Ondersteunen van strategische beslissingen
in het uitrollen van 'Fiber-to-the-Home'-netwerken:
techno-economische modellering in een multi-actoromgeving

Supporting Strategic Decisions in Fiber-to-the-Home Deployments:
Techno-Economic Modeling in a Multi-Actor Setting

Marlies Van der Wee

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Proefschrift ingediend tot het behalen van de graad van
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Gent, februari 2015
Marlies Van der Wee

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List of Acronyms

A

AC	Adoption Curve
ADSL	Asymmetric Digital Subscriber Line
ALOM	Active-Layer Open Model
AON	Active Optical Network
ARPU	Average Revenue Per User
AWG	Arrayed Waveguide Grating

B

BB	Broadband
BIPT	Belgian Institute for Postal Services and Telecommunications
BPMN	Business Process Modeling Notation
BU LRIC+	Bottom-up Long Run Incremental Cost Plus

C

CA-TV	Cable Television
CapEx	Capital Expenditures
CAN	Central Access Node
CBA	Cost-Benefit Analysis
CFH	Crown Fiber Holdings
CO	Central Office
CPE	Customer Premises Equipment
CRC	Conference of Media Regulators

D

DOCSIS	Data Over Cable Service Interface Specification
DSL	Digital Subscriber Line

DSLAM	Digital Subscriber Line Access Multiplexer
DVB-T	Digital Video Broadcasting – Terrestrial

E

EC	European Commission
ECMN	Equipment Coupling Modeling Notation

F

FTTB	Fiber-to-the-Building
FTTC	Fiber-to-the-Curb or Fiber-to-the-Cabinet
FTTH	Fiber-to-the-Home
FTTP	Fiber-to-the-Premises
FTTx	Fiber-to-the-X (generic, overarching term)

G

Gbps	Gigabits per second
GNA	Glasvezelnet Amsterdam
GPON	Gigabit PON
GUI	Graphical User Interface

H

HD	High Definition
HFC	Hybrid Fiber Coax
HP	Home Passed

I

IP	Internet Protocol
IT	Information Technology

K

kbps	kilobits per second

L

LLU	Local Loop Unbundling

M

Mbps	Megabits per second

N

NG(A)	Next Generation (Access)
NP	Network Provider
NPV	Net Present Value
NRA	National Regulatory Authority

O

ODF	Optical Distribution Frame
OLO	Other Licensed Operator
OLT	Optical Line Terminal (network side)
ONT	Optical Network Terminal (user's side)
ONU	Optical Network Unit (user's side)
OpEx	Operational Expenditures
OSI	Open Systems Interconnection

P

P2MP	Point-to-Multipoint
P2P	Point-to-Point
PALOM	Passive-Active-Layer Open Model
PIP	Physical Infrastructure Provider
PLOM	Passive-Layer Open Model
PNMN	Physical Network Modeling Notation
PON	Passive Optical Network
PPP	Public Private Partnership
PSTN	Public Switched Telephone Network

R

R&D	Research and Development
RBI	Rural Broadband Initiative (in New Zealand)
ROI	Return on Investment

S

SC	Street Cabinet
SCBA	Social Cost-Benefit Analysis
SGEI	Service of General Economic Interest
SMP	Significant Market Power

SP	Service Provider

T

Tbps	Terabits per second
TCO	Total Cost of Ownership
TCP	Transmission Control Protocol
TDM	Time Division Multiplexing
TPM	Technology-Policy-Market (framework for analysis)
TV	Total Value
TVP	Total Value Potential
TVP_a	Total Value Potential per actor a
TVP_i	Total Value Potential per service i
TDM	Time Division Multiplexing
TWDM	Time and Wavelength Division Multiplexing

U

UFB	Ultra-Fast Broadband (initiative in New Zealand)
ULL	Unbundled Local Loop
USA	United States of America

V

VDSL	Very high bit-rate Digital Subscriber Line
VOIP	Voice-over-IP
VULA	Virtual Unbundled Local Access

W

WDM	Wavelength Division Multiplexing
WTP	Willingness To Pay

Nederlandstalige samenvatting
- Dutch Summary -

Simpelweg surfen op het internet, bekijken van hoge-kwaliteit video streams of real-time video conferencing, het gamma van telecommunicatiediensten die vandaag beschikbaar zijn, is al erg groot en groeit nog steeds, zowel in kwaliteit en kwantiteit. Om deze reeks diensten tegelijk aan te bieden worden huidige telecommunicatienetwerken voortdurend geüpgraded, zowel in termen van apparatuur als transmissiemedia. Installatie van glasvezel in het gehele netwerk, vanuit het kern- naar het toegangsgedeelte, kan datasnelheden aanzienlijk verhogen. Hoewel het grootste deel van het netwerk reeds verglaasd werd, wordt de installatie van glasvezel in toegangsnetwerken (Fiber-to-the-Home, FTTH) vaak uitgesteld, omdat de huidige exploitanten niet voldoende potentiële inkomsten zien om deze hoge investering te kunnen dekken.

Door het ontwikkelen van uitgebreide, doch specifieke techno-economische modellen, richt dit proefschrift zich op de ondersteuning van huidige strategische beslissingen in het domein van de uitrol van FTTH-netwerken. Omdat het grootste deel van de investering voor deze netwerken te vinden is in de uitrol van de fysieke infrastructuur, kunnen de bestaande investeringsbarrières worden verminderd door het delen van de infrastructuur tussen meerdere exploitanten, waardoor duplicatie van dure infrastructuur kan worden vermeden en het investeringsrisico drastisch vermindert. Het delen van de infrastructuur vereist het opsplitsen van de verantwoordelijkheden van de netwerkuitrol en -operaties, dit doorgaans in drie conceptuele rollen. De aanbieder van fysieke infrastructuur (PIP) is verantwoordelijk voor de passieve glasvezelinfrastructuur en behandelt de toegangsrechten, graaft de geulen en plaatst de vezels en eventuele wachtbuizen. De netwerkaanbieder (NP) licht het passieve netwerk op door installatie van actieve apparatuur aan zowel de netwerkkant (in de lokale centrale) als de kant van de eindgebruiker (klantspecifieke apparatuur - CPE). De dienstenaanbieder (SP), ten slotte, maakt gebruik van de connectiviteit aangeboden door de NP om applicaties en diensten aan te bieden aan de eindgebruiker. Openen van het netwerk op glasvezel- of golflengtelaag laat toe dat meerdere NP's de infrastructuur van de PIP delen, terwijl meerdere SP's de connectiviteit aangeboden door een NP kunnen delen indien geopend wordt op bitstream-laag.

Het onderzoeken van de business case voor de uitrol van een FTTH-netwerk vereist dus evaluatie van de verschillende rollen afzonderlijk, doch niet onafhankelijk van elkaar. Bovendien laat het opsplitsen van de uitrol en onderhoud van het netwerk in deze verschillende, aparte rollen toe dat nieuwe spelers, zowel publiek als privaat, de telecommunicatiemarkt betreden. Om strategische aanbevelingen naar al deze spelers te kunnen verstrekken, is een grondige kennis van de randvoorwaarden nodig, op het gebied van technologische keuzes, marktstructuren en mogelijke ondersteunende of verhinderende beleidsmaatregelen. Om inzicht te krijgen in het belang van deze randvoorwaarden en hoe ze de parameters van de business case kunnen beïnvloeden, bestudeert dit proefschrift de achtergrond van enkele operationele netwerken. Afgezien van verschillende technologische variaties in FTTH-netwerken, zowel in termen van topologie (Punt-tot-Punt versus Punt-tot-Multipunt) als technologie (actieve versus passieve optische netwerken), worden een reeks van economische en politieke factoren in aanmerking genomen. De geografische ligging en bevolkingsdichtheid hebben een duidelijke invloed op de initiële investeringen, terwijl de nationale of regionale beleidsmaatregelen voor een groot deel de mogelijkheden van publieke financiering en betrokkenheid bepaalt. Afhankelijk van welke partners betrokken zijn, publieke of private, worden in de huidige netwerken verschillende business modellen toegepast, variërend van een verticaal geïntegreerde operator met volledige verantwoordelijkheid voor het netbeheer en dienstenaanbod, tot een volledig open model, waarin de passieve infrastructuur wordt gedeeld tussen meerdere, concurrerende netwerkexploitanten en dienstverleners.

Om deze technologische evoluties, de lokale marktstructuren en regelgevende voorwaarden op te nemen, wordt de traditionele kosten-batenanalyse uitgebreid naar de evaluatie van de business case voor meerdere actoren, hun specifieke kostenstructuur en inkomstenverwachting, evenals naar de extra kosten die noodzakelijke samenwerking met zich meebrengt. De economische evaluatie van de investering in passieve infrastructuur (PIP) los van de andere rollen, leert dat deze enkel winstgevend is in dichtbevolkte stedelijke gebieden waar de adoptie door eindgebruikers aan een agressieve snelheid gebeurt (uitgaande van een tijdshorizon van 20 jaar). In andere soorten gebieden (kleinere gemeenten of dunbevolkte landelijke terreinen), of in geval van een te trage adoptie, zijn de

investeringsvooruitzichten minder gunstig. Maatregelen op zowel reductie van de kosten als verhoging van de inkomsten kan de economische prognose van de uitrol van passieve glasvezelinfrastructuur in toegangsnetwerken echter drastisch verbeteren (denk bijvoorbeeld aan hergebruik van bestaande leidingen, het verzekeren van voldoende inkomsten vanaf de start van het project door vraagbundeling of economische maatregelen zoals het verlengen van de terugverdientijd). Installatie in landelijke gebieden blijft zelfs met combinatie van deze maatregelen niet economisch rendabel.
Installatie en onderhoud van de actieve apparatuur (NP) moeten worden geëvalueerd op een korter tijdsbestek (in de orde van 10 jaar). Indien een vergelijkbare tijdshorizon als voor de passieve infrastructuur (20 jaar of meer) gebruikt wordt, moet de analyse rekening houden met de migratie van de apparatuur en technologie. Investeringen in de NP-laag zijn winstgevend wanneer de initiële investering in CPE apart wordt aangerekend (in plaats van deze op te nemen in de maandelijkse vergoeding ten laste van de abonnees). Aangezien het dienstenaanbod (SP-laag) agnostisch is over het onderliggende netwerk, werd de evaluatie van de business case voor deze laag niet behandeld in dit proefschrift.

Het delen van een infrastructuur (op PIP- of NP-laag) onder meerdere concurrerende marktdeelnemers voorkomt dupliceren van hoge initiële investeringen in het aanleggen van parallelle infrastructuren, zoals hierboven vermeld, maar is uiteraard niet gratis. Ter uitbreiding van de business case evaluatie voor de individuele actoren ontwikkelt dit proefschrift een kostenmodel voor de berekening van de extra kosten voor het aansluiten van een nieuwe aanbieder (NP bij het delen van PIP-infrastructuur, SP bij het delen van NP-infrastructuur), het aansluiten van een nieuwe eindklant en het aansluiten van een reeds bestaande klant op een andere aanbieder (churn). De evaluatie leert dat de toename in kosten voor een nieuwe provider of eindgebruiker significant is bij het vergelijken van een gedeeld, open netwerk met dit van een verticaal geïntegreerde operator, maar erg laag wanneer in vergelijking gesteld met de uitrol van een parallelle infrastructuur.

Ingaande op de grote betrokkenheid van publieke spelers in wereldwijde uitrol van FTTH-netwerken bekijkt dit proefschrift tot slot ook hoe de specifieke doelstellingen van deze publieke actoren kunnen worden opgenomen in de techno-economische kosten-baten analyse. In tegenstelling tot particuliere bedrijven die maximalisatie van hun winsten nastreven, richten publieke actoren zich vooral op sociaal-economische doelstellingen. Het identificeren, categoriseren en monetariseren van de toegevoegde waarde van deze indirecte voordelen (zoals verminderde reistijd en kosten bij het werken van thuis) kan gebruikt worden als overtuigingsmiddel voor publieke betrokkenheid in netwerkuitrol, zij het direct of indirect.

Hoewel duidelijk gericht op de uitrol van FTTH, kunnen de raamwerken en modellen ontwikkeld in dit proefschrift eenvoudig worden aangepast om te worden toegepast op andere domeinen die vragen om een multi-actor benadering van techno-economische analyses die zowel gedetailleerde kostenberekeningen als inschattingen van directe en indirecte inkomsten omvat.

English Summary

From simply browsing the Internet, over watching high-quality video streams, to real-time videoconferencing, the range of telecommunication services that is available today is already very large, and is still growing, both in quality and quantity. To be able to offer this range of services simultaneously, current telecommunications networks are constantly being upgraded, in terms of both equipment evolutions and transmission media migrations. By installing optical fiber in the entire network, from core to access, data rates can be significantly increased. Although fiber has been introduced in the majority of the network, the investment in Fiber-to-the-Home (FTTH), which requires fiber to be deployed in the last mile towards the end user, is frequently postponed because current operators do not see sufficient revenue potential to cover for this high investment.

By developing extended, dedicated techno-economic models, this dissertation aims at supporting the current strategic decisions in the field of FTTH deployment. As the main part of the investment for FTTH lies in the rollout of the physical infrastructure, investment barriers can be reduced by sharing one network infrastructure among multiple operators, thereby avoiding duplication of expensive infrastructure and hence reducing investment risk. Sharing the infrastructure requires dividing the responsibilities of network deployment and operations, which is typically done in three conceptual roles. The Physical Infrastructure Provider (PIP) is responsible for the passive, dark fiber, infrastructure (Rights-of-Way, trenches, ducts and fibers). The Network Provider (NP) lights up the passive network by installing active equipment at both the network side (central office) and the end user's side (Customer Premises Equipment – CPE). The Service Provider (SP), finally, uses the end-to-end connectivity offered by the NP to offer content and applications in dedicated services to the end user. Multiple NPs can share the PIP's infrastructure if the

network is opened on fiber or wavelength layer, while multiple SPs can use the connectivity offered by one NP when opening on bitstream layer.

Evaluating the business case of FTTH deployment thus requires investigating the different roles separately, though not independently. Furthermore, as dividing the responsibility opens up the telecom market towards new players, both public and private, providing strategic recommendations requires a thorough understanding of the surrounding technological choices, market structures and policy drivers or barriers. To gain insights in the importance of these aspects and how they can impact the business case parameters, this dissertation studies a range of existing deployments worldwide. Apart from different technological variations in FTTH topologies (Point-to-Point versus Point-to-Multipoint) and technologies (active versus passive optical networks), a range of economic and policy factors are taken into account. The geographical setting and population density have a clear influence on the upfront capital expenditure, while national or regional policy conditions direct the opportunities in public financing and involvement of rollouts. Depending on which partners are involved, public or private, different business models are applied, ranging from one vertically integrated operator taking up full responsibility for network deployment, network operations and service offerings, to a three-layer open access model, in which one passive infrastructure is shared among multiple, competing network and service providers.

To incorporate these technological evolutions, local market settings and policy conditions, traditional cost-benefit analysis is extended to allow for the evaluation of the business case for multiple actors, their specific cost structure and revenue expectations, as well as the extra cost of cooperation. Evaluating the business for the PIP separately learns that it only flies in dense urban regions with an aggressive uptake by end users (assuming a time horizon of 20 years). In other types of regions (urban or rural), or when uptake is progressing too slow, improvement measures on both cost and revenue side can ameliorate the economic prognosis of passive fiber access infrastructure deployment (e.g. by reusing existing ducts, assuring sufficient revenues from the start by pre-aggregating demand or prolonging the return on investment period). However they might still not be sufficient to make deployment in rural areas economically viable. The NP's equipment installation and maintenance should be evaluated on a shorter time frame (in the order of 10 years) or take into account migration of equipment and technology when considering similar time horizons as for the PIP's business case. Investment in the NP layer is profitable when recouping the upfront cost for CPE through separately charged revenues, instead of including them in the monthly fee charged to the subscribers. As the SP's service offering is agnostic of the underlying network deployed, the evaluation of its business case was considered out of scope of this dissertation.

When sharing one infrastructure (on PIP or NP layer) amongst multiple competing operators, this avoids duplication of high upfront investment, as mentioned above, but does not come for free. As an extension to the business case evaluation of the individual actors, this dissertation develops a cost model for calculating the extra cost for connecting a new provider (NP when sharing PIP infrastructure, SP when sharing NP infrastructure), or connecting a new or churning end user. The evaluation learns that the increase in cost for a new provider or end user is significant when comparing a shared (open access) model to a vertically integrated one, but is very low when compared to the deployment of a parallel infrastructure.

Finally, as the analysis of existing case studies shows a clear involvement of public partners in FTTH deployment worldwide, this dissertation also focuses on including their specific targets in the business case. Contrary to private companies' pursuing maximization of their return on investment, public players strive at achieving socio-economic goals. Identifying, categorizing and monetizing the added value of indirect benefits (such as reduced commuting time and costs when working at home) can as such be used as a stimulus for public involvement in FTTH deployment, be it direct or indirect.

Although clearly focused on FTTH deployment, the frameworks and models developed in this dissertation can be easily adjusted to be applied to other application domains that ask for a multi-actor approach to techno-economic analysis which includes both detailed cost calculations as well as direct and indirect revenue estimations.

1 Introduction and publications

"You can't stop the future.
You can't rewind the past.
The only way to learn the secret…
is to press play."
- Jay Asher

Who could, a couple of decades ago, have imagined the applications we use today? Whereas 20 years ago, people were waiting on the typical dial-up tune to retrieve their emails, we now each have multiple connected devices. Where the network used to offer only telephone services, telecom now is a fast evolving domain, in which new applications can quickly take over, offer ever richer services, but also require more and more bandwidth. Recent developments in picture and video quality, social networks, the rise of networked storage and cloud computing require increasingly more bandwidth and benefit especially from higher upstream speeds. The trend to higher bandwidth applications (currently HDTV – High Definition television, 3D TV and online gaming, extended to 4K TV, videophones, thin clients, etc.) is to be expected and many of these applications are already technically feasible today. While clearly none of those applications is the "Killer App", the combination of all services would certainly benefit from higher bandwidth and lower latency. As such, telecom networks are also constantly being upgraded, by using enhanced hardware and software, but also by upgrading the legacy twisted copper pairs to fiber, which has the ability to transfer data at higher speeds and over longer distances. This process started in the core networks, and is gradually finding its way to the end user. The final step in this upgrading progress is the deployment of fiber in the "last mile", thereby reaching Fiber-to-the-Home (FTTH). By using optical fiber instead of twisted copper pair or coaxial cables to transmit data signals, data rates can be significantly increased.

The telecommunications sector is not only characterized by technological upgrades in both infrastructure and equipment, these upgrades also triggered a change in the structure of the market over the last couple of decades. The former telephone networks were typically owned and operated by the incumbent: one single company per country, such as British Telecom in the United Kingdom, Deutsche Telekom in Germany, Proximus (former Belgacom) in Belgium and AT&T in the United States, just to give some examples. The technical evolutions in equipment for transmitting bidirectional signals over coaxial cable introduced new players into the market: the former providers of analogue cable television (CA-TV). In countries where the coverage of this coaxial cable infrastructure was sufficient, operators such as Telenet in Flanders, Ziggo and UPC in the Netherlands, and ComCast in the United States of America (USA), could enter the broadband market and as such become competitors to the incumbents.

Recent advances in FTTH deployment made even more new players emerge, both public and private. Private investors recognize a business opportunity in this new type of infrastructure, and use new business approaches to start deploying FTTH access networks. The most well-known examples here are Reggefiber in the Netherlands and Google Fiber in the USA. On the public side, governments aim at tackling the digital divide by starting up projects to deploy fast and reliable broadband (not necessarily all FTTH), municipalities engage in projects to allow cheap and transparent connections for all public buildings, including wireless access for their citizens, and utility companies get involved because they recognize the possible cost savings of deploying multiple infrastructures (electricity, water, gas) in one trench. Examples of this public involvement range from very local initiatives (such as the deployment of a neutral fiber infrastructure in Stockholm, Sweden), over more regional approaches (e.g. deployment led by the Stadtwerke in the region of Cologne, Germany), to national initiatives (amongst others the Ultra-Fast Broadband initiative in New Zealand and the National Broadband Network in Australia).

On the other hand, telecom networks are no longer used only for voice services. Broadband Internet and digital television are commonly known and used, but more recently, applications in the security, health, entertainment and education sector broaden the telecom market as well. These services and applications are no longer only in the hands of the companies owning the infrastructure; but instead are owned by specific service providers that use the capacity of existing

networks to offer their own applications to end users. Think of massively used applications such as YouTube, Facebook and Skype, or services like Netflix and Internet Protocol (IP) cameras that directly connect to the police station, surveilling your home. Other service providers do not focus on new types of services, but try to compete with the established operators by offering a higher quality, better service or more features. These types of service providers also use the network of established operators, but on a lower layer: they only rent the physical infrastructure and provide their own active equipment. They are said to use the unbundled local loop (ULL) of the incumbent.
The incumbent is often obliged by regulation to provide this ULL access to new entrants, which brings us to the third dominant parameter in the telecommunications domain. As any market, the telecommunications market is subject to certain laws and regulations. These laws have a clear influence on the way the market evolves, the level of competition, the price setting for end customers, etc. A clear difference in telecommunication law can be observed across the world. In Europe, for example, apart from general competition law, specific regulations are in force to prevent anti-competitive behavior by dominant market players. To come back to the ULL example, incumbents in Europe having a significant market power (SMP) are obliged by the national regulators to open up their network for new entrants. Furthermore, investment of public (tax) money in new network deployment projects is only allowed in remote or underserved areas, where it is judged that no private player will provide decent broadband access. In the United States, the rules of the game are set differently. Regulation is rather absent, as one there claims that competition should set the market rules.

When analyzing strategic decisions in the telecom domain, such as the deployment of FTTH, it is clear that these decisions are not of pure technological nature, but are influenced by market evolutions and policy conditions. Here, the different actors on the market – operators, providers, suppliers, public instances – are interested in the evolutions of applications, customer demands, prices and technologies and the influence of all these parameters on their business models. Evaluating these strategic decisions thus asks for a clear understanding of the goals and drivers of the different involved actors, both separately as well as combined. Performing techno-economic analysis in a market that is characterized by such a complex interweaving of actors and responsibilities, requires an extension of traditional analysis methods (e.g. the well-known Net Present Value (NPV) calculation). The once united responsibility of "operating the telecommunications network" can therefore be split up into separate responsibilities, smaller roles. Typically, the telecommunications network is divided in three responsibilities, each taken up by a different conceptual actor. The physical infrastructure provider (PIP) is responsible for the deployment of the passive infrastructure (trenches, ducts and cables); the network provider (NP) connects active equipment to this infrastructure in order to provide end-to-end connectivity, which is then used by the service provider (SP) to offer specific applications. A detailed analysis per actor should be executed, while taking into account the allocation of shared costs, and an estimation of the additional costs that collaboration across the value chain entails.

