MASTER

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implications of scale economies and entry conditions in FTTH networks in the Netherlands

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MASTER'S THESIS

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Implications of scale economies and entry conditions in FTTH networks in the Netherlands

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Voorwoord

Voor u ligt mijn afstudeerscriptie, het resultaat van mijn afstudeeronderzoek bij VolkerWessels Telecom in Amersfoort. Ervaren mensen vertellen me dat teksten langer dan twee A4-tjes zelden worden gelezen, daarom zijn de twee eerste pagina's van deze scriptie gereserveerd voor dit dankwoord en een beknopte samenvatting.

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Bij het schrijven van dit verslag heb ik veel gehad aan de commentaren van vrienden die het met een kritische blik gelezen hebben (waarbij mijn gebruik van *pluralis modestiae* wel wat vraagtekens opriep). Daarvoor wil ik Henk-Jan en Bas danook bijzonder bedanken. Tot slot een heel groot dankwoord naar mijn ouders die me de afgelopen jaren altijd ondersteund hebben.

Deze scriptie vormt het einde van mijn studietijd. Als doorgewinterde (dat mag ik na acht jaar denk ik wel zeggen) student heb ik een mooie tijd gehad. Maar aan al het goede komt een einde en het is tijd voor een nieuwe uitdaging.

Marc
'Jonge onderzoeker'

Samenvatting

Dit onderzoek belicht de invulling van het ‘open netwerk’ concept in glasvezelnetwerken in Nederland vanuit de rol van de netwerk operator. Een glasvezelnetwerk ofwel Fibre-to-the-Home (FTTH) biedt voldoende capaciteit om alle mogelijke afnemers in het dekkingsgebied van alle gewenste diensten te voorzien. De aanleg van een netwerk zorgt echter voor zeer grote vaste en verzonken kosten. De schaalvoordelen van het netwerk zorgen voor sterk dalende kosten bij een hoge behaalde penetratiegraad, wat inhoudt dat het inefficiënt zou zijn om een tweede infrastructuur te bouwen.

Om toch te kunnen profiteren van de voordelen die concurrentie biedt, kunnen meerdere dienstenaanbieders gebruik maken van dezelfde FTTH infrastructuur: een open FTTH netwerk. Dit leidt, in tegenstelling tot de oude verticaal geïntegreerde telecomnetwerken waarbij de netwerkeigenaar ook de diensten aanbiedt, tot een desintegreerde marktstructuur met een netwerk operator en (meerdere) dienstenaanbieders. Een netwerk operator heeft de technische keuze hoe open toegang te bieden aan dienstenaanbieders. Specifiek kan de operator kiezen voor apparatuur die toegang biedt op laag 2 (data link) of laag 3 (IP) van het OSI netwerklagen model. Deze keuze is van invloed op de toegangsvoorwaarden voor dienstenaanbieders en de kosten voor de operator en dienstenaanbieders.

Met gegevens van twee FTTH projecten in Nederland is de mogelijke marktstructuur en concurrentie tussen dienstenaanbieders op een open netwerk berekend. Het eerste project is OnsNet, het relatief kleine glasvezelnetwerk in Nuenen, het tweede project is een nog te bouwen netwerk in een middelgrote stad. De berekeningen van de lange termijn kosten van de netwerk operator en dienstenaanbieders laten zien dat schaalgrootte van groot belang is om meerdere dienstenaanbieders op één netwerk te kunnen laten concurreren. Een klein netwerk als dat in Nuenen zou zonder de gekregen subsidie niet meerdere dienstenaanbieders kunnen ondersteunen. Een groter netwerk zoals in het stad-project kan meerdere aanbieders ondersteunen wanneer voldoende penetratiegraad wordt bereikt. Het onderzoek laat zien dat het bouwen van een technisch open netwerk niet voldoende is om concurrentie op dienstenniveau te waarborgen. Zolang netwerken te klein zijn om interessant te zijn voor dienstenaanbieders zullen ze slechts in naam open zijn en in de praktijk verstoken blijven van concurrentie.

Een onafhankelijke netwerkoperator kan het beste streven naar schaalgrootte, zowel in het bouwen van zijn netwerken als in het beheer ervan. Terwijl een laag 3 systeem meer geschikt is voor een verticaal geïntegreerd netwerk is een laag 2 systeem een betere keuze voor een onafhankelijke netwerk operator. Het kiezen voor laag 2 apparatuur verlaagt de beheerskosten voor een onafhankelijke operator, met name bij toegang voor meerdere dienstenaanbieders. Het koppelen van afzonderlijke netwerken is een manier om de totale schaal van alle gekoppelde netwerken te vergroten.

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Appendices

Chapter 1

Introduction

This thesis is the result of my research to obtain the degree of Master of Science in Technology and Policy at the Department of Technology Management of the Eindhoven University of Technology. The research was carried out at VolkerWessels Telecom in Amersfoort.

1.1 Motivation

Any discussion about Fibre-to-the-Home (FTTH) in the Netherlands invariably includes a reference to the fact that the fibre network has to be an 'open' network. Whether the speaker is a local government official, housing corporation representative or policy maker, the network being 'open' is always of vital importance.

But what exactly *is* an 'open' network? No precise definition of 'open' exists and the definitions used differ significantly. Below are a number of quotes from different FTTH projects in The Netherlands, that show some of the different views on what an open network is (emphasis added):

> "The network is an open network and is in principle *open to all providers.*"
> – Cooperative OnsNet in Nuenen

> ". . . was chosen for the open infrastructure model. This means the *ownership of the passive- and active network are in different hands.*"
> – Almere city fibre pilot

> "An important starting point is that the new network will be an open access network. This means that the *use of the infrastructure does not have to lead to obliged use of certain services.*"
> – Gigaport FTTH project, Deventer

As the emphasised texts make clear, no consensus on what an open network is exists, some projects refer to ownership while others focus on service providers. This thesis further explores the concept of an open FTTH network using real-world data from projects in The Netherlands.

1.2 Research goal

The goal of this research is to gain insight, from the perspective of the network operator, into the common desire in the Netherlands for FTTH networks to be an ‘open’ network. We investigate what an open network is, and how FTTH networks can be made open. De developments from the current emerging market for fibre networks towards a mature market will be discussed and an engineering cost model will be used to predict a likely market structure in these open networks.

We will use real-life data from the FTTH network in Nuenen. After accurately delineating the role of the network operator and what the implications of technical choices are, the effect on competition in the services market will be discussed. We will also use data from a larger network which will cover an entire city, to show differences with the Nuenen case and to illustrate the movement towards a more mature market.

1.3 About VolkerWessels Telecom

VolkerWessels is a Dutch-based construction group dating back to 1854 whose core activity consists of the design, development, realisation and management of construction projects. The entire group has a total of 17000 employees, spread over approximately 125 operating companies in Europe and North West America. The companies of the VolkerWessels group (Royal Volker Wessels Stevin NV) are divided in three fields: Building and Property Development, Infrastructure, and Specialisms (railroad and traffic systems, parking, etc.).

VolkerWessels Telecom is part of the Infrastructure field of the VolkerWessels group and designs, builds, maintains and manages fixed, mobile and wireless networks in the Netherlands and Europe. Amongst many other things, VolkerWessels Telecom builds and operates Fibre-to-the-Home networks for their principals.

1.4 Report outline

The outline of this thesis is as follows. After this introductory chapter, chapter 2 gives background information on Next Generation Networks and how market structure in these networks can be different from traditional networks. Chapter 3 provides more information on FTTH networks, while chapter 4 explores the concept of an open network and investigates ways of implementing this in FTTH. Chapter 5 defines the theoretical framework to assess the potential market structure in open FTTH networks and the methods to evaluate the available data. Chapters 6 and 7 apply the research methods from the previous chapter on empirical data from two real-world cases. Chapter 8 goes into the business implications of operating an open network, and provides advice for an operator of such networks. Chapter 9 concludes. A glossary with explanations of the terms used in this thesis can be found in appendix A.

Chapter 2

Next Generation Networks

This chapter discusses the concept of Next Generation Networks (NGN) and the available network technologies. The opportunities NGN offers for different market structures will be discussed in section 2.1. After that, section 2.2 describes different possible access network technologies and section 2.3 discusses the growth potential of these and possible infrastructure competition. Section 2.4 describes regulatory challenges for Next Generation Networks.

2.1 Vertical integration vs. disintegration

A few years ago, the telecommunications landscape was much simpler than it is today. Vertically integrated providers provided a single service over the network they owned, and thus the infrastructure said something about the service: telephone services were provided through the telephone network and radio/TV broadcast was provided via the cable network. Nowadays this distinction is less clear and disappearing. Cable networks were upgraded for two-way communication and the capacity of the copper network was expanded. Both networks are used to provide broadband Internet access and voice telephony can also be delivered through the cable network. The network is becoming more and more independent of the services offered, meaning any service can be offered through any of the available access networks.

This has implications for businesses, consumers and regulators. Businesses have to realise the opportunities and the new competitors they face. Business models have to change to reflect changes in the industry. Consumers have to realise that they do not necessarily need a telephone line to subscribe to telephone service. Research indicated many consumers would prefer to buy their telephone service, Internet access, and TV service from one company rather than several, which is common now [Isern & Perdomo, 2005; KPMG, 2005] (though they may prove reluctant to switch). Regulators have to adapt their regulatory framework to reflect the current trends in telecom.

The ITU definition of Next Generation Networks (NGN) gives more insight in the technological aspects of new telecommunications networks rather than traditional networks, in which services and networks are becoming independent of each other. The ITU defines a Next Generation Network as follows: “A packet-based network able to provide telecommunication services and able to make use of multiple broadband, QoS-enabled transport technologies and *in which service-related functions are independent from underlying transport-related technolo-*

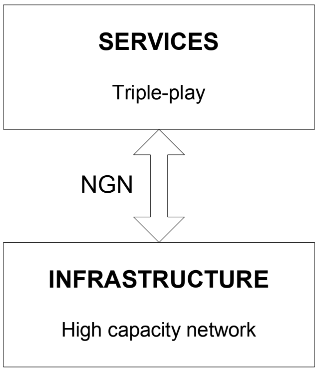


Figure 2.1: NGN technological layers

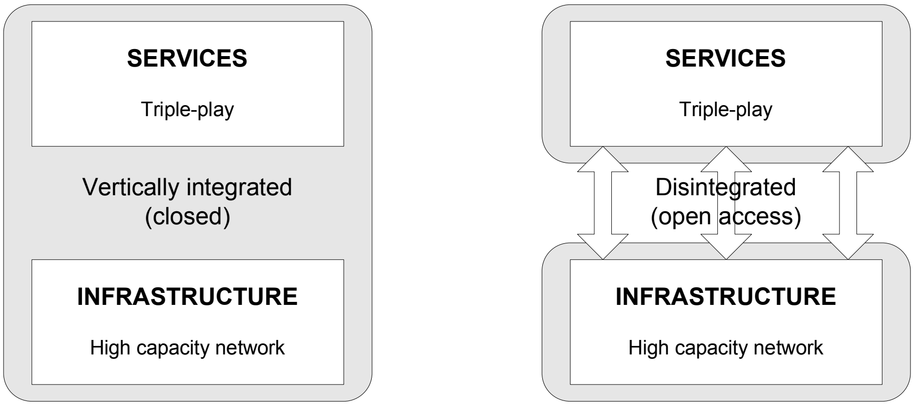
gies. It enables unfettered access for users to networks and to competing service providers and/or services of their choice." [ITU, 2004a, emphasis added].

One of the most fundamental characteristics of NGN is the separation of services and the underlying transport network, a two-layer model with a NGN transport layer (infrastructure) and a NGN services layer [ITU, 2004b]. The demands placed on the transport layer (by the service layer) will determine the next generation infrastructure, which is elaborated on in section 2.3. Figure 2.1 shows the technological separation of services (in this case triple-play, the combination of voice, video and Internet services) and infrastructure in Next Generation Networks.

The concept of layers in the telecommunications industry is not new. For instance, a "layered model of telecommunications and information service provision" was described in a study for the European Commission in 1994 [Arnbak et al., 1994], cited in [Vogelsang & Mitchell, 1997]. The industry has been moving technologically from vertical integration to horizontal layers for a long time which has had and will have its impact on the market structure.

As a result of technologically separating infrastructure from services, the market structure in Next Generation Networks has the possibility of a vertically integrated or a disintegrated (layered) market structure. Figure 2.2 on page 5 combines the technological possibilities of NGN networks with the possible market structures. While a vertically integrated company offers services on its own network, access networks can also be used by multiple service providers to provide services to consumers. This is known as 'open access' or an *'open network'*.

A transition from a vertically integrated to a layered market structure has important implications for telecommunications companies and service providers. Vertically integrated companies have to decide on a course of action. Dekker [2005] writes the strategy of the Dutch telephone incumbent KPN is to evolve from a company owning a valuable network on which it offers a number of services to a service provider, using its own or other networks. The focus on services shows in KPN's current corporate mission: "We are committed to providing



(a) Vertical integration

(b) Open access network

Figure 2.2: NGN market structures

a portfolio of modern, high quality *telecommunications services* to our customers. We want to help our customers to achieve their goals and to enrich their lives, whether for business or pleasure." [KPN, 2005b, emphasis added]. Of course the PSTN network is still a vital part of the company as an enabler for the services, but other networks can be used as well.[1] The implications of a layered market structure are not only visible in business decisions. Networks will have to be built with open access in mind, to be able to provide access to multiple service providers. This is not a trivial matter, as the rest of this thesis will show.

2.2 NGN and different access network technologies

A telecommunications network roughly consists of a backbone and an access network. The access network provides the 'last-mile' connection from the backbone to the consumers. This section provides an overview of the current broadband access landscape in The Netherlands, and the available access network technologies.

The level of broadband access in the Netherlands very high. The Netherlands has one of the world's highest penetrations of broadband subscribers[2] (over 25.3 subscribers per 100 inhabitants), third after Iceland (26.7) and South Korea (25.4). This 25.3% penetration rate corresponds to over 58% of all Dutch households [OECD, 2005; TNO, 2005; Webwereld, 2006]. The Netherlands noted the highest growth rate of all OECD countries in 2004, and the second highest in 2005 [OECD, 2004, 2005]. Iceland, South Korea, the Netherlands, Denmark and Switzerland are the top five OECD countries in broadband penetration per 100 inhabitants.

Two access networks currently dominate the Dutch broadband landscape: the telephone

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[1] KPN has made several (so far unsuccessful) attempts to gain access to the cable companies' networks for providing ISP services and TV broadcasting.

[2] The OECD uses always-on DSL or cable connections for statistics, or other technologies providing similar or faster connections.

network (±60%) and the cable network (±40%) [OECD, 2004; TNO, 2005]. These two access networks will be discussed in sections 2.2.1 and 2.2.2. Two alternative technologies will be discussed after that: wireless technologies in section 2.2.3 and FTTH in section 2.2.4.

2.2.1 Telephone network

The primary access network in the Netherlands and most of the world is the copper PSTN (Public Switched Telephone Network), the old telephone network. This access network is owned by the incumbent telephone operator KPN. Broadband internet over copper pair is provided using DSL (Digital Subscriber Line) technology. The most commonly used form of DSL at the moment is ADSL (Asymmetric Digital Subscriber Line). Due to universal service obligations, any home in the Netherlands can get a telephone line. DSL broadband does not fall under universal service obligations (yet), however all KPN switching offices have been upgraded and are capable of offering DSL services. This provides DSL coverage to 99% of all households [TNO, 2005] (100% is not achievable due to distance limitations in copper networks).

European Open Network Provision (ONP) regulation (found in the Access Directive [EC, 2002a], part of the New Regulatory Framework of the European Commission) has forced the telephone incumbents to provide access to their network (local loop) to competing service providers. This has resulted in a multitude of xDSL ISPs providing service to consumers using a number of backbone networks,[3] but all necessarily sharing KPNs access network. Fierce competition in the ISP market has been the result, which was the aim of the ONP regulation.

Current speeds of ADSL Internet subscriptions range from several hundred kilobits per second to 8 Mbps download. Being asymmetrical, upload speeds are much lower, up to 1 Mbps. Newer ADSL2+ and VDSL standards can achieve higher speeds, currently up to 20 Mbps is being offered, though upload speeds[4] are still 1 Mbps. These high speeds are never guaranteed as the distance between the subscriber and the central office dictates the maximum achievable speed.

The layout of the telephone network is such that each house has an individual line running from the premises to the central office. This means that the access network is not shared and oversubscription can only take place upstream. Oversubscription rates (statistical multiplexing) upstream from the central office typically range from 1:25 to 1:40.[5]

Voice telephony is obviously possible though the telephone network, and several ADSL ISPs are offering VoIP or VoDSL services through their DSL connection. Radio and TV broadcasting over the copper network is not yet done in large numbers. The incumbent telephone operator KPN had focussed on digital broadcasting through the ether (DVB-T) for radio and TV by taking a majority share in the only company offering DVB-T, Digitenne, though IPTV plans have been announced recently.

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[3] Networks available to consumers (coverage) include KPN (99%), BBned (90%), Versatel (65%), and Tiscali (52%). The business market is even more competitive with additional competitors including MCI, Global Crossing, Easynet and BT.

[4] Speeds according to providers, offered to consumers in October 2005

[5] Oversubscription rates are not specified for consumer DSL subscriptions, nor is data on this publicly available. In business DSL subscriptions the oversubscription rate is explicit and ranges from 1:1 to 1:20. The consumer oversubscription rates are gathered from various Internet sources and OPTA reports [OPTA, 2005].

In the telephone network, KPN has decided to stop using copper in greenfield situations in favour of fibre. The current network will be increasingly upgraded to fibre as well with a Fibre-to-the-Curb upgrade. The last drop will use VDSL over the existing twisted copper pair. This upgrade will take years however, and it is as yet unclear what FTTC/VDSL coverage will be achieved. In the meantime, all of the copper network will become IP-based, all circuit-switched equipment will be retired. This 'All-IP' update is planned to take 5 years [KPN, 2005a].

2.2.2 Cable

The coaxial cable network was originally built for broadcasting analogue radio and TV signals. The networks are vertically integrated local monopolies, owned and operated by the same company. The largest cable companies in the Netherlands are UPC, Essent and Casema. The Netherlands has the highest coverage of cable in the world, over 97% in 2001 [VECAI, 2005]. Most of the cable networks have been upgraded to provide 2-way broadband access.

The cable network was originally built for analogue broadcast purposes. This has resulted in a network structure with a shared coax cable running from the central office past a number of houses in a block or region. This means that the access network is shared, which makes oversubscription in the access network possible but also implies a capacity bottleneck.

The cable companies have their own ISP and effectively block access to other ISPs. Current speeds range from several hundred kilobits per second to 20 Mbps download. Uploads are similar to DSL, up to 1 Mbps.[6] Due to oversubscription in the access network, the actual achieved data rates can vary significantly. The bandwidth of (high speed) subscriptions is never guaranteed.

Cable is used by most of the Dutch households (approximately 90%) for reception of TV and radio broadcasts [EZ, 2004b]. Some cable companies also provide VoIP telephony over the cable network.

While DSL and cable are the dominant access technologies at the moment, other alternative access technologies exist. Section 2.2.3 and 2.2.4 list two alternatives, though this is not an exhaustive list.

2.2.3 Wireless access technologies

Wireless technologies are available in a number of forms and the future of broadband access is believed by some to involve a large component of wireless services. Lehr et al. [2004] write that wireless technology can be a component in, complement to, or substitute for traditional wired access networks. While we recognise that wireless technology can sometimes substitute wired infrastructure (i.e. mobile phones are replacing fixed lines) and be an important component of a network (e.g. using point-to-point microwave links as a backbone for GSM and UMTS antennae), the use of wireless technology as a large-scale high-speed access network is debatable.

No 'single' wireless access technology exists, but a multitude of products and technologies are used: proprietary or standards-based, using different ranges of spectrum, aimed at mobile

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[6] Speeds according to providers, offered to consumers in October 2005

or fixed use, etc. We will briefly discuss three alternatives, 3G Cellular, WiFi and Wireless Local Loop (WiMax).

3G Cellular

3G Cellular telephony (3^{rd} generation networks, in Europe: the UMTS standard) is the upgrade to the 2^{nd} generation mobile phones (GSM), designed to carry voice and data traffic. UMTS can offer data rates of 384 kbps up to 2 Mbps (in theory) [Lehr & McKnight, 2003]. However, this higher figure is the maximum capacity of an entire cell for a stationary user. The capacity will be shared by all users in the cell, so this number will probably never be achieved. 3G (and in the future 4G) are obviously designed for mobile use, and cannot match the bandwidth offered by wired access networks, required for true broadband services. 3G Cellular is no alternative to a fixed broadband access network [Weeder & Nijland, 2002], but a complement to wired infrastructure, offering less bandwidth but more mobility [Baken, 2003].

WiFi

WiFi was originally developed as a replacement for cables in office LANs but it can also function as an access technology [Lehr & McKnight, 2003]. Current IEEE 802.11g standard equipment can achieve data rates of 54 Mbps, which seems adequate for broadband services in the immediate future. However, the actual data rates achieved depend on the quality of the wireless signal. WiFi operates in the unlicensed 2.4 Ghz (802.11b/g) and 5 Ghz (802.11a) bands. While the use of unlicensed bands has the advantage that the spectrum is 'free',[7] it implies that there can be numerous sources of interference from other devices, WiFi or other, licensed or not. The 'Shannon limit' (named after the work of Claude Shannon [1948]) dictates the maximum achievable capacity of a communications channel is related to the bandwidth used and the signal to noise ratio. If the noise (interference) becomes too large, the capacity will drop given that the signal strength and available bandwidth are constant. The spread spectrum techniques used in WiFi make the devices less susceptible to noise, but there is currently no telling what will happen if very large numbers of (WiFi and other) devices using the same spectrum are used in the same area. The growing number of unlicensed devices makes this an uncertain aspect in the WiFi business case. In any case, no Quality of Service (QoS) guarantees can be given.

