fiber architecture is and the more expensive will be the project, but the more competitive the services will be, particularly the number of video streams in high definition to be delivered to the subscribers. The other important parameter, greatly influenced by the proximity of fiber to the subscriber, is the upstream performance of the subscriber connection. This parameter will gain its importance the more the subscribers will generate or share content from their location, again particularly video content.

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Chapter 2
Drivers for Broadband in Europe

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Abstract In this chapter we present the current status of broadband deployment in Europe and discuss the drivers for further deployment and the expected evolution in terms of the market, the services, the choice of technical solutions, and the main players. The main drivers for broadband are identified and discussed in the context of the European environment. We present an overview of the broadband regulatory framework in Europe as well as expected developments and discuss its impact on the evolution of broadband in this part of the world.

2.1 Introduction

Datacom services have become an integral part of our everyday lives in the course of the past decade. Information, communication, and entertainment are converging, the PC and the TV are merging with our phone. The changes we are witnessing in the access network today are at least as dramatic as the changes introduced by the telephone at each home in the previous century. The access network is being literally transformed from a network of plain old telephone services at 64 kbit/s carried on

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