1.1 Overview of this dissertation

This dissertation tackles the strategic decision of FTTH deployment in the multi-actor setting telecommunications is in today. Leaning on technological, market and policy characteristics, this research employs extended techno-economic evaluation techniques to compare cost and revenues in the business case for the different actors involved, thereby evaluating them separately, though not independently. This work extends traditional techno-economic cost-benefit analysis to a multi-actor environment, thereby impacting both the cost side (by dividing the responsibilities among multiple actors and including collaboration costs), as well as the revenue side (by extending revenue analysis to indirect effects). The different chapters of this book rely on the results of various publications, of which a list is included in the next section. Furthermore, the work leading to this dissertation was also based on extensive collaboration with both academic and industry partners worldwide, who helped providing international benchmarks for the obtained results. This section will give an overview of the contents per chapter, and link to the related publications where applicable.

This dissertation starts by providing a historic overview of the development of telecommunications in Flanders in chapter 2, which discusses the evolutions of the PSTN (Public Switched Telephone Network) and the CA-TV network. Following the necessary technological upgrades, aided by market developments and regulatory decisions, both these networks are currently used to provide broadband services to residential customers. Taking this technical duopoly in Flanders as a starting point, it is compared to other regions in Europe that have different geographical characteristics and historical developments, thereby leading to other settings in their telecom sector. Although Flanders (and Belgium) currently take a leading position in terms of broadband coverage, speed and uptake (think also about the recent investment announcement by Telenet), the process of deploying fiber all the way to the customers' homes is up till now mostly being postponed. The comparison with other regions in Europe learns that the strategic decision for FTTH rollout relies on more than a pure technological upgrade: it is severely influenced by surrounding market conditions and regulatory settings. Before going into the quantitative evaluation of the FTTH deployment decision this dissertation tackles, a good overview of the technological, market and policy characteristics needs to be achieved. Therefore, an interaction framework focusing on these three domains was developed. [7], [10], [18] and [22].

Chapter 3 focuses on these characteristics from the technological side. By telling the story of how fiber has penetrated through the network, starting in the core, arriving in the access, the necessary background on telecom networks and FTTH is provided. Leaning on the well-known five-layer Internet protocol stack, the different roles in the deployment and exploitation of an FTTH network are introduced: the PIP, NP and SP. As new trends in the market show that these roles are taken up by different actors, it should be technically possible to separate the roles by opening up the value chain (different responsibilities in the network are taken up by different entities). The last part of chapter 3 describes the different possibilities of opening up the network from a technical point of view by indicating the extra equipment, processes and transactions needed. In between the PIP and the NP, the network can be opened at fiber layer or wavelength layer, while the NP can grant access to multiple SPs on the bitstream layer. This opening of the network is referred to as unbundling or open access. Unbundling refers to the case in which a single actor is exploiting both a particular layer and the layer on top of that, while still allowing the co-existence of other actors on top of its own passive infrastructure/network (e.g. PIP also acts as NP, in competition with alternative NPs). Open access, on the other hand, refers to the situation in which the lower layer is provisioned in a nondiscriminatory way to different actors on the layer above (PIP is only allowed the role of PIP). The main difference with unbundling is that the actor responsible for the lower layer is not allowed to act in the layers above. [4], [5] and [8].

The market and policy pillar of the interaction framework are covered in chapter 4. Conclusions about the boundaries these domains set are drawn using the analysis of several FTTH deployment cases worldwide. These cases are evaluated on a number of characteristics: the region type and scale of deployment, making the distinction between dense urban, urban and rural on the one side and city-level, regional or country-wide on the other; the policy conditions, which differ significantly between Europe and other parts of the world; the initiator and key drivers, thereby identifying who (public and/or private) and what (direct or indirect revenues) drove the deployment; the financing structure, ranging from a 100% public investment, over a cooperation in terms of a Public Private Partnership, to a 100% private initiative; the applied business model, indicating how the responsibilities are divided among the different actors; and finally existing competition, describing both competition in between different infrastructures (inter-platform) as well as competition on top of the same infrastructure (intra-platform).

The analysis of worldwide cases provides important insights in existing, operational FTTH deployments, and can thus serve as international benchmark for the techno-economic evaluation of the strategic decisions in FTTH investment. [1], [6], [7], [9], [18] and [20].

This techno-economic evaluation is the subject of the final chapters of this book. First, the analysis for the different, separate roles is executed: the investment in the passive infrastructure – the role of the PIP – and the investment in the active equipment – the role of the NP. The investment analysis for the service provider is considered out of scope of this research, as services can be offered independently of the type of underlying network. To evaluate the business case for the PIP and the NP, different cost and revenue models are developed (first part of chapter 5). On the cost side, we first describe models that acknowledge the existing infrastructure and geographical constraints. Secondly, planning for long-term infrastructure investment will also have to take into account migration of equipment, as the lifetime of active equipment is limited in comparison to passive infrastructure (ducts and cables). The cost models developed make the distinction between models for the infrastructure deployment itself (PNMN – Physical Network Modeling Language), for the installation and maintenance of equipment (ECMN – Equipment Coupling Modeling Language), and for the evaluation of the cost of processes (BPMN – Business Process Modeling Language). On the revenue side, reliable forecasting of direct revenues is an uncontestable need for ensuring the business case. Here, existing willingness to pay for known services should be combined with forecasted uptake curves to get an idea about the profitability of the business case. The developed revenue models allow for fixed pricing or varying pricing set based on the overall or yearly costs incurred. [8], [9], [16] and [17].

The second part of chapter 5 discusses the actual results of the business case evaluation for PIP and NP. The investment for the PIP is analyzed for different geographical regions, over a time horizon of 20 years. The quantitative analysis performed indicates that the business case is in most cases not economically viable. Therefore, as a second step, the section investigates possibilities and opportunities to improve the business case of the PIP, for instance by prolonging the planning horizon, ensuring revenue from the start of the project by performing demand aggregation or examining where public funds might help. The business case for the NP is evaluated for the same regions. However, since the lifetime of equipment is limited, the time horizon for the business case evaluation should be shortened, or a migration scenario should be taken into account. Both options are studied for active and passive optical networks. [3], [8], [12] and [13].

On top of analyzing the investment for the roles separately, the multi-actor environment entails more possible extensions to the techno-economic evaluation, which are described in chapter 6 and 7. Chapter 6 focuses on extending revenue modeling towards including indirect effects, while chapter 7 elaborates on the costs of collaboration. Indirect effects are effects on one domain, caused by the actions in another domain. In telecommunications, they comprise all effects that result from the deployment of a broadband network and are beneficial to society (e.g. the well-known example of reducing traffic by allowing people to work from home). They are especially important for public partners, as they envisage not purely monetary revenues from their involvement in the deployment of FTTH. The chapter describes a bottom-up model for identifying, categorizing and quantifying indirect benefits and applies it to two cities: Ghent and Eindhoven. The comparison of these two cities allows for evaluating the impact of FTTH on the indirect benefits, as both cities are quite similar with one main difference: an FTTH network is already operational in Eindhoven, while non-existent in Ghent. [2] and [11].

The second extension of cost-benefit analysis focuses on evaluating the cost of collaboration, which is a consequence of the opening of the value chain to allow for multiple actors taking up different responsibilities. This chapter (7) proposes a cost breakdown into equipment, process and transaction costs to evaluate the additional costs fiber and bitstream open access (allowing for multiple NPs and SPs, respectively) entail. [4] and [5].

A conclusion on performing techno-economic evaluation on FTTH deployment in a multi-actor environment is formulated in the last chapter of this dissertation, chapter 8. It summarizes the results of the previous chapters and draws on these results to provide some guidelines on the strategic decisions within FTTH deployment, focusing on the multi-actor aspect. An overview of possible directions for future work concludes this book.

Because of the multi-disciplinary character of this dissertation, a reading path is included to end this introduction, so as to guide the audience to the different chapters, depending on their background.

- The more technical audience with a strong background in fiber optics might skip chapter 3, and spend more time in exploring the results of chapters 5 (sections 5.3 and 5.4) and 7.
- Experts on Belgian broadband evolutions and regulations might spend less time on the first sections of chapter 2, and instead fast forward to the comparison with other countries in section 2.4.
- The most important results for policy makers can be found from the comparison of cases (chapter 4), the monetary value of indirect effects (chapter 6) and the impact of the different open access models on cost (chapter 7).
- Researchers may set the focus in the overall work but especially in chapters 5 and 6 if they look for cost-benefit models and analysis.

1.2 List of publications

The models, analyses, results and conclusions of this work have been published in scientific journals and were presented at both national and international conferences. The following section provides an overview of the publications realized during this PhD research.

1.2.1 A1 publications (listed in the Science Citation Index)

[1] **Van der Wee, M.**, Mattsson, C., Raju, A., Braet, O., Nucciarelli, A., Sadowski, B., Verbrugge, S. and Pickavet, M. (2011) Making a success of FTTH. Learning for case studies in Europe. *Journal of the Institute of Telecommunications Professionals (ITP), 5*(4).

[2] **Van der Wee, M.**, Verbrugge, S., Sadowski, B., Driesse, M. and Pickavet, M. (2014) Identifying and quantifying the indirect benefits of broadband networks for e-Government and e-Business: A bottom-up approach. *Telecommunications Policy*, Available online 5 February 2014, ISSN 0308-5961.

[3] **Van der Wee, M.**, Verbrugge, S., Tahon, M., Colle, D. and Pickavet, M. (2014) Evaluation of the Techno-Economic Viability of Point-to-Point Dark Fiber Access Infrastructure in Europe. *Journal of Optical Communication Networks, 6,* 238-249.

[4] Dixit, A., **Van der Wee, M.**, Lannoo, B., Colle, D., Verbrugge, S., Pickavet, M. and Demeester, P. (2014) Fiber and Wavelength Open Access in WDM- and TWDM Passive Optical Networks. *IEEE Network Magazine, 28*(6).

[5] **Van der Wee, M.**, Casier, K., Dixit, A., Verbrugge, S., Colle, D. and Pickavet, M. (2014) Techno-economic evaluation of open access on FTTH networks. Submitted to *Journal of Optical Communications Networks.*

1.2.2 Publications in international conferences

[6] **Van der Wee, M.**, Mattsson, C., Raju, A., Braet, O., Nucciarelli, A., Sadowski, B., Verbrugge, S. and Pickavet, M. (2011) How to measure the success rate of fiber-based access networks? Evaluation of the Stokab case and comparison with other European cases. *50th FITCE*

Congress-"ICT: Bridging an Ever Shifting Digital Divide", September 2011, Palermo, Italy.

[7] **Van der Wee, M.**, Verbrugge, S. and Pickavet, M. (2011) Value Network Analysis for NGOA networks and its impact on the costs and benefits for the different actors involved. *2nd PhD Seminar at the ITS conference*, September 2011, Budapest, Hungary.

[8] **Van der Wee, M.**, Casier, K., Bauters, K., Verbrugge, S., Colle, D. and Pickavet, M. (2012) A modular and hierarchically structured techno-economic model for FTTH deployments: comparison of technology and equipment placement as function of population density and number of flexibility points. *16th International Conference on Optical Network Design and Modeling (ONDM),* April 2012, Colchester, United Kingdom.

[9] Verbrugge, S., Van Ooteghem, J., Casier, K., **Van der Wee, M.** and Tahon, M. (2012) Cost-efficient NGN rollout. *Proceedings of Telecommunication Economics, Lecture Notes in Computer Science.*

[10] **Van der Wee, M.**, Verbrugge, S. and Lemstra, W. (2012) Understanding the dynamics of broadband markets, a comparative case study of Flanders and the Netherlands. *ITS Europe conference*, July 2012, Vienna, Austria.

[11] **Van der Wee, M.**, Driesse, M., Vandersteegen, B., Van Wijnsberge, P., Verbrugge, S., Sadowski, B. and Pickavet, M. (2012) Identifying and quantifying the indirect benefits of broadband networks: a bottom-up approach. *19th ITS Biennial Conference 2012 (ITS World-2012)*, November 2012, Bangkok, Thailand.

[12] Verbrugge, S., **Van der Wee, M.** and Fernandez-Gallardo, M. (2012) Some insights in regulation and potential profitability of passive fiber infrastructure in Europe. *19th ITS Biennial Conference 2012 (ITS World-2012)*, November 2012, Bangkok, Thailand.

[13] **Van der Wee, M.**, Casier, K., Wang, K., Verbrugge, S. and Pickavet, M. (2013) Techno-Economic Evaluation of FTTH Migration for a Network Provider: Comparison of NG-AON and TWDM-PON. *Asia Communications and Photonics Conference* (pp. AW3I-3). Optical Society of America. November 2013, Beijing, China.

[14] Evenepoel, S., **Van der Wee, M.**, Verbrugge, S., Lannoo, B. and Pickavet, M. (2013) Mapping Physical Network Roles to Relative Abstract Roles in Financial Models: Measuring Business Characteristics for Internet-based Services. *ITS Europe conference*, October 2013, Florence, Italy

[15] Tahon, M., **Van der Wee, M.**, Verbrugge, S., Colle, D. and Pickavet, M. (2014) The impact of inter-platform competition on the economic viability of municipal fiber networks. *Conference on Optical Fiber Networks (OFC)*, March 2014, San Francisco.

[16] Casier, K., **Van der Wee, M.**, Verbrugge, S., Ranaivoson, H., Coenen, T. and Reynders, C. (2014) Multi-level Business Modeling and Simulation. *International Symposium on Business Modeling and Software Design (BMSD)*, June 2014, Luxembourg, Luxembourg.

[17] Casier, K., **Van der Wee, M.** and Verbrugge, S. (2014) Cost evaluation of innovative offers using detailed equipment, process and network modeling languages. *16th International Conference on Transparent Optical Networks (ICTON),* July 2014, Graz, Austria.

[18] **Van der Wee, M.,** Beltrán, F. and Verbrugge, S. (2014) Evaluating the impact of financing structure decisions on FTTH deployment. A comparison between New Zealand and Europe. *42nd Research Conference on Communication, Information and Internet Policy (TPRC),* September 2014, Arlington, USA.

[19] **Van der Wee, M.,** Verbrugge, S. and Pickavet, M. (2014) Value Network Configurations suitable for municipal FTTH deployment: Qualitative and Quantitative evaluation. *Conference on Competition and Regulation in Network Industries (CRNI 2014),* November 2014, Brussels, Belgium.

[20] Domingo, A., **Van der Wee, M.,** Verbrugge, S. and Oliver, M. (2014) Deployment strategies for FTTH networks and their impact on the business case: a comparison of case studies. *20th ITS Biennial Conference 2014 (ITS World-2014),* December 2014, Rio De Janeiro, Brazil.

1.2.3 Other publications

[21] **Van der Wee, M.**, Verbrugge, S. and Pickavet, M. (2011) Value Networks and Quantitative Social Cost-Benefit Analysis for the different actors in telecommunication access networks. *12th UGent-FEA PhD symposium*, December 2011, Ghent, Belgium.

[22] **Van der Wee, M.**, Verbrugge, S. and Laroy, R. (2014) The Case of Belgium. In: Lemstra, W. and Melody, W.H. (Eds.). The Dynamics of Broadband Markets in Europe: Realizing the 2020 Digital Agenda. Cambridge: Cambridge University Press.

2

The need for and barriers to deploying Fiber-to-the-Home

"Almost overnight, the Internet's gone
from a technical wonder to a business must."
- Bill Schrader

Telecommunications started a long time ago, but developed faster and faster as time went by. Starting from communicating via the use of carrier pigeons in the Middle Ages to telegraph systems in the beginning of the 1800s, telephone networks were starting to be deployed at the end of the 19th century, while coaxial cable networks for broadcast services emerged in the 1950s. The liberalization and privatization of the former PSTN (Public switched Telephone Network) led in the 1990s to the introduction of broadband on both DSL (Digital subscriber Line) and CA-TV (cable television) networks. Nowadays, a society without telecommunications networks and especially the Internet is hard to imagine, on the contrary, their importance in everyday life keeps on growing.
As a more elaborate introduction to the entire book, this chapter will provide a description of the evolution and the dynamics of the broadband market in Flanders (Belgium), thereby relying on the analysis performed in [2.1] and [2.2]. Following the location of Ghent in Belgium and Flanders, the history of telecommunications in Flanders in this chapter is used as a starting point, from which the comparison to Europe and the rest of the world will be drawn in the

following chapters. Some observed trends in this chapter will be highlighted to provide a clear motivation for the performed research.
This chapter will first give an overview of historical developments of PSTN and CA-TV networks and the Telecom Reform in Flanders (section 2.1), after which the current duopoly situation of telecommunications in Flanders is elaborated on in section 2.2. This analysis is further used in section 2.3 to describe the possible paths that could (or should) be taken to comply with ever increasing demands for higher bandwidth in the future. The observed trends in Flanders are linked to other countries in Europe in section 2.4, and provide a motivation for the framework used further in this PhD dissertation (section 2.5).

2.1 Historical developments in PSTN and CA-TV networks in Flanders

In order to get to a full overview of the historical developments, we will begin our analysis at the end of the 19th century, when the first telephone networks were deployed. We will focus on the evolutions in both twisted copper pair (PSTN) and coaxial cable (CA-TV) networks, since both currently play an important role in the offering of broadband. In this section, we will describe how private initiatives were soon taken over by local and national authorities, how monopolies long ruled, and how liberalization and privatization, triggered by the European Telecom Reform, aimed to introduce more competition and dynamic efficiency in telecommunications markets. The most important events for the developments of both networks are summarized in Figure 2-1.

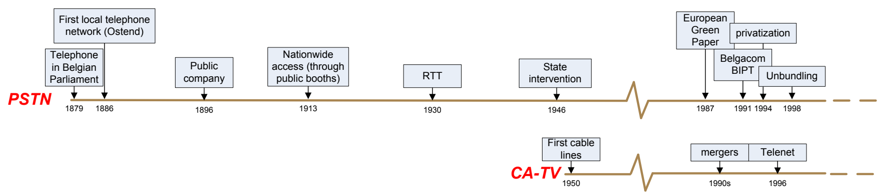

Figure 2-1: Overview of historic events in both PSTN and CA-TV networks in Flanders

2.1.1 The development of the PSTN network: from private initiatives to a monopolist situation

The first introduction of the telephone in Belgium originated from the Belgian Parliament (1879), but the public became acquainted with the telephone thanks to the American International Bell Telephone Company [2.3]-[2.4], which built the first local telephone network in Ostend in 1886. The networks owned by this and other private organizations covered the densely occupied cities, but did not reach out to the rural areas. The State recognized the value of a nation-wide telephone network and therefore invested in establishing a public company that received total control of the network.

As a consequence of the First World War, the Belgian authorities had to deal with great financial troubles and could no longer support the public telephone company. To avoid losing telecommunications facilities by the lack of financial means, a new company was founded: the RTT (Regie Telegraaf en Telefonie) in 1930. This public company received the monopoly over the whole telephone network, but was created as an autonomous entity, no longer depending on the funding provided by the government. Competition was out of the question, as all threats of entry and substitute products were locked out by law, which determined that the RTT not only had the monopoly of owning and exploiting the PSTN network, but also the sole rights on offering telephone services.

To repair the damages experienced during the Second World War, the State decided to intervene financially to give a boost to the telecommunications sector. While in theory the company was autonomous, in practice, the involvement of the State was never far away. This intervention of the State gave the RTT the possibility to invest in the development of its network. The booming economy at the time provided the opportunity for the Belgian population to subscribe to the telephone network. The growing demand of subscribers stimulated the RTT to invest even more in its network (the expansion of demand led to an expansion of investment, from 350,000 connections in 1946 to 1,049,000 in 1965) making the Belgian telephone network one of the most developed and progressive at the time with a penetration of 33% of households [2.5].

Although the RTT was a successful company, its monopoly rights (not only on ownership and exploitation of the PSTN network, but also on the providing of services and equipment) made the telecom market in Flanders quite inefficient, as the RTT was not obliged or incentivized to offer the most innovative products at the lowest prices. At the end of the 1960s, the saturation of the market put a stop to the increasing revenue trend, which revealed inefficiency problems of the RTT. Customers (especially business subscribers) began to realize that the prices they were paying were too high. This awareness also rose in other countries and was the major cause for European-wide regulatory intervention.

2.1.2 Developments of CA-TV networks: private initiatives and the influence of the municipalities

Distribution of television channels by coaxial cable networks originated in the USA in 1947. Belgium was the first country on the European mainland that established cable distribution networks in the early 1950s. The first lines were installed in large apartment buildings where the residents invested jointly in one antenna and distributed the signals using coaxial cable. Soon, some of those networks were combined into inter-municipal networks, sometimes with participation of private firms. The number of subscribers grew rapidly: more than 50% of the Belgian viewers had subscribed by 1976. By 1996, 38 cable companies with a total subscription base of 95% of the households, made Belgium the world's leader regarding cable penetration. Competition was not present at the time, since each cable company operated in its own dedicated geographical region. The growing demand resulted in serious expansion campaigns during the 1980s-1990s, thereby enhancing the quantity and quality of the offered TV services. Starting in the 1990s, many companies merged in order to be able to keep up with the required investments. This resulted in a few big companies, geographically separated, operating the coaxial cable networks.

2.1.3 Telecom Reform

The first legislation concerning the use of the telephone was published in 1896, with the monopolization of the network and the foundation of the first public company. The first real Telecommunications Law appeared in 1930, together with the formation of the RTT. This law remained roughly unchanged for more than sixty years, as nothing fundamentally changed concerning the monopolistic situation of the RTT.

So far, telecommunications services had remained firmly in the hands of the national operators, but this would change with the 1987 landmark document "Green Paper on the development of the common market for telecommunications services and equipment" [2.6]. The first and politically acceptable step in the process of liberalization aimed at introducing competition at the service level, while the infrastructure could remain under monopoly control. However, "the Commission recognized that the gains in innovation, productivity improvements and price re-structuring would only come about through competitive entry in infrastructure, be it at a local level by upgrading cable networks or building new ones, or more immediately through alternative backbone investments" [2.7]. By the end of 1994, the European Council officially recognized the principle of liberalization and set January 1st, 1998 as the date "by which all remaining restrictions on service competition would be lifted" [2.8].