The number of devices needed to cover an area is very large with WiFi because of the limited range of the access points (no more than 100 m, less when obstructed by walls and interference). This makes future upgrading of the network expensive since all of the access points will have to be replaced. Furthermore, the access points require some form of backhaul connection to the Internet ('second-mile'), the alternatives for which have varying disadvantages. A DSL backhaul limits the total capacity of all users on a given access point to the speed of a DSL line; setting up numerous wireless point-to-point microwave links is impractical in a densely built country like the Netherlands. A mesh network will not provide enough capacity to effectively compete with incumbent wired infrastructure.

The almost universal availability of WiFi chips in laptop computers and PDAs makes

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[7] While the use of the spectrum may pose no cost to the end-user, releasing the spectrum for unlicensed use has opportunity cost associated with it to society.

WiFi a technology very much suited for use in 'hotspots' by nomadic users. Current WiFi standards are not well suited to be a complete substitute access technology in stead of wired infrastructure, but are a valuable complement [Baken, 2003].

Wireless Local Loop

WiMax (the IEEE 802.16 standard family) has been developed specifically as a standard wireless access technology, sometimes called BFWA (Broadband Fixed Wireless Access) or WLL (Wireless Local Loop). Proprietary systems exist, but we will focus on this standardised technology. WiMax is designed to work over tens of kilometres, but it is not simply a range extension for WiFi. Unlike the omnidirectional antennas used with WiFi, WiMax uses directional antennas aimed at a base station to provide internet access. As such, it is better suited as a replacement for a wired access network [Cherry, 2004].

WiMax is a possible Wireless Local Loop replacement for wired access networks [Lehr et al., 2004] but has some disadvantages. WiMax can use several frequency bands, some of which are licensed while others are not. The unlicensed bands pose the same interference risks as with WiFi. The higher used frequency bands (10–60 Ghz range) require Line-of-Sight between the rooftop antenna and the base station, which is practically impossible in cities. At certain frequencies, rainfall and other weather conditions can also affect signal strength. Furthermore, the capacity of the base station will have to be shared, limiting the number of subscribers in a region to assure sufficient bandwidth for each subscriber [Vaughan-Nichols, 2004]. The maximum bandwidth provided by a WiMax connection ranges from 70 to 155 Mbps at short ranges, with speed dropping as the signal attenuates width distance. This provides sufficient capacity for the mid-term, but again this will have to be shared between all users connected to the same base station.

The advantage of WLL is that deploying a wireless network is much cheaper than building a wired network which requires massive amounts of construction work. The use of unlicensed frequency bands, while posing some risk, could further reduce cost.

Concluding, Wireless Local Loop technologies such as WiMax could be a cost-effective access technology for rural areas. However, in more densely populated areas like most of the Netherlands, the use of WLL is not an alternative to high-speed wired access because of the shared capacity and Line-of-Sight requirements of the base stations.

2.2.4 FTTH

Fibre-to-the-Home (FTTH) is available in a few places in The Netherlands. Some cities or housing corporations have decided to build fibre networks, and fibre is being commercially deployed in a number of business parks that are unserved by DSL.[8] Commercial investment in Fibre-to-the-Home is now starting as well. An elaborate discussion on FTTH networks will be done in chapter 3, but a general overview is given here.

Optical-fibre transmission has several advantages over copper (and other metallic) networks such as DSL and cable. The advantages of fibre systems are [Flood, 1997]:

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[8] Business parks generally do not have cable.

1. Optical-fibre systems operate at much higher frequencies and are able to provide much wider bandwidth.
2. Signal loss per km of fibre is much lower than that of metallic cables.
3. Fibre provides electric isolation between transmitter and receiver (less risk of power peaks over the network).
4. Transmission is unaffected by electrical radiation (usable in environments with high interference).
5. No cross-talk between fibres because light is contained within the fibre.
6. Fibres are smaller and lighter than electrical cables of the same capacity.

Disadvantages of optical-fibre systems are [Flood, 1997]:

1. Fibres are very thin and therefore vulnerable to mechanical stress.
2. Splicing and connecting fibres is more difficult than metallic cables.
3. Electric power cannot be transmitted through fibre (so no devices can be powered through the network like a traditional telephone).
4. Locating faults in fibres is more difficult than in cables.

Fibre-to-the-Home can be deployed as a point-to-point network or as a star (point-to-multi-point) network. This decision has consequences for the cost and capacity. In a star network, part of the access network between the central office and the users is shared between users, so the total capacity is shared. This sharing resembles the sharing of the access channel in cable systems. A point-to-point network has a dedicated fibre from the central office to each of the end-users. This vastly increases capacity because the full bandwidth of the fibre is available to each of the end-users, but is more expensive because it requires more dug fibre [Banerjee & Sirbu, 2003]. Different architectures and their advantages will be discussed in more detail in section 3.2.

The bandwidth offered by fibre optics is theoretically virtually unlimited,[9] currently limited only by the equipment used at both ends of the fibre. The FTTH networks currently built in the Netherlands are generally prepared for 100 Mbps symmetrical (up- and download) access to all of the connected houses. Speeds of internet subscriptions that are currently offered with triple-play packages over FTTH networks range from 10 to 100 Mbps (symmetrical). Fibre-to-the-Home is qualitatively superior to the other technologies and is most future-proof access network technology available.

2.3 Infrastructure requirements and competition

The network layer in the next generation market structure will have to provide sufficient capacity to offer the required services to the subscribers. This section will summarise previous research on the capacity growth potential of access network technologies that showed that fibre-optic access networks are the most future-proof access infrastructure, and in the long term the only alternative offering sufficient capacity and growth possibilities. This information will be combined with the possibilities for integrated or disintegrated market structures described in section 2.1 to assess possibilities for infrastructure or service competition in NGN.

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[9] Bell Labs researchers calculated the theoretical limits of fibre optic communications at approximately 100 Tbps (Terabits per second) [Mitra & Stark, 2001].

Numerous speed definitions of ‘broadband’ exist; usually awe-inspiring superlatives are used to indicate speeds even broader than broadband, for examples in research on triple-play by TNO [van Wolfswinkel, 2005]. Sirbu et al. [2004] qualify a network that is able to provide triple-play services and symmetrical data rates in excess of 10 Mbps as a “next generation” infrastructure. Since definitions by bandwidth become outdated very fast (a few years ago two times the speed of dial-up ISDN was considered broadband) we will not use bandwidth figures to define broadband, but we will focus on the results of previous research on the requirements of access networks.

2.3.1 Traffic growth demands infrastructure investment

Worldwide Internet traffic has been growing since its beginnings, and is continuing to double every year from 180 petabits per day in 2002 to a predicted 5175 petabits per day in 2007 [Cheng et al., 2005]. This increase in data traffic, resembling Moore’s law in computing, has been and is being caused by the fact that more and more users are using the Internet, and the fact that they are using more and more bandwidth intensive applications and content. The continuous increase in data traffic creates a demand for networks with higher capacity.

The amount of traffic on the Internet can be measured by looking at the data transferred at Internet exchanges, major continental and intercontinental hubs in the Internet backbone. The Amsterdam Internet eXchange (AMS-IX) is one of the largest Internet exchanges in the world, and traffic at the exchange has been growing exponentially since it was founded in 1997. The increase in traffic[10] is shown in figure 2.3. The speeds at which data is transferred are growing enormously as well. At the end of October 2005, the AMS-IX was the world’s first Internet exchange to achieve a throughput of 100 Gbps [Doorenbosch, 2005a]. There is no reason to expect the amount of traffic, and the transfer speeds required, to level in the future. On the contrary, both the amount and the speed of transferred traffic will continue to grow rapidly. Four reasons for the continuous increase in Internet traffic can be observed:

High quality content requires bandwidth. Multimedia webpages require more bandwidth than just text and images, higher quality music or video downloads require more bandwidth, etcetera. Users with fast connections expect high quality (and therefore bandwidth intensive) content, including for instance video streaming.

More subscribers online using always-on broadband connections. The number of broadband subscribers is growing every year, as are the speeds with which they are connected.

More use by the same users is increasing traffic. People use the Internet more than they used to, and also use their broadband connections for other purposes such as voice conversations or watching streaming video.

More concurrent users per household are using the same broadband connection. Whereas only a single PC used to be connected to the Internet, in-home networks allow many users to share a single connection.

All these aspects will keep pushing the amount of data traffic on broadband connections and the Internet higher. The services that are currently of most interest are ‘triple-play’

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[10] Source of data: `www.ams-ix.net`, September 2005 – March 2006

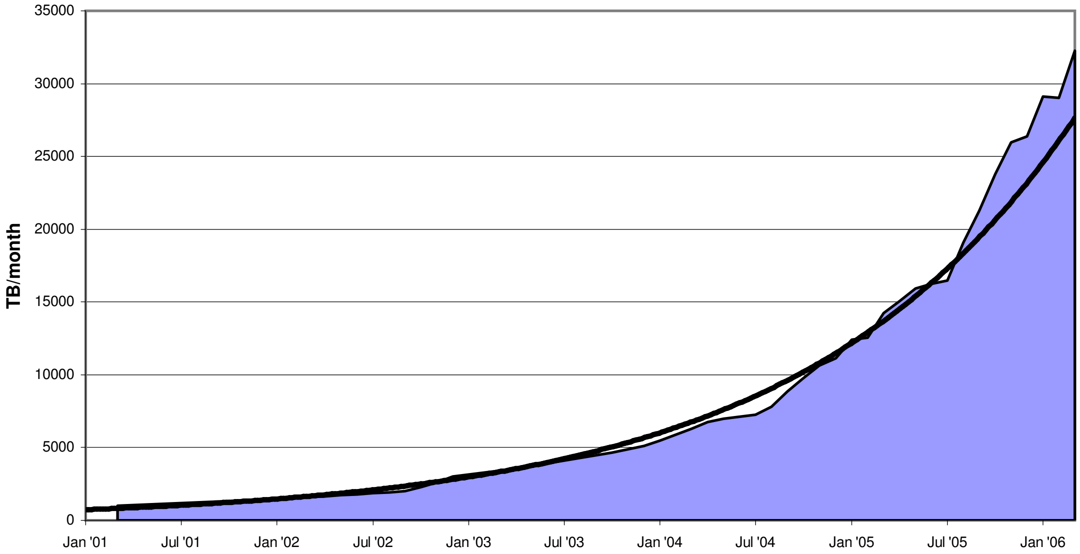

Figure 2.3: Exponential growth of Internet traffic at AMS-IX

services: voice, video and Internet. Video includes normal TV broadcast, but also Video-on-Demand. The bandwidth requirements of triple-play services will be increased by on-demand video services and High-Definition TV. Research by TNO has shown that higher quality and more (concurrent) use will drive the bandwidth requirements per home up to 100 Mbps and even 1 Gbps [van Wolfswinkel, 2005].

2.3.2 Consumer demand for more upstream bandwidth

The need to invest in new broadband access technologies also becomes apparent from the lack of upstream capacity of the current networks. Consumers have a demand for more upstream bandwidth than current broadband networks can deliver, though not all players in the telecommunications industry will welcome or support this statement. The recent report ‘Do market failures hamper the perspectives of broadband?’ from Bureau for Economic Policy Analysis (CPB) concluded differently, that consumers do not demand symmetric broadband connections [van Dijk et al., 2005]. Below in an excerpt from the report and what the authors have to say about consumer demand. We quote the report at length to provide all necessary information for the discussion.

Consumers do not demand symmetric broadband

Today, consumers choose deliberately for asymmetric broadband. This preference for asymmetric broadband is not surprising, as for most of the current activities a high download speed is more important than a high upload speed. Empirics point to the following. Consumers most often use broadband respectively for e-mail, to search for specific information and for downloading software and music[. . .].
These activities require more downstream than upstream speed. Therefore, asymmetric DSL (i.e. ADSL) is popular. In its latest reports on broadband and use, Dialogic (2005) supports this conclusion. Upstream activities such as upload of movies, music or photos are still in their infancy and appear to be not related to the upstream capacity. [. . .]
An additional empirical finding is that most of the consumers are willing to pay for downstream speed and not for upstream speed. This is a result of the analysis of price formation of Internet[. . .]. Moreover, consumers can choose from a variety of subscriptions with a range of speed[. . .]. Therefore, consumers that prefer more bandwidth speed can choose that kind of subscription if they are willing to pay higher prices. Consumers with extreme wishes of upstream speed can fulfil their preferences by moving to the business segment. [. . .]

Source: [van Dijk et al., 2005, pages 86 and 87]
Cited Dialogic report: [Maltha et al., 2005]

Van Dijk et al. and Maltha et al. conclude that there is no demand for higher upstream bandwidth because the applications that are used most require more downstream than upstream bandwidth. We believe cause and effect are being mixed up in their reasoning. Is there no demand for upstream bandwidth because the mostly used applications require more downstream bandwidth? Or are the mostly used applications the ones that require more downstream bandwidth because upstream bandwidth is insufficiently available? The main statements by Van Dijk et al. [2005] in the CPB report are discussed below.

“consumers choose deliberately for asymmetric broadband”
Wrong. A deliberate choice requires an option. The only option for the vast majority of consumers (using cable or xDSL) is asymmetric broadband. The popularity of asymmetric broadband is not because consumers prefer asymmetric connections, but because these are the only connections offered to them. The reason for this is are technical limitations in the cable and DSL networks, not choice.

“Consumers most often use broadband respectively for e-mail, to search for specific information and for downloading software and music. These activities require more downstream than upstream speed. Therefore, asymmetric DSL (i.e. ADSL) is popular.”
Causal relationship unclear. As described above, asymmetric broadband is popular because this is the only available option for most people. As upstream bandwidth is very limited with ADSL and cable, it is not surprising to see applications that use much upstream bandwidth are less popular.

“consumers are willing to pay for downstream speed and not for upstream speed”
Debatable. The claimed statistical significant correlation: “The upstream speed hardly de-

termines the subscription rate" [van Dijk et al., 2005, page 74] is questionable because of the limited upstream offerings. Downstream bandwidth ranges from 256 kbps to 20 Mbps, while upstream bandwidth ranges from 256 kbps to 1 Mbps. Prices for faster subscriptions are obviously higher, and a correlation between downstream bandwidth and price will obviously be greater than that between upstream bandwidth and price, given the range of possibilities and the fact that all 'heavy' subscriptions have 1 Mbps upstream bandwidth. The conclusion that consumer are willing to pay for downstream bandwidth is correct; the conclusion that consumers are not willing to pay for upstream bandwidth can not be drawn from this data.

"Consumers with extreme wishes of upstream speed can fulfil their preferences by moving to the business segment."
Unrealistic. The prices for business subscriptions are prohibitively expensive for consumers. Symmetrical 2 Mbps or 2.3 Mbps SDSL connections cost over € 200 and upward per month,[11] whereas consumer ADSL subscriptions are a factor 10 less expensive. Clearly, business subscriptions are not an option for consumers.

To summarise, the conclusions of the Netherlands Bureau for Economic Policy Analysis about consumer market for upstream bandwidth are flawed at best. The demand for upstream bandwidth can best be observed at users who already have fast symmetric connections: mostly students in university dormitories and residents of neighbourhoods where FTTH projects have been deployed. Future use of bandwidth can best be predicted by looking at the way young people are using it now. Users with fast symmetrical connections utilise all of their their upstream bandwidth, just like many users with asymmetrical connections. Current FTTH subscribers with 10 Mbps symmetrical connections are uploading more data than they are downloading.[12] This clearly indicates a demand for upstream bandwidth.

Unfortunately, current DSL and cable networks are not technically equipped to offer high speed upstream bandwidth. Therefore, demand for upstream bandwidth is not welcomed by current network owners. The authors of the CPB report interviewed several persons from the telecommunication industry when writing their report. The interviewees included two employees from KPN, one from Versatel, and one from the cable operators (VECAI), who all have interests in current access infrastructures. None of these is likely to admit a large demand for upstream bandwidth exists.

2.3.3 Capacity growth potential of access infrastructures

As the previous two sections have shown, the capacity of the access networks has to grow to meet future demand in up- and downstream bandwidth. A TNO report offers an extensive discussion of the growth potential of several access technologies, including the most important ones: DSL, cable and FTTH [van Wolfswinkel, 2005]. The report discusses the bandwidth, QoS, security and network availability aspects of the different technologies. Below is a summary of the potential in bandwidth growth.

Current DSL techniques used on the PSTN telephone network (ADSL, ADSL2+) can be upgraded to higher speeds with VDSL and VDSL2. However, this can only be achieved at short distances as high frequency signals attenuate with distance in the copper wires. The

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[11] Prices for business SDSL subscriptions from `http://www.versatel.nl/sdsl` and `http://www.xs4all.nl/alle diensten/toegang/bdsl/specificatiessdsl.php`, December 2005

[12] Personal communications with Theo Goumans, Volker Stevin Telecom, December 2005

promised high speeds can therefore only be achieved closer from the central office to the subscriber. Bandwidth can then be upgraded to higher speeds, 50 Mbps is possible up to 300m with VDSL, 100 Mbps could be possible in future. Speeds are mostly asymmetrical, though VSDL could be configured symmetrically if desired.

In the cable network, new technologies and upgrades to the network can increase current speeds up to 100 Mbps and possibly more, but also at the expense of pulling fibre closer towards the subscriber. Even higher speeds up to 1 Gbps are theoretically possible, but only with a dedicated connection to each subscriber. Since the cable network uses a shared access channel, this is not achievable without massive digging. Such a plan is pointless because in that case fibre could be deployed just as well. Cable offers asymmetric connection speeds, though some improvements are being made. (The future EuroDocsis 2.0 standard will offer 52 Mbps downstream and 30 Mbps upstream capacity. CableEthernet offers symmetrical 100 Mbps connections.)

Fibre-to-the-Home offers the highest capacity of the three infrastructures, but has the highest construction costs since each subscriber has to be connected which involves a huge amount of construction work. Current point-to-point ethernet FTTH systems already offer 100 Mbps to each individual user; PON systems are able to offer 1 Gbps which is shared between several subscribers. Both FTTH variants deliver fast symmetrical connections.

Concluding, the capacity of existing networks can and will be increased to higher speeds in the coming years by new technologies and pulling more fibre deeper into the network. This will allow for high quality triple play services. With future even higher quality services and more concurrent use Fibre-to-the-Home will become the most futureproof alternative and the only technology able to realise the required speeds [Baken, 2001; van Wolfswinkel, 2005].

2.3.4 The future is fibre

Fibre-to-the-Home is the logical next step in the "evolutionary growth of access technologies." Apart from completely new fibre deployments, an all-fibre network is also a logical evolution of replacing copper by fibre in existing networks. Sooner or later, the transition to fibre is inevitable, concluded the 'Expert Group Broadband' unanimously in an advice to the government[13] [Expertgroep Breedband, 2002].

Predictions about *when* the switch to fibre will happen differ and depend on several factors. First of all a difference can exist in when advanced services can be offered (technology push) and when consumers want the advanced services (demand pull). Also, content owners such as movie studios and service providers can delay the introduction of new services. Furthermore there is a significant difference in when a service or network technology first enters the market, and when it is available to all or most consumers (mass market availability) [van Wolfswinkel, 2005].

Incumbent network owners (KPN and the cable companies) have an interest in exploiting their current copper networks as long as possible. Cable companies fight legal battles against FTTH,[14] while KPN plans to migrate to VDSL, a transitional step towards FTTH. None of

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[13] The expert group included members from technology companies (Arcadis, Cap Gemini Ernst & Young, Cisco, Ericsson), universities (Delft, Twente), and the government (Ministry of Transport, Public Works and Water Management), but also from the telephone incumbent (KPN), and a large cable company (Casema).

[14] Lobbying activities and legal battles by VECAI and UPC can be read about in newspapers and magazines

these companies is likely to roll out a full FTTH network soon, but to be prepared for market demand in the not so distant future, and given the time required to build networks, fibre deployment should begin now [Expertgroep Breedband, 2002].

Some authors believe massive FTTH deployment is unlikely in the near future because of the lack of a *"killer app"* that requires massive bandwidth. Frigo et al. [2003] see no visible application that demands FTTH, which makes it unlikely that major players will build out a fibre network. However, even they believe that a third party network operator who is not vertically integrated could change this prospect, by enabling the provisioning of numerous services by several other providers (as described in section 2.1).

While proponents say investment in fibre is required now to be ready for the future, and opponents argue that the possibilities offered by fibre are not needed yet, real options analysis (by Dixit & Pindyck) may to be able to offer insight beyond traditional cost/benefit analyses. Incorporating real options analysis is complex, but can create value and vision for companies [Baken, 2001]. Dixit & Pindyck [1995] argue that an investment decision is not a *now-or-never* proposition, but that the situation may change over time: the decision to invest can be made again in the future. Alleman [2002] explains these insights are very important in strategic planning in telecommunications and argues delaying investment can have value and offer advantages. Waiting for new information and newer technology to become available may lead to a better investment decision in the future, but the option to wait is not the only available strategy. While delaying an investment has a value (being able to wait for more information or improved technology, plus financial advantages), investing now in a new network can also create valuable new options that were not available before. Large first mover advantages also decrease the value of the option to delay [Hubbard & Lehr, 2000] since being the second to invest greatly reduces the value of the investment. The debate on real options and the decision to invest in telecommunications is still open, but it is important to notice that delaying investment is not the only way to increase value; investing and thereby creating new possibilities are equally suitable investment possibilities.

International FTTH experiences

Fibre-to-the-Home is a fast growing access technology in several other countries. FTTH is already a significant access platform in Japan, one of the largest markets in terms of broadband subscribers (19 million subscribers, second only to the USA). In Japan, over 4.6 million subscribers already have a fibre broadband connection, which accounts for 26% of all broadband connections and the number is growing [OECD, 2005]. Other countries with significant FTTH deployments are the United States, South Korea and Scandinavian countries such as Sweden and Denmark.