On 21th March 1991, the proposals from the Green Paper were incorporated in Belgian Law [2.9], which led to the foundation of two institutions: Belgacom[1], an autonomous telecommunications operator with a monopoly concerning the PSTN network and the BIPT (Belgian Institute for Postal Services & Telecommunications), the Belgian National Regulatory Authority (NRA). Belgacom was created as a successor of the RTT and subsumed the entire

[1] Please note that Belgacom recently changed its name to Proximus. As most of the contents of this chapter deals with historical developments, the company will here be referred to as Belgacom.

Belgian telephone network. The main difference between the RTT and Belgacom concerned the degree of monopoly. The RTT had the monopoly of exploiting the whole telephone network, while Belgacom only inherited the monopoly on the "public telecommunications".[2]

Furthermore, as a response to the Bangemann Report [2.10], the government decided to privatize Belgacom in that same year by selling just under 50% of its shares to industry, the State remaining as such the major shareholder. The State believed this privatization to be necessary to counter competition from international rivals, because of the attractive position of Belgacom as the only telecom operator in a country in the center of Europe, but also to be able to face the competition emerging from the domestic CA-TV operators.

The European Commission (EC) liberalization directive obligated Belgacom to open up its network to new entrants starting from January 1998. The consequence of this liberalization was the emergence of many new OLOs (Other Licensed Operators) in the following years. The fragmentation of the PSTN market however remained limited, as the new entrants had to combine the investments attached to the starting-up of a new company with lower prices and/or better products, because they had to overcome customer loyalty for the existing brands. With more firms on the market, the customers could play competitors off against each other while forcing down prices or demanding higher quality or more services.

Although limited, the opening of the PSTN market stood in great contrast to the intense concentration of the market for coaxial cable networks. In the latter, one specific public initiative: "Multimedia in Vlaanderen" in 1996 [2.11]-[2.12], set up by the Flemish government, initiated drastic changes. The main driver for this project was to close the 'digital gap', but also other targets – job creation and promotion of R&D in the IT sector – played their part. The major element of the project was the establishing of Telenet, set up to interconnect and ultimately unite the independent Flemish cable companies to achieve an interactive broadband network offering broadcast, telecommunication and multimedia services. Although the business plan for Telenet was ambitious, the first Internet access offer, branded Pandora (launched in August 1997), was too expensive (about €50 per month), leading to a delay of the expected boom in take-up and very high debts. Furthermore, Telenet (Pandora) only received revenues from offering additional services, the network revenues stayed with the network

2 The Law of 1991 classified public telecommunications as:

- construction, maintenance, modernization and operation of public telecommunications infrastructure;
- the exploitation of the reserved services (including telephone and telegraph service, provision of fixed links for third parties);
- the construction, maintenance and operation of the publicly accessible and on public domain located establishments intended for telecommunications.

owners (privately owned and geographically divided ‘intercommunales’). In 2002, the newly appointed CEO, Duco Sickinghe, changed the strategy of the company. He bought the intercommunales (UPC Belgium in 2006, Interkabel Vlaanderen in 2008) in return for a share in the larger Telenet. As such, he could claim the ensured revenues from the network (CA-TV revenues, which previously were destined for the intercommunales), thereby securing the business case and making Telenet the only true competitor to Belgacom in Flanders.
Apart from the strategy change, the NRA, BIPT, had an important influence on the business case for Telenet: they allowed asymmetric termination fees in the advantage of Telenet [2.13], which meant a large extra income for Telenet, and saved the company to some extent. Some even considered this regulation as an indirect subsidy from Belgacom to Telenet, justified in the context of creating a level playing field in telecoms in Flanders. Although this justification may be subject to discussion, it led to the current duopoly situation where Belgacom and Telenet compete for broadband customers.

2.2 Development of broadband in a commercial and technical duopoly

Although the European Telecom Reform aimed at introducing more competition by allowing new entrants to compete on the twisted copper pair network, it mostly resulted in a competitive duopoly between the incumbent operator (Belgacom) and the cable operator (Telenet). This section will describe the evolutions and most important events in the development of broadband (Internet), while focusing on the tit-for-tat competition between twisted copper pair and coaxial cable (Figure 2-2).

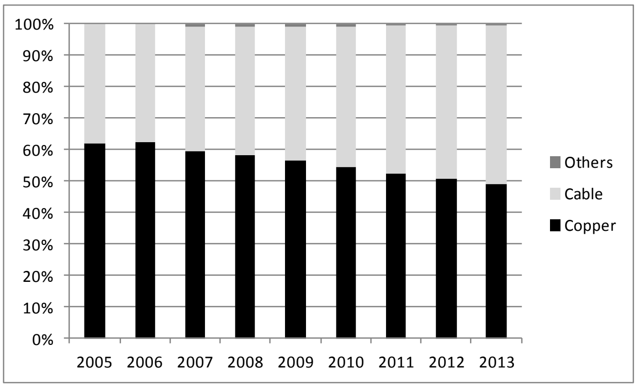

Figure 2-2: Market shares per technology over time clearly show the competition between twisted copper pair and coaxial cable (entire Belgium) [2.14]

Important to mention here is that, although this chapter focuses on fixed broadband markets, we also include a timeline for mobile communications because both operators offer quadruple play services (including television, Internet and fixed and mobile telephony).[3] We refer to Figure 2-3 and Figure 2-4 for a graphical representation of the most important events for both networks.

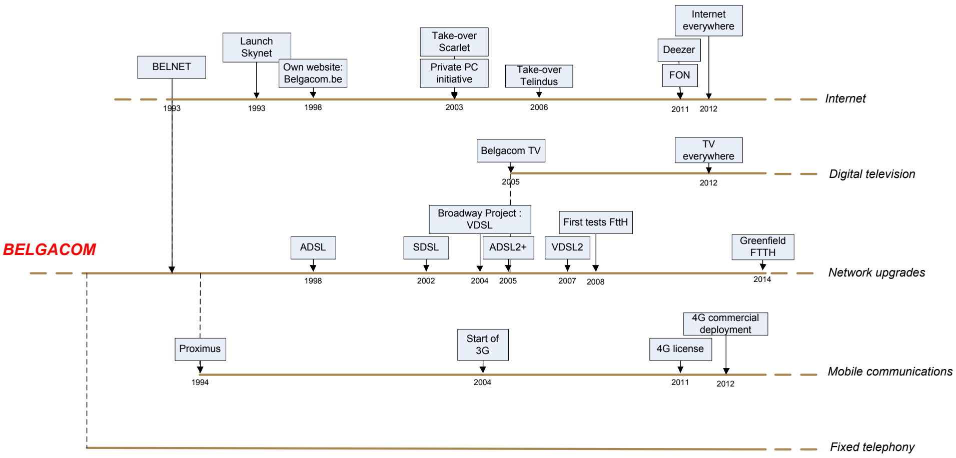

Figure 2-3: Overview of developments in the PSTN network of Belgacom

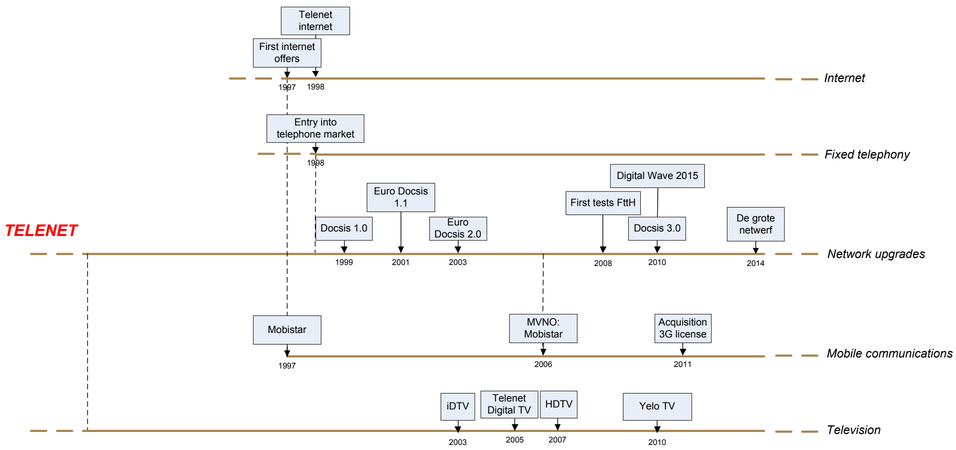

Figure 2-4: Overview of developments in the network of Telenet

[3] Telenet offers mobile services in collaboration with Mobistar, who owns the license.

The introduction of the Internet in Belgium was realized by the research centers, who wanted to provide their researchers with the possibility to connect to powerful remote computers. The first narrowband (64 kbps – kilobits per second) network was operational in 1993 by BELNET [2.15]. Belgacom entered the Internet market in 1996 with the acquisition of Skynet, a company providing Internet services founded in 1995.

Flanders discovered the opportunities of broadband Internet competition in 1997. In July, Telenet finished rolling-out an extensive backbone in fiber of about 600 kilometers in order to connect the individual networks of the different cable companies and replacing the amplifiers all over the network with bidirectional versions to allow broadband traffic in both directions. The first broadband connections were installed in August 1997, using Telenet's HFC (Hybrid Fiber Coaxial) architecture.

The introduction of broadband Internet over the twisted copper pair network followed with the execution of a pilot project for the testing of ADSL (Asymmetric Digital Subscriber Line) in 1998. Because of the success of the project, Belgacom Skynet was one of the first operators worldwide to commercially introduce ADSL in April 1999. Within short, ADSL covered 30 to 35% of Belgacom's telephone customers. The intention was to achieve a coverage of 70% by the end of 2000. This objective was exceeded when, in November 2000, ADSL services were available to 75% of Belgian population. By the end of 2002, the coverage was almost complete when 98% of the inhabitants had access to the ADSL services [2.16], making Belgium the leader in Europe.

The need for higher data rates made Belgacom explore the opportunities of fiber deployment within the scope of the Broadway Project that was launched in 2004. This project aimed at upgrading the network to a combined twisted copper pair and optical fiber network. The goal was to connect the Central Offices to the street cabinets using optical fiber (the so called Fiber-to-the-Cabinet, FTTC) and to roll out a VDSL (Very high bit-rate Digital Subscriber Line) platform between the street cabinets and the end users. This VDSL technology offered data rates up to 8 Mbps (Megabits per second) download and 400 kbps upload by the beginning of 2005. Because the equipment vendor Alcatel Lucent didn't support the particular VDSL technology any longer (it was incompatible with ADSL and had a too high spectral noise) and because the need for higher data rates was urgent due to the introduction of digital television, Belgacom implemented ADSL2+ in 2005 as a temporary solution until the new VDSL2 standard would be ready at the end of 2007. By 2009, a total investment of about €500 million had led to the deployment of 14,000 km of fiber, connecting 17,000 remote optical platforms representing an FTTC (Fiber-to-the-Cabinet) coverage of about 70%. Thanks to the early investments in the Broadway project and the high ranking of the VDSL2-coverage (2^{nd} place in Europe in 2009), Belgacom

received the “2009 Innovations Award” from Global Telecommunications Business [2.17]-[2.18].
Because of the increasing demand for higher bandwidths and in order to stay competitive vis-à-vis the cable operator Telenet, Belgacom decided to invest further in applications using optical fiber. The first tests concerning Fiber-to-the-Home (FTTH), bringing the optical fiber into the living room of the customer, were executed in Rochefort in 2008, extended to Sint-Truiden and La Louvière in 2009 [2.18], and recently added three new test projects in Bredene, Brussels and Brecht [2.19]. Although the focus lies on improving the quality on the VDSL network, Belgacom also communicated to consider plans for deploying FTTH, possibly by considering aerial (on the buildings’ facades) instead of buried deployment [2.20]. Starting from December 2014, FTTH will be deployed in greenfield areas (“all new residential zones that are sufficiently large”) [2.21].
On the one hand, Belgacom is deploying VDSL2 to all its customers, having reached a national coverage of 78.9% at the end of 2011, and over 87% by the end of 2013 [2.22]. On the other hand, Belgacom recognizes the limitations of VDSL2, and therefore already communicated their “Get to fast, faster” strategy [2.23]. In a partnership with Alcatel-Lucent, Belgacom aims at maximizing the VDSL2 throughput by using the new state-of-the-art vectoring technology. The graph in Figure 2-5 provides an overview of the most important changes concerning the available data rates for residential users (for a more general overview of the different DSL technologies, we refer to Figure 3-4).

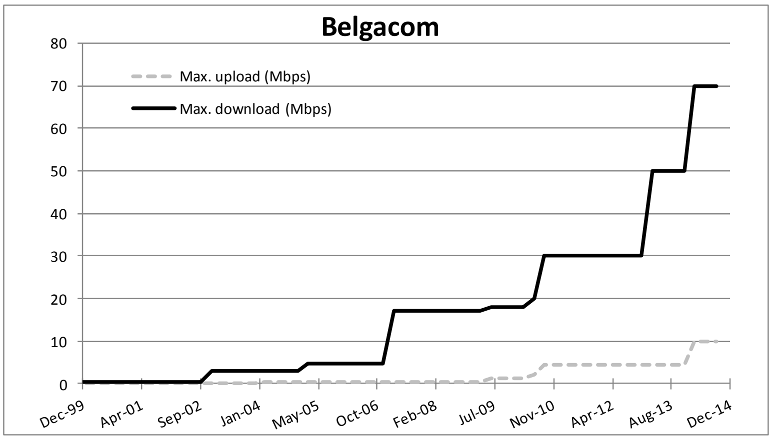

Figure 2-5: Graphic representation of the evolution of the offered bandwidth by Belgacom (maximum download and upload data rate for residential customers); [2.24]-[2.31].

Figure 2-6 shows the evolution of the data rates offered by Telenet. To provide its services, Telenet uses a HFC network, which consists of fiber backbones and coaxial access in the serving areas. To provide broadband access, Telenet uses the DOCSIS (Data over Cable Service Interface Specification) technology. Over the years, Telenet launched different new products, each time increasing the data rates. Telenet Internet XL, for example, came to the market in September 2000, providing a downstream of 1 Mbps and upstream of 256 kbps. In 2002, Telenet Internet XL offered download data rates up to 4 Mbps, while download data rates increased to 20 Mbps in the fall of 2005. In March 2010, Telenet launched 'Digital Wave 2015', a project aiming at improving the existing network over the next five years, with an investment sum of about €30 million every year. Now, Telenet uses the European version of DOCSIS 3.0 and is expanding to DOCSIS 3.1, which allows them to offer a download data rate of 100 Mbps and more [2.32]-[2.33]. Recently, the company announced further investments in their network: €500 million over the next 5 years, thereby making it possible to reach data rates of up to 1 Gbps to end users [2.34]. This investment will be focused on broadening the "information superhighway" from 600 MHz to 1 GHz, which will require the replacement of 150,000 amplifiers and 1.8 million other components. Plans for deploying FTTH were not communicated so far.

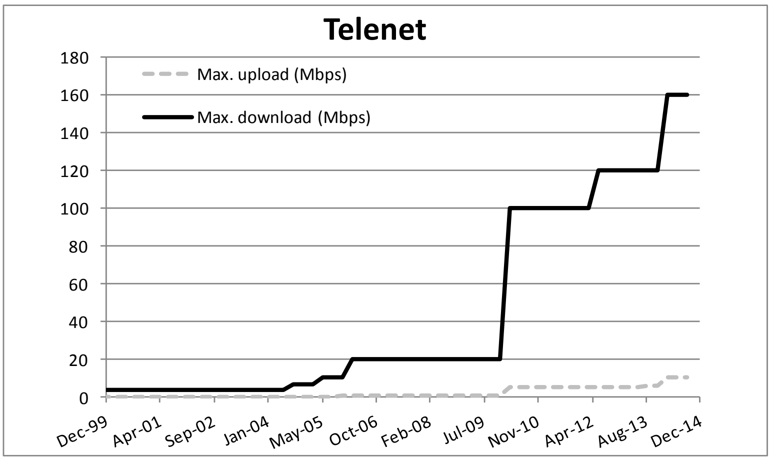

Figure 2-6: Graphic representation of the evolution of the offered bandwidth by Telenet (maximum download and upload data rate for residential customers) [2.35]-[2.41].

These evolutions led to the current situation in Flanders: a duopoly between Belgacom and Telenet, both taking up almost half of the market share, leaving only a few percent for other operators. Both upgrade their network gradually, but are not inclined to take on high-risk investments [2.42]. Mid 2014, Belgacom offers to residential users a maximum download speed of 50 Mbps and a maximum upload speed of 5 Mbps, while Telenet's limits are at 160/10 Mbps (down/up) [2.40],[2.43].

To face the competition, both Belgacom and Telenet expanded their range of services (Figure 2-3, Figure 2-4). Currently, both Belgacom and Telenet are quadruple play operators, offering broadband Internet, fixed and mobile telephony as well as digital television [2.43]-[2.44]. Important to mention here is the share that digital television takes up in the Internet bundles. Of all Internet bundles offered (on a Belgian scale), about 80% includes digital television [2.45]. Telenet acquired a license for Digital Video Broadcasting – Terrestrial (DVB-T) broadcasts in Flanders in 2010, but because this service was not successful, it is no longer commercialized. At the moment only a free terrestrial broadcasting service (customers can get this service just by buying a digital antenna) is available in Flanders offering the channels of the public broadcaster VRT.

Belgium is one of the leaders of the market when it comes to coverage of ultrahigh broadband; according to Akamai, Belgium ranked 10th globally with average data rates observed of 6.1 Mbps and ranked 6th on peak data rates observed of 26.7 Mbps [2.46] in 2012. In the first quarter of 2014 however, Belgium went down to place 14 globally (average speed of 10 Mbps), while the peak speed reported is 44.6 Mbps (leading to a 12th place globally) [2.47].

2.3 Does the duopoly setting with tit-for-tat competition suffice to realize the Digital Agenda targets?

For a very long period, telephone service provisioning in Belgium has been characterized by a monopoly regime. It was the imminent threat of competition, supported by the pressure from 'Europe' that incentivized the Flemish government to a project, which would radically change the telecom market structure in Flanders. Telenet was founded and became the key competitor for the incumbent Belgacom in the Flemish fixed broadband market, and as such, competition, innovation and price reduction were stimulated.

On the other hand, Europe also sets concrete targets for telecommunications networks, published as part of its Digital Agenda for Europe [2.48], which specify that: "By 2020, all Europeans should have access to Internet of above 30 Megabits per second (Mbps) and 50% or more of European households have subscriptions above 100Mbps". By describing concrete examples and events, this section will analyze the dynamics of the Flemish broadband market and provide insights in the road to reach Europe's Digital Agenda targets.

2.3.1 Marketing strategies: focus on own strengths

From the previous section it has become clear that, although there are some smaller niche players present, the fixed broadband market in Flanders is dominated by Belgacom and Telenet, each having a close-to-100% coverage with their networks (DSL and DOCSIS, respectively). However, since the available data rates on those networks differ significantly (maximum download data rates for residential users are 70 Mbps for Belgacom versus 160 Mbps for Telenet), both players market their offer using different key services and promotions.

Since mid-2012, Telenet focuses its marketing strategy on data rates and simplicity, both for the fixed and mobile market. In July 2012, Telenet launched King and Kong, two straightforward tariff schemes for its mobile customers. Both are bundles, including voice, SMS and mobile data, for a fixed charge per month. To attract or convince fixed Telenet customers, discounts are given. In June 2013, Telenet launched a similar offer for its fixed services: Whop and Whoppa, bundles including digital television, Voice-over-IP (VOIP) telephony, a fixed broadband connection and Wi-Fi Internet through their Wi-free hotspots. Their advertising emphasizes the high data rates reached (Whoppa: "for whom fast isn't fast enough") and the inclusion of all services into one simple and transparent bundle.

Belgacom, as a quadruple play operator, goes one step further in bundling its services. The company offers both mobile and fixed Internet in one package: the "Generation pack". Different options exist, for different download limits, voice and SMS usages, etc. Their strategy focuses as such more on the services, as the maximum download rates on VDSL are less than half of Telenet's offers.

2.3.2 Regulatory setting: unbundling obligations for both Belgacom and Telenet

1998 was the year of the liberalization of the European telecom market. The incumbent Belgacom was obliged to open up its network to new entrants. Belgacom remained owner of the network, but had to provide network access to other operators. The consequence of this liberalization was the rise of many new OLOs in the following years (e.g. British Telecom, MCI, Colt, Versatel, Coditel, Tele2, Dommel, EDPnet, Mobistar, Eleven and Scarlet). This fragmentation of the market in the field of the DSL network stood in great contrast to the intense concentration of the market in the coaxial cable network. This is an important observation: while Belgacom was obliged to open up its network, the cable companies merged into a united network.

However, the fragmentation of the market remained limited, as the new entrants had to combine the significant investments attached to the start-up of a new company with the need to offer low prices to attract customers. New entrants had to offer cheaper and/or better products than the incumbent, because they had to break the customer loyalty for the existing brands. This ongoing price pressure

made it hard for the new entrants to survive, forcing some to end their activities (e.g. Eleven) or to sell their activities to another operator (e.g. Versatel, Tele2).
Other operators managed to develop a customer base of significant size. An excellent example here is the operator Schedom, which provides a cheap Internet connection for urban subscribers under the brand name Dommel. Its success is hidden in the selection of the market segment. By focusing only on urban, densely populated areas (consisting of many students and gamers) and offering unlimited broadband packages, Schedom could keep its line prices low while still acquiring a significant part in that specific global market [2.49]. Now that the other operators started offering unlimited packages, their unique selling position disappeared. Other operators, like Scarlet, were taken over by Belgacom, although Scarlet remains an autonomous subsidiary [2.50].
The impact of the unbundling obligation remained marginal until the BIPT lowered LLU (Local Loop Unbundling) prices in 2006. The scale of the alternative operators was by then large enough to climb the ladder of investment further and to invest in unbundling. These investments were stopped in 2008 when the economic crisis hit and when Belgacom announced that it intended to close down 10% of its MDFs as a consequence of the move to an all IP infrastructure and VDSL deployments in the sub-loop. Because the planned closure impacted 40% of the unbundled lines, the BIPT intervened with additional obligations[4] to guarantee a fair return on investments (ROIs) for the alternative operators, but the investments in unbundling never recovered.

Although Telenet long enjoyed a monopoly on the HFC network and services, the CRC (Conference of Media Regulators) and the Belgian NRA (BIPT) published a proposal for opening up the cable network in 2010. This proposal was transformed into a formal decision on July 1st, 2011, in which the regulatory authorities regulated Telenet and the other cable operators, and created an obligation to provide wholesale access to analogue television and broadband Internet services, as well as opening up the digital television platform. The analogue TV offer should allow an alternative operator to resell Telenet's offer, although the offer itself would not change. In the digital access, an alternative operator can inject their own signals into the digital platform of Telenet, thereby having the opportunity to differentiate the offer by providing alternative content. Allowing OLOs broadband access, finally, will only be allowed in combination with TV [2.22].
Telenet responded stating that regulating analogue TV is not useful, because of the declining number of subscribers, and that regulating digital TV is not necessary, as in that market there is enough competition from different platforms

[4] Decision of 12 November 2008 concerning the addendum NGN/NGA complementing the market analysis of 10 January 2008.

(cable, IPTV, satellite and Internet TV). They furthermore argued that regulating the most important competitor to the SMP incumbent will definitely not enhance the infrastructure-based competition the European Commission favors [2.51]-[2.54]. On the other hand, the regulators argued that the unbundling obligation can also be favorable for Telenet, as it would allow the company to expand its services to Brussels and Wallonia (the southern part of Belgium). Furthermore, the unbundling obligation will allow mobile operators (such as Base and Mobistar) to offer TV services in bundles with their mobile subscriptions. Finally, and most importantly, unbundling the cable operators will stimulate competition on wholesale level and as such increase competition and reduce retail prices.

The regulators and operators are now defining the implementation of the decisions, and final decisions were reached in September 2013 (qualitative decision) and December 2013 (tariffs decision on a retail-minus basis). A first letter of intent was signed by Mobistar to Telenet, Brutélé and Tecteo in January 2014 (the latter two are cable operators in Brussels and Wallonia); the cable operators then having a six-month period for implementation. Friendly user tests are expected for the second half of 2014 [2.22].

Concerning the current LLU and bitstream access regulation of Belgacom's network, the BIPT is also re-evaluating its models for calculating the price caps, following the European guideline to stabilize the prices for copper lines between €8 and €10 per month, as such increasing the flexibility for the deployment of fiber-based networks.

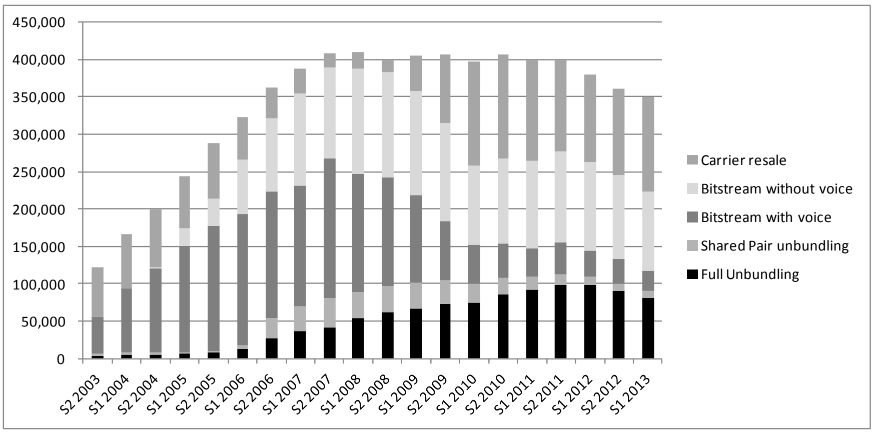

Figure 2-7: The use of wholesale access on fixed services remains limited in Belgium

A final regulatory intervention worth mentioning is the recent withdrawal of the VDSL sub-loop unbundling requirement by the BIPT [2.55]. For VDSL vectoring to function properly, i.e. to effectively cancel out cross-talk, the copper lines connected to the DSLAMs (Digital Subscriber Line Access Multiplexer) should be handled as one bundle, which would imply the bundle to be controlled by the same operator. Moreover, the business case for sub-loop unbundling is less attractive as the aggregation point moves lower into the network, hence it does not attract many OLOs, BIPT has decided to withdraw this obligation in order to stimulate the commercial deployment of VDSL vectoring, thereby ensuring the competitiveness of Belgacom's DSL with Telenet's DOCSIS network. Because of the withdrawal of sub-loop unbundling, the BIPT enhanced in the same decision the obligation to provide bitstream access by adding multicast functionality and allowing more differentiation possibilities for active access at local and regional level. This enhanced form of bitstream is also called Virtual Unbundled Local Access (VULA).

2.3.3 Realizing the Digital Agenda targets

Concerning the 100% coverage goal of 30 Mbps or more, set out by the Digital Agenda for Europe, 98% was reached by the end of 2011: 85% of households via VDSL, 95.5% via the DOCSIS 3.0 technology. Belgium is the leader when it comes to the uptake of high data rate broadband (30 Mbps or more). The second goal, reaching 50% take-up of high-data rate broadband (>=100 Mbps) by 2020, is further away: an uptake of 3.4% was reached by the end of 2012.

Forecasts however are optimistic for Belgium. Analysys Mason communicated that Belgium is one of six countries that should reach the 50% take-up goal of high-data rate broadband by 2020. However, the road to reach these targets differs strongly from other countries sharing the same goals. Belgacom communicated the VDSL vectoring strategy to achieve the goals set out in the Digital Agenda to the European Commission [2.56], while FTTH is more common in other countries. In Belgium, FTTH coverage remains small: coverage of 0.2% was registered at the end of 2011. Therefore, Belgacom commented that the Commission should assure "technological neutrality when considering investments in broadband infrastructure in view of reaching the Digital Agenda". They stated that the focus is too much on FTTH, while the developments made by Alcatel-Lucent clearly indicate that the targets can also be reached with gradual upgrades of VDSL.

Whereas Belgacom reaches data rates of 50 Mbps to 1.5 million households (limited availability of 70 Mbps (through vectoring), 30 Mbps elsewhere [2.20]), Telenet is far ahead, offering theoretical data rates up to 160 Mbps using their DOCSIS 3.0 technology, which is available to 95.5% of households.

However, ranking 10th in Akamai's 2011 report, Belgium dropped a few places, now only ranked 14th (first quarter of 2014) on average speed, and even dropped from 6th to 12th place on peak speed [2.47]. Furthermore, although both operators communicate not to opt for a revolutionary FTTH deployment (replacing their current networks), the opportunities and possibilities for such a rollout are still

being examined by the operators and the NRA [2.57], following the lead taken in other countries and by Europe [2.58]. This examination includes thorough cost analyses, assessing the relative weight of the trenching costs versus the service provisioning and operational costs, investigating opportunities of synergetic rollout with other utility network owners, as well as assessing the impact of Public Private Partnerships involving the local municipalities. The Belgian NRA proposes to harmonize and standardize the Right of Way, to stimulate sharing of infrastructure (e.g. empty ducts), to investigate the opportunities of decreasing the price for the last mile (by e.g. allowing aerial deployment or micro-trenching), etc.
The next section will link these more generally observed trends to some historical facts described in the sections above, thereby providing a motivation for the framework for investigation used in this research.

2.4 Comparison of Belgian duopoly to generic trends across Europe

The previous sections detailed the duopoly situation in the telecommunications sector in Belgium, where the future road clearly focuses on evolutionary approaches for both DSL and DOCSIS upgrades. Although Belgium holds a leading position in Europe in terms of high data-rate (> 30 Mbps) broadband uptake [2.59], it is still far behind in comparison to Asian countries such as Korea and Japan, and its leading position in Europe is also slowly declining.
When comparing the path followed in Belgium, we notice that it differs significantly from other countries in Europe, or the world, where fiber-based access networks are already operational or being deployed. In the Netherlands or France, for example, the alternative operators Reggefiber and Free started nationwide FTTH rollouts, while Portugal Telecom is upgrading VDSL to all-optical networks. In rural communities, state aid is used for deployment, thereby reducing digital divide. As this study aims to go beyond the Belgian borders, this section links the observed trends of this chapter to more general trends observed in Europe, based on the conclusions drawn on a comparison of twelve countries [2.60]. By focusing on specific case studies, this view will be extended to the worldwide situation in FTTH in chapter 4.

2.4.1 Different technical roads

As mentioned above, Belgium having (almost) no FTTH networks is rather an exception in Europe. The gradual upgrade for both DSL and DOCSIS based networks stands in clear contrast with for instance most East European countries, where PSTN networks only covered parts of the population, and where CA-TV networks are also limited, or only seen as broadcast network, i.e. the switch to broadband networks was never (successfully) made. As in these countries, the investment choice now lies between deploying FTTH and deploying DSL, most (if not all) initiatives prefer the future-proof fiber solution, as the investment for both types of networks is comparable.

In the Western European countries, different trajectories are observed, ranging from gradual upgrades from ADSL to VDSL to FTTH (as seen in the example of Portugal, see also further in section 4.2.4), over Fiber-to-the-Building deployments where existing cabling in apartments is reused (e.g. in Munich, Germany), to full FTTH deployments (e.g. in Amsterdam and other cities in the Netherlands – section 4.2.3.a).

Observing these different technical trajectories across Europe, asks for an adjusted approach when analyzing the business case for FTTH rollout, thereby taking into account the evolutionary (gradual upgrade) or revolutionary (greenfield FTTH rollout) approach. Furthermore, the choice between Point-to-Point (P2P) and Point-to-Multipoint (P2MP) deployments (see section 3.2.1 for more information) is an important technical decision to be made.

2.4.2 Alternative investors and impact of uptake

Following the historical development of the creation of the CA-TV networks by the municipalities in geographically distinct cable networks in Flanders, and the later merging of those intercommunales, it is worthwhile to investigate whether municipalities will also take the lead in taking the initiative in setting up NGA (Next Generation Access) networks. Although this is not directly seen in Belgium, the impact of municipalities, and other alternative investors, is clearly observed in other EU countries.

The most well-known example perhaps is the FTTH deployment by Stokab in Stockholm, Sweden (section 4.2.1), which is a public company founded by the city of Stockholm. Another example can be found in Amsterdam, where both the city and the housing corporations invested in a rollout (section 4.2.3.a). Other cases of municipal involvement can be found in Germany, where the majority of the investments are made by the municipal public utility companies (Stadtwerke).

On the other hand, alternative providers also emerge, thereby making the case for private deployment. Two examples are most stringent here: Reggefiber in the Netherlands, using demand aggregation to ensure revenues from the start, and Iliad/Free in France, that used the access to the Paris sewer system to start deploying FTTH.

On this range of cases, which is far from exhaustive, it can be concluded that the market for FTTH is no longer only dominated by the incumbent and cable operators, as is the case for Belgium. Multiple actors, not necessarily having telecom as their core business, are emerging to compete in the field.

Furthermore, the presence of alternative investors can shake up the available offers for end consumers, and hence impact the uptake for the different networks. As uptake has an important influence on the business case for FTTH deployment [2.61], the market structure and consumer preference is an important factor in the analysis.

2.4.3 Strong impact of regulation and policy

Following the historical analysis of Flanders in the previous sections, the impact of regulations is significant. The asymmetric regulation of BIPT in the beginning period of Telenet is said to have avoided a bankruptcy and hence ensured competition in the broadband market. More recently, the unbundling obligation on the DSL network was expanded to the DOCSIS network, thereby hoping to ensure competition on wholesale level as well.
These are just a few examples from Belgium that demonstrate the influence of policy decisions in the telecommunications domain. When comparing it to other countries in Europe, more examples can be found: the functional separation of British Telecom in the UK, the obligation for sharing the in-building wiring in France and Poland, the regulatory unbundling holiday in Portugal, etc. Furthermore, policy has a strong impact on who is allowed to deploy NGA networks, on different hierarchical levels. On a European level, for example, state aid rules dictate where public involvement in deployments is allowed (section 4.1.2.a).
Following these examples, it is clear that the policy level can have a significant impact on the business case evaluation, ranging from direct involvement, over financial aid to laws and guidelines for operators to follow, and should therefore be included in the analysis of FTTH deployment.

2.4.4 Conclusion

Following the broader, European analysis, it is clear that answering the question on how the need for higher broadband will be covered is not straightforward. Technological variety of solutions, be it on topology (P2P versus P2MP), architecture (e.g. Active or Passive Optical Network - AON or PON) or upgrade approach (evolutionary versus revolutionary), makes a standard economic analysis fall short. The impact of multiple actors, both public and private, as well as the amount of policy laws, directives and guidelines, on different hierarchical levels, is of even bigger importance. Hence, our research question is thus not only of technological nature, but involves multiple actors, and depends strongly on historical developments and market settings, in both legacy networks and policy laws. Solving the question therefore requires looking beyond typical economic investment techniques, as well as beyond standard technological solutions. Multiple public and private entities will take decisions on different

domains, thereby influencing the business case for FTTH deployment, as well as each other.
By investigating the goals and targets of these multiple actors, as well as their costs, benefits and cooperation mechanisms, conclusions can be reached about the way to analyze the FTTH investment problem.

2.5 Technology – Policy – Market (TPM) interaction framework

Although the development of new products and services is facilitated by technology, they only make it into the market when demand for them has built up. Similarly, if market dynamics do not provide enough incentives for operators to, for instance, adopt new technologies and upgrade the networks, government intervention in the form of acts, laws or regulation could be justified. Finally, markets don't develop or evolve independent from policy decisions or technological innovations. These statements are true in general, for multiple types of projects, but have been proven to be of significant importance in the FTTH investment research question as well. Before evaluating the business case for FTTH (evaluating economic viability by comparing costs with potential revenues), a thorough analysis of these different domains and their interactions is needed to be able to set the right boundary conditions. In a second step, these conditions can be used to evaluate the business case for FTTH, using both standard and extended evaluation techniques.

As such, following the argumentation followed above, the road and barriers to FTTH should be investigated within a framework that uses these three domains: technology, policy and market. Following the research by Melody [2.62], who identified the impact of technology through applications, the impact of markets through services and the impacts of policy through the regulations, this book will use the interaction between technology, policy and the market to sketch the underlying conditions that make up the business case for FTTH deployment, uptake and operations (Figure 2-8).

The *technology* pillar groups all innovations, both in network upgrades and applications and services development, not limited to the telecom sector only. Within the scope of FTTH networks, it includes the choice of network topology (Point-to-Point or Point-to-Multipoint), network architecture (Active Ethernet or Gigabit Passive Optical Network (GPON)), deployment method (aerial or buried), equipment innovations (e.g. on network or customer side), etc.
Policy comprises all laws, guidelines, regulations and directives that impact the deployment of FTTH either directly or indirectly. They can be made on local,

regional, national or international level. Examples include wholesale price regulation, competition law, Digital Agenda guidelines, etc.
The third and final pillar, the *market*, combines all commercial and strategic decisions, both by the end-user and by the industry players itself. Examples include the customer's decision to take up on a fiber connection, the SP's service offers in terms of speeds and caps and the FTTH platform's wholesale tariff structure.
By focusing on the decisions made by actors in the three different pillars of the framework, the effect of their decisions on the other pillars can be studied, and possible interaction identified.

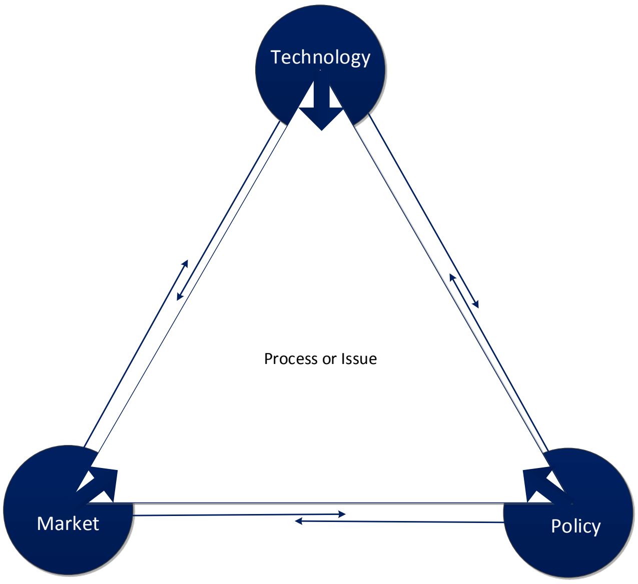

Figure 2-8: Technology - Policy - Market Interaction Framework

The following chapters will apply this framework: chapter 3 will discuss the technological pillar, while focusing on open access FTTH networks, while chapter 4 will describe the boundary conditions set by the market and policy pillar.

2.6 Conclusion

Starting by the evolution of PSTN (telephone) and CA-TV (broadcast) networks, this chapter provided the overview of historic developments of broadband networks in Flanders, Belgium. Developments of two separate networks, both capable of offering broadband access, led to the current situation of fixed telecommunications in Flanders, where one DSL and one DOCSIS operator compete for customers in a duopoly setting. Leaning on the historical developments in Flanders, and comparing to other European countries, leads to the conclusion that FTTH is the future for Next-Generation Access networks, but that the investment decision is hard, which leads to different paths that are followed by different actors across different countries. The deployment is moreover not only a technological decision, but is strongly influenced by market evolutions and policy decisions. To study the business case for FTTH, one should therefore make use of a technology-policy-market interaction to clearly define the boundary conditions for different settings, and focus not only on inter-platform, but also on intra-platform competition in a multi-actor setting when evaluating the business case.

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3

Technical possibilities for deploying an open FTTH network

"It turns out that all Netflix streaming peak on Saturday night can fit inside a single fiber optic, which is the size of one human hair."
- Reed Hastings

Following the developments described in the previous chapter, the telecommunications sector has experienced many evolutions, on technological, policy and market domains. This chapter will focus on the technological evolutions in the telecom domain, while chapter 4 will detail the important boundary conditions set by policy decisions and market evolutions. This chapter relies on the work done in [3.1]-[3.3], but is only descriptive in nature. The resulting analyses in terms of costs will follow in the next chapters.

The starting point of this chapter is based on the penetration of fiber throughout the network structure: from core over metro and aggregation to, more recently, fiber-based access networks, more commonly referred to as Fiber-to-the-Home (FTTH). FTTH is the most future-proof technology for the deployment of Next-Generation Access networks. It is therefore important to understand the technical characteristics of these FTTH networks. Here, the well-known protocol stack, consisting of five layers, will be used to describe the different responsibilities in the FTTH access network, which will be each assigned to different entities: the service provider (SP), the network provider (NP) and the physical infrastructure provider (PIP). The latter is responsible for the passive network (trenches, ducts, fibers); the NP for the active network (end-to-end equipment in central office and customer premises) and the SP for the services and applications offered using the NP's end-to-end connectivity. As this work researches the business case of the network deployment itself, not the applications offered on top, the focus will lie on the description of the responsibilities of PIP and NP only.

As recent trends (see chapter 2) show that these entities move from one company taking up all responsibilities, to a divided model in which each entity is taken up by one single, or multiple competing, firm(s), the business case evaluation of FTTH should be split up, not only economically, but also technically. In order for multiple parties to collaborate, extra equipment, process or transaction steps might be needed. The cost of these steps is often referred to as "the cost of collaboration" or "the cost of open access" – following the open access business models which will be described in the following chapter.

A second part in this technological chapter focuses on describing the different forms of collaboration, i.e. between an SP and an NP on the one side, and between an NP and a PIP on the other, resulting in different types of opening the network. The impact on the technological offer of opening at fiber layer, wavelength layer and bitstream layer will be discussed, whereas the cost for opening at these layers will be evaluated in chapter 7.

3.1 The penetration of fiber through the network

Transmitting signals using light pulses originated not too long after the invention of the telephone, in the form of the Photophone (1880, Alexander Graham Bell) [3.3]. However, apart from a few specific uses, such as guiding ships, true optical communications did not develop at the same speed as electrical communication did. As fiber cables use the total internal reflection of light to transport signals, they allow high transmitting speeds, and hence provide for an alternative to twisted pair copper and coaxial cables.

Fiber cables consist of a glass core encapsulated in a cladding material with a lower refraction index. To transmit signals over a fiber medium, there is a need for convertors of electrical to optical signals and vice versa, at the source and destination of the link, respectively. At the source node, a laser diode serves as the transmitter of the light pulses, thereby serving as electrical-to-optical convertor. At the destination node, the optical-to-electrical conversion is executed by a photo-diode, thus serving as a receiver of the optical signal. This is graphically represented in Figure 3-1.

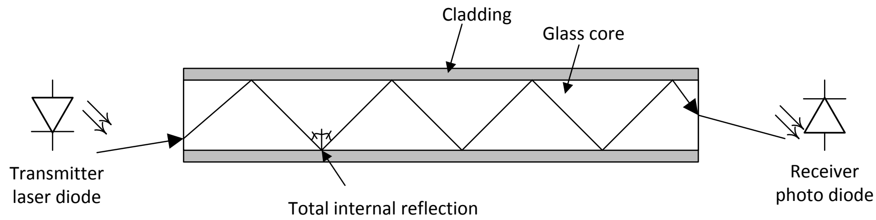

Figure 3-1: Transmission of signals through optical fiber

By the 1960s, fibers were used for medical imaging, but the attenuation (which at that time was close to one decibel per meter) was considered to be too lossy for use in communications on greater distances. Attenuation is the reduction of the intensity of the light beam as the distance the beam travels increases, and hence decreases the maximum length that can be covered in a link. However, the huge information-carrying capacity of fibers (reported as “equivalent to about 200 TV channels and 200,000 telephone channels” by Kao in Laser Focus (edition April 1, 1966) [3.5]), supported the research to reduce this attenuation loss. By 1970, Corning Glass Works announced they could produce fiber with an attenuation below 20 dB/km. By 1980, Bell Labs announced the installation of the first transatlantic fiber-optic cable, with an attenuation of below 0.5dB/km. This first cable introduced fiber-optic technology in the telecommunications domain, and was able to transmit 565 Mbps through two operating fiber pairs (in 1988) [3.3]. This capacity was enhanced by the introduction of optical amplifiers and transmission at multiple parallel wavelengths (see further for an explanation of so-called wavelength division multiplexing). For example, the submarine cables installed in 1998 could transmit up to 20 Gbps (Gigabits per second) through a single pair of fibers.

These fast evolutions in transmitting capacity of fiber-optic cables, as well as the increasing demand for higher data rates at the nodes of the network (the end user), sparked the interest to install fiber closer to the end user, in the access network and even the customer premises (Figure 3-2).