Broadband developments in Japan are similar to those in The Netherlands in some respects, but different in others. In Japan, the first broadband connections used the cable network, which became the main broadband network. After some time, a migration from cable to ADSL and subsequently to faster forms of DSL (ALDS2+, VDSL) took place; the telephone network became the mostly used broadband network. Now, Japanese subscribers are moving towards fibre connections, not only high-end users but also general consumers.

[see for instance: Dekker, 2006; Olsthoorn, 2006; Eijsvoogel, 2006]. Remarkably, UPC daughter NOOS in France is experimenting with FTTH itself [Guerrier, 2005].

No *"killer app"* was driving the move to faster speeds, but it was a result of competition between providers [Shinohara, 2005]. These migrations in access technologies are similar those in the Netherlands. However, the difference between Japan and the Netherlands is that Japanese providers focussed on data-only (Internet) subscriptions, and are only now moving from single-play towards triple-play offers. In the Netherlands, providers already decided to move to triple-play offers as a strategy, so the networks that will be built here must be able to offer all these services. In Japan, most deployed FTTH systems are optimised for data traffic.[15] A different choice in technology is more likely in the Netherlands because of the local (triple-play) market demands.

While the Netherlands is among the leading countries based on broadband penetration, deployment of Fibre-to-the-Home is trailing. While Japan, the USA, Sweden, Denmark and South Korea all have significant FTTH deployments in absolute and relative numbers, the percentage of FTTH connections in the Netherlands is virtually nil [OECD, 2005]. To keep at the forefront of broadband countries in terms of high-capacity networks, Fibre-to-the-Home deployment in the Netherlands will have to be increased.

Fibre-to-the-Home, a natural monopoly?

A Fibre-to-the-Home access network is a decreasing cost industry. With increasing penetration, the substantial fixed and sunk costs are shared by a larger number of subscribers [Banerjee & Sirbu, 2003; Expertgroep Breedband, 2002]. In the theoretical situation where there are only single-product firms, an industry or market in which a single provider can produce all goods for the entire market the most efficiently is known as a natural monopoly [Viscusi et al., 2000]. In this case, and when this is a sustainable situation, a monopoly market structure leads to least-cost production. Economies of scale are not sufficient to constitute a natural monopoly in the context of a multi-product firm. For a multi product firm, the natural monopoly cost function has to be subadditive [Sharkey, 1982].

Fibre-to-the-Home is an access network with a very high sunk initial investment in the infrastructure, and a decreasing average cost with higher penetration. Additionally, multi-product advantages exist when offering multiple services on the same network, as the cost of the network occurs only once. This indicates the cost function of the bundle of triple-play services may be subadditive.[16]

Whether it is a natural monopoly or not, a duplication of an already built FTTH network in the Netherlands is highly unlikely. Though infrastructure competition may not be impossible to sustain, it would be inefficient, at least while many other possible locations for FTTH deployments are available. This gives the first party to build a FTTH network in a region significant first mover advantages. The first one to build will probably be the only FTTH network operator in this region, at least until competing incumbent network owners (possibly) upgrade to fibre. This makes owning last mile optical network strategically important. The last mile network operator has a good value proposition in the telecommunications services value chain because this market in the chain is the least competitive [Andy Ng et al., 2004].

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[15] Several FTTH architectures exist, explained in chapter 3. The EPON systems mostly built in Japan are well suited for data traffic but less for TV broadcast.

[16] The actual proof of the subadditivity of the cost function is not the topic of this research, but is an interesting subject and could be important for telecommunications policy.

The reasoning that FTTH is a (likely) natural monopoly, and the observation that a second FTTH infrastructure is highly unlikely to be built at least in the coming years, bring questions of competition at the level of end-user services. If only one vertically integrated FTTH network is availably in a given region, consumers will not benefit from the choice in services and price competition resulting from having several providers. Disintegration, a separation of the functions of the network operator and the service providers (i.e. a 'wholesale-retail split', or an 'open network') is a solution to this. Whether this structural separation happens by choice or regulation, it is a viable solution to benefit from the least-cost production of a single network, and the virtues of competition on the level of end-user services. This thesis focusses on the concept of an open network in NGN and specifically FTTH from a techno-economic perspective.

2.4 Regulatory challenges

The 2002 New Regulatory Framework of the European Union for telecommunications, defined by the Framework Directive [EC, 2002b] and the accompanying Specific Directives, is this main source for regulation in the Dutch telecommunications industry.[17] In the EU Framework Directive, the concepts 'communications network' and 'communications service' were defined. The separation of these two concepts, the network and the service, corresponds to the two technological layers in the ITU definition of Next Generation Networks.

The European Union has been very successful in promoting competition in broadband access through regulation such as local loop unbundling for Digital Subscriber Lines (DSL) [Marcus, 2005] in the Access Directive [EC, 2002a]. However, problems with the Framework (which is currently under review) exist as well. The regulation is mostly focussed on the telephone incumbent's network (KPN), and does not warrant much attention to emerging markets and technologies. The dynamic character of the telecommunications industry is the cause of a regulatory 'lag', in which the behaviour of existing or new market parties is followed only after some time by regulators.

Open access in emerging Next Generation Networks is not currently subject to regulation but open networks can become very important in fostering service competition where infrastructure competition is unlikely. Some attention on this subject and the matter of interconnection between network and service layers might be warranted.

2.5 Summary

Telecommunications services are becoming independent of telecommunications networks traditionally associated with them. Next Generation Networks differ from traditional telecommunications networks in terms of horizontal network layers and network capacity. The future market structure in telecommunications might continue the trend away from vertically integrated companies to a layered industry structure. In this disintegrated market structure, network providers and service providers will operate in their respective markets; provisioning of services (triple-play or other) will become independent of owning and operating a network.

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[17] The EU framework was implemented in the Netherlands in the 2004 adaptation of the telecommunications act (in Dutch: Telecommunicatiewet).

Network operators using open network business models can sell access to several independent service providers. While this does not rule out the possibility of vertical integration, it is very different from a vertically integrated industry structure. This thesis focusses on the open network concept in Next Generation Fibre-to-the-Home networks.

The Netherlands has one of the highest penetrations of broadband Internet connections in the world. The two most important access networks are PSTN and cable. The DSL services on the PSTN network are highly competitive because of European open access regulations. Both DSL and cable offer competing broadband subscriptions with a variety of packages including Internet, telephony and radio/TV. The bundle of these three services is known as triple-play. Fibre-to-the-Home (FTTH) is the technology with the highest capacity, offering many advantages but at high cost to build.

The capacity of (next generation) networks will have to grow to cope with the increase in traffic in the future. The network topology and physical limitations of the current copper infrastructures limit the possibility of upgrading the old networks. As the demand for capacity grows, the PSTN and cable networks will no longer be able to offer the required bandwidth. Fibre optic networks do not suffer from signal loss over large distances the way this happens with electric signals in copper. A single thread of fibre can carry vast amounts of information, and the capacity can be increased by replacing the equipment at both ends. Fibre-optic networks (FTTH) are the future of access network infrastructure, the migration from copper to fibre infrastructure is visible globally; mostly in Asia but also in the USA and Europe.

A full Fibre-to-the-Home network has sufficient capacity to serve the data-requirements of an entire market and is the most future-proof solution. The bandwidth provided by a FTTH network is such that a single network can provide all services to all consumers. The huge sunk investment and large capacity offered by a fibre network make it possible that a FTTH network is a natural monopoly. The implication of this would be that facilities-based competition is an unlikely outcome. When facilities-based competition is inefficient or prohibitively expensive, an open access business model is preferred, so competition between service providers will be possible.

Chapter 3

Building a FTTH network

After identifying key factors influencing the network investment decision, this chapter describes three possible FTTH architectures and highlights the key factors in each of them. Subsequently, the fibre networks that have been built by VolkerWessels Telecom are described.

Several variants of fibre-optic access networks exist, collectively referred to as FTTx. One of these variants is Fibre-to-the-Home, where fibre is used in all of the access network into each residence. Other forms of fibre-optic access networks include hybrid 'deep fibre' solutions where fibre is brought near but not into the home: more specifically FTTC (Fibre-to-the-Curb) or FTTP (Fibre-to-the-Premises). In FTTC deployments, fibre is brought to the neighbourhood near the home, but the last drop from the 'curb' to the consumer is realised using another technology. Options for the last drop include copper, coax, UTP cabling, powerline communications or wireless technology. FTTP deployments are similar to FTTH, but differ in the aspect that internal wiring in flats can be done using UTP cabling. We will focus on FTTH in this report.

3.1 Key factors in network investment

Any network owner has to make a substantial investment to build the network before it can be exploited. Given the high capital expense which is sunk on investment, and the long economic lifespan of networks, the decision about which type of network to build is of paramount importance. Panesar [1997] identified key factors in the investment decision for investing in mobile and fixed telephony networks, which are true for all telecommunications networks (including fibre-optic networks) and which we will highlight in the FTTH architectures:

Demand: Proper assessment of future demand in traffic volume and the mix of traffic types is very important, in order to design the network to be able to cope with the required traffic now and in the future. Network (spare) capacity and the possibility to upgrade the network are important.

Capital costs: The immense capital investment in building the network needs to be recovered over a part of the lifespan. Minimising the required investment is important, but only in relation to other expenses. Too little investment in the network can lead to significantly higher operating costs or inability to cope with future demand, requiring additional investment.

Operating costs: Operating costs make up a significant part of any network. These will matter a great deal to anyone exploiting the network because operating costs are recurring, as opposed to the capital investment.

Benefits: A certain type of network may provide improved or reduced performance in terms of security, reliability, quality of service or additional features, apart from the networks capacity. The ability to provide open access also differs. These aspects need to be part of the investment decision.

3.2 FTTH architectures

In literature, three basic network architectures are described for FTTH deployments: point-to-point, active star, and passive star. They differ in the amount of deployed fibre, sharing of network resources between users, complexity of open access and required investment. Each architecture will be described below.

3.2.1 Point-to-point

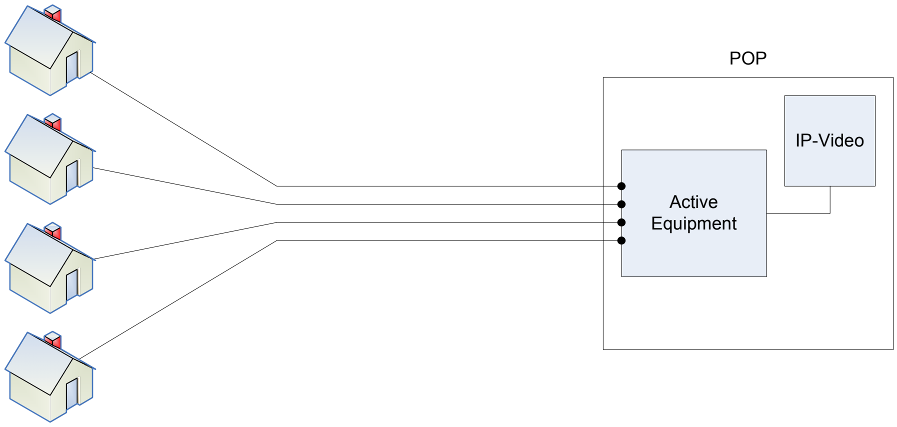

Figure 3.1: Point-to-point FTTH architecture

In a point-to-point architecture, a separate fibre is deployed from the central office to each of the subscribers. This requires the most fibre of all architectures, and one OLT (Optical Line Termination) port per subscriber. A point-to-point architecture is similar in layout to that of the PSTN network. The benefit is that no sharing takes place in the access network beyond the Point of Presence[1] (POP), which gives full control over each fibre and therefore each subscribers connection. A point-to-point architecture therefore has the highest possible

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[1] Sometimes referred to as Central Office or CO. Both terms are used in literature, we will use Point of Presence (POP) throughout this document.

capacity in the access network, oversubscription will take place upstream in the distribution network. All equipment is concentrated at the POP, which reduces operational cost compared to distributed equipment. Aggregation of active components can also lead to a lower required investment in active equipment, but investment in fibre is high because of the fibre-rich architecture.

3.2.2 Active star

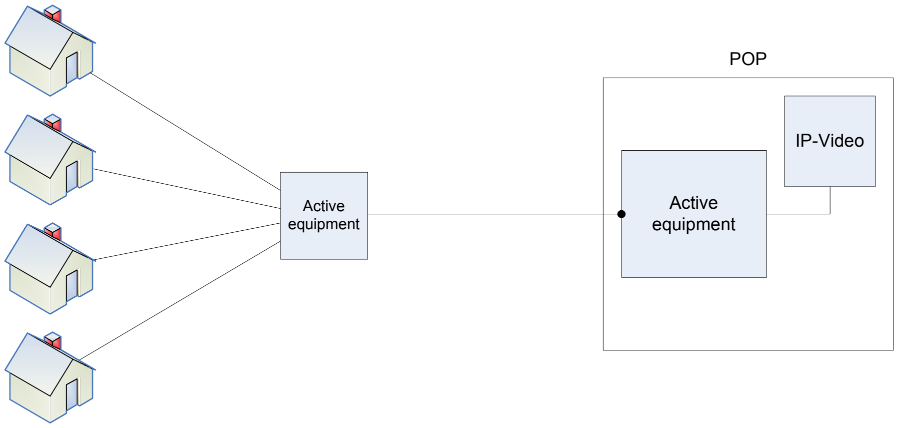

Figure 3.2: Active star FTTH architecture

In a star architecture, the amount of fibre used is reduced by placing a remote node with a shared feeder fibre between the subscribers and the point of presence. The remote node has routing equipment which aggregates traffic from subscribers onto the feeder loop. This presents a bottleneck in capacity, the available capacity for all of the subscribers behind one node is limited by the capacity of the feeder loop.

An active star architecture is said to be more cost-effective to build than a point-to-point architecture because of the reduction in the required amount of fibre and OLT ports in the POP. However, since in practice construction plans for point-to-point and star networks in an area tend to follow the same paths, the only reduction in fibre is the feeder loop. Most of the construction cost is in trenching and not in the cost of fibre itself, and an active star network adds the cost of placing and equipping remote nodes. In practice, how much an active star architecture reduces investment (if at all) is uncertain.

Operational costs in an active star network are higher compared to that of a point-to-point network because the active equipment is placed at numerous nodes on different locations.

3.2.3 Passive star (PON)

In a passive star or Passive Optical Network (PON), the remote node as used in the active star architecture does not have any powered equipment. A passive splitter sends the signal from the feeder loop to each of up to 32 subscribers. In this architecture, the entire access network is shared between the subscribers, indicating a capacity bottleneck. This resembles the shared

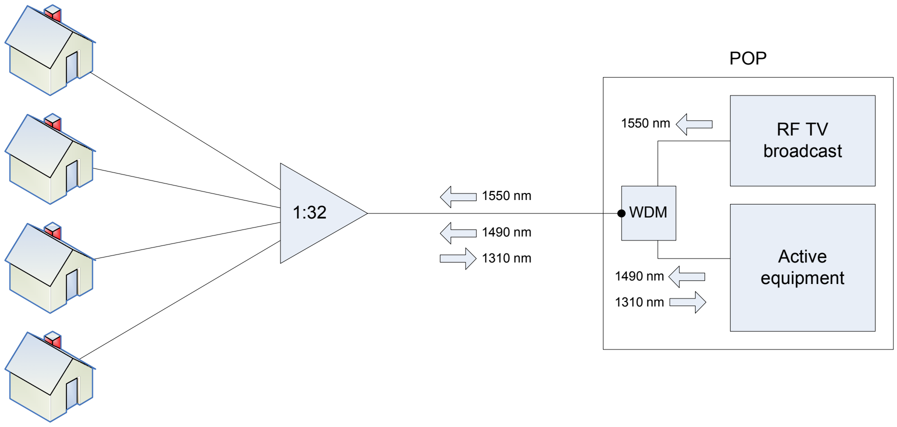

Figure 3.3: PON FTTH architecture

access channel in a cable network. Several variants of PON technology (B/G/EPON) exist; BPON and GPON have the advantage of offering an RF video overlay using WDM. All variants use the same PON network architecture with a shared feeder fibre and an optical splitter.

The PON network uses the same amount of fibre as an active star, which is less than a point-to-point network, but also eliminates the use of active components at numerous locations which results in lower operating costs than an active star network. However, the sharing in the access network poses a capacity bottleneck and certain forms of open access may prove to be more difficult (discussed in chapter 4).

3.3 VolkerWessels Telecom FTTH solutions

As explained in the introductory chapter, VolkerWessels Telecom engineers, builds and operates Fibre-to-the-Home networks. When developing a plan to build a fibre-optic network in a city or neighbourhood, a number of important technology choices are made. In this section, a typical network and the associated design considerations by VolkerWessels Telecom are described.

3.3.1 Architecture

All of the existing FTTH networks in the Netherlands have used a point-to-point architecture. This provides the most future-proof network and offers several options for open access. A point-to-point architecture eliminates the need for outside-plant active equipment, which is an advantage in terms of network maintenance and operating costs as opposed to an active star network. A PON architecture offers the same advantage, but point-to-point and star networks tend to follow the same routes, so the amount of trenching is similar in all network architectures. Since construction work and trenching present the bulk of the costs, the incremental cost of the extra fibre required for a point-to-point architecture as opposed to a star

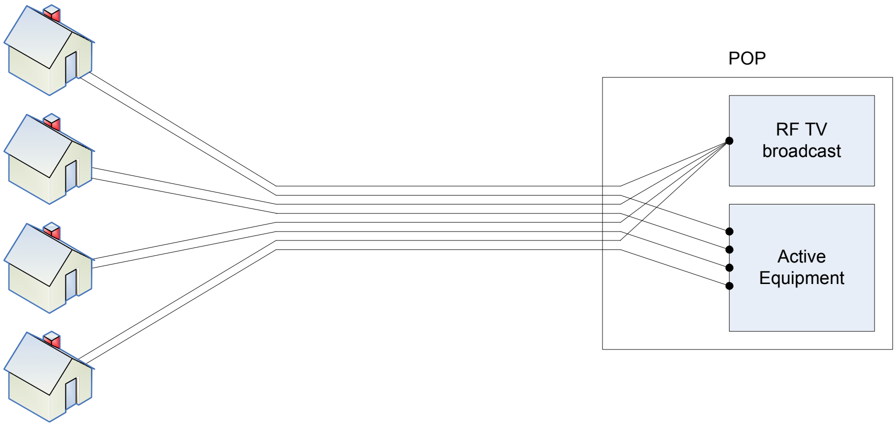

Figure 3.4: VolkerWessels (double point-to-point) FTTH architecture

architecture is relatively small. A schematic of the architecture of the FTTH networks that have been built by VolkerWessels is shown in figure 3.4.

As the figure shows, subscribers have two fibres coming into the premises. One is used for IP traffic such as internet and VoIP telephony, the second one is used for traditional (analogue) RF radio/TV broadcast (similar to existing coax infrastructures). Broadcast could technically have been delivered via IP on a single fibre, however this would require set-top boxes to decode the signal. The high cost of the set-top boxes (plus the fact that subscribers often own multiple TVs and would need set-top boxes for all of them) made a second fibre a more economical option. Installing excess capacity is often economic in deployments of last mile fibre networks, because much of the cost is in construction, ducts and structures, and “the costs are not significantly increased by placing multiple fibers (sic)” [Sirbu et al., 2004]. If equipment prices fall in the future or televisions become capable of decoding an IP-based signal, a switch in the network to IPTV can easily be made.

3.3.2 Real-world network construction experiences

Literature on (FTTH) network construction is available in plenty, but the real world is seldom as straight-forward as in literature. While literature necessarily deals with general aspects and simplifications of the real world, actual network building comes with many practical problems and limitations. This section gives insight in the reality of building networks in the Netherlands, describing some examples of real-world practical problems and limitations encountered when building communications networks. Appendix B describes a typical citywide VolkerWessels Telecom FTTH deployment.

Fixed communications networks in the Netherlands are always deployed underground, as is the power grid (with the exception of high-voltage long distance distribution lines). No aerial cabling is used any access network, which means that all FTTH deployments are buried as well.[2] As a result, massive trenching is required to build a FTTH network, which makes

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[2] While it technically might not be illegal to build an aerial network, in reality this is impossible to accomplish. Permits for aerial cabling on poles would not be given.

it much more expensive than an aerial deployment on (existing) utility poles. Using costing data from Banerjee & Sirbu [2003, table 4.2 and table 4.3], we calculated the cost difference between buried and aerial deployment. Calculations[3] show that buried deployment can cost up to 5 times more than aerial deployment in suburban areas, and up to 10 times more in urban areas (for the cost of the poles, trenches and fibre; no other costs were included). A buried FTTH deployment is more expensive (though less prone to damage), but is inherent in building networks in The Netherlands. The use of real-world data in our calculations reduces uncertainty in the results noted by Banerjee & Sirbu [2003].

The use of active equipment in the field (in an active star architecture) has several disadvantages which make it an undesirable option. Distributed equipment increases operational complexity and cost. It requires powered, uncontrolled remote sites and does not benefit from possible reductions in investment by aggregating equipment.

The fibres eventually converge on the Point of Presence (POP). The amount of fibres coming into a POP varies, POPs can be built with as little as 2000 or as much as 10000 connections. Fibre-optic communications experience very little signal loss with distance, this creates an opportunity to aggregate many connections at one location. Using larger (and thus fewer) POPs to cover an area is preferred. Equipment can then be aggregated at one location, which can reduce the initial investment in components [Banerjee & Sirbu, 2003]. Maintenance costs are also reduced because less time spent locating a problem and travel between locations.

A disadvantage of using large POPs however are the space requirements which can be significant. As the size of the POP becomes larger, finding suitable locations can prove to be challenging especially in the densely populated cities in The Netherlands. Cooperation from local parties can therefore be very important. If the local government is one of the initiators of a FTTH buildout, construction permits will probably be easier to obtain. Similarly when a housing corporation is the initiator, cooperation from them in finding suitable locations can be expected. When an external investor wants to build a FTTH network in a city, local governments can frustrate the permit process, delaying the deployment or making it prohibitively difficult. Cooperation from local parties can be essential in the permit process and a successful rollout of FTTH.