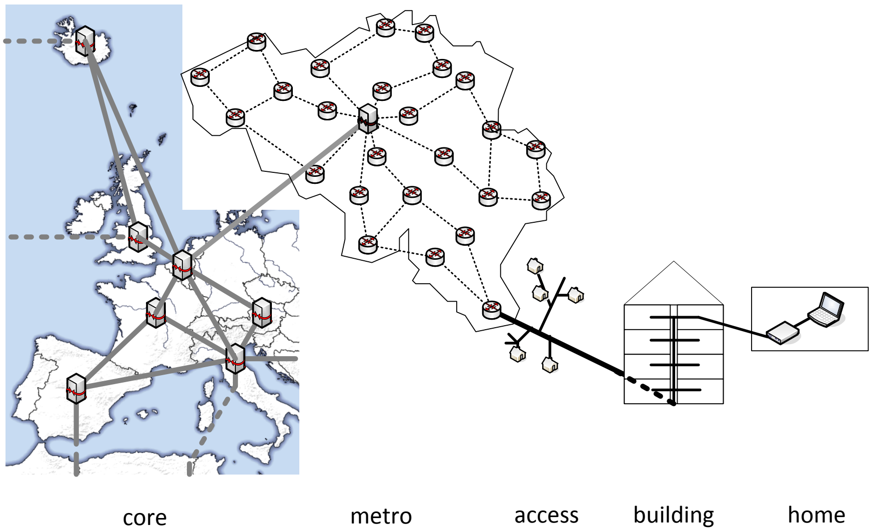

Figure 3-2: The structure of the telecommunications network

The core network connects countries and continents over large distances, frequently using submarine cables. Its topology is strongly meshed, and the newest, fastest technologies are used to transmit huge amounts of data over thick cable bundles. This is the first part of the network where fiber-optic cables were used, as described above. Nowadays, wavelength division multiplexing (WDM, see further) is used to transmit multiple parallel signals over different multiplexed wavelengths on one fiber. The current challenge is to reach over 100 Gbps on one wavelength channel, thereby reaching up to 8 Tbps (Terabits per second) per fiber over 80 channels.

The core or backbone network is connected to specified nodes of the metro network (so called Internet Exchanges – e.g. Ams-IX in Amsterdam). This metro (or metropolitan) network connects cities, or larger areas within cities, in less densely, though meshed networks. Frequently, ring structures are used to connect the network nodes (referred to as central offices). At the time of this writing, most/all of the metro networks are constructed out of optic-fiber cables. Typical is the use of WDM and 10 Gbps channels.

The next part of the network is the access, which connects the metro nodes (central offices) to the buildings, be it single homes, businesses or multi-dwelling units. In the latter part, an intermediate network is added: the in-building network, before going into the Local Area Networks (LANs) of the single homes. The access network is typically built up as a tree structure, where redundancy is limited to the connections of business users, mostly in a ring structure. Figure 3-3 gives a more detailed overview of this tree structure in the access network: a feeder cable connects the central office (CO) to multiple aggregation points (street cabinets – SC), from which a distribution cable runs to the single homes. Note that, although only one level of street cabinets is shown here, multiple levels are possible, each time aggregating multiple cables. Typical data rates in the access network range from 100 Mbps to 1 Gbps per end user.

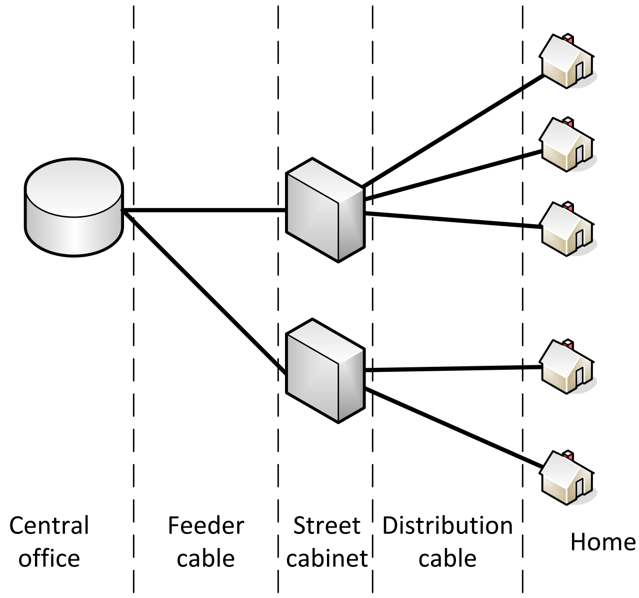

Figure 3-3: Overview of the access network

Over the years, multiple technologies were used in the access network, the main differentiator being the physical medium used for transmission: twisted copper pair, coaxial cable, optical fiber or wireless spectrum. We will only describe the evolution of the wired media, as this is the focus of this research.

In the case of twisted pair copper networks, the evolution of the DSL technology has to be described (Figure 3-4). As noted in section 2.2, the first broadband offered on these networks was ADSL, introduced by Belgacom in 1998. Nowadays, more than three quarters of Belgian households are covered with VDSL2, offering data rates up to 50 Mbps (downstream, see further), while future evolutions of VDSL will allow for even higher speeds. VDSL2 vectoring is a noise-cancelling technology that will allow to use VDSL2 at its theoretical data rates, which will lead to rates of 100 Mbps and beyond to be transmitted on twisted copper pairs. Belgacom opts for this upgrade, because it will bring high data rate broadband to the end-consumer in a fast and cost-effective way. Tests of VDSL2 vectoring started at the end of 2012, and VDSL2 vectoring was officially introduced in February 2014, thereby offering download rates of up to 70 Mbps.

Apart from vectoring, other technological upgrades on VDSL are possible to boost bandwidth capabilities. In VDSL bonding, two physical twisted pairs to each customer are used instead of one which almost doubles the data rate. As there are however little spare copper pairs in Belgium, it is unlikely that this upgrade can be implemented for every customer. Phantoming adds a third – virtual – twisted pair, which would bring data rates up to 200 Mbps to each individual household. However, Alcatel Lucent has recently halted phantoming research [3.8], [3.9].

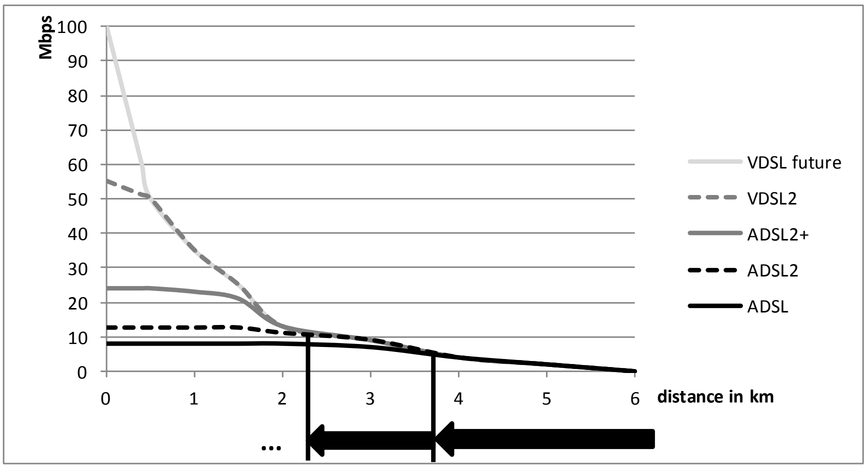

Figure 3-4: Evolution of download data rates versus distance from exchange/cabinet for the different DSL types (based on data from [3.6] and [3.7])

Important in this evolution is the "shift" in the access network, where a clear trend of increasing data rates is supplemented with a clear decrease in distance the twisted copper pair can span. With each new technology that is introduced, the fiber cable is hence brought closer to the end user.
A similar evolution can be found in the HFC networks, which are operated by cable operators (e.g. Telenet in Flanders). By introducing new versions of the DOCSIS standard and reducing the service areas, data rates are increased. As the attenuation of coaxial cable networks is much lower than twister pair copper cables, the speed evolution on the DOCSIS network precedes the evolution on the DSL network (see also section 2.2).

As the access network gets more and more "fibered up", the technology moves from DSL- or DOCSIS-based to fiber-based, and hence does the naming. In general, three types of fiber-based access networks are currently distinguished: Fiber-to-the-Cabinet or Fiber-to-the-Curb (FTTC), Fiber-to-the-Building

(FTTB), and Fiber-to-the-Home (FTTH, also referred to as Fiber-to-the-Premises (FTTP)).
In FTTC, the fiber runs from the central office (CO) to the street cabinet (SC), while the rest of the connection relies on twisted copper pair or coaxial cable. FTTC is thus the same as DSL (ADSL or VDSL depending on the distance from the cabinet to the home), and DOCSIS, in which the size of the service area determines the coaxial sub-loop. FTTB draws the fiber all the way to the basement of multi-dwelling units, from where existing cabling connects to the individual living units. FTTH finally, connects the single homes or living units with optical fiber, removing the need for legacy cabling. Inside the living unit, wireless connections are now most frequently used to connect individual devices, although future applications could require fiber to every room. Current in-house wireless nodes are capable of transmitting speeds of 300-450 Mbps (shared among all users in the house), which suffices when compared to typical access speeds of 100 Mbps to 1 Gbps. In-house fiber cables will therefore only be needed when the access network capabilities go well beyond 1 Gbps.
Recently, telecom vendors have researched more intermediate solutions, such as G.fast, which brings fiber to the distribution point (located between the cabinet and the building) [3.10].

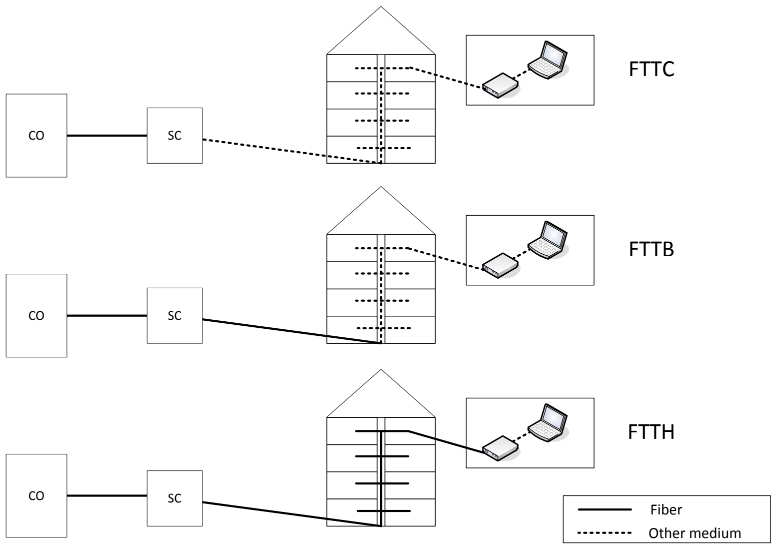

Figure 3-5: Overview of different flavors of fiber-based access networks

As this dissertation focuses on evaluating the business case for FTTH, we will focus on the different topologies and architectures of this flavor only, although FTTC and FTTB can be treated similarly.

3.2 Different responsibilities within one network

The functioning of a network, and thus the interaction between its nodes, is often abstracted in a layered model, in which each layer uses the functionalities offered by the lower layer. There are two commonly used methods for representing the layered structure of the Internet: Open Systems Interconnection (OSI) [3.11] and the Transmission Control Protocol/Internet Protocol (TCP/IP) model [3.12], but we will use here a hybrid model: the protocol stack [3.13] (Figure 3-6).
The application layer controls the services and applications the end consumers directly use. This layer is responsible for exchanging messages between applications, running on different end systems. The second layer, the transport layer, transports data segments along a path that is set up between two end-users, thereby guaranteeing delivery and control against errors. The most well-known protocol on the transport layer is TCP. The next layer is the network layer, which operates the IP protocol. This layer ensures end-to-end connectivity and transfers datagrams from sources to destinations. Transfers from one network entity to a neighboring entity are the responsibility of the link layer, while the physical layer transfers raw bits.

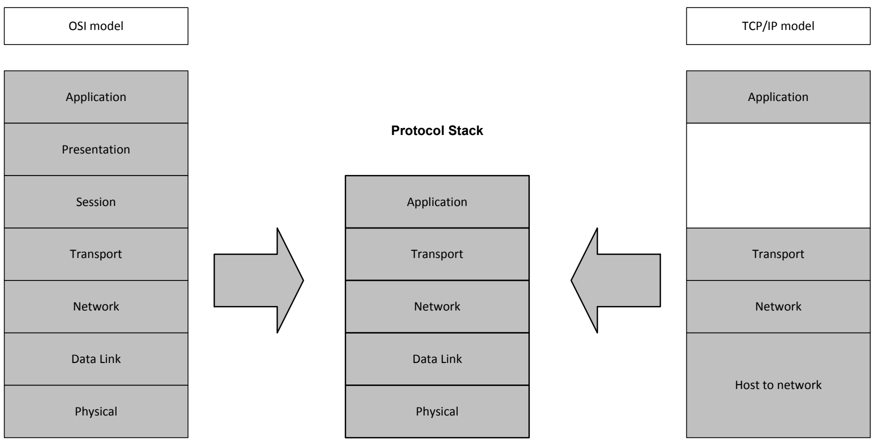

Figure 3-6: Different representations of the layered character of telecommunications networks (based on [3.14])

In chapter 2, it became clear that the deployment of FTTH is frequently postponed by incumbents, and showed that multiple, different entities are claiming their part in the FTTH rollout. As not all entities take up all levels of responsibility, the business case evaluation for FTTH should be split up, evaluating the strategic decisions for different levels of responsibility separately. In general, three generic roles can be defined on a business level (Figure 3-7).

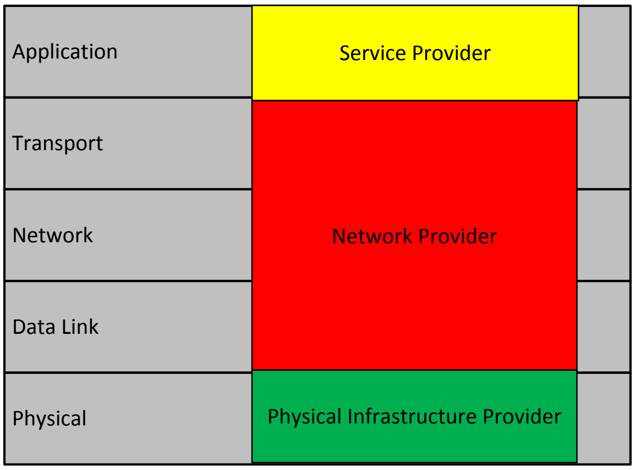

Figure 3-7: Business roles mapped on network layers in the access network

The **Physical Infrastructure Provider (PIP)** is responsible for the physical layer: obtaining Right of Way (RoW, the right to open up the streets) and performing the digging works itself, installing ducts and fibers or blowing the fibers afterwards. The PIP can also take care of other passive infrastructure, such as the housing of the Central Office (CO), installation of empty racks, provisioning of man- and handholes and so on.

The **Network Provider (NP)** deploys and operates all the active equipment necessary to provide an end-to-end connectivity between the customers and the CO. They install specific equipment at the CO and at the customer's premises and are responsible for the other network equipment (e.g. switches) in between.

When an end-to-end connectivity is present, the **Service Provider (SP)** can use the active network to offer services and applications. His responsibility is to install the service-specific equipment (e.g. a set-up box for digital television) and to send the right content and applications to its subscribers.

This allocation of network layers to conceptual roles was based on two parameters: the distinction between active and passive on the one hand, and the network dependency on the other. The PIP only deploys passive infrastructure, thus only taking up the physical layer. All network-specific, active equipment in deployed and operated by the NP, hence the choice for data link, network and transport layer. The SP, finally, is agnostic about the underlying network topology and technology, but only considers the end points, hence the choice of only allocating the application layer.

The following paragraphs of this section will describe the different topologies and architectures for FTTH for the PIP and the NP, respectively. As mentioned in the introduction of this chapter, the analysis for the SP falls outside the scope of this research and will therefore not be taken into account.

3.2.1 Physical Infrastructure Provider

The PIP is responsible for the deployment of the passive infrastructure, and is hence only interested in the layout – or topology – of the network, i.e. the structure in which the trenches are dug and the cables are laid. In general, only two topologies exist within the tree-based deployment of an access network: a Point-to-Point (P2P) and a Point-to-Multipoint (P2MP) network (Figure 3-8).

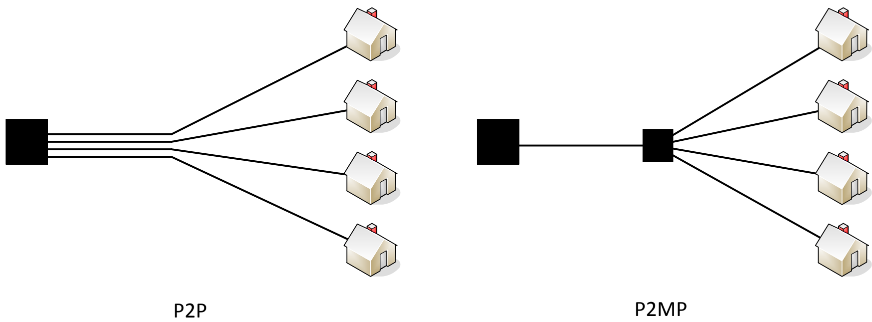

Figure 3-8: Graphical representation of the P2P and P2MP topology

In the P2P topology, a dedicated fiber connects each end user (household or business) to the central office, while a P2MP scenario connects each user with an individual fiber to a flexibility point (street cabinet), after which the different signals are aggregated on one fiber to the central office. The P2P topology has the highest fiber count (number of fibers equals the number of end users), and hence a higher deployment cost, but offers on the other hand a full fiber's capacity to each end user, whereas this capacity is split amongst multiple users in the P2MP topology.

3.2.2 Network Provider

The NP is responsible for providing end-to-end connectivity, and therefore needs to install equipment at the network's side (central office), in the field (at the flexibility points, or also referred to as (street) cabinets, aggregation points or remote nodes) and at the customer's premises. Independent of what technology is used in the field (e.g. TDM or WDM aggregation, see further), the line should be terminated at both endpoints, using an Optical Line Terminal (OLT) at the network's side and an Optical Network Unit (ONU) at the user's side. An OLT performs conversion between the incoming signals received from the service provider's equipment to the signals used in the optical network and coordinates the multiplexing between the ONUs. An ONU performs conversion between the incoming optical signal from an optical network and the in-house cabling at the customer's premises. An Optical Network Terminal (ONT) is a special case of an ONU that serves a single subscriber.

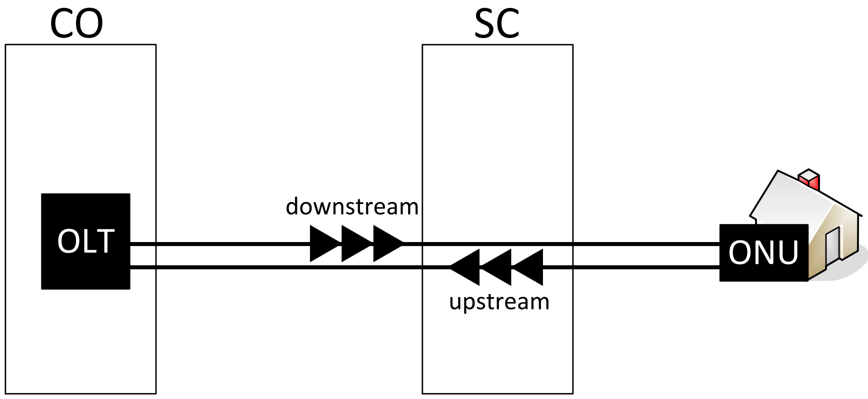

Figure 3-9: Downstream and upstream directions of traffic in the access network

Because the traffic is bidirectional, both OLT and ONU consist of a transmitter (laser diode) and receiver (photo diode). The traffic that flows from the OLT to the ONU typically takes up the largest part of the traffic and is referred to as downstream. The other direction – from ONU to OLT – carries the upstream traffic (Figure 3-9).

Applications that demand high data rates are mostly video-based. Broadcast High Definition (HD) television requires 8-15 Mbps downstream, and new 4K and 8K video with or without 3D will require 100-300 Mbps downstream, although 8K video is not commercially available yet for residential users. High upstream traffic consuming applications are video conferencing and uploading of data in e.g. the cloud.

To transmit both downstream and upstream traffic in between OLTs and ONUs, a multitude of technologies can be used. In general, a distinction is made between passive optical networks (PON) and active optical networks (AON) [3.15]. The main difference between these two types is the presence of active equipment in the outside plant (meaning between the central office and the customer's premises): AON relies on active equipment in the flexibility point(s), while in PONs, only passive components, such as splitters or arrayed waveguide gratings (AWGs, see further), are needed there. As such, there is no need to provide energy supply to the flexibility point(s) in a PON, thereby avoiding the extra costs of powering and maintaining active equipment in the field. Note that we mention here both single and multiple flexibility points, as the signal can be aggregated at one or multiple stages.

3.2.2.a Passive Optical Networks

When using a PON, only passive components are used in the field to aggregate the signal of multiple end users. The main advantages of these passive components are that they don't require electrical energy or regular maintenance. Multiple types of aggregation possibilities exist, of which two will be discussed here: Time Division Multiplexing (TDM), which is the most commonly used in operational deployments, and Wavelength Division Multiplexing (WDM), which is widely used in core networks and is slowly finding its way into access as well.
TDM-PON (Figure 3-10a) allocates different time slots to the end users, which the latter can use to send and receive their data packets. The allocation of time slots happens in the central office and requires precise synchronization of the packet transmission instants of the ONUs. The power splitter at the flexibility point is passive, it only aggregates the signals coming from the different ONUs (upload traffic) and sends the downstream traffic originating from the OLT side to all ONUs. The ONUs decide which data to receive based on the same allocated time slots. The OLT is shared by multiple ONUs (and hence end users), which reduces the available capacity per end user. Typical power splitting ratios are 1:16, 1:32, 1:64 or 1:128 as a practical upper bound in today's deployments.
GPON (Gigabit PON) and EPON (Ethernet PON) are the most commonly used TDM-PONs at the moment. GPON is considered the preferred technology of most incumbent operators deploying FTTH (e.g. Portugal Telecom, see also the cases in chapter 4), while EPON is mainly used by Asian operators (e.g. as China Telecom [3.16]). Typical downstream data rates of 1Gbps (EPON) and 2.5Gbps (GPON) can be achieved on the feeder fiber (and are shared amongst all users aggregated on a splitter). By increasing the processing speed and upgrading the transceivers, the capacity can be increased to 10/2.5Gbps (down/up) in XG-PON and even to 40/10Gbps (down/up) in future technologies such as XLG-PON.

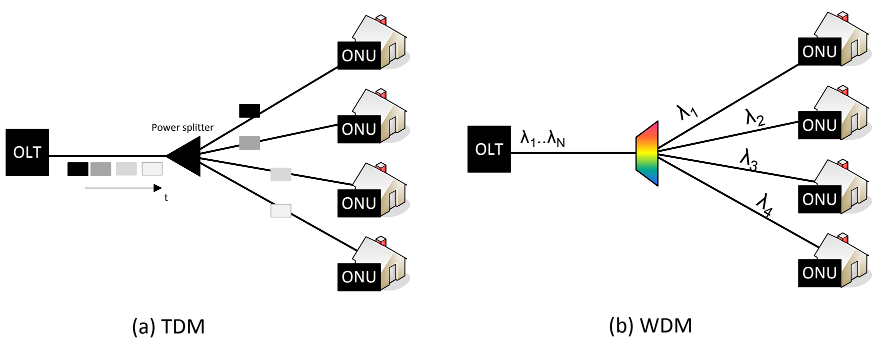

Figure 3-10: Schematical representation of the aggregation techniques in PONs

The second aggregation technique, WDM, makes use of an AWG to demultiplex the feeder fiber signal (in between the OLT and the flexibility point) in different

wavelengths (amount depending on the wavelength spacing, varying between 16 to 160, with 32 as the most commonly used in today's access networks [3.17]) (Figure 3-10b). Each customer then receives one or multiple dedicated wavelengths (if one output port of the AWG is connected to one user, each user will receive its own dedicated wavelength). In upstream direction, the different ONU wavelengths are multiplexed by the same AWG. The main advantage of the WDM technique is that it generates independent channels, thereby increasing the security of the communication. The disadvantage is that each ONU needs a wavelength-specific laser diode, which can transmit the signal to the AWG at the assigned wavelength, but is very costly too (great loss of economies of scale in production and more complicated maintenance). As a solution, colorless (non-wavelength specific) ONUs may be used, to which a tunable (adjustable to the right wavelength) in-field multiplexer to cut out the right part of the spectrum must be added. This of course reduces the cost (economies of scale), but also decreases the available optical power, which limits the reach of the system.
As mentioned above, because of cost considerations, WDM systems these days are rarely used in access networks (e.g. South Korea, UNET in the Netherlands), but already widely deployed in core and metro networks. Future implementations could furthermore combine both TDM and WDM concepts in hybrid architectures, which use the advantages of both. Whereas WDM increases the capacity by allowing to transmit data signals using multiple wavelengths over one single fiber, it does not optimize the network utilization. As the usage of the Internet capacity follows the Pareto principle (80% of traffic is generated by 20% of the users), it makes sense to combine the parallel wavelength capacity with the efficient utilization of this capacity that TDM offers. This TWDM-PON architecture combines both AWGs and power splitters (Figure 3-11) and is the primary solution for the NG-PON2 range, which is currently being standardized [3.18].

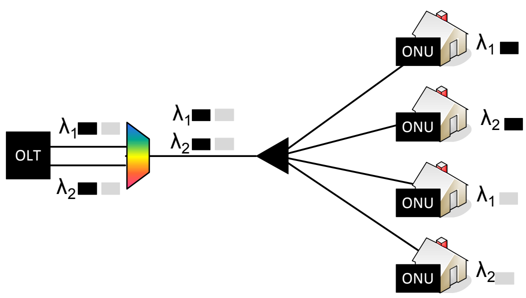

Figure 3-11: Schematical representation of combining TDM and WDM aggregation techniques into TDWM PON

3.2.2.b Active Optical Networks

AONs use active equipment to direct the signals to the right end users. The difference can be made between an active star architecture (on top of a P2MP passive infrastructure) and a home run architecture (on top of a P2P topology) (Figure 3-12).

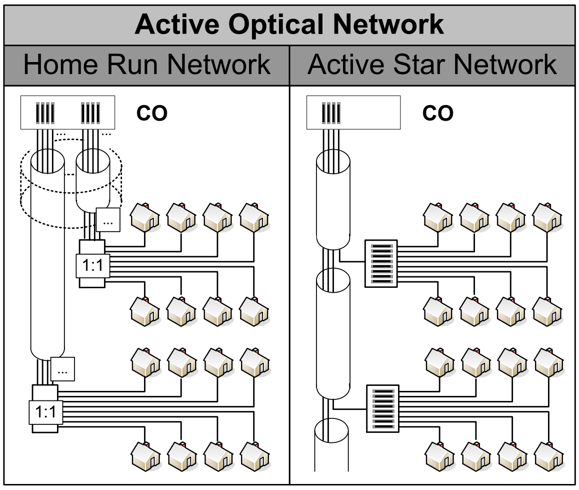

Figure 3-12: AON architectures: Home Run network and Active Star network

In an active star architecture, a shared feeder fiber sends all aggregated traffic to a flexibility point, in which active equipment (e.g. an Ethernet switch) then transmits the right data to the intended end user. In a home run architecture, all the active equipment is located in the central office, from which a dedicated fiber connects to each house. As there is no aggregation of signals in the field, there is in theory no need for flexibility points, although they are frequently installed for ease of deployment and maintenance.
To conclude this section, Table 3-1 gives an overview of the considered architectures.

Table 3-1: Overview of parameters of considered architectures

Architecture	Downstream speed	Upstream speed
Ethernet P2P	1 Gbps	1 Gbps
EPON	1 Gbps	1 Gbps
GPON	2.5 Gbps	1.25 Gbps
XG-PON	10 Gbps	2.5 Gbps
XLG-PON	40 Gbps	10 Gbps
WDM PON	1 Gbps (per λ)	1 Gbps (per λ)
TWDM PON	40 Gbps	10 Gbps

3.3 Opening the network on different layers

While the previous section focused on the specific responsibilities of PIP and NP separately, this section will describe the extra features that are necessary if the different business roles are executed by different entities. Parts of the network will as such be shared by entities operating on a higher layer, and the network can be referred to as "open". The part of the network where multiple providers (NPs or SPs) are brought together on the same device (e.g. Optical Distribution Frame or ODF, splitter, etc.) is referred to as the provisioning interface, what is offered to the higher layer is called the provisioned element.

Three types of opening the network can be identified: at the fiber, wavelength and bitstream layer.

Opening at the fiber layer means that different parallel fibers are available in the same cable / trench infrastructure, so that each user is connected by a dedicated fiber (feeder and/or distribution fiber, depending on the topology, see further), and as such can choose NPs. The provisioned element is the fiber. The network is opened at the PIP level. This model allows NP competition. The main disadvantage of opening at the fiber layer is the higher fiber count.

Opening at the wavelength layer means that the end users can select NPs based on different available wavelengths. The provisioned element is the wavelength and the model is opened on top of the PIP level. Note that the mapping between customers and the wavelengths required to reach them is dependent on the architectural design. In order to allow a user to connect to multiple NPs simultaneously, multiple transceivers are required. Those form the provisioning interface. This model allows NP competition.

Opening at the bitstream level means that there is a provisioned element on the network layer 2 or layer 3. Here, the network is opened at the NP level, so that SP competition is allowed. This way of opening the network has lower complexity (no problems arise from the co-existence of multiple operators' equipment), albeit that it only allows competition amongst SPs, not amongst NPs.

For each of the three types, a qualitative description will be given below.

3.3.1 Opening on fiber layer

Opening of the fiber layer allows multiple NPs on top of one PIP. Hereby, the PIP is responsible for the passive infrastructure, meaning the trenches, ducts, fibers and passive equipment like power splitters in the street cabinets.

As the type of opening on fiber layer is influenced by the topology that is being used in an FTTH network, this section will make a distinction between P2P and P2MP topologies, where the latter only considers time-division multiplexed (TDM) architectures (e.g. GPON, which is the most used TDM flavor). Theoretically, there is no upper limit to the number of competing NPs in fiber open access but the assumption was made that never more than five network providers will be active in the same geographical area at the same point in time. This follows the study of existing fiber deployments (see chapter 4).

3.3.1.a Point-to-Point access network

Within a P2P network, a dedicated fiber runs from the central office to the end user. All the active equipment and supporting equipment is stored within the central office. The PIP will provide a general layout to put all the necessary equipment. This consists of the needed floor space, an Optical Distribution Frame (ODF) to terminate the incoming fibers, cooling equipment and system racks. On the other hand, the NP will provide all the active equipment. The NP will place different OLTs to ensure the communication to the end user, alongside an Ethernet Aggregation Switch (EAS) at the Point of Interconnect (POI), to which the SP can connect its router (see further). At the customer's side, the NP installs an ONU, to which the SP's Residential Gateway (RGW – which is service-specific) can be connected (the case for bitstream layer 2, see further).
Figure 3-13 shows the impact of opening up the network. The difference between the single and multi-NP network when it comes to a P2P network, only lies within the central office. Here an extra patch panel has to be installed to connect the different NPs to the different dedicated fibers. This cross-connect allows for connecting the right NP to the right end user as it will function as a cross-bridge between the fiber termination side of the PIP and the system side of the NP. The equipment of the NP should furthermore be installed in fully separated racks with access control mechanism in order to prevent physical tampering of other parties' equipment. At the end users' premises no extra equipment will be needed.

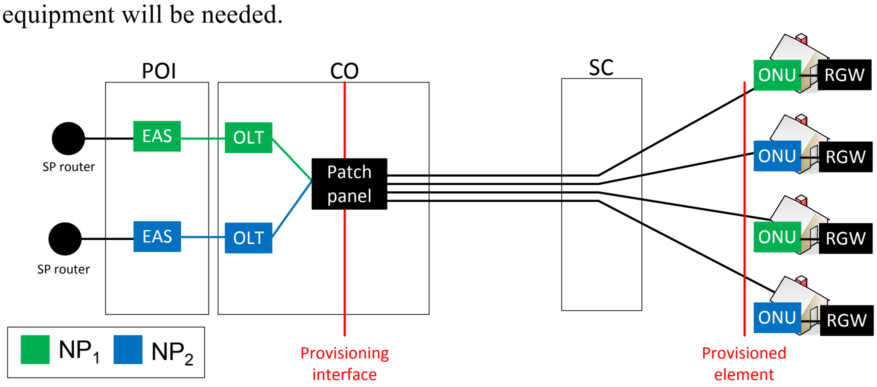

Figure 3-13: Opening on fiber layer for a P2P topology

3.3.1.b Point-to-Multipoint access network: GPON

The second topology for the access network is P2MP. In this network, there is only a dedicated fiber between the end users and the street cabinet. From the street cabinet onwards to the central office, there are only a limited number of feeder fibers, each of them corresponding to one single NP. Hence, the maximum number of NPs per geographical area is limited to the number of feeder fibers that serve the street cabinets; in realistic scenarios this maximum is around five. As an example, in the case of a fiber network with two feeder fibers, this means that each end user within a geographical area can only choose between two NPs.

As a reference, we will use the GPON technology, which is an example of a TDM-PON, on top of the P2MP topology. In a TDM-PON, power splitters located at the street cabinets will distribute the downstream and aggregate the upstream signals. Although we focus on GPON, a similar reasoning can be followed for implementing an open network on fiber layer on other TDM-PON technologies (e.g. EPON, XGPON [3.21]).

The effect of opening the network on fiber layer for a P2MP topology becomes clear from inspecting Figure 3-14. The main impact of open access is located at the street cabinets (flexibility points). Alongside each NP specific feeder fiber a NP-specific power splitter will have to be installed in the street cabinets. In case an end user wants to connect to a certain NP or wants to switch between different NPs, next to a change on ONU and OLT side, the dedicated fiber from the end users premises to the street cabinet will need to be (re)connected to the right NP's splitter. Note that, although the figure indicates only one stage of splitters, it is possible to have multiple stages as well (e.g. a 1:32 split divided in a cascaded 1:4 and 1:8 split). The splitters then need to be duplicated for the available NPs at all stages.

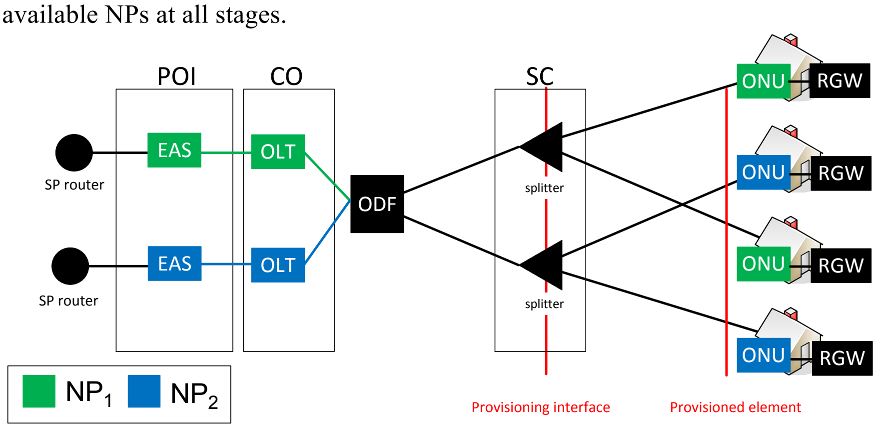

Figure 3-14: Opening on fiber layer for a P2MP topology

In case there is an imposed maximum of NPs, a different approach may be applied. In this case, the PIP can provide multiple distribution fibers per premise (one for each possible NP), either voluntarily or regulated by the government, which allows the switching between different NPs to occur at the end users' premises. The different distribution fibers will already be connected to the different NP specific splitters and a fiber switch will be installed at the end users' premises. The connection to an NP or the switching to a different NP can therefore be made by switching to a different fiber in the switch. This model is applied in Switzerland and France, where the "building operator" (the PIP chosen by the building owner) is obliged to deploy multiple fibers to the building, for each alternative operator requesting them [3.19]-[3.20]. As this method is not applicable everywhere, it will not be evaluated further.

3.3.2 Opening at wavelength layer

Next to opening at fiber layer, another type of opening exists on the interface between the PIP and the NP. In wavelength open access, different wavelengths will be assigned to different NPs. When an end user connects to a specific NP, the equipment of the end user should be able to receive the NP specific wavelength(s). In case the wavelength spectrum allows for enough differentiation, the use of user-specific wavelengths can be achieved. However, this would require tunable ONUs at the end users' premises. Offering opening on wavelength layer allows providing a dedicated channel to each end user, thereby making it comparable to opening on fiber layer.

Wavelength open access is a fairly cheap and easy option (depending on technology), only requiring limited extra equipment to divide the wavelengths among the NPs on the central office side, and among the end-customers on the Customer Premises Equipment (CPE) side. The main disadvantage is that this way of open access is not technology-agnostic. Depending on the (T)WDM PON architecture and equipment used (e.g. split factor of AWG), different equipment should be installed, and should therefore also be replaced when switching to next-generation options.

3.3.2.a Feeder fiber based wavelength open access

The first possible architecture for wavelength open access is feeder fiber based wavelength open access (Figure 3-15) [3.22]. Within this architecture, each NP has a separate and dedicated feeder fiber to transport the signals to the AWG. Similar to the opening on fiber layer on top of the P2MP topology, the number of feeder fibers determines the maximum number of NPs. However, the signals of different NPs might be combined into one feeder fiber, but this leads to additional complexity in terms of complexity and cost through the sharing of a particular spectrum of wavelengths. The AWG in the street cabinet will then split up the signals by sending the signal with the right wavelength into the dedicated fiber to the end users' premises.

Opening at wavelength layer through feeder fiber will mostly have an impact on the equipment. The OLTs in the CO must be able to transmit signals at different wavelengths. Furthermore, an AWG must be installed to combine the signals of different wavelengths into one feeder fiber. Within the street cabinet an M:N AWG is required, meaning that the AWG is able to take the incoming signals from M feeder fibers and split them towards the N outgoing fibers. Finally, at the end users premises, a tunable ONU will be needed in order to select the right wavelength of the selected NP.

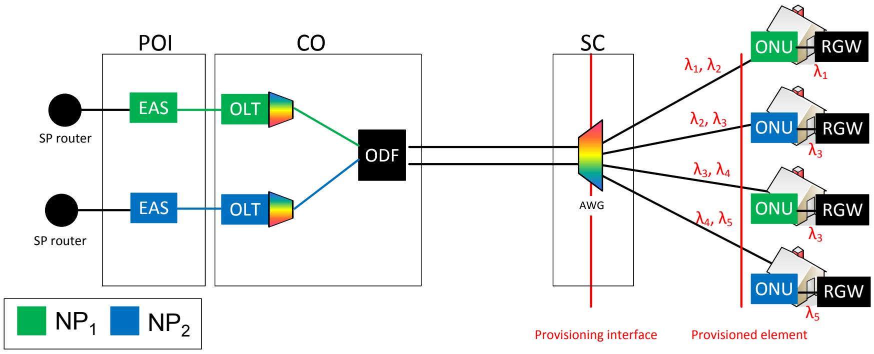

Figure 3-15: Opening on wavelength layer, feeder fiber based access

3.3.2.b Wavelength open access based on manual patching

The second type of opening at wavelength layer considers manual patching (Figure 3-16) [3.22]. Within this architecture, open access is realized by the installation of a patch panel. Also, this architecture will only have N wavelengths available where N equals the number of end users within a geographical area. When an end user wants to connect to a certain NP, the output port of the central AWG in the CO will be connected through the patch panel onto the corresponding NP-specific OLT.

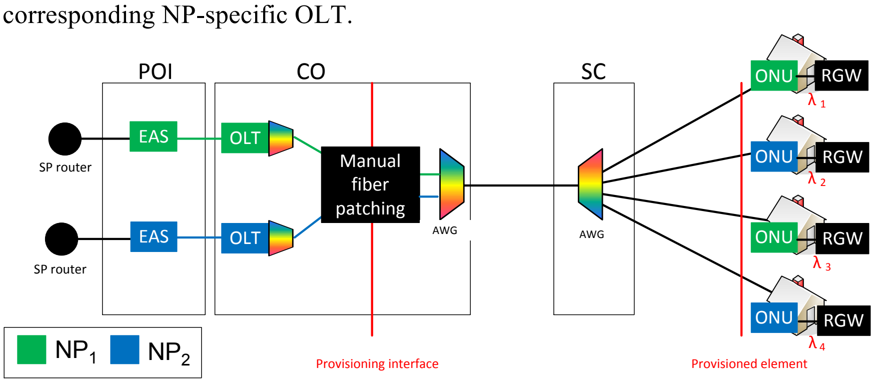

Figure 3-16: Opening on wavelength layer, manual patching

Offering wavelength open access through manual patching will impact both the equipment to be installed and the processes to be executed. Within the CO, the OLTs of the different NPs must be able to transmit signals at the N different wavelengths. This means that every OLT must be able to transmit as many different signals as there are end users within the geographical area. Furthermore, an additional AWG is needed to combine N different signals (one for each end user) onto one feeder fiber. Between this AWG and the different OLTs, a manual fiber patch panel will be installed. This patching panel is necessary so that a fiber connection can be made between the output port of the AWG, containing the right end user specific wavelength, and the OLT of the corresponding NP. Within the street cabinets, the power splitter must be replaced by an AWG. This AWG will split the signals for the incoming feeder fiber onto the right fiber towards the end user. Finally, the ONU at the end user's premises must be able to receive the specific wavelength. This can be arranged through the use of fixed receivers.

3.3.2.c TWDM-based wavelength open access

The third option for wavelength open access is the use of a TWDM architecture (see section 3.2.2.a), in which each network provider is allocated one (or multiple) dedicated wavelength. On each wavelength, the network operator itself can deploy a TDM-based architecture, which allows to differentiate between end users (Figure 3-17). This wavelength open access option seems to be the most promising, as it does not put direct requirements on the number of feeder fibers and it does not require manual patching.
Though, similar to the two previous options, the OLTs should be able to transmit only at specific wavelengths, ONUs should be tunable, and there is a need for an installation of an extra AWG in the CO. However, contrary to offering wavelength open access using feeder fibers or manual patching, these equipment requirements are not only needed for offering open access, they are part of the TWDM architecture. An important drawback of this TWDM option, however, is that the different NPs are not isolated, i.e. all signals are transmitted to all ONUs. A rogue ONU (misbehaving ONU – deliberate or not) could effect the service of another NP.

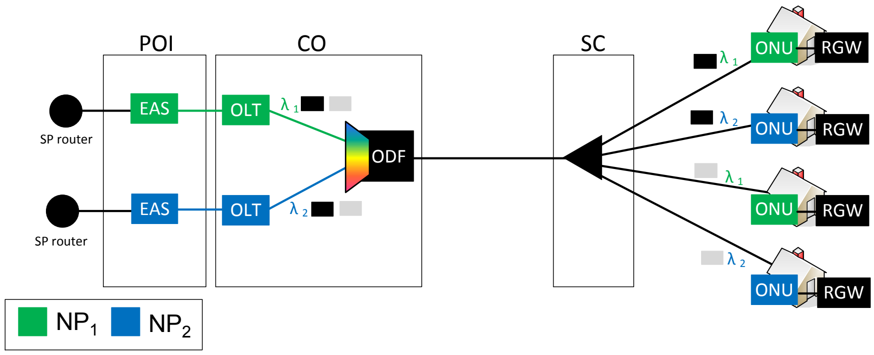

Figure 3-17: Opening on wavelength layer, TWDM-based

Although being described here, opening on wavelength layer is not realistic yet, as WDM PONs are only rarely used in current operational deployments, and as all options described above have significant downsides (the need for manual patching, the extra feeder fibers or the lack of NP isolation). We will therefore not elaborate on opening on wavelength layer in the quantitative cost analysis of chapter 7.