Cost reduction can be important in stimulating investment in FTTH. Opportunities for cost reduction in the passive network are possible, but presumably small. Ducts and fibre have become cheaper and more readily available in recent years and are no longer the major factor in the passive network costs; construction (trenching) forms the bulk of the costs. Experienced network builders have substantial expertise in cost-effective network building and only through ‘smart digging’, opportunistically placing cables in trenches together with other construction work, can occasional cost reductions take place. The active network has the most potential for cost reduction in the price per connected house.[4] Active equipment has been bulky and expensive in early deployments, but improvements are being made in the equipment market which is maturing and becoming more competitive.

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[3] Using an average distance between utility poles of 200 ft (~ 61 m).

[4] Personal communications with Egbert Eshuis, VolkerWessels Telecom, October 2005

3.4 Summary

A (FTTH) access network is a long-lived investment which has to balance key factors in network investment: meeting traffic demand now and in the future, capital costs to build the network, operating costs exploiting the network, and the benefits certain technical choices in the network offer.

Three basic architectures for FTTH networks are commonly identified: point-to-point, active star and PON. Both active star and PON networks use a shared feeder fibre to a remote node, the difference is that no equipment is placed at the node in a PON (passive star) network.

The networks built by VolkerWessels have used a double point-to-point architecture with two fibres per subscriber. One fibre is used for (IP) data transport while and the second fibre is used exclusively for RF radio/TV broadcast. Because the bulk of the cost of the network is in construction, the cost of the second fibre is relatively small. The advantage is in customer comfort, subscribers do not need a set-top box for each of their television sets.

Network construction in the Netherlands is characterised by the fact that all fixed telecommunications are deployed underground as opposed to an aerial deployment on poles. In a buried deployment, the bulk of the cost is in trenching en construction costs, so the incremental cost of a second fibre per subscriber is relatively small. Space requirements for large POPs are significant and finding suitable locations can be challenging in densely populated cities. Cooperation from local authorities and other stakeholders can be a very important asset in finding locations. Significant cost reductions in the construction of the passive network are not expected, but active equipment prices can be expected to fall as the equipment market is maturing and becoming more competitive.

Chapter 4

Open FTTH networks

Most FTTH networks currently built in the Netherlands are so-called ‘open networks’. This chapter first describes what an open network is, and secondly discusses regulation regarding open access. The third section describes the different technical layers in a communication network and possible implementations of open access at these layers. The fourth section explains which implementations are possible in the different FTTH architectures. Section five summarises open access implementations found in the available literature, and section six concludes.

4.1 Defining an open network

As the quotes in the introductory chapter showed, different opinions about the definition of an ‘open network’ exist. Basically, three crude categories of definitions can be defined:

- definitions by ownership[1] (of different layers such as the active/passive network);
- definitions regarding the obliged use of services[2] (linked to use of the network);
- definitions regarding multiple service providers[3] on a single network.

We will use and explore the third definition of an open network. A single open network with multiple service providers is inherently linked to the concept of a layered industry (see section 2.1) in which network providers and service providers are separate. An earlier paper on open access networks refers to open access as “sharing a common infrastructure to provide competitive communication services”, which can offer freedom of choice for users, freedom of service development for service providers, and lower costs for deployment and usage [Battiti et al., 2003]. The main concept is that in an open access network, the network owner sells wholesale capacity on the network (i.e. access) to service providers who provide retail services to subscribers. Therefore, open access is sometimes called a wholesale-retail split (e.g. by Banerjee & Sirbu [2005]).

Several possibilities exist for role of the network operator in an (open) network. Selling “access” to service providers can be done in several ways, as the rest of this chapter will

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[1] Stedenlink: Almere Fiber Pilot, Almere

[2] Gigaport: FTTH Driebergenbuurt, Deventer

[3] OnsNet, Nuenen / Glazen Maas, Rotterdam / ICT en de stad, Dordrecht

describe. TNO has defined three basic roles for the operator of a network [van den Ende et al., 2004]:

Customer comfort: Focus is on providing everything the customer may need, from network connectivity to services. This is essentially vertical integration and offers little choice for consumers.

Integrated: In the 'integrated' role, the operator takes responsibility for the passive as well as the active network. The end-product is an access network for service providers to offer services to customers.

Price/performance excellence: Here, all three parts of the value chain (passive network, active network, services) are provided by different parties who specialise in their role.

Our focus is on the 'integrated' role as this is employed by VolkerWessels Telecom, but the other roles will be discussed as well when necessary.

An open network as defined above is sometimes referred to as an 'open access network'. Regulators do not give a clear definitions of what 'open access' is. The European regulatory framework gives a technologically neutral definition of 'access' in communications networks to facilitate national lawmakers and harmonise regulation:

> *"access"* means the making available of facilities and/or services, to another undertaking, under defined conditions, on either an exclusive or non-exclusive basis, for the purpose of providing electronic communications services.
> [EC, 2002a]

In contrast to the the definition of access, the definition of 'open' is less clear. The mostly used definition is that multiple service providers can use the network; Sirbu et al. [2004] argue this is insufficient. For example, the 'Expert Group Broadband' defined an open network as a network that offers access to service providers at transparent, reasonable and non-discriminatory conditions [Expertgroep Breedband, 2002]. But is a network open when two service providers are possible, or should any number of service providers be allowed access? Furthermore, can a network be open for one service, but closed for another (e.g. open for data services, but closed for video services). Do all triple-play and other services have to be offered by multiple service providers for the network to classify as an open network? Taking multiple services into account, should consumers be able to choose for a different provider for each service, or is it sufficient to be able to choose between providers for the whole package of (triple-play and other) services? No single definition of open access as it is offered in practice exists [Sirbu et al., 2004].

The definition of an open network which will be used in this thesis is that a network is open when any service provider, local or otherwise, can use it to offer services to subscribers. Providers are able to offer any number of services; subscribers are able to choose an individual service provider for each of the services they choose to subscribe to.

Motivations to choose an open network model can differ for private investors or municipal networks. Municipalities building fibre access networks can choose open access to increase competition in the downstream service markets. Also, building a vertically integrated municipal network would increase accusations of competing against companies using government support. Private investors can choose open access because they acknowledge that exploiting a network and being a service provider are two different businesses. An investor can make the decision to take an interest in the long-term investment in the access network, not in the highly competitive service provider market. An open access network allows for higher utilisation of the network by many service providers, generating revenue for the network owner from several service providers in stead of only one. As such, an open access network is very much tailored for future growth in network exploitation. Additionally, a network that is suitable for open access exploitation might be a more valuable acquisition candidate for other companies in case of an intended sale.

4.2 Open network policy and regulation

As describes above, regulators are unclear on the subject of open networks. The definition for 'access' by the EC was part of the Access Directive which forced telephone incumbents to make available part of their network to competitors as unbundled network elements, but no definition of 'open' is given in terms of allowing multiple service providers to compete.

The legal obligation for operators to provide access can be given by the national regulatory agency (NRA), OPTA in the Netherlands. However, NRAs act in accordance with the EU regulatory framework and only assess competition in telecommunications markets, followed by possible measures. For this to happen, two conditions have to be met: the relevant market is not competitive, and the operator in question has significant market power in this market. The relevant product markets are defined in the EU regulatory framework; the NRA defines relevant geographical markets. All broadband markets in The Netherlands are defined to be national.[4] Legal obligations to provide open access are unlikely for FTTH networks in the short term, because the market share to FTTH networks will be much lower than that of other networks in the near future. This situation might change if: (a.) in the long term a very large market share is achieved and a position of significant market power is attained in an uncompetitive market. (b.) the relevant product markets are redefined and FTTH networks are considered a different product market (for instance Next Generation Networks) from the older networks, for instance because FTTH enables many new applications that cannot be delivered through the older networks. No indications lead to believe the latter is going to happen soon in the new EU regulatory framework. (c.) the geographical markets are redefined in a way that a local FTTH network has a significant market share. Access regulation for FTTH seems unlikely in the near future.

NRAs assess market power in pre-defined markets and can order access obligations, but do have the power to decide on policy decisions such as guidelines for open networks, which for instance the European Commission, ETSI or the Ministry of Economic Affairs could. The Ministry of Economic Affairs is obviously occupied with the subject of open FTTH networks, mostly with municipal and housing corporations projects, shown in a multitude of policy documents and guidelines [Burgmeijer, 2005; EZ, 2004a; EZ et al., 2005; EZ, 2005]. These policy documents however are mostly occupied with how municipalities can prevent their involvement in FTTH networks to be classified as illegal state aid, which has proven to be a problem in the planned Appingedam municipal FTTH network [Schouten, 2005]. In their

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[4] A subject which could fill a second thesis.

advice, the Ministry of Economic Affairs stresses the importance of an open network, but does not indicate *how* networks should be 'open'. Later in this thesis we argue that the way in which networks are open is important, and that more than just a technically open network is required.

4.3 Network layers and open access

Technologically, open access to a network can be implemented at various layers in the network. A wholesaler that provides access to dark fibre differs significantly from one that provides managed IP transport on 'lit' fibre. The Open Systems Interconnection Reference Model (or OSI seven layers model) is a layered abstract description of the functions of a communications protocol. The origin of the model is in the computing and networking industry, where a subset of the model is loosely adhered to.

The seven layers of the OSI model are: 1. Physical layer; 2. Data link layer; 3. Network layer; 4. Transport layer; 5. Session layer; 6. Presentation layer; 7. Application layer. The layers are shown in high-to-low order in figure 4.1 on page 31.[5] The four highest layers are implemented in software (not every one is always implemented) and are not part of the network. The lowest three layers (1–3) are the network layers, all of which can be the point at which open access to service providers is made available. A description of layers 1 through 3 and ways to offer open access at these layers is given below. In addition to these, Sirbu et al. [2004] also define access at 'layer 0', where conduits (empty ducts) and collocation facilities would be provided. 'Layer 0' access is not included in this research. Combined sources for much of this section are Sirbu et al. [2004], Banerjee & Sirbu [2003], Tseng [2001], and O'Donnell [2000].

4.3.1 Layer 1: Physical layer

The physical layer defines all electrical or optical specifications for devices on the network. This includes the use of cables, connectors, and frequencies; and the modulations and representation of digital data used. This effectively defines the physical communications channel. ISDN, DSL, 100BASE-TX and 1000BASE-SX are examples of physical layer definitions.

Open access at the physical layer essentially means 'unbundling' the strand of fibre from a central point to the consumer. This is analogous to the Unbundled Network Elements (UNE) which an incumbent PSTN network owner has to provide to competing ISPs. The service provider's equipment is located at the OLT, and the fibre is connected to the provider's equipment. This gives the service provider (who essentially becomes an active network operator as well) full control over the last mile network, which could also include placing a specific CPE at the customer.

Open access at layer 1 effectively limits the network operator's involvement to the passive network. These are the elements of the network with the longest economic lifetime. Active electronics, which have a shorter economic life, are deployed by other parties. This approach is therefore sometimes preferred by municipalities who want to become network providers.

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[5] Source: `www.wikipedia.org`

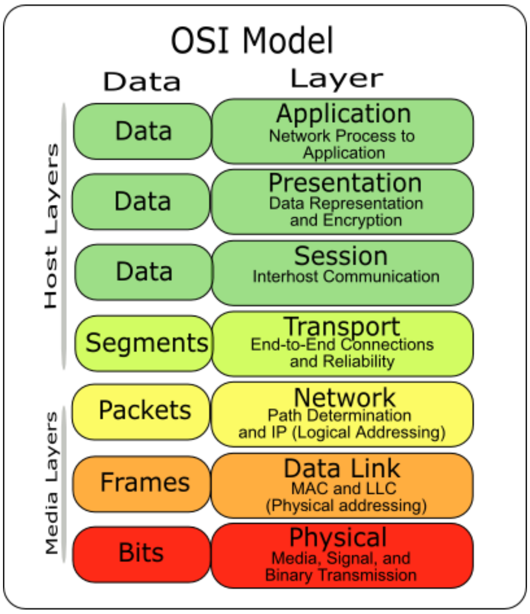

Figure 4.1: OSI seven layers model

4.3.2 Layer 2: Data link layer

The data link layer provides the means to transfer data over the physical network, detecting and correcting errors in the physical layer and providing an addressing scheme between locally connected hardware devices (MAC address). The data link layer provides data transfer on a single fibre, forwarding information to the next hop in the network. The layer has two components, Logical Link Control (defines where a frame of data begins and where it ends) and Media Access Control (determines who may access the media at a given time). ATM and Ethernet are examples of data link layer protocols.

When layer 2 access is provided, the network operator deploys active data link layer equipment at both sides of the fibre. Depending on the data link equipment used, the traffic streams of the different providers can be separated. In packet-based deployments (Ethernet), traffic can be assigned to a provider's VLAN. In cell-based deployments (ATM), traffic can be separated by assigning a specific virtual circuit to a provider. The latter also happens in DSL deployments, where each DSL provider uses his own virtual circuit. Layer 2 access is the most used option in open access networks [Sirbu et al., 2004].

4.3.3 Layer 3: Network layer

The network layer is responsible for transmitting messages of variable length from the source to the final destination. This includes translating logical addresses into physical addresses, global addressing and routing, and splitting/combining messages. Where the data link layer is responsible for node-to-node packet delivery, the network layer is responsible for end-to-end delivery. IP is the most well known example of a network layer protocol.

Layer 3 open access provides a fully functional IP based communications network. Virtual Private Networks or routing technology can be used to distinguish data from different providers. An extensive overview of how open access can be implemented in cable networks, using elaborate routing or tunnelling of traffic, can be found in a paper by O'Donnell [2000]. The solutions are similar to what could be achieved in FTTH networks.

All of the underlying network layers are provided by the network operator and shared by all providers, and are therefore the same for all providers. While this minimises investment for service providers, it also gives control over aspects like Quality of Service and management of traffic to the network operator.

4.4 FTTH architectures and access layers

Providing open access to a network is not simply a technical matter. When multiple providers share the network, "issues of control, network management and quality of service (QoS) arise" [Tseng, 2001]. The sharing of resources in a network makes open access more difficult. Different network architectures have different parts of the network which are shared between subscribers. The point in the network where traffic from one consumer must first contend for network resources with traffic from another consumer is likely to be the point where open access becomes problematic [O'Donnell, 2000].

Observe that everything in a communications network which is shared is under control of the network operator, not the service provider. This includes aspects of the service which could just as well be the service provider's technological or business decision. While sharing is often a good thing in communications technology to reduce trunking inefficiencies and under-use, more sharing is not always better. Extending control of the network owner beyond the bottleneck facilities reduces competition in parts of the network where competition could otherwise be possible. This reduces product differentiation possibilities for service providers and choice for subscribers.

A number of approaches to categorising open access possibilities in access networks has been used. Banerjee & Sirbu [2003] and Sirbu et al. [2004] start with the different services provided (voice, data and video broadcast) and look at possibilities of competition in these service markets on different FTTH architectures. Tseng [2001] describes how open access could theoretically be provided in FTTH architectures, and O'Donnell [2000] describes how this has been achieved in DSL and HFC deployments, which have some similarities to FTTH networks. Our starting point is the FTTH architectures, for each of which we will evaluate possible options for open access at the different network layers. This approach is more similar to that of Tseng than that of Banerjee & Sirbu and Sirbu et al., who are more service oriented. We will also discuss practical limitations of theoretical possibilities mentioned by Tseng which are ignored in literature but are of great importance in real-life network construction.

The FTTH network architectures described in section 3.2 allow or disallow certain levels of open access. FTTC solutions also allow or disallow levels of open access due to technical characteristics or practical limitations. Sections 4.4.1 through 4.4.2 describe the possibilities for open access at layers 1 through 3 in the network architectures under consideration. This will allow us to discuss the benefits and disadvantages of each architecture.

4.4.1 Point-to-point

Open access in a point-to-point network is easy to implement because there is no sharing of network resources in this architecture. Layer 1 open access is possible by simply plugging the OLT unit from a given subscriber into the equipment of another provider. Providers can co-locate their own equipment at the POP, and connect a distribution network of choice from there. Layer 2 access is also possible, in this case the providers could use a shared switch which uses VLANs to separate traffic for the providers, who would connect to the switch. Naturally, if layer 2 access is possible layer 3 access is also possible, using a different configuration in the active equipment.

4.4.2 Active star and FTTC

In an active star network, all subscribers have an individual drop loop, but the feeder loop is shared and active equipment is placed at the remote node. FTTC is similar to an active star, except that the final drop is not made using fibre but for instance the traditional twisted pair, coax or UTP cabling.

Layer 1 open access in an Active Star network is not a trivial question. Because only the drop loop is unshared, open access at the physical layer would have to take place at the remote node. O'Donnell [2000] suggests a similar approach for locating DSL equipment, but this poses practical problems. The remote node is invariably a small street cabinet or handhole which houses the network operator's equipment. Since space is an issue in almost all places, these nodes are generally just large enough to house the required equipment, but do not leave room for other providers' equipment, let alone more than one. Practical limitations make co-location at the node impossible. Furthermore, even if this were possible, the feeder loop would still be shared between the providers and under control of the network operator. This makes layer 1 access at the node pointless, since capacity has to be shared again in the feeder loop. Adding feeder loops for each individual provider could be done if ducts with spare capacity were used in the feeder loop (since digging is prohibitively expensive), but the problem of housing equipment remains.

In an active star network, everything from the CPE through the drop loop, active node, feeder loop and the first router in the POP is under control of the network operator. Providers share the entire access network and can place their own active equipment at the POP, from where on they can choose their own technology. Access at layer 2 is possible at the POP, but all providers have to use the network operator's choice of technology (ATM, Ethernet, etc) in the access network and the operator has influence in the QoS and other characteristics of the network. Again, layer 2 access makes layer 3 access possible as well.

Open access in a FTTC network is only possible on wholesale basis, i.e. layer 3 access. The new rollout of VDSL by KPN, a FTTC solution (see also section 2.2.1), will only be open to other ISPs at layer 3, because of space limitations in the street cabinets [Doorenbosch, 2005c]. KPN's competitors do not consider this offer an option because "the possibility of adding value to such a product is very limited" [Doorenbosch, 2005b], however space for co-location in street cabinets is limited indeed.

4.4.3 PON

A PON is a star architecture just like an active star, but without active components at the node, just a passive optical splitter. Here, all users behind a splitter share the up- and downstream capacity of a single fibre; the entire access network is shared, making layer 1 access impossible. Like in the Active Star, the network operator has full control over the quality of the access network.

Layer 2 access is simple in ATM PON networks, where virtual circuits can be used to separate traffic from providers (like in DSL). In Ethernet PON networks, layer 2 access is slightly less straightforward but possible nonetheless. Layer 3 open access is a possibility which is used in some shared cable networks in the United States.

Open access for video is different and difficult in PON deployments, because this implies IPTV. The high bandwidth requirements (up to 18 Mbps per channel for HDTV) stretch the limits of shared PON networks (30 Mbps per subscriber available) [Sirbu et al., 2004].

Theoretically, optical layer 1 unbundling is possible in a (shared) PON architecture by using Wavelength Division Multiplexing (WDM). Each provider (using CWDM) or each subscriber (using DWDM) could have his own wavelength, separating the data streams on the same fibre. However, the cost of (D)WDM equipment is such that optical unbundling is not (yet) economically feasible [Banerjee & Sirbu, 2003].

4.5 Literature case studies

Open access fibre networks have been built in several countries, most of them are a result of municipal initiatives. A list of municipalities and their choices in open access has been compiled in previous research on open access networks [Sirbu et al., 2004, table 4]. Many deployments on the list are US-based, but the list also includes the deployments in Stockholm and Amsterdam. In their research on municipal networks and open access, Sirbu et al. observe that access at layer 2 is the most widely used layer at which open access is provided.

Additional insights must be noted here. We already indicated that the list mentioned above is mostly focussed on the USA, where star architectures (active star and PON) are more popular than point-to-point architectures, while point-to-point networks are more popular in most of Europe. A number of reasons for this difference could probably be found, but the larger distances in the United States are a likely factor which make a reduction in the amount of fibre attractive.

Since only point-to-point architectures provide the option of access at layer 1, it is not surprising that layer 1 open access is rare in the USA. Looking at the two European deployments in the list, we see that the municipality in Stockholm exclusively provides layer 1 (dark fibre) access. In Amsterdam, dark fibre (layer 1) is leased by the city to a franchisee who sells wholesale access at layer 2 to service providers. The municipal HFC networks in the list offer open access at layer 3, note that this is their only possibility due to technical limitations. None of the FTTH deployments in the list choose to offer open access at layer 3.

At first sight, it appears most municipalities tend to offer access at the lowest possible network layer when given the choice between layer 2 and layer 3, but this is not always the case. The network in Nuenen offers access at layer 3. The city of Amsterdam will own the passive infrastructure of its future Citynet together with an investor (ING Real Estate) and five large housing corporations, but leaves the exploitation of the network to private parties (BBned won the tender for the active infrastructure). The same is true in Stockholm, but another way of selling layer 1 access was chosen.

Commercial exploitation of communication networks differs from that of municipalities. Competitors in the US choose to keep their networks closed to other service providers, also because the FCC has freed fibre networks from open access obligations. Commercial exploitation of networks on an open access basis is an equally viable alternative however, as shown by Banerjee & Sirbu [2005]. Commercial network exploitation (in Europe) appears to prefer providing layer 2 access in stead of layer 1, following an integrated passive/active business model.

Another preliminary conclusion that we can draw from this, is that the layer at which access to service providers is offered, is mostly driven by the technical characteristics and limitations of the network. Sirbu et al. [2004] have also shown that the technical choice of the network architecture dictates which types of services can be offered by multiple providers and at which network layer.