3.3.3 Opening at bitstream layer

The third possibility at which the network can be opened is the bitstream layer. Two types exist and the classification of the different types depends on the specific layer of activity: on layer 2 (Ethernet) and layer 3 (IP). In this dissertation, we will only evaluate bitstream on layer 2. Bitstream on layer 3 can be handled similarly, as both come down to providing a secure bandwidth pipe. The main advantage of opening at bitstream layer is the low additional cost in comparison to opening on fiber or wavelength layer. On the other hand, the competing service providers only receive access to a dedicated bandwidth pipe, and have as such less choice in terms of functionality or control (whereas network providers have greater flexibility by installing their own equipment).
Within Ethernet bitstream open access, the network is opened at layer 2, meaning that one NP gives access to multiple service providers on layer 2. This type of open access can be offered over any topology or architecture; it is technology-agnostic in that sense that it only considers the endpoints. To gain access on bitstream layer, an interface needs to be provided at both the user side and the network side (mostly at the POI or local exchange), see Figure 3-18.

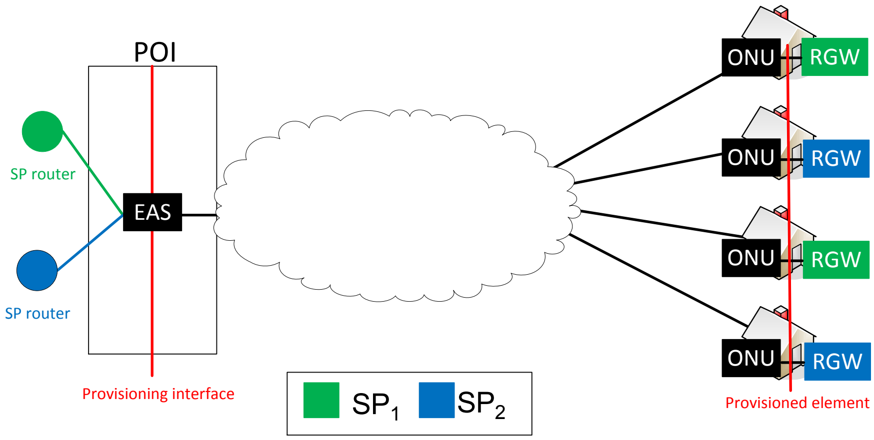

Figure 3-18: Opening at bitstream layer 2

At the end user's side, the SP should install a residential gateway (RGW) and connect it to the ONU, which is installed by the chosen NP. The installation of the RGW does not necessarily require a physical visit from a technician. If easy and well-documented, the connection and installation could be done by the end user itself, which will reduce costs significantly.

There are basically two options for the connection RGW-ONU [3.23]. In the first option, the network provider will place the ONU while the service provider will place the RGW. In the second option, the equipment at the end users' premises will consist of one box and this single piece of equipment will act as both the physical line termination and the residential gateway. This one box will be provided, configured and managed by the SP. Advantages of this one box solution are the fact that it will be cheaper, will consume less power and less space, and may therefore be seen as more suitable by customers. A disadvantage of this implementation is the fact that interoperability has to be established. It furthermore complicates the provisioning of services from multiple SPs. The first option gives a clearer separation between the different functionalities of ONU and RGW, and will therefore be considered first. However, the cost savings for using a standardized RGW will be calculated as well (see section 7.3).

At the exchange side, access needs to be provided to both the access and the backhaul network. The connection of an SP to the access network is a one-time procedure similar to the connection of a new NP to a geographical area. The process is referred to as "establishing the handover point" which connects the SP equipment (frequently a layer 3 router) to the EAS of the NP, the latter being located at the POI. The establishing of the handover point occurs according to the MEF (Metro Ethernet Forum) External Network-Network Interface (E-NNI) standard and allows for a 1 Gbps or 10 Gbps interface carrying multiplexed traffic streams. The E-NNI is considered to be the physical and logical demarcation point for the offered services and is implemented at the EAS. The SP must ensure that there is enough backhaul capacity from the L3 router to the handover point. On the end user side the User Network Interface (UNI) will be the demarcation point. An Operator Virtual Circuit (OVC) works as the association between a UNI and an E-NNI. Furthermore, a certain amount of dedicated bandwidth can be assigned per OVC and priority can be given to certain types of contents. The amount of content that can be given priority depends on the amount of Committed Information Rate (CIR - the minimum bandwidth that is available to the end user's OVC at all times) purchased by the SP.

Alongside the dedicated bandwidth a difference can be made between a unicast and a multicast OVC. A unicast OVC refers to a single link between provider and end user. Here, all end users have a unique OVC and the delivered service is user specific. Examples include Voice over IP (VoIP) and most broadband Internet services, as well as Video on demand (VOD), where each end user can request a distinct service. A multicast OVC on the other hand, consists of a single root or parent transmitting the same signal to multiple children nodes. As a result, all end users using a multicast OVC receive the same service, e.g. IPTV.

As multicast transmits content simultaneously towards multiple end users, the data stream should be carried as far into the network as possible before replication, which can lead to significant bandwidth savings [3.24].

Next to the generation of the different OVC, the SP must make sure that there is enough capacity from the EAS to the different OLTs in the CO. This connectivity is ensured through the use of a connectivity virtual circuit (CVC) and this virtual circuit aggregates the capacity of different OVC from the EAS to the designated OLT.

When looking to a geographical area, the number of COs will be much larger than the number of POIs. By connecting at one of the POIs, an SP can as such provide services to an entire region, which is rather cost-efficient. As such, SPs can connect on a coverage area by coverage area basis, where each coverage area roughly corresponds to the households served by one POI.

Connecting a new end user to an established SP is rather easy, and does not involve any manual labor. It basically comes down to a business-to-business interaction and only involves a software configuration: the connection of the right EAS port, which is a virtual port, to the right SP. As such, the cost for connecting a new end user, as well as the cost for churn (customers changing provider, see section 7.3.3) will be relatively low. Changing SPs thus involves the installation of a new RGW and a software configuration of the EAS-SP router link. Furthermore, the relative burden for the user is relatively low, no "staying at home for technicians to show up" is required, and outage can be as short as 1 hour.

3.4 Conclusions

Following the steady increase in consumed bandwidth in all parts of the network, this chapter provided an overview of the possibilities fiber brings to tackle this increase. After having given an overview of the different parts of the network, the focus shifted to fiber-based access networks, in which the different types were listed (FTTC, FTTB, FTTH). As business trends indicate that not all responsibilities within an FTTH deployment will be taken up by a single entity, they were split up based on the protocol stack, in three conceptual layers: the physical infrastructure provider (PIP), the network provider (NP) and the service provider (SP). For both PIP and NP, an overview of the different technical deployment implementations was given, where at the PIP level, the distinction was made between Point-to-Point and Point-to-Multipoint, whereas for the NP, active optical networks were compared to passive optical networks. The SP was not taken into account, since its activities are agnostic of the network deployed (only interested in the endpoints).

Different entities taking up different roles not only have implications for the separate entities, it also requires additional costs in terms of equipment, processes and transactions. Although this cost of collaboration will be analyzed in more detail in chapter 7, this chapter already listed the different possibilities of opening up the network, thereby sharing the underlying infrastructure. In between the PIP and the NP, the network can be opened at fiber or wavelength layer, while opening the network at bitstream layer allows collaboration in between the NP and multiple SPs. At fiber layer, each user is served by a dedicated fiber in case of a P2P topology, whereas each NP receives a dedicated fiber in a P2MP scenario. Two types of opening at wavelength layer were discussed: based on feeder fiber access and based on manual patching. However, since WDM is not yet common in access networks, this opening option will not be taken into account in the further analysis. Finally, opening on bitstream layer provides opportunities for collaboration between the NP and the SP, where the SP gets a dedicated Operator Virtual Circuit, which can be used to serve its end customers.

This chapter served as the necessary technological background for understanding the evolutions and possibilities in the FTTH domain, and will be used in the analysis sections of the following chapters.

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4

The impact of collaboration, competition and regulation on the FTTH market

"People have a hard time accepting free-market economics
for the same reason they have a hard time accepting evolution:
it is counterintuitive. Life looks intelligently designed,
so our natural inclination is to infer
that there must be an intelligent designer--a God.
Similarly, the economy looks designed, so our natural inclination is
to infer that we need a designer--a government.
In fact, emergence and complexity theory explains how the principles of
self-organization and emergence cause complex systems
to arise from simple systems without a top-down designer."
- Michael Shermer

Where the previous chapter focused on the technology pillar of the TPM framework introduced in section 2.5, this chapter will describe the policy and market pillars of that framework, as they serve as important conditions for setting up techno-economic models. The goal of this part of the research is to investigate, on a case-to-case basis, the links between the different policy and market characteristics of FTTH deployment, so that they can serve as inputs and/or boundary conditions to the quantitative evaluations performed in the following chapters. First, the identified parameters and their theoretic foundations and background will be described, while they are applied to selected cases in a second step. The parameters aim at describing the surrounding conditions that impact the FTTH business case: the region type and scale of deployment, the policy conditions, the initiator and key drivers, the financing structure, the applied business model, and finally the existing competition. The case studies were chosen based on their variation in the identified parameters: a public dark fiber infrastructure deployment in Stockholm, Sweden; the national Ultra-Fast Broadband initiative in New Zealand; Google Fiber's private investment supported by demand aggregation in Kansas City, USA; a Public-Private Partnership under the Market Economy Investor's Principle in Amsterdam, the Netherlands; and finally the incumbent deploying FTTH driven by the competitive threat of the cable operator in Portugal. By including more cases in a third step, this chapter ends with general conclusions about the impact of the market and policy pillar in FTTH deployment. The results described in this chapter are based on a number of publications [4.1]-[4.5], each focusing on different case studies.

4.1 Defining the parameters for comparison

Within the evolution of telecommunications access networks, the deployment of FTTH is a worldwide trend. However, given the huge investment needed to deploy new networks, traditional incumbent operators in Europe generally postpone the large-scale rollouts, leading to a broad range of smaller-scale initiatives, steered by different economic models and technological requirements. The different cases furthermore find themselves on different stages of development with one case already fully operational for several years and another being in a very early phase of construction. Getting to conclusions about the linkage between these different types of policy- and market-related parameters, seems therefore a right step in analyzing the overall business case for FTTH.

4.1.1 Region and scale of deployment

A first parameter denotes the region and scale of deployment. In order to link the cases with the quantitative results from the following chapters, three generic area types will be defined, based on number of households, surface and therefore also cable distance. The defining parameters per area type are based on average numbers of buildings per square km and average number of households per Multi-Dwelling Unit (MDU). They were discussed amongst members of the OASE project [4.6], so that they would represent generic areas in Europe. They are summarized in Table 4-1.

Table 4-1: Parameters for the area types (note HH = households)

Area type	Number of HH	Surface (km^2)	Household density (HH/km^2)	Total trenching length (km)	Trenching length per HH (m)
Dense urban (DU)	15,600	5	3,120	12,950	6.75
Urban (UR)	8,640	24	360	14,040	19.00
Rural (RU)	3,060	57	54	7,840	16.50

4.1.2 Policy conditions and constraints

Although the mindset of all regulatory authorities is set in the same direction, namely towards offering broadband to all, the variety of policy measures and government-imposed laws, make it hard to draw general conclusions. The European Union, for instance, aims at achieving one single telecommunication's market across Europe, which however needs to be implemented by many different regulatory institutions on regional, national and European level, all having their own rules. This section will therefore focus on the regulatory setting in Europe, and compare it to other best practices abroad.

4.1.2.a Regulation in Europe

In general, European telecommunication law consists of competition law and telecom-specific regulation, and aims at reaching sufficient broadband quality at a fair price. These goals are, amongst others, listed in the Digital Agenda [4.7]. This section will first give, as background information, an overview of the different ways to implement an obligation or guideline, to continue with the different measures on these levels for telecom operators in Europe, as they set boundary conditions to the FTTH business case.

EU Instruments to implement legislation and objectives

There are various instruments used by the European Commission (EC) to implement its objectives and goals and they have diverse degrees of enforceability vis-à-vis the Member States' legislative bodies (i.e. obligation to follow a given instrument); thus, such instruments (treaties, directives, decisions, recommendations and regulations) may have a direct or indirect effect on the laws of the EU's Member States.

- Any action undertaken by the EU is founded on *Treaties* approved by the EU Member States. To achieve the target goals, legislative acts such as regulations, decisions, directives and recommendations are used.
- *Regulations* are binding legislative acts that have to be implemented in their entirety across all EU Member States. For example, the EU has capped the maximum amount telecoms companies can charge a user for

the roaming costs of their cellular telephone (EC Regulation No 544/2009) [4.8].

- *Directives* are, just as regulations, binding legal instruments. The main difference with regulation is that the transposition from European to national level can take into account national circumstances. In the Framework Directive (Directive 2002/21/EC) for instance, the EC set out a roadmap in establishing a harmonized regulatory framework for electronic communications networks and services [4.9].
- *Decisions* are binding legislative acts that are directly applicable to whom it is addressed (e.g. The European Commission's March 2004 Microsoft Decision, [4.10]).
- *Recommendations* are not binding. Instead they express the known views of an institution. In its recommendation of 30th of March 2012 (Action for Stability, Growth and Jobs), the EC stressed the potential of the ICT industry in a job-rich recovery for the EU [4.11].

Current Regulation

The current rules which govern the telecommunication sector in the European Union (EU) were set in 2002 and revised by the European Parliament and the Council of the European Union. This revision entered into force on 18 December 2009 (after two years of discussions), and has been implemented into Member State legislation since May 2011 [4.12].

Currently, broadband is regulated in EU Member States by national telecoms regulators in order to avoid distortions of competition. However, a new Recommendation was put forward in October 2014, aiming at reducing ex ante sector-specific regulation progressively [4.13]. This Recommendation proposes two approaches for regulating telecom markets. In case there is a separate retail market, this market should be assessed on competitiveness using a forward-looking approach. If concluded that this retail market is competitive, there is no need to regulate the corresponding wholesale market.

In case of vertically linked markets, the so-called three criteria test should be applied on the wholesale market. This test consists of three cumulative conditions that should be filled before one can regulate:

1. The presence of high and non-transitory barriers to entry. Barriers can be structural (cost and demand conditions) or legal (legislative, administrative or other measures that have a direct effect on the conditions of entry and/or the positioning of operators in the relevant market).
2. The assessment that the market structure does not tend towards effective competition within a relevant time horizon, including both infrastructure-based and other competition. Effective competition as such can be expressed as evidence of positive dynamics, or a “limited -

but sufficient - number of undertakings having diverging cost structures and facing price-elastic market demand".

3. When competition law alone is insufficient to adequately address the identified market failure(s).

One important focus point of this new Recommendation, is that ex ante regulation should only applied on wholesale level, downstream markets should be competitive. Furthermore, ex ante regulation should never be applied on newly emerging markets, as the three criteria test is hard to apply and might hinder innovations.

This recently published Recommendation follows the same road as has been taken in the C(2013) 5761 Directive on consistent non-discrimination obligations and costing methodologies to promote competition and enhance the broadband investment environment [4.14]. This Directive has three main goals.

1. By applying a non-discriminatory obligation, the Directive wants to assure Equivalence of Inputs and as such a fair level playing field for all operators. Equivalence of Inputs refers to the wholesale operator using exactly the same downstream products, same price, same transactional processes, as he offers to other retail providers.
2. It aims at setting a predictable and stable regulated wholesale copper access prices by obliging the use of the BU LRIC+ (Bottom-up Long Run Incremental Cost Plus) approach. This approach calculates current costs based on forward-looking basis (based on new technologies, expected demand etc.) and estimates the current cost that a hypothetical operator would incur to build a modern and efficient NGA network.
3. Finally, the Directive details the non-imposition of regulated wholesale prices for NGA services: when Equivalence of Inputs is assured and competitive safeguards (sufficient uptake on competitors' offers) are in place, no price regulation is needed.

The third and final relevant document, the Broadband Guidelines [4.15], outlines the rules and conditions on how public funding could be provided to build broadband networks in line with the European Union State Aid rules (see next section). These Guidelines provide guidance for governments and public authorities on how to finance very high speed, NGA networks, as well as addressing the funding of traditional broadband networks (like ADSL, DOCSIS, Wi-Fi networks).
The main aim of the Guidelines is to facilitate a rapid deployment of NGAs in Europe by providing to all stakeholders (including local and regional authorities, as well as network operators) a clear, predictable and comprehensive framework for the public financing of such networks.

State Aid

In case a Member State Member supports the roll-out of broadband by way of an equity participation or capital injection into a company that is to carry out the project, it becomes necessary to assess whether this investment will be regarded by the EU as State Aid. In principle, State Aid can play a useful role in cases where the market does not provide sufficient broadband coverage.

In order for a measure to qualify as State Aid, the following cumulative conditions have to be met:

1. The measure has to be granted out of State resources;
2. it has to confer an economic advantage to undertakings;
3. the advantage has to be selective and distort or threaten to distort competition;
4. the measure has to affect intra-Community trade.

On the other hand, there are two scenarios in which public investment is not regarded as State Aid in accordance with the Case-law of the European Communities ("ECJ"):

- When the capital placed by the State - directly or indirectly- is at the disposal of an undertaking in circumstances which correspond to normal market conditions, it cannot be regarded as State Aid (Market Economy Investors Principle);
- When the Member State may consider that the provision of a broadband network should be regarded as a service of general economic interest ("SGEI") [4.15] as qualified by the Altmark[5] criteria, the State funding may fall outside the scope of State Aid.

In order for the EC to assess whether State Aid for NGA networks is allowed, black, white and grey area designations are used. Because this designation is mostly in the assessment of traditional broadband development, it requires a

[5] The four conditions to meet in accordance with the Altmark criteria, as defined in Article 86(2) of the Treaty of the European Community, are: (a) the beneficiary of a State funding mechanism for an SGEI must be formally entrusted with the provision and discharge of an SGEI, the obligations of which must be clearly defined; (b) the parameters for calculating the compensation must be established beforehand in an objective and transparent manner, to avoid it conferring an economic advantage which may favor the recipient undertaking over competing undertakings; (c) the compensation cannot exceed what is necessary to cover all or part of the costs incurred in the discharge of the SGEI, taking into account the relevant receipts and a reasonable profit for discharging those obligations; and (d) where the beneficiary is not chosen pursuant to a public procurement procedure, the level of compensation granted must be determined on the basis of an analysis of the costs which a typical undertaking, well run, would have incurred in discharging those obligations, taking into account the relevant receipts and a reasonable profit.

more refined definition [4.15] to take into account the specificities of the NGA networks, as explained below.

- The *white area* refers to an area where NGA networks do not at present exist and where they are not likely to be built in three years. It certainly includes an area where there is no basic broadband infrastructure. It also includes areas where only one basic broadband provider is present or there are several basic broadband providers. However, in the latter case, Member States must prove that the current services are not sufficient to satisfy the needs of citizens and business users and there are no less distortive means. Recent examples of rural areas (regarded as white since no broadband or NGA services were available) that have been deserved are Ireland and Slovenia, as per decisions no. N 607/2009 and N 172/2009 where the European Commission decided favorably for the granting of State-Aid.
- The *grey areas* are areas where only one NGA network is in place or is being deployed in the coming three years. In order to have such State Aid approved by the Commission, Member States must provide evidence that the current or planned NGA network is not sufficient to satisfy the needs of citizens and business users and there are no less distortive means. This was the case in Appingedam [4.16], where various broadband offers were already provided over two existing networks (KPN and cable), at prices similar to those of other regions in the Netherlands. The measure would distort competition due to its discriminatory impact on existing or future private networks; consequently, the construction of an additional network with state funding would address neither a market failure nor a cohesion problem, so State-Aid was prohibited.
- Finally, *black areas* are areas where more than one NGA network exists in a given area or will be deployed in the coming three years: no subsidies are allowed in this case.

4.1.2.b Asia Pacific

Where Europe applies clear rules about state aid, only allowing it in certain geographical areas, the regions of Asia and the Pacific (comprising of Australia, New Zealand and the surrounding islands) have clearly another view on government involvement. In both Australia and New Zealand, the government initiated a national broadband project, with significant financial involvement of the State. Telecom law is therefore partly taken out of the hand of the national regulator, as (wholesale) prices for the NGA network were set by the government. In New Zealand, other specifications of the contracts the government concluded with the deployment partners included open access obligations, thereby forbidding the deployment partner to act as a retail provider (see further in section 4.2.2). In Australia, the project dictated that the new network would replace the incumbent's one, in which policy thus sets the rules for a monopolistic infrastructure.

Asia is clearly leading the deployment of high-speed fiber access networks: Japan and Korea showing up as top countries in most coverage and uptake graphs. Laws vary significantly from country to country (e.g. regulation favoring inter-platform competition in Korea versus intra-platform competition in Japan, see also section 4.1.6), but public involvement is not as restricted as in Europe.

4.1.2.c United States of America

Regulation in the USA is governed on two levels: federal and state. In theory, regulation is in the hands of the federal government, but as the state police are responsible for the citizens' health, safety and general welfare, they consider price and business service regulation for public utilities their responsibility. Friction in between both levels of regulation thus happens regularly [4.17]. Regulatory institutions in the USA take legislative, executive and judicial decisions: they write the laws (legislative), they carry out and enforce the laws (executive) and they resolve legal disputes (judicial).

Telecommunications specific policy in the USA is governed by the Federal Communications Committee (FCC), and is based on two landmark documents: the Communications Act of 1934 and the Telecommunications Act of 1996. The latter is a revision of the first, and leans on the strength of competition in organizing and steering the USA telecommunications market. The goal of this Act was to "let anyone enter any communications business—to let any communications businesses compete in any market against any other" [4.18]. The Act includes three methods for local telephone service entry: the construction of an own, competitive network; the leasing of dedicated line at the network of the incumbent (AT&T) or buy and resell the incumbent's service.

Contrary to Europe and Asia, fixed telecommunication network ownership has been in the hands of private, investor-owned providers [4.19]. State intervention has always been limited, until recently, where the government (both state and municipal) has become involved in deploying backbone and wireless networks, as a response to the slow deploying pace of the private investors.

Currently, there are several problems with the legislative power of the FCC. In the USA, two service types exist: *basic telecommunications* and *enhanced services or data processing (value-added services).* These latter were considered 'essentially competitive', thus there was no need for regulating them. As the Internet is a "software protocol that moves packetized information amount computers", it is regarded as a value-added service, and can hence not be regulated.

4.1.3 Initiator and key drivers

A third parameter that allows for comparison of cases, is the initiator of the case combined with what drove this party to start up the FTTH project. Roughly, the initiator can be a public or a private party, or of course a combination of both. Public parties are authorities (on national, regional or municipal level) who can allow easy Right-of-Way, or public utility network owners (electricity, water, gas, sewerage) that can use their expertise in infrastructure deployment and look for synergies with telecom networks. Private partners are of course the incumbent telecom operators, owning a legacy twisted copper pair (DSL) or coaxial cable (HFC) network, or other large investment firms (e.g. banks).