4.6 Summary

Technologically, access for service providers can be implemented at layers 1 through 3 of the OSI network layers model. With layer 1 (physical layer) access, dark fibre is provided. With layer 2 (data link layer) access, active equipment to light the fibre is provided to which service providers can connect. With layer 3 (network layer) access, complete wholesale IP transport is provided.

Different FTTH architectures can support varying network layers of access. A point-to-point network offers the most options (1–3), active star and PON networks can support layer 2 and 3, FTTC only supports layer 3 access. Literature shows layer 2 access is the most widely-used option in open networks in the Unites States.

No consensus exists on the definition of an open network. The definition used in this thesis is that an open network offers access to any service provider, local or otherwise, who can then offer services to subscribers. Providers are able to offer any number of services; subscribers are able to choose an individual service provider for each of the services they choose to subscribe to. Open access in Fibre-to-the-Home networks in the Netherlands is (in general) supported by the government, though policies are unspecific in how open access should be implemented.

Chapter 5

A framework for FTTH market structure

While many networks can be built under the premise of facilitating an open network, the question remains what actual competition can be expected between the service providers on the network. Networks that can technologically support many service providers will remain deprived of competition if other conditions are unfavourable.

We focus on the Fibre-to-the-Home network and its operator and establish a general framework to assess the probable market structure in FTTH networks in the Netherlands. The FTTH networks and their market structure in the Netherlands will likely be different in the introduction phase of FTTH than in a mature market. The framework provided in this chapter will be used in the successive chapters to describe the Nuenen case as an introduction phase network, and the City case as a step towards a mature market.

5.1 Theoretical framework

Earlier research already indicated that a fibre access network has natural monopoly characteristics, a subject also explained in section 2.3.4. A natural monopoly can be described as a market equilibrium where only a single firm can survive or as a production environment where a single firm can provide for the entire market at least cost [Gasmi et al., 2002]. The concept of an open network is that one is willing to accept a monopoly position for the network, in exchange for competition at service level. Multiple service providers can use the network to compete in providing services to their subscribers. The optimal long-term competitive market structure in FTTH is one with a common supplier of the network that is not vertically integrated [Banerjee & Sirbu, 2003]. Such a wholesale-retail split is a viable market structure and vertical integration is not required for the network operator to recover cost [Banerjee & Sirbu, 2005]. But how many service providers will actually enter this market; how many service providers can an open FTTH network support in sustainable competition?

The number of sellers in an industry is determined by scale economies and entry conditions [Viscusi et al., 2000]; a market with more sellers (in this case: more service providers) will have increased competition. Both scale economies and entry conditions will therefore need to be assessed to draw conclusions about the market structure in open FTTH networks.

Entry conditions for the service providers are essentially determined by the network operator. The way in which the operator implements open access for the providers is vital. Technological choices in the network and non-technological access conditions determine entry conditions which may or may not be favourable for providers.

A shared infrastructure removes significant barriers to entry in a (geographical) market for the service providers since they do not have to build their own network. However, each provider will still incur a significant fixed cost associated with providing services, for example: "an ISP retailer will need to invest in servers (e-mail, DHCP) as well as middle mile transport; a video service provider needs a headend, contracts with content providers, operations support and billing systems, etc. The size of these investments imply a minimum market size for retailer viability, and thus a limit on the number of retailers sustainable over a given infrastructure" [Sirbu et al., 2004]. The network operator has control over these costs as he can choose which parts of common infrastructure to provide. With this, he determines the entry conditions and also a part of the fixed costs for the service provider. Section 5.2 describes the entry conditions which are important to assess the probable market structure in open FTTH networks.

Scale economies are crucial in determining the number of possible sellers in an industry. The point at which the long-run average cost curve of a firm becomes horizontal, indicates the minimum efficient scale of the firm. At all outputs below this level, the firm is producing at sub-optimal scale and does not benefit from least-cost production. The minimum efficient scale of the firm determines the maximum possible firms that can exist in an industry in the long-run competitive equilibrium, and is therefore a crucial determinant of the number of firms in an industry [Lyons, 1980].

De Fontenay et al. [2005] argued in a recent article that any scale or scope economies that may exist in telecommunications are related to certain network layers instead of the traditional vertically integrated firm as a whole. Any economies should therefore be examined at the level of individual network (sub)layers and not for vertical "end-to-end" services. De Fontenay et al. already pointed to large economies of scale and scope in the passive network (i.e. related to trenching and the use of fibre and buildings). They also suggested economies could exist that are not bounded geographically in the manner that the physical layer is, an example would be in network management, however lack of data was seen as the main problem in this field. We have been able to overcome these problems with data from VolkerWessels Telecom on network construction and operation, and can do calculations which prove the scale economies in telecommunications and draw conclusions from them.

The costs of a FTTH network (per subscriber) decline with the achieved penetration, but are also lower as the size of the network grows. The possibility to use more shared backbone infrastructure and to spread the costs over more subscribers imply economies with size and penetration. Since competing networks are omnipresent in the Netherlands, competition from these networks determines a maximum total price one is able to charge consumers for the network and the services. This implies scale economies for the operator are important in providing low-cost access to subscribers for service providers, in order to collectively compete with the PSTN and cable networks.

Sharing the bottleneck facility of a network can be efficient but defining which part of the network is the bottleneck facility is difficult. Banerjee & Sirbu [2003] mainly focus on multiple competitors in the active network layer using a single passive infrastructure. These competitors could then offer services to consumers. We focus on a business model where the network operator operates a common passive and active infrastructure, and offers transport for services on the network to service providers. Our focus corresponds to the 'integrated' business model defined by TNO [van den Ende et al., 2004]. Using an engineering cost model (described in section 5.3), we calculate the costs for the network operator and service providers in an open FTTH network in order to predict a possible market structure.

In our research we evaluate the cost functions to assess the long-run competitive equilibrium. How these costs are recovered in the form of pricing agreements (who to charge, what pricing scheme to use, and how much to charge) is beyond the scope of this research. An excellent work on pricing in telecommunication networks can be found in a book by Courcoubetis & Weber [2003]; Dippon [2001] and Tardiff [2003] investigate pricing of wholesale and bundled services.

5.2 Entry conditions: implementation of open access

The network operator who builds and operates an open FTTH network defines the entry conditions for potential service providers. The technological choices in the network and the non-technological access conditions influence the way service providers have to interconnect to the network, which facilities they have to provide for themselves, and which facilities are shared. This makes the choices the operator makes a significant factor in the extent of possible competition in the service market.

An exact definition of the boundaries of the access network is required. Additionally, the role of the network operator and the definition of which elements are part of the access network can (and will) change in the future. A definition of exactly what the access network is, will delineate the role and responsibilities of the access network operator. Furthermore, capital and operational costs are involved as the access network is defined including or excluding certain elements. The access network has to be defined in two dimensions: the physical boundaries (the objects that are part of the network) and the functional boundaries (the technical functions that are preformed by the network). The definition of boundaries of the FTTH access networks is given in sections 5.2.1 and 5.2.2. The definition of the access network is independent of which technology is chosen to build the network (point-to-point, PON, etc.). Section 5.2.3 will describe the implementation of the previously mentioned requirements and the other non-technological conditions for access.

5.2.1 Physical delineation of the network

A schematic representation of a (FTTH) access network is presented in figure 5.1. When discussing an open network, it is vital to exactly determine *what the network is.* If the network operator only operates the FTTH access network (but does not offer services), one needs to answer the question which elements are considered part of the access network, and which elements are not? In other words, which objects or pieces of equipment are defined to be part of the access network, and are under control and responsibility of the network operator?

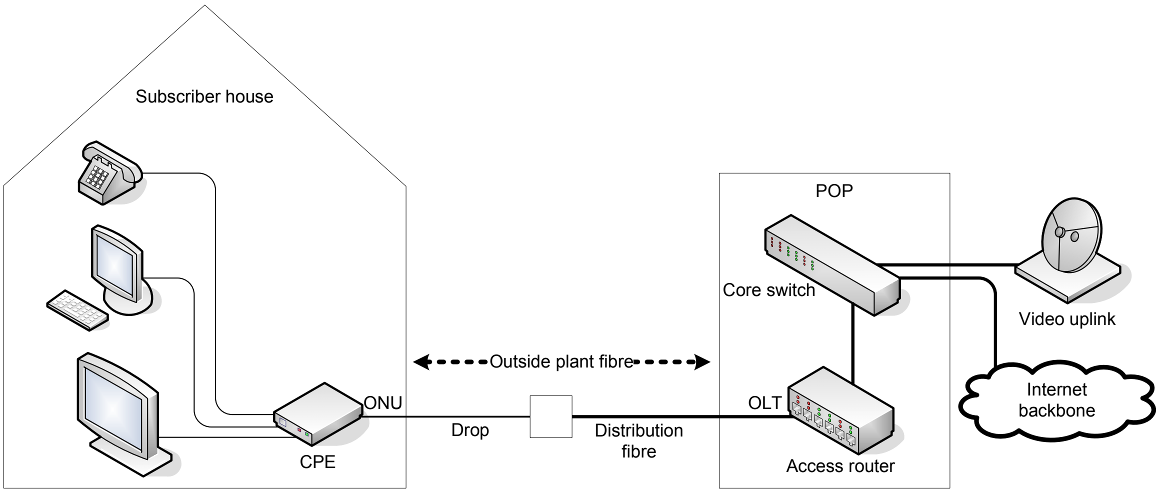

Figure 5.1: Schematic representation of a FTTH network

The POP housing and facilities, the access and core routers therein, and all outside plant fibre including the drop fibre into the subscriber's premises are defined as part of the access network. The upstream and downstream boundaries of the network are more interesting. The physical delineation of the network in the following chapters will determine if, in a given situation, the CPE on the downstream side of the network is considered part of the access network. Similarly, the upstream boundaries of the network (for instance the backbone Internet connection or video headend) have to be clearly defined.

The physical delineation of the network will determine which elements are the responsibility of the network operator (for which he incurs costs) and which elements are not. Note that the passive infrastructure is determined to be the responsibility of the network operator, but this is irrespective of ownership issues. The passive infrastructure could be owned by a different party (for instance an investor or municipality) but the network operator is assumed to be responsible for maintaining it. The physical boundaries of the network also limit the possibility space in which the functional requirements demanded from the network have to be implemented technically.

5.2.2 Functional delineation of the network

The physical boundaries of the access network delineate which network elements are part of the access network and which elements are either upstream or downstream from the access network. However, this does not fully address the question which technical functions are performed by this access network. To evaluate which functions are considered part of the network, recall the network layers of the OSI-model explained in section 4.3. The first (lower) three layers in this model constituted the network layers which are of significance to us. All higher layers are not part of the network, but are the services provided to subscribers. These 'application layer' services are some form of data transported over the network, the contents of which are irrelevant to us. The original model is condensed into the four important layers in figure 5.2.

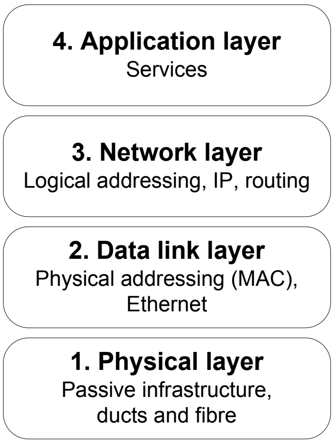

Figure 5.2: Functional network layers

The functional delineation of the network determines which layers in this model are performed by the network operator of the access network. This immediately leaves the functions performed by the service provider. The importance of setting clear boundaries in this respect becomes clear when costs are associated with each of the functional network layers, which should be attributed to certain parties. The main choice here for the network operator is between layer 2 or layer 3 equipment. The party operating layer 3 services such as the handout of IP addresses and DNS services has to constantly manage these and solve problems with them such as abuse. This implies operational costs for network management. Furthermore, the choice of active equipment plays an important role. The way in which equipment manufacturers technically implement open access, and the layer at which access is offered, affects the functional delineation of the network. Vice versa, the desired functional delineation can influence the choice of equipment. Sections 6.2 and 7.2 will discuss the delineations in the two cases and in section 8.2, conclusions on this subject for the network operator can be found.

5.2.3 Implementation

The requirements defined in section 5.2.2 have to be implemented in the network in the active equipment used (which was defined in section 5.2.1.). As was already mentioned in the previous section, the way equipment manufacturers technically implement open access and the layer at which access is offered differs. The chosen equipment may limit the options for delineation of the network, or the functional requirements may limit the choice of equipment.

A second concern are the factors which are outside the technological scope of the access network. The conditions at which service providers can gain access to the network are an important entry condition. General conditions may for instance include:

- availability of a backbone connection to the Internet,
- interconnection possibilities for service providers,
- where to interconnect,
- possible requirements for services.

These aspects will be discussed as well, as costs are involved which have to be allocated to organisations in the value chain. Technological as well as non-technological issues in implementation will prove to be important drivers for competition in certain scenarios.

5.3 Scale economies: cost model

We are interested in open FTTH networks in the sense that they allow for service level competition. To evaluate the extent of possible competition, and with this a probable market structure, we need to assess the costs a network provider and service provider would incur in an open network scenario. In a split industry structure, correctly allocating costs to market parties is of vital importance. To whom costs are allocated will have an impact on the attractiveness of certain roles in the value chain, and will influence competition (or lack thereof) in that part of the value chain. This section describes the cost model and assumptions used in later chapters.

5.3.1 Description of the model

In an open network business model, subscribers choose to take services from independent service providers. The role of the network operator is restricted to operating the FTTH network and offering access to it. Our interest in this business model is if an open FTTH network can recover cost and if the network can sustain competition at service level. For this to happen, three necessary conditions must hold:

1. The network operator must be able to recover cost.
2. The service provider(s) must be able to recover cost.
3. The total price for the subscriber must be competitive.

The importance of the first two conditions is trivial, since no operator or service provider will invest in a loss-making network. The third condition is caused by competition from other infrastructures (the PSTN and cable networks) and will be explained later. We use a simple model on the available data in the two cases to calculate the long-run average cost curves of the network operator and the service providers. To calculate the cost curves, we assume both the operator and provider are single-product firms.

Network operator

The network operator builds and operates the fibre network and offers wholesale access to providers. The operator focusses solely on wholesale access and does not offer services to subscribers. The network operator incurs costs from building the network and from operations. In the model the network operator's cost is split in Capital Expenditures $CapEx$ from building the network and Operational Expenditures $OpEx$ from network operations:

$$Cost_{Network} = CapEx + OpEx \tag{5.1}$$

Capital Expenditure is split in the Investment I in the active part a and passive part p of the network, which are both annualised (using the function "Payment" Pmt) according to their respective capital requirements. Parameters for the annual cost of the investment are the rate of return r and number of payments n, which is the depreciation period in years.

$$\begin{aligned} CapEx &= CapEx_p + CapEx_a \\ &= Pmt(r_p, n_p, I_p) + Pmt(r_a, n_a, I_a) \end{aligned} \tag{5.2}$$

The split in active and passive network at this point is important since both have very different capital requirements. The active equipment has only a short economic life while the passive infrastructure has an extremely long lifetime. Due to financing risks or because of a possible different ownership of the active and passive network, the rate of return requirements can be different as well.

In the calculations, we have assumed a 10% rate of return on the capital investments in the active and passive network. The depreciation period for the passive network is set to be 25 years because of the long lifespan of the network. The depreciation period of the active equipment is assumed to be 5 years. The required investment I in both the active and passive network has a fixed part and a variable part that depends on the achieved penetration. Investment figures are specific for a given network since local conditions heavily influence these costs.

Operational Expenditures for the network operator are caused by maintenance of the physical network and operating the active network and infrastructure. Scale economies exist in network operation and can be significant because fixed cost can be spread over all the controlled connections. A Network Operations Centre is required for 24/7 monitoring of the network, but costs for monitoring do not increase linearly with the number of connections. The $OpEx$ for the network operator is calculated as a per-subscriber cost for a network of a given size. The network operator has a large fixed/sunk investment and fixed marginal cost (proof in appendix C), which is a clear decreasing-cost industry.

Service providers

All potential service providers are assumed to be single-product firms who sell only the bundle of triple-play services to their subscribers. In this simplified model, providers do not offer individual services, and all are assumed to provide fairly homogeneous products to subscribers; providers compete on price, level of service, and brand. For a given market penetration, all service providers are assumed to have an equal market share; profits are calculated as zero for service providers because of competition. Providers therefore have identical cost curves, we will use calculations for one to three providers but any number is possible.

Service providers incur costs SP in the form of a fixed part and a variable part per subscriber:

$$Cost_{Services} = SP_{fix} + SP_{var} \tag{5.3}$$

The variable part corresponds to per-subscriber costs, for instance required data storage servers which can be bought as subscribers sign on or broadcasting rights for television stations. The fixed costs are costs related the service provider's investment to gain access to the FTTH access network. This includes costs such as a backbone connection or investment in a video headend. These costs are annualised according to the same capital requirement parameters as the active equipment of the network operator. The investment for the service provider is fixed.

$$SP_{fix} = Pmt(r_a, n_a, I_{SP}) \tag{5.4}$$

Revenue

The third condition we gave for the open network business model to be successful was that the total price for the consumer (network + services) has to be competitive. This is required because service providers will have to compete with providers on the PSTN and cable networks.

While the market structure and expected on-network competition is the research interest of this thesis, FTTH networks in the Netherlands are rarely the only telecommunications network to which a house has access. Until a *"killer app"* emerges which requires the bandwidth of a fibre network, infrastructure competition from telephone and cable companies will be fierce as these networks will offer triple-play services as well. While these copper infrastructures cannot match the bandwidth of a fibre network, price competition from other infrastructures will limit the penetration the FTTH network achieves. If the costs of service provisioning are such that a FTTH service provider is much more expensive than a PSTN or cable service provider, many consumers will choose a different network. Since the bandwidth of a fibre connection cannot be matched by copper networks, a premium price may be charged for high-bandwidth services, but not all services require high bandwidth. Furthermore, not all consumers may value a fast connection equally high. This means the costs of the network and the costs of the services together need to be competitive. This also indicates why we can accept a monopoly position for the network operator. While a monopolist network operator could raise prices for service providers, price competition from other networks would cause subscribers to choose a different network, which would reduce the operator's profits. Competition limits the achievable market penetration and consumer price.

Obviously, the total cost in the open network is the cost for the network operator plus the cost for (any one of) the service provider(s). The total cost has to be below the marginal revenue MR (revenue per subscriber), so the restriction on the revenue side is:

$$Cost_{Total} = Cost_{Network} + Cost_{Services} \tag{5.5}$$

with

$$Cost_{Total} \leq MR \tag{5.6}$$

In the calculations, we have used a constant and fixed marginal revenue per subscriber per month as we assumed service providers to be single-product firms. We assume a total consumer price (for network and services) of € 50 per month, including VAT. This is at the moment a competitive price for a high-quality triple-play service in the Netherlands[1]. Prices are low already (compared internationally), but are expected to fall even more in the future.

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[1] The current triple-play offer of 10 Mbps symmetrical ISP service, telephone and radio/TV on the Portaal housing corporation's fibre network is € 50.00 (`www.xtramediaservices.nl`). The price for a similar package with OnsNet in Nuenen is € 59.39 (`www.onsnetnuenen.nl`).

5.3.2 Influences on model parameters

The model will use quantitative data from VolkerWessels Telecom to calculate the cost functions of the network scenarios. The use of real-world data will provide a realistic view on the costs of FTTH networks. Some of the model parameters are dependent on assumptions or will provide additional insight, these will be described here.

Investment parameters

The Capital Expenditures for the network operator, defined in equation (5.2), are the annualised costs for the active and passive network. The two parts of the fibre network have very different lifetimes so the distinction is important. Each asset should be annualised according to its own specifications. The equation for $CapEx = Pmt(r, n, I)$ is based on the investment in the network I (for both parts of the network). The result is dependent in the capital requirements in the formula: the rate of return r and the number of payments n. Our assumptions seem reasonable and the results have shown to be fairly robust.

The investment I in the active and passive network itself is based on cost calculations from VolkerWessels Telecom. For the passive network, POP housing and construction and the basic distribution infrastructure including labour are calculated as fixed cost. The variable cost is caused by installing the drop fibre to the subscriber's house, and is therefore dependent on penetration.

For the investment in the active network, the core data switching equipment, system management equipment and CATV broadcast equipment including labour are calculated as fixed cost. The variable cost is caused by the subscriber's CPE, subscriber CATV modules and access routers which can be bought as subscribers sign on, so all these costs are therefore dependent on penetration. A certain amount of active equipment is assumed to be pre-installed for flexibility when subscribers sign up at the start of the network and price advantages from large vendor contracts with equipment suppliers.

Network size and OpEx

Size matters. Scale economies exist within a given FTTH network (as penetration increases), but additional scale economies exist when networks become larger. Small networks will have higher average cost for maintenance and control than large networks. In subsequent chapters, a distinction will be made between the small local network in Nuenen and the larger City network. We have used OpEx data from the firm to do our calculations, which was based on costs for a network of a given size. Both networks are operated by the same company, offering cost advantages, but to properly assess competition on the networks in the individual cases, we have used calculations for the individual network sizes.

Entry conditions

The investment for the service providers is partially determined by the entry conditions described previously in section 5.2. A network operator who offers more common infrastructure will change the investment required by service providers and possibly their operational expenditures. The technical implementation of the open network described in the cases will be taken into account when calculating the costs for the service provider.

5.3.3 Remarks on the model

All models are a simplification of reality under certain assumptions which necessarily leaves out information which is less relevant or too complex. Therefore, the assumptions in the model have to be reviewed critically.

We calculate our model for single-product firms. Of course, in reality these firms can (and are likely to) be multi-product firms. In a real-world scenario, subscribers can choose to subscribe to each of the services in the triple-play bundle (telephony, TV and Internet) individually, or to any combination of services. Adding additional services such as Video on Demand increases the number of possible combinations exponentially (2^n for n services). This means the current subscriber has 8 possible service combinations to choose from the triple-play bundle.

Each of these services has specific costs associated with it, related to interconnection, call termination, broadcast rights, ISP backend servers, etc.; all are likely to have their own cost structure and price. Modelling each of these possibilities is complex and available data on the cost of services is unspecific. Furthermore, non-services related costs exist from activities such as billing, helpdesk, and marketing. Since we are mainly interested in the role of the network operator, the service provider is assumed to be a single-product firm selling the triple play bundle, incurring a fixed and per-subscriber cost. Future research could use specific costing data for separate services to focus on the service provider's role in stead of the operator's role.

Competition form other networks (PSTN and cable) is incorporated in this model as the revenue per subscriber, total cost has to be below this revenue to be considered "competitive", which would induce a subscriber to take service. The competition is implicit in that it limits the maximum achievable penetration for a network. Future research could explicitly incorporate infrastructure competition.

5.3.4 Results from the model: limits on market structure and competition

In both of the investigated cases we will evaluate the effects on possible competition of the operator and service provider roles in the value chain and the technological and non-technological aspects of the FTTH network. Entry conditions and scale economies described in the previous two sections will be evaluated to draw conclusions on a sustainable market structure in open FTTH networks.

5.4 Summary

An open FTTH network is designed to let multiple service providers offer several different services on the network to subscribers. We are interested in the concept of an open FTTH network from the perspective of a network operator and from a policy perspective. Competition between service providers will offer benefits to the consumers in the form of more choice, lower prices and/or better service. While competition in the end-user services is the goal of an open network, we question whether building an open network is enough to promote this competition. Given an open FTTH network, how much competition between service providers can we expect, in other words how many service providers can co-exist in sustainable competition on an given FTTH network?

The theoretical framework on the subject of market structure and competition in telecommunication networks indicates that two main drivers for the extent of possible competition on services in an open network exist: the entry conditions and scale economies. Scale economies are important for the operator and the service provider alike.

Entry conditions for service providers are essentially determined by the network operator. To determine these, the physical and functional delineation of the access network has to be clear, as described in section 5.2. An engineering cost model, described in section 5.3, will be used to assess scale economies in FTTH networks.

The framework described in this chapter defines how entry conditions for service providers and scale economies in FTTH networks will be evaluated for two cases of Dutch FTTH networks in the following two chapters.

Chapter 6

The Nuenen case

6.1 Introduction

OnsNet (which translates to “Our Net”) is a suitable name for a cooperative network which is owned by its subscribers. OnsNet is a Fibre-to-the-Home network in the Nuenen municipality near Eindhoven. The Eindhoven region was chosen by the Ministry of Economic Affairs as a broadband testing ground for new services under the name ‘Kenniswijk’. The inhabitants of Nuenen were eligible for a state subsidy for a next-generation broadband network and services.

The availability of the Kenniswijk subsidy (€ 800 per subscriber) was the main motivation to build a FTTH network in Nuenen. However, the subsidy was available only to *consumers* who could apply. Local entrepreneurial enthusiasts who were dissatisfied with UPC and KPN set up the plan for network ownership and financing. A cooperative (OnsNet) was set up, and this organisation was authorised by the subscribers-to-be to receive the subsidy on their behalf. The subscribers were the members of the ‘Cooperative Association OnsNet’ and thereby partially owned the network. External investors were found to fund the rest of the project with a loan. Subscribers were offered a free year-long 10 Mbps symmetrical Internet subscription if they would join the cooperative. This of course induced many to subscribe: 7445 households subscribed in the first year (which corresponds to a 97% penetration rate).

The success of achieving such a high penetration from the start had many advantages, the main advantage being the large sum of subsidy (almost 6 million euro). Another large advantage was in the construction of the network. Since almost every house had to be connected, the construction work to make the house connections could be done at the same time as the work to pass the homes with distribution cabling. There was no need to come back later to make numerous house connections and open up the streets again. This reduced cost and hinderance for the inhabitants.

Starting 2006, the inhabitants of Nuenen had to sign up and become members of the cooperative association OnsNet. The paid service achieved a penetration rate of 75% from the start of 2006. At the moment, the full bundle of triple-play services is offered by OnsNet. The business model[1] currently employed is the customer comfort model. Everything for the

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[1] See section 4.1.

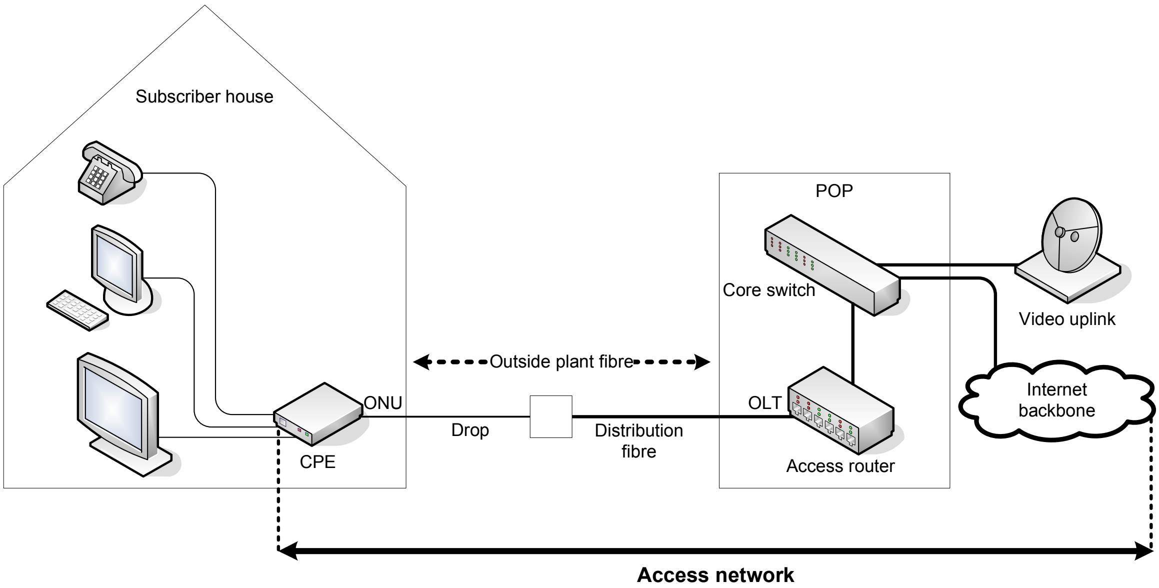

Figure 6.1: Physical network boundaries in Nuenen

consumer is taken care of by the network operator/service provider, who is essentially fulfilling all roles in the value chain. This reduces uncertainty related to a new technology in the initial stages of FTTH, but offers little choice for consumers. A number of new services have been developed such as small-scale local community television, partly by individual members, which is not done by any of the large multiregional cable companies. As an open network, OnsNet does offer access for other service providers but none have entered after one year.

An important part of the success of the network in Nuenen is attributed to the enthusiasm of local stakeholders and their success in creating a real “we-feeling” amongst the subscribers and members of “Our Net”, to which the special cooperative ownership system contributes. This is an example of the fact that FTTH is an inherently local affair. No standards for the networks exist and many projects so far have been different in construction, ownership and financing. Much more can and has been written about the unique fibre project in Nuenen,[2] but we necessarily focus on the aspects of the network which are most important to us: the implementation of the open network and its entry conditions for service providers and scale economies.

6.2 Implementation of open access

6.2.1 Physical delineation of the network

The FTTH network in Nuenen was the first large-scale community-wide rollout of FTTH in the Netherlands. The project was not initiated by one of the large telecom players so no

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[2] Examples from the press: [Schouten, 2005; ED, 2005; Doorenbosch, 2006; Olsthoorn, 2006].

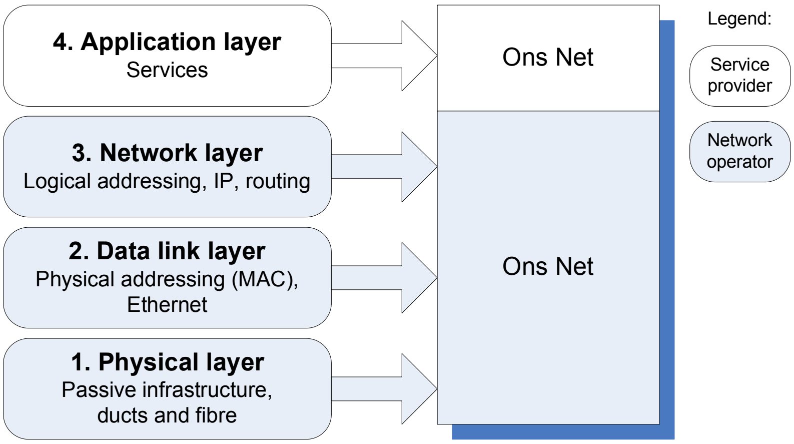

Figure 6.2: Functional network boundaries in Nuenen

existing facilities were available; everything had to be built and arranged from the ground up.

The physical network boundaries in Nuenen are shown in figure 6.1. As the figure shows, the CPE is included as part of the access network. This is a necessary decision because the market for FTTH access and FTTH equipment is still developing. The CPE has to work with the access router at the OLT, and to assure everything functions properly the network operator chooses and supplies the CPE for the network.

In the Nuenen network, OnsNet operates as network operator as well as service provider (the customer comfort model, essentially vertical integration). To be able to offer services, the network needed its own Internet backbone and a TV broadcast headend. This was also induced by the requirements for the Kenniswijk subsidy as part of the subsidy needed to go to services, not just infrastructure. OnsNet offers access to other service providers as an open network, however other service providers have to arrange their own means of local interconnection with the network.

6.2.2 Functional delineation of the network

The functional network boundaries in Nuenen are shown in figure 6.2. The lower three shaded layers show the layers of the access network operated by the *network operator* OnsNet, who provides access to the *service provider* OnsNet. As the figure shows, the network offers access to the service provider(s) at network layer 3.

The choice for a layer 3 system was mainly decided by the fact that this offered a complete, integrated system which could be used by OnsNet to offer services. No additional equipment needed to be bought which made an integrated layer 3 system a more economical option than a layer 2 system.

6.2.3 Implementation

The FTTH network in Nuenen has a double point-to-point architecture as described in section 3.3. The network connects 7445 homes in the Nuenen municipality. A single POP is used to aggregate all connections, and two fibres are deployed to each connected house. On one fibre, Internet and telephony services are provided, the second fibre is used for RF TV broadcast.

The equipment used on the data network is an integrated layer 3 system by Swedish vendor PacketFront. The PacketFront system is capable of delivering IPTV on the same fibre, however this requires set-top boxes for the consumers. The high cost of the set-top boxes (subscribers often own multiple television sets) made deploying an additional fibre for normal TV broadcast a more economical option. Additionally, subscribers would then not be deterred by the inconvenience of using a set-top box instead of their normal television remote control. A set-top box is still required for video-on-demand or future digital transmissions over the RF broadcast fibre.

The PacketFront system is optimised for municipalities (or operators) wishing to provide services themselves, while still offering the option of open access for services. The ASR 4000 series access routers have an integrated network operation system called 'BECS' (Broadband Ethernet Control System), which makes it an all-in-one solution.

In a layer 3 system, the network operator has more tasks than in a layer 2 system, specifically managing the IP layer. On this subject, PacketFront itself writes in 'Delivering Service to a PacketFront Network': "Even though the IP Addresses are owned by the service provider, they are handed out (via DHCP) by systems in the Network Operators network and therefore required to be delegated to the Network Operator." And: "the technical requirements put on the service provider are reduced to providing a pool of IP addresses and specifying service parameters (Bandwidth, QoS etc). The rest of the delivery is handled by the network operators control system."

The use of this integrated system essentially reduces the service provider for services like telephony to someone that sends bills; and service provisioning by an Internet service provider is stripped of basic tasks as well. Many of the tasks are now preformed by the network operator, who takes on a significant amount of system management. Experience with the network so far has indicated that in a split network and services cost structure, almost all of the costs would be allocated to the network operator. Apart from the costs for broadcasting rights and some servers for the Internet services, almost all operational costs would be accounted for by the network operator.

6.3 Cost model

With the entry conditions for service providers as described in the previous section, we evaluate scale economies for the network operator and service providers in the Nuenen network. Our model assumed both the network operator and the service providers to be single-product firms so the Nuenen network operator in the model is assumed only to provide network access.

Network operator

Because of the substantial Kenniswijk subsidy, the business case in Nuenen is quite different from that of a normal FTTH rollout in a similar community. We therefore distinguish the current subsidised situation from a 'normal' scenario.

In the current Nuenen network, a subsidy of € 800 per subscriber was available. In order to maximise the incoming subsidy, subscribers were offered one year of free 10 Mbps symmetrical Internet service when they signed on, which led to a 97% penetration rate in the first year. The advantage of this penetration has a downside: virtually all of the required active equipment to serve the entire community had to be installed. When paid service began after the first year, a drop in subscribers took place[3] which rendered part of the equipment unnecessary. To calculate the costs in the current subsidised scenario, the real investment figures for the first year were used, since the subsidy has to be offset against high costs of pre-installed equipment. For the long-run cost calculation however we are interested in the years after the first year where penetration will vary.

The active and the passive network have different payback periods. The costs for the active network are therefore relatively higher (a € 1000 investment in the active network has a higher annual cost than a € 1000 investment in the passive network). The subsidy of € 800 per subscriber therefore has to be divided (in our model) over the active and passive network. While the amount was put into the project as a form of lump sum payment, the description of the subsidy still specified € 500 of it to be for the infrastructure, and € 300 for services. We have used this as a proxy for dividing the subsidy into € 500 for the passive, and € 300 for the active network.

Network equipment has a short depreciation time, we have assumed a 5-year depreciation period for the active equipment. The passive network was assumed to have a 25-year depreciation period, interest on both was assumed to be 10%. Marginal revenue per subscriber (remember the service providers sell only the triple-play bundle) is € 50 per month.

In a normal scenario, a network operator would not receive the subsidy but also would not pre-install all of the equipment. In our models we have assumed 40% of the variable active equipment (access routers, etc.) is pre-installed, more is installed as higher penetration rates are achieved. Pre-installing 40% is a reasonable assumption because a significant penetration is required to recover large investment in the network. The difference between the 'current' and 'normal' scenarios is therefore in the amount of pre-installed equipment and subsidy, they are the same in all other respects. The normal scenario is representative for a FTTH rollout in a small community.

The long-run average cost curves for the current and normal network operator in Nuenen are shown in figure 6.3 on page 53. The two curves are the long-run average costs per subscriber per month, the horizontal line is the limit on revenue per subscriber per month. The figure shows a number of things, one being that the LRAC curve is decreasing for all possible outputs. The costs for the subsidised network are obviously lower than that of the normal scenario. The difference in cost increases with penetration because the house connection and active equipment in the subsidy scenario are already available while a normal operator would have to build and invest more. At very low penetration ratios the difference is very small because of the under-utilised investment in house connections and active equipment

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[3] Though penetration in Nuenen is still impressive at over 75%.

in the subsidy scenario.

We use this data on operator cost curves and limited revenue to assess the position of service providers next.

Service providers

Service providers can connect to the FTTH network in Nuenen to offer services to consumers. As described in section 5.3, providers incur a fixed cost related to gaining access to the network, and a variable per-subscriber cost related to the actual provisioning of services.

As section 6.2 on entry conditions for service providers in Nuenen explained, the network is an all-in-one system that requires no investment in layer 3 equipment for the service providers. This reduces fixed costs but significant costs have to be made nonetheless, for example to provide a backbone Internet connection, so scale economies do exist.

Service providers are assumed to be identical and to have equal market shares for any achieved total penetration. The cost curves for service providers are therefore identical. We have done calculations for one through three service providers on the network. Under our assumptions, the cost curve for two providers is that of a single provider with every point on the curve shifted right to twice the penetration of a single provider. The shift to a three-provider LRAC cost curve is similar to that. Figure 6.4 on page 53 shows the LRAC curves for one to three service providers in Nuenen.

6.4 Market structure and competition

For an open network with multiple service providers to be successful, the collective price of the network and the services must be competitive. Under this restriction we assess possible market structure and service provider competition in the Nuenen network.

For the network operator to be able to focus solely on wholesale transport and not on services, he has to be able to recover his cost plus a reasonable profit margin. Under the assumed price restriction by competition, this leaves the area between the operator's LRAC curve and the marginal profit line in figure 6.3 as the possibility space for service providers. This area, the difference between the MR and operator LRAC curve, is plotted in figure 6.4 as the maximum cost for the service providers in the current and normal scenario.

Any service provider offering services on the network needs to be able to offer services below the price of the maximum cost curve in figure 6.4. By plotting the LRAC curves for multiple providers we can assess at which achieved penetration rate sustainable competition between multiple providers is possible.

For the current scenario, figure 6.4 shows that a single service provider is able to achieve the required scale to deliver services at a competitive price at 50-55% penetration. The two-provider curve intersects at 55-60% while the three-provider curve intersects with the maximum cost at 60-65% penetration. These are the minimum penetration rates required for the service providers to be able to recover cost.

While the calculations show that the subsidised network in Nuenen could support multiple service providers, the 'normal' investment scenario is very different. The blue curve for

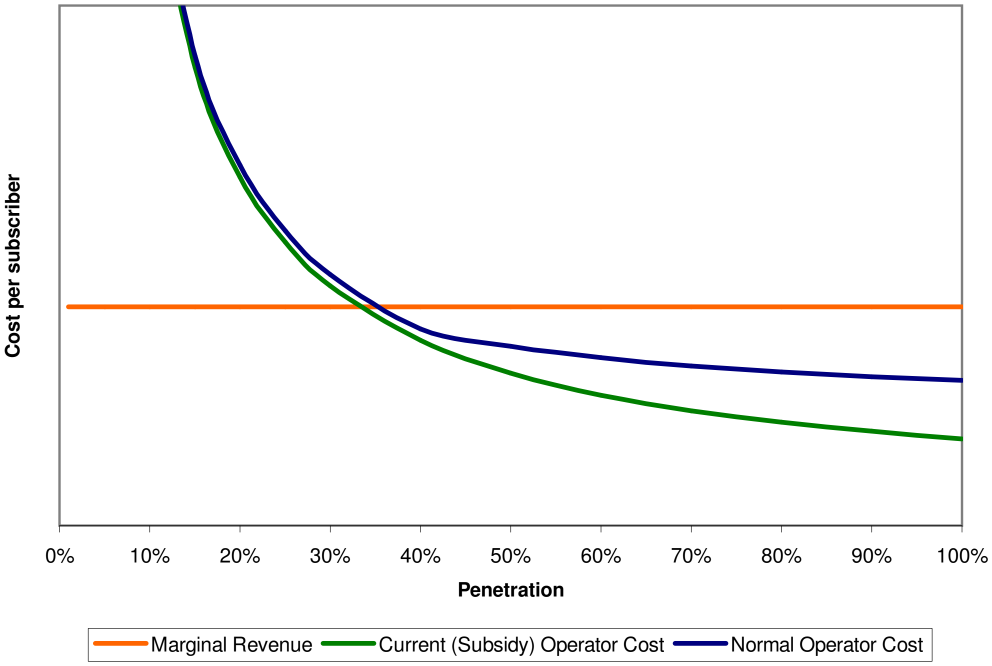

Figure 6.3: Cost per subscriber for network operator Nuenen

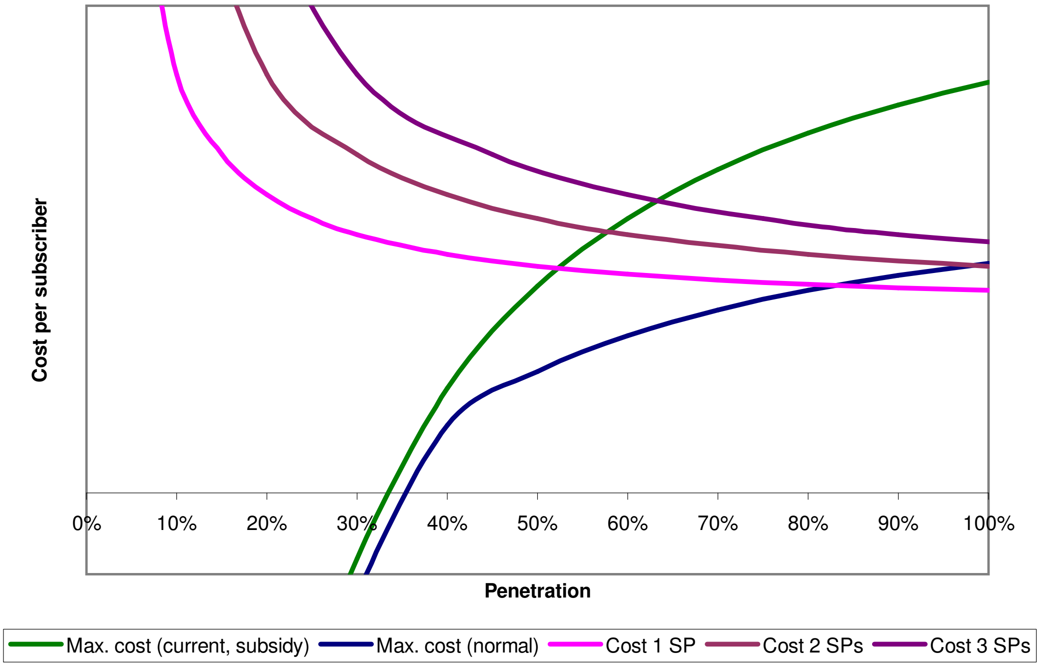

Figure 6.4: Service provider cost curves Nuenen

the normal investment scenario in the Nuenen network differs significantly from that of the subsidised scenario. The LRAC curve for two service providers intersects with the normal maximum cost curve at almost 100% penetration.

We must conclude that in a normal scenario without subsidy, the network in Nuenen would not be able to function as an open network. While the network can technically offer access to multiple providers, the scale of the network is too small to support multiple service providers in sustainable competition. We suspect a minimum efficient scale exists for FTTH networks to truly function as an open network, and will test this by performing the same analysis for a larger city-wide network in the next chapter.

6.5 Summary

The FTTH network 'OnsNet' in Nuenen was initiated by local enthusiasts, the network was started with support from the Ministry of Economic Affairs in the form of a large 'Kenniswijk' subsidy. Subscribers were eligible for a € 800 subsidy to be used for next-generation infrastructure and services. A cooperative was formed which collected the subsidy and found external investors to fund the network.

Subscribers were offered a free year-long 10 Mbps symmetrical Internet service if they would subscribe, which was a very effective way of attracting subscribers and subsidy: 7445 subscribers joined in the first year which is a 97% penetration rate. The second year with paid service still achieved a very successful penetration of over 75%. OnsNet operates the network and provides services, following a customer comfort business model (which is essentially vertical integration), but the open network can also offer access to other service providers.

The CPE, video (TV) headend and internet backbone are all part of the network, though another provider (besides OnsNet) would have to arrange an own backbone connection. The network has a double point-to-point architecture with a single POP and uses a layer 3 integrated system for the operator. Analogue TV broadcast is done on the second fibre.

Results from our cost model have shown that the current network can support multiple service providers. However, a similar normal network in a small community without the subsidy would not be able to compete with existing infrastructures. Only at extremely high penetration rates would one or more service providers be able to recover cost. We therefore conclude that a minimum efficient scale must exist for the open network concept to be effective in the Dutch competitive environment. A 'technologically open' network in a small community will remain 'economically closed' because sustainable competition cannot be achieved.

Chapter 7

The City case

7.1 Introduction

In the ‘City’ case we use data for a FTTH network which is to be built in a medium-sized city in the Netherlands. This project would pass all houses in the entire city with a fibre network, potentially a little under 37000 subscribers. This increment in scale is a step up from the small Nuenen network. We expect FTTH networks to start out as small localised networks such as the Nuenen municipality, the Tongelre neighbourhood in Eindhoven, or the Almere Fiber Pilot in part of the city of Almere. A network covering an entire city is a next step in the evolution towards larger (even regional) networks and a mature FTTH access market. The ‘City network’ has not been built yet, but is in an advanced stage of planning and development so all required data is already available. The project is not initiated as a municipal network but as an investment by a private (non-incumbent) party.

7.2 Implementation of open access

7.2.1 Physical delineation of the network

The physical boundaries of the access network in a split network operator/service provider industry structure are shown in figure 7.1 on page 56. Equivalent to the Nuenen network, the CPE (which is managed by the network operator) is part of the access network solution because and no standardised equipment exists (yet). In the future it may be preferable to exclude the CPE from the access network from the operator’s point of view, and only provide a fibre termination point for an optical network unit. This would reduce cost for the operator, while offering options for service providers and consumers. In a mature equipment market with clear standards, subscribers could choose the CPE which best suits their needs: some CPEs could be simple and cheap, while others could offer more functionality at a higher price. Service providers could also choose to supply their subscribers with a CPE upon subscribing to their services. These possibilities are currently already employed in the market for ADSL equipment, which is a mature market. Consumers can go to a store and buy an ADSL CPE with more options (for instance including a wireless router or a VoIP interface) if they so desire. However, until fibre-optic access equipment has reached mass-market availability, the

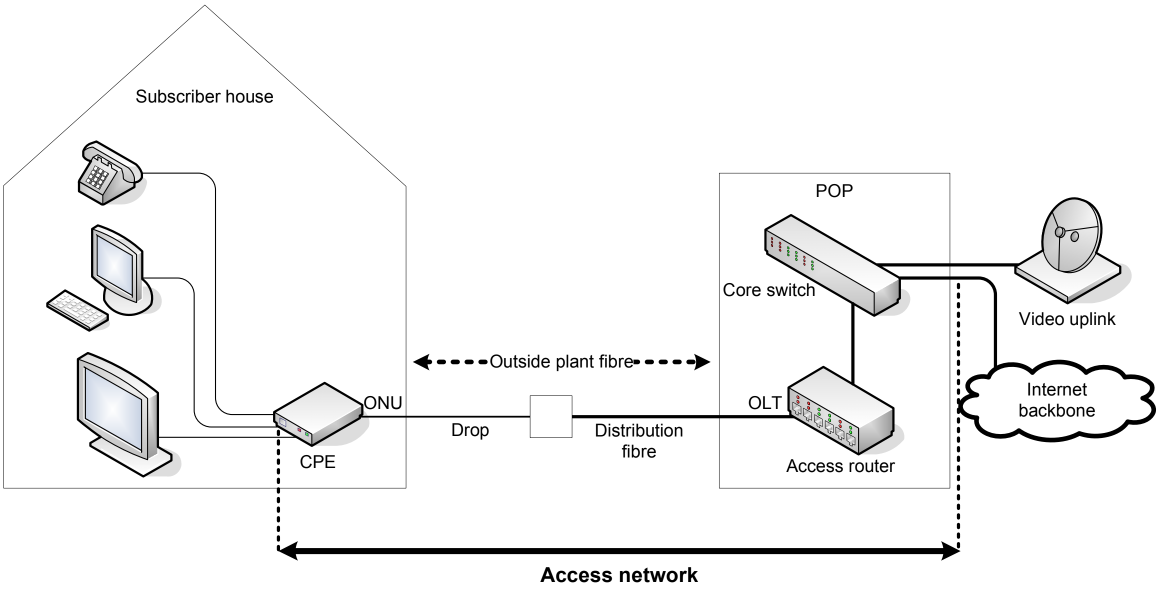

Figure 7.1: Physical network boundaries in City

CPE needs to be supplied by the operator as part of the access network.

In figure 7.1, the backbone connection to an Internet Exchange (e.g. AMS-IX) is not considered part of the access network, nor is the video headend. In this split industry structure, facilities are present the main POP of the city to make provisioning of Internet, TV or other services by service providers possible (the interconnection point). The providers themselves are responsible for bringing their signal or connection to the POP. However, since the network is not actually up and running yet, the situation could be different and an own backbone could still be provided as well. This depends on several factors including negotiations with service providers (for instance large providers may have their own backbone) so some reservations are made on this point. We will focus on this delineation for our cost model.

7.2.2 Functional delineation of the network

Figure 7.2 on page 57 shows the functional delineation in the City network. The figure shows a layer 2 solution for the network operator. The network layer (layer 3) and services on top of that are the responsibility of independent service providers, not affiliated with the network operator.

The decision for layer 2 equipment in this network is taken from the perspective of the network operator as well as that of the service providers. The aim of the network operator is to have multiple service providers offering services on the network. Management of the IP layer is a significant task and becomes more complex as the open network model is more successful offering access to more providers and more different services for subscribers. In a layer 2 system, service providers retain control over the IP addresses for which they are responsible. A more elaborate discussion of the choice between a layer 2 or layer 3 solution can be found in section 8.2.

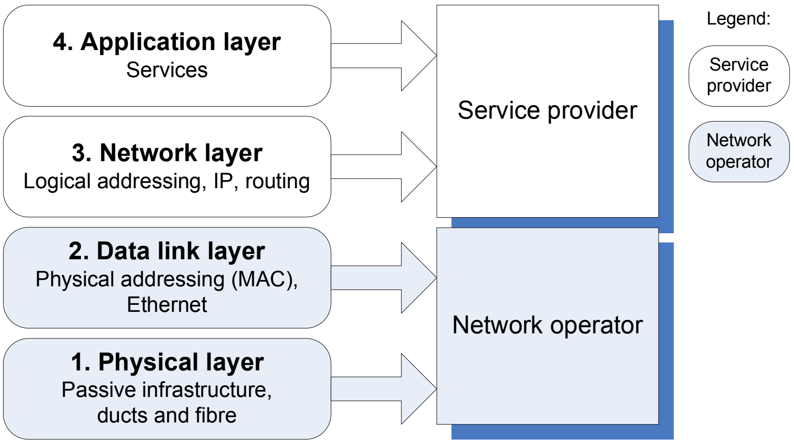

Figure 7.2: Functional network boundaries in City

7.2.3 Implementation

Since the network is not passed the planning and negotiations stage some reservations have to be made about the implementation of the network, but several important aspects of the network have been determined.

The network will pass all 37000 houses in the city in a double point-to-point architecture. A total of 6 POPs will be required to aggregate the subscriber connections, the POPs will be connected via a cityring. In the active network, layer 2 equipment from a major vendor will be used on the data fibre.

7.3 Cost model

The costs of construction and operation of the City network will be used to evaluate the scale economies for the network operator and service providers of the City network. We will use the same basic calculations as in the Nuenen case, from the framework defined in chapter 5.

Only a single cost curve for the network operator will be calculated since no subsidy has to be incorporated. All concerned parties are privately owned companies. The cost curve for the operator will therefore be calculated like the ‘normal’ scenario in the Nuenen case: the basic infrastructure and core active equipment are fixed as well as a 40% pre-installment of the variable active equipment. Variable costs for the passive network are obviously fully dependent on penetration since house connections can only be made when a subscriber’s address is known.

The capital requirements are the same as for the Nuenen case: a 5-year depreciation period for the active equipment and a 25-year depreciation time for the passive network. Interest on both parts of the network is calculated at 10%. Marginal revenue for the triple-play bundle is € 50 per month, service provider profits are not calculated.

Network operator

The long run average cost (LRAC) curve for the network operator is shown with the marginal revenue for the network and triple-play bundle in figure 7.3 on page 59. The slope of the curve is similar to that of the 'normal' operator in Nuenen, however it reaches a lower per-subscriber cost at high penetration. This is caused by the larger scale of the network which allows fixed and sunk costs to be shared amongst more subscribers.

Service providers

Service providers who connect to the City network incur higher costs than those in Nuenen. Since the network operator offers open access at network layer 2, each service provider will have to provide its own layer 3 equipment in addition to the other costs such as a video headend or Internet backbone. While a layer 2 network requires more capital investment because of the added layer 3 equipment, this provides better allocation of costs and responsibilities to specific parties in the value chain and is therefore to be preferred. The calculations will show that these added equipment costs are not a problem at sufficient scale. The cost curves for one to three service providers are shown in figure 7.4 on page 59. Again, service providers are assumed to be identical and to have equal market shares for a given penetration.

7.4 Market structure and competition

The collective price of the network and the services is critical in determining if the open network can compete with existing infrastructures. Using a marginal revenue of € 50 per subscriber we assess the long-term competitive market structure on the City network.

Assuming the network operator charges according to his cost curve, can multiple service providers compete in this environment? The difference between the marginal revenue and the operator's cost per subscriber (see figure 7.3) is the allowed cost for a service provider on this network to remain below the marginal revenue limit.

The possibility space for service providers (the difference between marginal revenue and the operator cost curve) is shown as the maximal cost for service providers in figure 7.4 on page 59. The LRAC of the service providers needs to be lower than this maximum cost for the providers to be able to offer services in sustainable competition. The figure shows the LRAC curve for a single SP crossing the maximum cost curve at approximately 60%. Two providers can compete at approximately 65% penetration, three at approximately 70%.

The conclusions for the City network are significantly different that that of the Nuenen network. Whereas the 'normal' scenario in Nuenen could not support multiple service providers (only at extremely high penetration rates), the City network *can* support multiple providers under normal private investment. The fact that service providers are faced with increased fixed cost to connect to a layer 2 network does not interfere with the viability of offering service on the network.

The calculations for the City network support the theory from the precious chapter that a minimum efficient scale exists for a FTTH network to be able to operate as a truly open network. Calculating the exact minimum is problematic since building the network is a

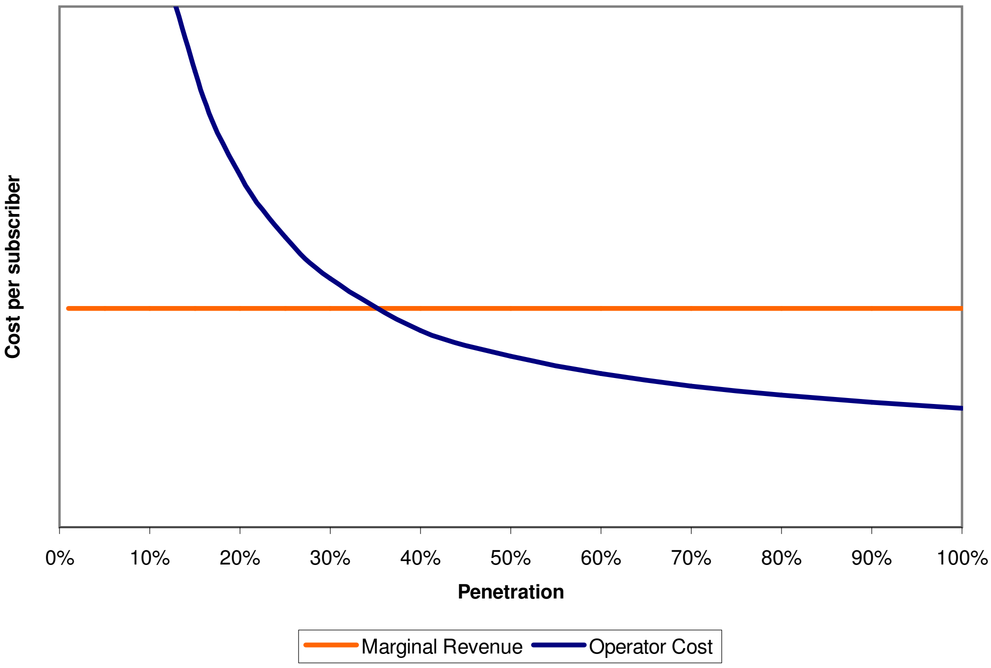

Figure 7.3: Cost per subscriber for network operator City

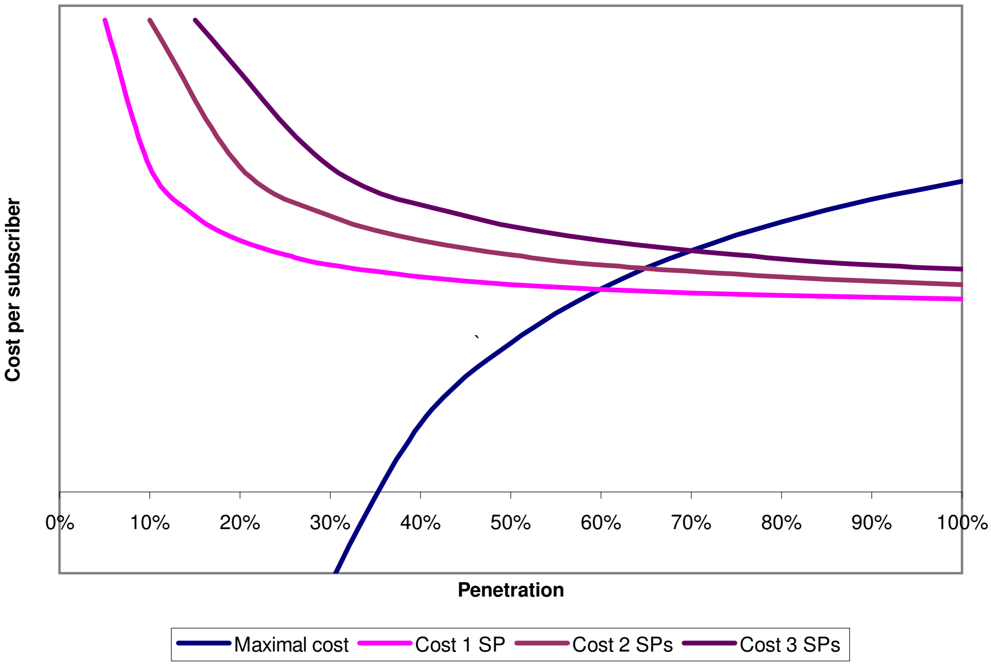

Figure 7.4: Service provider cost curves City

custom task in every situation. The local geography, town layout, population density, type of housing, presence of parks, highways, railroads or water, etc. influence network cost and are different in every situation.

7.5 Summary

The City case used data from a network in advanced stages of planning, which will provide an entire city in the Netherlands with FTTH access. The privately owned network will pass a total of almost 37000 houses.

The network will be built using a double point-to-point architecture, using layer 2 equipment to light the data fibre and RF TV broadcast on the second fibre.

Results from our open network cost model have shown that the City network can support multiple service providers under normal private investment. At sufficient penetration, the network has sufficient scale to support multiple triple-play service providers in sustainable competition. The network operator can focus on providing wholesale access to service providers.

Chapter 8

The role of the network operator

Using information from literature and experiences from actual FTTH cases, this chapter aims to describe success factors and choices that are important in exploiting a FTTH network with an open access business model. The goal is to provide advice to an operator from a business and technological perspective. More specifically we further define technical characteristics for a network operator focussing on the 'integrated' business model as defined by TNO, where the operator provides the active and passive layer of the fibre network [van den Ende et al., 2004].

8.1 Business implications of open access

8.1.1 The importance of local support

Constructing an access network is an inherently local affair, in which cooperation of local parties is very important. While not specific to open network exploitation, experience has shown that when local authorities have a positive attitude towards the project many of the legal processes are streamlined. Resistance or non-cooperation by local government by refusing or delaying certain required permits may not be sustainable in the long run, but it can delay and hinder the project for so long that it becomes a significant problem.

On the other hand, cooperation by local authorities can speed up the process. Bundling demand from local government (and for instance educational and healthcare) institutions can help in creating a positive attitude. While direct or indirect investment by the local government is often believed to be a good strategy to stimulate FTTH deployment, other options may prove to be far more effective. A local government wishing to foster investment in a fibre network in their community can do this by pro-actively working with the investors in the planning and permit phase by issuing permits flexibly and speedily. Providing locations for network POPs (for normal financial compensation) is another way to alleviate network construction difficulties and thereby foster private investment.

8.1.2 Attracting subscribers

Any network needs subscribers, but a new FTTH network will need to convince consumers to switch from their existing networks. Because of the local nature of an access network, local services can be an effective way to add value for consumers to the network. Competing networks (the telephone and cable networks) operate on a national or large regional scale, and a new (local) network can provide specific local services which might convince subscribers to switch.

While attracting subscribers might seem a task solely for the service providers, in the early phase of a network it is probably even more vital to the network operator because of the large investment made. As empirical results have shown, the number of service providers, who can use their brand name and (bundles of) services to attract subscribers, will probably not be very high in a small network. This might require more effort of the operator in the early stages of the market.

An open FTTH network is more attractive to potential subscribers when more service providers are available to choose from. This choice for consumers is an advantage relative to a vertically integrated network. Evidence suggests that bad previous experiences with a provider can cause consumers never to return to that provider.[1] In a vertically integrated network, this would lead to a lost customer for the operator as well, while this is not necessarily the case in an open network.

Having several of the large ISPs on the network decreases switching costs for subscribers. If an XS4ALL ADSL subscriber can migrate to XS4ALL on the FTTH network, he can keep his e-mail address, account settings and the services he appreciates and benefit from the speeds of the new network. Multiple service providers makes the FTTH network attractive to potential subscribers.

8.1.3 Attracting service providers

In order to attract subscribers with multiple service providers, how to attract the providers? The two subjects are related since having many subscribers attracts service providers. Large networks are interesting markets for providers to offer their services to. Achieving the scale to become an interesting market for providers must therefore a primary goal for an operator of an open network, or the connected service providers will remain limited to smaller local parties.

Two options to achieve the necessary scale in network exploitation are building (or expanding) larger networks and interconnecting multiple individual networks. In the current early stages of FTTH deployments, many FTTH networks will exist as localised spots on a map rather dan covering large geographical areas. A service provider wishing to gain access to subscribers on these networks will need to provide a backbone uplink to interconnect to each of these networks, and probably equipment at all of these places. This causes significant fixed costs for a provider to reach all of the (possibly small) networks. Creating a way for service providers to interconnect to all operated FTTH networks at once essentially creates one large network from the provider's perspective. This way, small networks that might not

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[1] Past problems with the quality of the Internet service and helpdesk of Chello (UPC), though possibly no longer applicable, still plague their reputation for reliability and service.

be interesting by itself form one large network which makes it more interesting for providers.

Achieving large scale in network operation by creating larger networks and interconnecting individual networks is vital to attract large service providers.

8.2 Technical implications of open access

8.2.1 Network layer of providing access

Which of the possible network layers is the best option for a network operator? This choice is of paramount importance since it not only dictates which type of active equipment to buy, it also affects the costs and responsibilities of the network operator as described in section 5.2.

For a network operator in the 'integrated' business model, two options are available: layer 2 and layer 3 equipment. Section 4.5 described literature about previous open access case studies. It showed that most operators in the United States choose for the lowest possible layer of providing access, which is layer 3 for HFC and layer 2 for PON FTTH networks. Previous research has also indicated the importance of these technical considerations, and concluded (from a municipal network perspective) that layer 3 access would support the most dynamic range of service-level competition [Sirbu et al., 2004]. However, they also noted that this would require the operator to become a full-fledged provider of wholesale services and that this would limit possible facilities-based competition for service providers.

Looking at the only large (more or less) open network in The Netherlands, the incumbent telephone network, we see that ADSL service providers generally use layer 2 access. Only where white-label wholesale service by the network operator is offered to a reseller does this happen at layer 3. The implication of this is that most large Dutch ISPs are used to interconnecting at layer 2 and have their organisation and equipment set up for layer 2 interconnection. In addition to this, the service providers have their own pool of IP addresses for which they are responsible. Should problems occur with one of the addresses (for instance spam or viruses are being distributed from one of their IP addresses), the owner of the address is responsible for taking action. This responsibility is taken on by the network operator in a layer 3 system, but many service providers may not be willing to relinquish control over their addresses.

Management of the IP layer is a significant task and becomes more complex as the open network model is more successful offering access to more providers and more different services for subscribers. While in a simple network each subscribed house may only have a single IP address (say for an Internet service). Adding additional services (such as VoIP and IPTV) will require several IP addresses per subscriber, assume one IP address for each subscribed service, which increases complexity. Furthermore in an open network with multiple service providers, they each will have their own pool of IP addresses to give out. As subscribers sign on for more services from different providers and the open network is more successful, the operator is faced with an increasingly complex network operation environment which increases operational costs. Looking at the experience from the (layer 3) FTTH network in Nuenen, we see that the network operator essentially has to do almost all of the work in operations, with few tasks being done by the service provider. Shifting these tasks to the providers therefore lowers system management costs for the operator. It also gives service providers more (financial) room to operate and compete in.

We agree with the observations of Sirbu, Lehr & Gillett, but conclude differently that a layer 2 network, rather than a layer 3 network, is the best option for a network operator (in The Netherlands) from a business and a policy perspective. A layer 2 network better allocates costs and responsibilities to the suitable party, moving activities from the operator to the service provider. It also gives service providers more possibilities to compete and create value, fostering effective competition on service level.

8.2.2 Network architecture

Critical in the understanding of network construction is that in the end, the choice of network architecture is not an *engineering* but an *investment* decision. As Koonen [2005] writes: "cost effectiveness is a key issue, and will be decisive for the network topology choices." A commercial party wanting to invest in a FTTH infrastructure will seek to minimise investment and maximise return on investment within a certain time frame. Even when the investor and network operator would want to operate the network on an open network basis, the required investment may lead to a decision to build a network which is not future-proof and which does not support open access for all services. Since different FTTH architectures have different costs we briefly discuss the options here.

Looking at the available choices for a layer 2 architecture, both PON and point-to-point architectures are suitable options. Point-to-point offers the highest potential bandwidth and options, but is a more expensive option than PON. An intermediate solution is a possibility as well. Since PON and point-to-point networks generally follow similar routes, one could build a PON network with excess empty ducts in the distribution (feeder) part of the network. The stock of empty ducts creates a cheap real option to upgrade the network to a point-to-point network without any additional digging, which constitutes the bulk of the construction cost. Existing PON connections can then be migrated by relocating the splitter to the POP. One could then replace the CPE and POP equipment when required. A switch in architecture seems unlikely though since the active equipment in PON networks can also be upgraded in the future.

The total cost of a network however is always dependent on negotiations with suppliers. A blanket decision is difficult and the price difference between the two options might not be very large. Operation of a point-to-point network appears less complex while PON equipment is more energy-efficient. A mixed environment creates its own complications in operation. Predictions about the best alternative are heavily dependent on local conditions as a prediction about the cost of construction also differs in every community (because of the local layout of the area, including main roads, water, parks, railroads, possible POP locations, etc.).

8.3 Summary

For a FTTH network operator, achieving scale in network operation is key. Building larger networks and interconnecting individual networks to form a single large market for service providers can attract multiple large service providers to the network. The richness of options and possible services this brings to the network makes the network attractive to subscribers.

An operator supplying the passive and active network to independent service providers (the TNO ‘integrated’ business model) can best choose layer 2 network equipment. Service providers provide the layer 3 (IP) services, which gives them the appropriate control and responsibility. This allocates costs and activities to the suitable parties and provides the most possibilities for service level competition.

Both a point-to-point and a PON architecture are suited for a layer 2 open FTTH network. In a PON network, installing excess empty ducts in the feeder part can create a cheap real option to upgrade to a point-to-point network in the future.

Chapter 9

Summary and Conclusion

The goal of this research was to explore the open network concept in Fibre-to-the-Home from the perspective of a network operator in The Netherlands. Broadband penetration in the Netherlands is very high and is dominated by DSL and cable. Both networks are being upgraded and are increasingly able to offer triple-play services (the combination of voice, data and video service). This is only made possible by deploying fibre closer to the end-user. The ultimate form of this is a full Fibre-to-the-Home (FTTH) network, which offers the most bandwidth and the highest possible service quality. Eventually FTTH is the technology of choice for the long term. FTTH is not (yet) being deployed by traditional telecom players but mainly by combinations of local governments, housing corporations and external investors.

A Fibre-to-the-Home infrastructure in an area has the capacity to serve the entire market and poses significant sunk cost on investment; costs per subscriber decrease with penetration over the entire range of possible outputs. FTTH is therefore a decreasing cost industry which implies a second network would be inefficient. For consumers to be able to benefit from competition, multiple service providers can provide services on a single infrastructure: an open network. This is consistent with the trend in telecommunications away from vertically integrated companies to a layered, ‘next generation’ industry structure.

The way in which open access is technically implemented by the network operator defines the entry conditions for the service providers and is therefore important for the eventual competition on service level. A precise definition of the open network is required in terms of network components and functionality. In terms of the OSI layer model, a network operator has the option to use layer 2 (data link) or layer 3 (IP) equipment. While layer 3 equipment is an option more suited for a vertically integrated operator, layer 2 equipment offers functionality which is more suitable for the operator and provides more possibilities for competition in the services market. Most current Internet Service Providers are set up for layer 2 access. Open access at layer 2 is possible in both point-to-point and PON FTTH architectures.

We used data from two real-world cases in an engineering cost model to assess the possible market structure in open FTTH networks. We calculated the long run average cost curves for the network operator and triple-play service provider(s) to predict a long run competitive equilibrium. The first case was the small FTTH network ‘OnsNet’ in Nuenen which has been operating for little over a year, serving almost 7500 subscribers in its first year. The second case is a larger network covering an entire city of almost 37000 houses.

Evidence from the Nuenen and City cases has shown that scale economies in network operation are vital in determining the possible extent of competition between service providers. The network in Nuenen is a layer 3 network and open for other service providers, however the small scale makes it unlikely that large non-local providers will enter this network. The City network is now planned to be a layer 2 network and has the potential to be attractive for multiple triple-play service providers if sufficient penetration is achieved.

The Nuenen and City case show that that small local networks, which are likely to exist in the introduction phase of FTTH, are different from large networks in a mature market. As FTTH networks start out small and localised, a trade-off between less 'openness' (more vertical integration) and cost may be observed. As the network grows and the market matures, more possibilities for 'openness' become possible. A move from small, vertically integrated networks (based on a 'customer comfort' business model) to large, more open networks (based on an passive/active 'integrated' or a 'price/performance excellence' business model) offering more choice and competition for consumers is likely in the future.

For an open FTTH network operator, achieving scale in network operation is key. Building larger networks and interconnecting individual networks to form a single large market for service providers can attract multiple large service providers to the network. The richness of options and possible services this brings to the network makes the network attractive to subscribers. Both service providers and subscribers can be sources of revenue for the network operator.

Many government officials who wish to build a Fibre-to-the-Home network in their municipality support their build plans by claiming the next-generation infrastructure needs to be an open network; investments by the local government are often seen as a way to create these open networks. We have shown that the definition of the claimed open network needs to be much more precise than is generally done and should incorporate technical characteristics. Furthermore, a network which is technically 'open' will remain vertically integrated from an economic perspective if it is to small and entry by service providers is unprofitable. An open network architecture is a necessary but not a sufficient condition for competition on service level, so an open network by itself does not guarantee competition.

After initial municipal and cooperative projects, private investment in FTTH now seems to be starting. While municipal investments have been very important in jump-starting the market and investment in FTTH, other means of stimulating FTTH deployment than by direct investment may now be a more suitable option for local governments. Providing suitable locations for housing network equipment (POPs) is a way to assist private network operators. By proactive participation and cooperation with regard to permits and legal dues, local governments can do much to stimulate private investment in FTTH in their community.

Discussion and recommendations for future research

Using engineering cost estimates as an *ex ante* prediction of economies of scale includes, like any prediction, some reservations. Lyons [1980] argued engineering estimates offer hypothetical ideal situations in static conditions and the estimates will not be particularly relevant for the position of a potential entrant. However, the other approaches to estimation of minimum efficient scale he identifies (time-series statistical cost curves and the survivor technique), including his method using census data, all require significant amounts of data which are only available *ex post*. We feel that the predictions about possible market structures in open FTTH networks we can do *now* using engineering cost estimates of real-world data are a valuable addition to the field of telecommunications and competition policy. Policy makers, investors and companies require reliable predictions to base their decisions on, and when information on the past is unavailable or not usable because of changing technologies, engineering cost models can offer the required insight. Using engineering cost models to assess possible competition is valuable since the way in which FTTH networks are built now can influence competition on these networks the coming years.

Earlier research already suggested the possibility of margin squeeze by the network operator in the service provider market. "The owner of the network can use his power to charge monopoly prices or engage in discrimination between service providers to leverage market power into downstream markets. The incentive to do so is greater if the owner also competes in downstream markets" [Sirbu et al., 2004]. Though possible, in the wider context of our research we feel that this is unlikely in Dutch FTTH networks at the moment. In these early stages of FTTH deployments, the operator has more incentive to attract service providers and subscribers to his network, plus the network operators (including VolkerWessels Telecom) often do not compete in (downstream) service markets. Networks where public parties (local government) are involved also seem unlikely to engage in anticompetitive behaviour. Furthermore, since the FTTH network is virtually never the only access network in a region, a service provider has a choice of available networks to reach consumers.[1] An attempt at margin squeeze by the FTTH operator would simply drive providers to another network. *Ex post* competition policy should be sufficient in solving margin squeeze problems that may arise in the near future; premature *ex ante* price regulation in this emerging field seems neither wise nor necessary since it might deter investment in next generation infrastructure.

Future research on this topic might incorporate better cost data from service providers to be able to distinguish between the three products in the triple-play bundle: television, telephony and Internet. Modelling service providers as multi- rather than single-product firms can offer more refined information on service provider competition. As an example, Banerjee & Sirbu [2005] have used a two-product model (data and video) and a "bivariate correlated normal distribution of willingness to pay for data and video services" to investigate the viability of a wholesale-retail split industry structure. Consumer demand is incorporated in our model as the achieved penetration at a total consumer price of € 50. More explicit knowledge of consumer demand could also improve the model.

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[1] FTTH, PSTN, perhaps even cable if this were permitted by the network owner.

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List of Figures

Appendix A

Glossary

Active network	Routing, switching and other equipment, required to use (activate) the passive network, in other words: to light 'dark fibre'.
CPE	Customer Premises Equipment, sometimes called ONU (Optical Network Unit) in fibre optic networks.
Dark fibre	Fibre that has been deployed into ducts but has not yet been used.
DSL	Digital Subscriber Line
DVB-T	Digital Video Broadcasting–Terrestrial, a standard for digital television sent through the ether.
FTTC	Fibre-to-the-Curb, a fibre optical network that almost reaches the home but where the last drop is achieved using another technology.
FTTH	Fibre-to-the-Home, a full fibre optical network that stretches all the way from the POP into each house.
FTTP	Fibre-to-the-Premises, a FTTH variant where internal cabling in MDUs is done using non-optical cabling, e.g. UTP.
FTTx	Collective name for all 'Fibre to the ...' variants.
HFC	Hybrid Fibre Coax
IP	Internet Protocol
IPTV	Television sent over a data network using IP
ISP	Internet Service Provider
LRAC	Long Run Average Cost
MC	Marginal Cost
Next Generation Network (NGN)	A telecommunications network with a layered market structure (separation of network and service provider) and a capacity of at least 1 Gbps symmetrically.

NRA	National Regulatory Agency
OLT	Optical Line Termination (unit), the end of an optical fibre in the access network at the POP or aggregation node.
ONU	Optical Network Unit, the end of an optical fibre in the access network at the subscriber.
Operator	Short for ‘network operator’. Operates the active and passive network and offers access to providers.
Passive network	Non-active physical network components, including ducts, manholes, dark fibre, etc.
PON	Passive Optical Network
POP	Point of Presence, sometimes called Central Office (CO). Aggregation node in an access network with active equipment.
Provider	Short for ‘Service Provider’. Uses the network of an operator as a transport mechanism to offer services to subscribers.
PSTN	Public Switched Telephone Network
QoS	Quality of Service
RF	Radio Frequency, used for normal (not IP-based) broadcast of radio or TV signals.
SP	Service Provider
Triple-Play	The combination of voice, data and video services.
VoDSL	Voice over DSL
VoIP	Voice over IP
WDM	Wavelength Division Multiplexing, separation of data streams in a fibre by using different wavelengths. Coarse (CWDM) and Dense (DWDM) WDM is possible, depending on how many wavelengths are used. In radio transmission, the same principle is known as Frequency Division Multiplexing (FDM).
xDSL	Collective name for all DSL-variants including ADSL, ADSL2+, SDSL, and VDSL.

Appendix B

Typical FTTH access network layout

A typical citywide VolkerWessels Telecom FTTH deployment layout is shown in figure B.1 on page 78. The layout is the result of real-world experience and limitations in actual deployments, which we will describe in this appendix.

The maximum size of the POP is approximately 10000 connections, though 9000 is a more workable number. Beyond this, the sheer number of fibres coming into one location becomes so large it is extremely complex to handle physically. Space limitations are also of great concern, because of the number of fibres and the space requirements of the active equipment at the POP. With current equipment, a POP for 9000 connections is approximately the size of a small house. Smaller POPs are possible as well of course, anything between 1000 and 10000 is possible. The trade-off is between the number of POPs and the number of connections at one location. More locations raises exploitation cost and can increase the expenditure in active equipment, so if suitable POP housing can be arranged, a POP size of approximately 9000 is preferred.

The length of the DB24 cable is usually limited to ≤300 m (though it can range from 200 m to at most 400 m), not for technical fibre-related reasons, but because of civil engineering costs. If the length of the DB24 cable becomes longer than 300 m, it is usually more efficient to build another node.

The average lengths of the feeder fibres and ducts is dictated by the side of the POP and the length of the DB24 cable (of which the latter is used in approximate 300 m radius areas). The population density of the area is significant here, because a higher population density will obviously lead to shorter feeder lengths. In our example, the length of the 576 GVK ranges from 800 m to 1200 m, and the average length of the 192 GVK is 200 m.

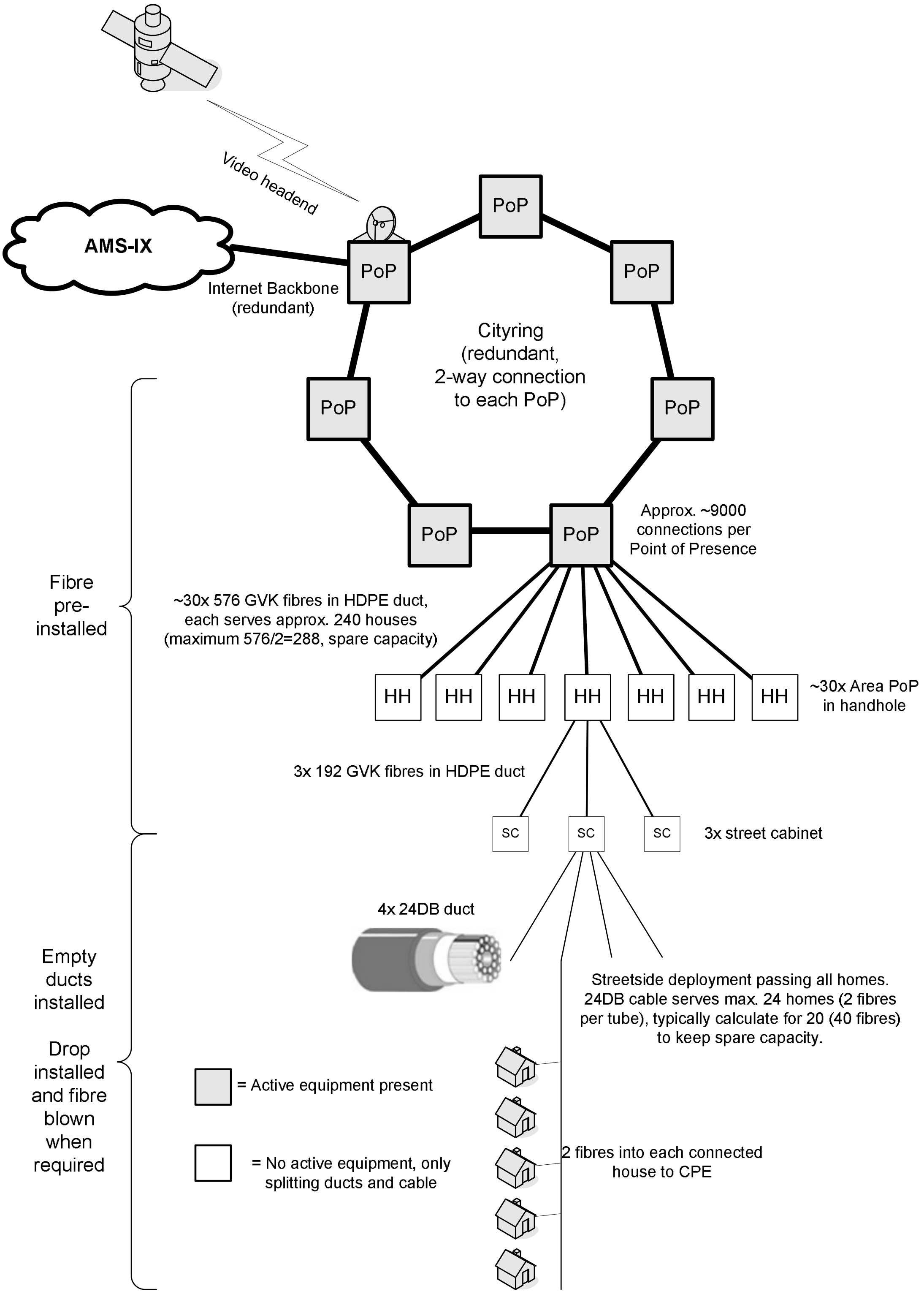

Figure B.1: Typical FTTH network layout

Appendix C

Marginal cost of the network operator

In theory, a perfectly competitive environment would lead to a market equilibrium situation where price equals marginal cost. However, a single product firm with large sunk and fixed cost and constant marginal cost (MC), has a declining long run average cost (LRAC) for all outputs, which is one characteristic of a natural monopoly. The network operator in our model is a single-product firm with constant marginal cost and decreasing average cost over the relevant range of outputs. Marginal cost is the change in total cost resulting from a unit increase in output; output for the network operator is defined as the number of subscribers on the network. Marginal cost pricing would not allow the operator to recover his cost, and is therefore not a suitable option. Calculating the marginal cost of the operator is still of interest however, since this allows us to better realise the advantages of a larger scale network.

The costs a network operator incurs are caused by the capital investment ($CapEx$) in the network, plus the cost of maintenance and network operations ($OpEx$). The marginal cost is therefore equal to the marginal increment in $CapEx$ plus the marginal increment in $OpEx$. This section will show that the marginal cost curve of a network operator is constant and will derive a formula to calculate this cost.

The total investment of a network operator is defined by the capital required for the active and passive network. The operational costs are calculated as an amount per month per subscriber and are valid for a network of a given size. A larger network has a lower per subscriber cost for maintenance because of scale economies in network operation.

The $CapEx$ of a network can be calculated using equation (5.2) repeated here:

$$\begin{aligned} CapEx &= CapEx_p + CapEx_a \\ &= Pmt(r_p, n_p, I_p) + Pmt(r_a, n_a, I_a) \end{aligned}$$

Since the interest r and number of payments n are constant, the only determining variable is the investment I in the passive and active network. The total investment I for a given number of subscribers is dependent on fixed investment fix and variable investment var for the passive network p and the active network a. The variable part of the investment is determined by the number of subscribers s:

$$\begin{aligned}
I_{(s)} &= I_{p(s)} + I_{a(s)}\\
I_{(s)} &= (fix_p + s \cdot var_p) + (fix_a + s \cdot var_a)\\
I_{(s)} &= fix_p + fix_a + s(var_p + var_a)
\end{aligned}$$

To calculate the marginal cost, we first have to calculate the investment required to serve one additional subscriber on the network I^+. Intuitively, this is equivalent to the variable investment, but this can also be shown:

$$\begin{aligned}
I^+ &= I_{(s+1)} - I_{(s)}\\
I^+ &= \Big(fix_p + fix_a + (s+1)(var_p + var_a)\Big)\\
&\quad - \Big(fix_p + fix_a + s(var_p + var_a)\Big)\\
I^+ &= (s+1)(var_p + var_a) - s(var_p + var_a)\\
I^+ &= var_p + var_a \qquad\qquad\qquad \text{Q.E.D.}
\end{aligned}$$

To calculate the marginal cost from the additional investment, the investment has to be annualised according to the investors requirements (the Excel function *Pmt* stands for "Payment"). Given a rate of return r and n payment periods, the annual payment for the additional investment is:

$$Pmt(r, n, I^+) = Pmt(r_p, n_p, var_p) + Pmt(r_a, n_a, var_a)$$

The operational expenditures *OpEx* for the network operator are given as a per-subscriber cost per year which is valid for a given network size. The resulting marginal cost *MC* (calculated per year) is the sum of the marginal investment and the operational expenditures:

$$\begin{aligned}
MC &= Pmt(r, n, MI) + OpEx\\
MC &= Pmt(r_p, n_p, var_p) + Pmt(r_a, n_a, var_a) + OpEx
\end{aligned}$$

Contract periods for consumer subscriptions in telecommunications are generally one year, so there is no need to calculate the payment for shorter periods. This allows us to use years to indicate the payback period which improves readability. The monthly payment is calculated simply by dividing the annual payment by 12, so the monthly marginal cost for the network operator is:

$$MC = \frac{Pmt(r_p, n_p, var_p) + Pmt(r_a, n_a, var_a) + OpEx}{12} \tag{C.1}$$

All variables in equation (C.1) are constant for a given network. We have shown that the marginal cost for the network operator is constant for a given network in that it is independent of the number of subscribers who take a subscription on this network. The marginal cost *MC* for the network operator can be calculated using equation (C.1).