It is clear that these initiatives are driven by different actors that have different goals [4.20]. In general, these drivers to investment can be identified:

- **Competition** from other infrastructures as a driver for investment, which will lead to private initiatives (as in the case of Portugal, see section 4.2.4);
- **Public contract**, where the government takes the leading role in a pure public procurement model (Australia), or as a partner in a Public Private Partnership (PPP, in New Zealand (section 4.2.2) and Amsterdam (section 4.2.3.a));
- **Regulation**, which can force the current operator (e.g. incumbent) to deploy, either directly or through other stimuli (e.g. regulatory holiday in Portugal, section 4.2.4);
- **Societal value of broadband,** detailing the indirect effects a broadband network can entail, thereby increasing GDP and reducing the digital divide (e.g. Stockholm, see section 4.2.1).
- **Political incentive,** whereby an authority gives a financial or other stimulus to help improving the business case, e.g. through a subsidy or risk premium, following the examples of Australia and New Zealand;
- **Horizontal integration,** in which a utility company expands its area of expertise to telecom, and reduces costs by applying synergies in deployment and operations (e.g. the initiatives by German "Stadtwerke").

4.1.4 Financing structure

As mentioned multiple times in this book, the business case for FTTH deployment is rather difficult, and will as such not always be taken up by a private party alone. Over time, different mechanisms are used to start an FTTH deployment. Figure 4-1 gives an overview of the six main financing structures that can be identified for large projects (and as such not limited to telecommunication networks deployments).

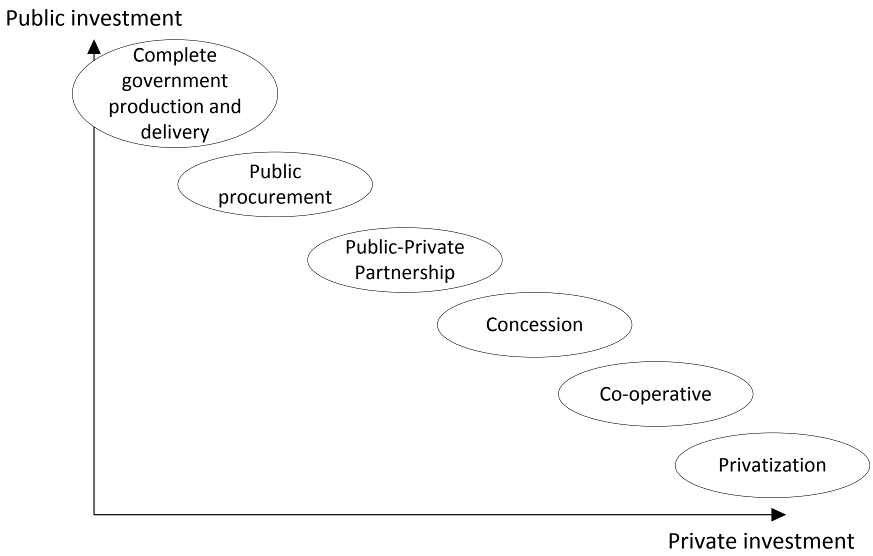

Figure 4-1: Overview of types of public private collaboration possibilities (Adapted from [4.21])

They range from 100% public investment to 100% private investment:

- In the **complete government production and delivery**, the public sector constructs and operates the network itself, retaining full control and offering services on a retail or wholesale basis.
- When a public party invests the funds and retains ownership, but outsources the execution (and possible operations or maintenance) of the project to private partners, the investments mechanism is referred to as **public procurement or public outsourcing**.
- A **Public-Private Partnership (PPP)** finds the middle point between public and private investment, and is defined as a contract between an authority (e.g. the national government or a municipality) and one or more private partners [4.21]. By including both public and private money, the alignment of objectives can be assured: the service-delivery objective of the public parties along with the profit-maximization of the private parties [4.22], making the agreement mutually beneficial and economical [4.23]. Another approach is considering PPPs as lying between the government and the market [4.24], with the government representing centralized control of transactions and the market representing decentralized control. Because of this, a PPP seems to be favored as Howell argues that the “most efficient organization is always within institutions positioned somewhere along the continuum between the market and the government”. The decision on where to draw the line between the government and the market then depends on the cost of

transactions, which represent the added or reduced cost of trading on or off the price of producing.
- The fourth mechanism is a **concession**, frequently also referred to as a **tender**. In this case, the public party grants a private partner the rights to deploy and operate an infrastructure (or to execute and maintain a project). The private partner relies on revenues from the project's users, to recoup its investment. Notice that, in this case, the private investment (and risk) is higher than in the case of a PPP.
- A **co-operative or bottom-up investment**: a group of end users decides to invest in the deployment of a network. Public involvement is usually limited to issuing grants or guaranteeing loans, and/or facilitating access to publicly owned infrastructure such as ducts.
- **Privatization** is the final financing structure, and involves no public investment.

This range of six investment mechanisms are, although possible, not allowed in every deployment case, especially with regard to the level of government involvement. In general, competition law dictates that government intervention should only be allowed in cases where the market is not delivering the right quality and/or quantity. Lemstra and Groenewegen argue that governments should only intervene in case of a market failure, where it has been proven that the private market players have tried to correct the failure without any result [4.25]. In this situation, the authorities can use competition law to correct the abuse of market power; they can set specific regulation on standards (quality of service) or impose price corrections through the use of taxes and subsidies.
One key aspect that differentiates PPPs from traditional procurement models is the fact that the agreement involves private money at stake, i.e. the private partners in a PPP bear their fair share of the risk, and as such are incentivized to deliver the product as efficiently as possible. PPPs are expected to deliver high value-for-money, but while also achieving the same goals as public procurement models. On the other hand, the involvement of public money is also key, and provides the main differentiator to privatized projects. Public money ensures that government can impose their coverage targets and can provide a type of "subsidy" to ensure the economic viability of the entire project.

4.1.5 Applied business model

One of the most important issues when analyzing an FTTH deployment is the identification of the business model: who is responsible for which role and does this mapping of actors to roles allow for competition. Three actors were identified (see section 3.2): the Physical Infrastructure Provider (PIP), the Network Provider (NP) and the Service Provider (SP).

Depending on which roles these different market actors take up, the network will be open at different levels and different business models will arise, as illustrated in Figure 4-2. Here, the difference should be made in between open access and unbundling, based on the existence of a vertically integrated operator.

- *Open access* refers to the situation in which the lower layer is provisioned in a non-discriminatory way to different actors on the layer above (models a, b, c, d). This is a typical situation in a newly deployed network where split responsibilities can be one of the objectives from the start.
- *Unbundling* refers to the case in which a single actor is exploiting both a particular layer and the layer on top of that, while still allowing the co-existence of other actors on top of its own passive infrastructure/ network (models e, f, and g). The main difference with open access is that the actor responsible for the lower layer can also act in the layers above. For example, unbundling on the bitstream level means that the actor offering the connectivity at the network layer, the NP (potentially integrated with the actor on the physical layer, the PIP) is also offering services at the service layer (and thus also acts as SP).

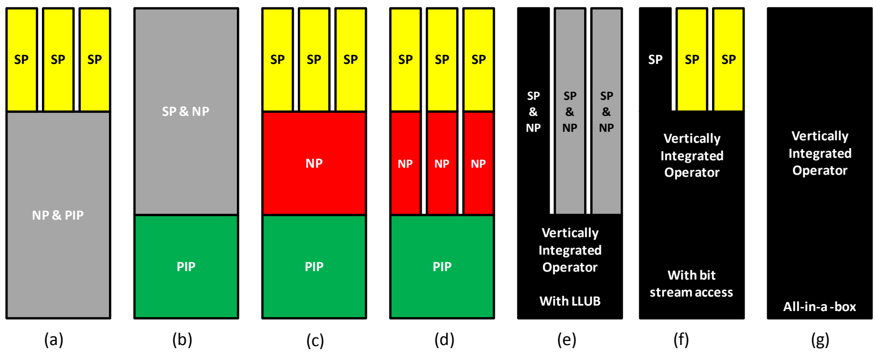

Figure 4-2: Access network business models

A single actor may act as PIP and NP (a), in which case the network is open at the service level. In this case, the business model is referred to as **Active-Layer Open Model (ALOM).** If the roles of NP and PIP are separate (b), openness at infrastructure level is achieved, which corresponds to **Passive-Layer Open Model (PLOM)**. Although this model is theoretically possible, no real case example was found so far. In case all three roles are taken up by different actors (c, d), the model is referred to as **Passive-Active-Layer Open Model (PALOM).** Generally, one PIP operates the infrastructure, while one or several NP can be allowed to operate the active infrastructure generally over a fixed period of time, at the end of which the contract may or may not be renewed (in

which case a new NP is designated and active equipment may need to be replaced).
The unbundling models vary on the same levels of opening up the network. When one party takes up all the roles, the business model is said to be **Vertically Integrated** (g). In (e), the incumbent's network is unbundled using Local Loop Unbundling (LLU), while bitstream access is used to allow competitors on the service level in (f).
Most often, economies of scale make it impractical to have a truly multi-NP network (although larger networks may assign the operation of different geographical parts of the network to different NP). Independently of the specific model, however, the NP should offer different service providers access to the network (and therefore the users) on non-discriminatory conditions. The end users typically purchase services directly from the service providers. The NP receives revenue from the SP and pays a connection fee to the PIP for network access.

4.1.6 Inter-platform and intra-platform competition

The final parameter used for case comparison is the level of competition present in the investigated broadband market. Two types of competition are possible: intra-platform and inter-platform. Inter-platform competition can be defined as technology competition as such. The main competitive technologies for FTTH can be wireline or wireless based ones. It can be all kind of hybrid fiber copper solutions as FTTC and FTTB in combination with xDSL were x stands for all DSL flavors like A, S or V, or HFC networks of the former cable operators. Wireless technologies, such as WiMax, 3G and 4G, can be seen as competitive inter-platform technologies, but as they will rather serve a complementary goal, they will not be taken into account in the case comparison further down in this chapter.
Intra-platform competition is defined as competition between different initiatives, operating on the same network (and hence focuses on competition between NPs (network level) and SPs (service level). It is clear that, given the limited maturity of FTTH deployment, evolution is expected in the future.

4.2 Detailed analysis of selected cases

After having described the different parameters for analysis, some specific cases will be detailed: Stockholm, where a public company operates a dark fiber network; the Ultra-Fast Broadband initiative in New Zealand, the private Google Fiber project in Kansas city and around in the United States, a PPP led by the municipality in Amsterdam and an incumbent deploying FTTH in specific areas in Portugal. These cases were selected as they provide a wide variety of possibilities, thereby familiarizing the reader with the concept of the parameters from section 4.1. In the third section of this chapter, the list of cases will then be elaborated, in order to draw more general conclusions about the impact of regulations and market conditions on the FTTH deployment initiative and business case.

4.2.1 A public company operating a dark fiber network in Stockholm

Driven by the incentive to increase the economic attractiveness of the region of Stockholm, the city decided to invest in an FTTH deployment [4.28]. Stokab, founded in 1994, is a public company, 100% owned by the city of Stockholm, and was established to deploy a point-to-point, dark fiber access infrastructure (thereby acting only as PIP) to all businesses and households in the Stockholm region. The company was founded as a public infrastructure company (comparable to other public firms responsible for road, railway etc.): all the development, deployment and operations is in direct hands of the company, no outsourcing is done. As the deployment started before the EU State Aid regulation was established, its public involvement was not questioned.

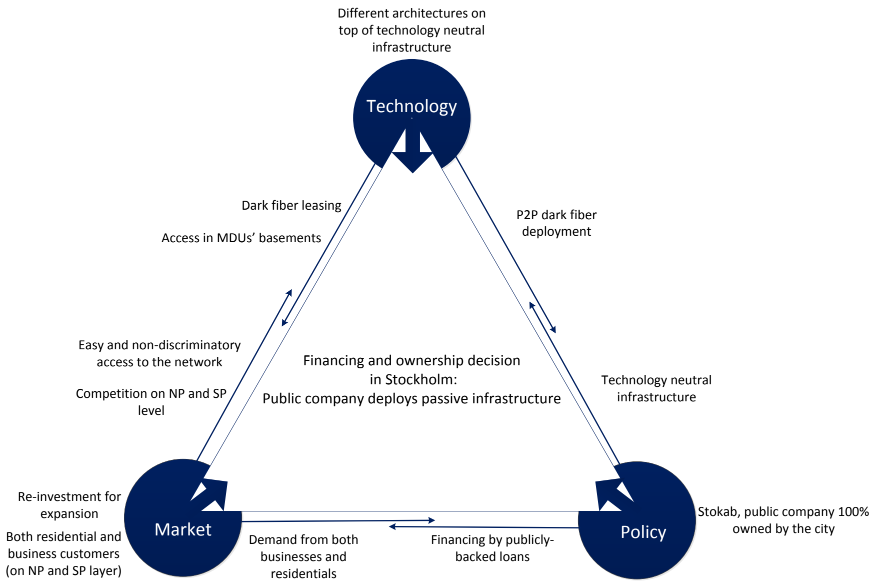

Figure 4-3: TPM interactions for the public deployment by Stokab in Stockholm

In its initial phase, the network rollout was financed by publicly-backed loans. As a first goal, the network aimed at connecting mainly public and educational institutions, but was quickly expanded towards private businesses, which requested to be connected on the dark fiber circuits. The initial €300 million investment was based on loans backed by the city of Stockholm, while the customers' revenues provided the necessary funds for a later expansion of the network. Stokab reached a breakeven point in 2001, and is now a profitable company, although the majority of their profits are still re-invested in maintenance and further expansion of the network.

The goal of creating ultrafast reliable connections to the highly knowledge-intensive region that would "meet future communications needs, stimulate competition, promote diversity, offer freedom of choice and minimize the need for excavation" [4.29], has definitely been reached. Stockholm is now home to a number of successful international companies (e.g. Ericsson, Spotify and Transmode), all of which were attracted to the "the most densely fibred city in Europe".

The deployment and operations of the FTTH network in Stockholm is provided by three types of actors: one PIP: Stokab, a couple of NPs and over 90 SPs, thus follows the business model of PALOM. Stokab is responsible for the passive infrastructure in between the Central Office (CO) and the basements of the Multi-Dwelling Units (MDUs), as well as in between the different COs (redundant connection). They do not own any active equipment. They lease out dark fiber and rack space for the active equipment to all operators (NPs) for less than it would cost them to build their own network. The NPs provide transmission capacity to the end-user or to the SP, by lighting up the dark fiber rented from Stokab (by installing active equipment). An NP typically has contracts with different SPs, so that competition exists between SPs serving the same customer.

Next to these telecom-oriented actors, over 500 enterprises make use of Stokab's network. These companies (banks, media, security and more) rent point-to-point connections directly from Stokab and provide their own equipment (or via outsourcing to an NP) to light up the network and have their own (security-sensitive) services. Important to note is that about 50% of Stokab's revenues originates from this type of clients.

4.2.2 The Ultra-Fast Broadband initiative in New Zealand

Following a 2009 election promise, the New Zealand government committed NZD $1.5 billion to an FTTH deployment aimed at reaching 75% of households and businesses, an initiative known as the Ultra-Fast Broadband (UFB) [4.30]-[4.32]. The remainder of households is to be served mainly by the Rural Broadband Initiative (RBI), through investment in wireless connectivity and VDSL connections, a result of Telecom NZ's cabinetization program in the mid-to-late 2000s. Crown Fibre Holdings (CFH), a publicly-owned company, was created to manage the investment funds. A tender process saw four private companies win shares in the total investment funds to deploy the UFB. The four partnerships so created are known as Local Fiber Companies (LFCs) and will eventually own and operate the network on a wholesale-only basis, and thus act as PIP & NP while allowing competition on service level (ALOM). They are: NorthPower Fibre, UltraFast Fibre, Enable and Chorus; the latter was established from a demerger of Telecom New Zealand into Chorus (the wholesale company owning the network) and Telecom Retail (now Telecom, providing the retail services which include mobile).

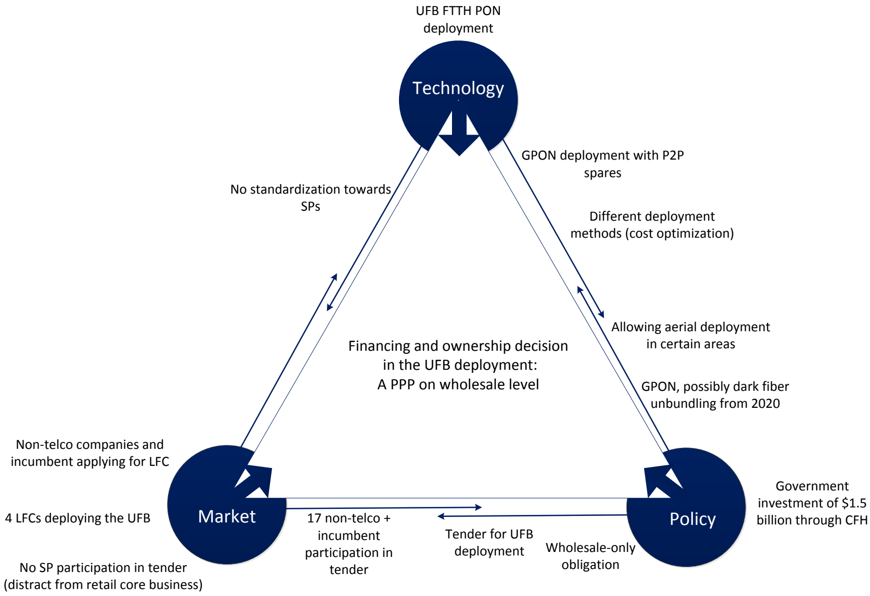

Figure 4-4: TPM interactions for the UFB deployment in New Zealand

The PPP was structured in two different models: the "funds-recycling" model with the LFCs, and the "investment" model with Chorus. The contract with the LFCs is based on the recycling of capital in which CFH funds the fiber passing (the dark fiber, Layer 1 network deployed along the streets). When a customer shows interest to subscribe to fiber services, the LFC then funds the drop section (from the street to the customer's premises) and a subscription-based retail commercial relation starts between the customer and a retail service provider, which in turn pays for capacity to the LFC at wholesale prices. This income can then be used by the LFC to buy a share in the UFB network (so far owned by CFH), gradually acquiring ownership of the entire network. CFH in turn can re-invest the regained funds in network deployments elsewhere. The contract signed with Chorus is different in that sense that CFH directly invests in Chorus as a company, but Chorus bears the main risks of the uncertain demand uptake. In return for this government loan, Chorus has to comply with specific coverage and uptake goals, set on milestone dates.
The business model applied in the UFB is open access based, as the LFCs are not allowed to interact with end-users (they are not allowed to act as SP). On SP

level, there are over 65 SPs active on the New Zealand market [4.33], among which two (Vodafone and Telecom) take up more than 75%.
As the deployment has not matured enough, it is hard to draw conclusions about the success of the UFB initiative. What can be mentioned, is the struggle for uptake, given the uncertainty regarding the wholesale copper pricing (an ongoing debate between the regulator, Chorus and the government) in comparison to wholesale fiber pricing (which has been fixed in the CFH-LFC contracts), as well as the need for a minimum market (thus minimum coverage) for service providers before starting marketing campaigns.

4.2.3 Demand aggregation in the United States: the case of Google Fiber

Google, a best-known search engine company that gets its revenues from advertisement and pay-per-click, recently started a new department: Google Fiber. The main purpose of this department was to find an area to deploy a fiber network with the best conditions possible: maximizing the value of every dollar spent on the new network while providing an outstanding broadband symmetric offer (a symmetric 1 Gbps connection).

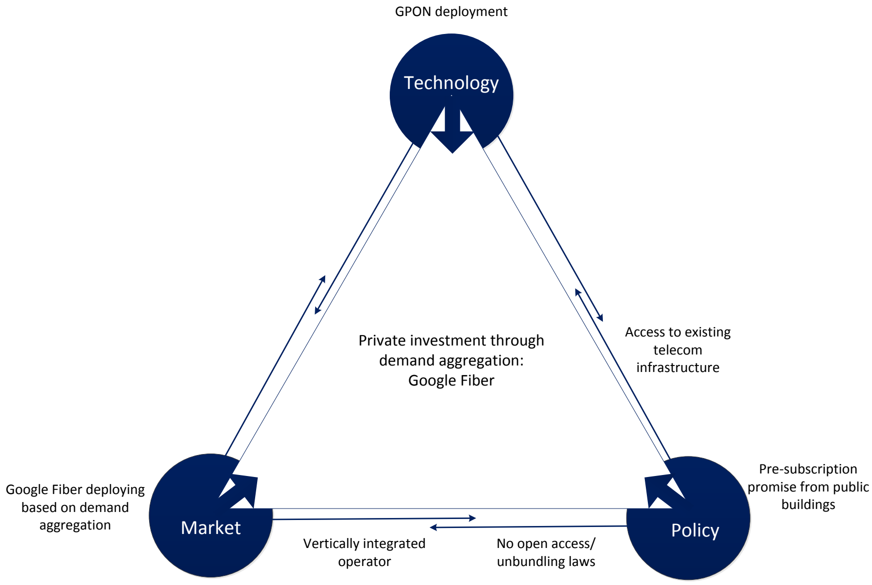

Figure 4-5: TPM interactions for the Google Fiber deployment in the USA

Municipalities from all around the USA answered to a public contest launched by Google and provided as much data as possible about their already existing facilities and some proof of engagement of their population to the project. After the first contest in 2010, Google received data from over 1,100 communities and local governments, endorsed by more than 194,000 individuals, all of them applying to get fiber deployed in their towns and cities.

From these applications, Google selected Kansas City. There, Google divided the city into fiber-hoods (smaller than neighborhoods) that allowed them to set some goals of pre-engagement before starting any deployment. If a fiber-hood does not reach the minimum engagement needed, Google does not deploy fiber there. Having those levels of pre-subscribed users allows a better planning to deploy the new fiber network (passing and connecting houses at once) while it reduces the risk of investment. After this first deployment, Google is expanding into other cities along the USA like Austin and Provo (in the states of Texas and Utah respectively).

Google's model seems to be reaching more than the minimum presubscription goal per fiber-hood. According to Sanford C. Bernstein it could reach 50 to 60% of possible subscribers in two years after deployment [4.34].

The model, although not being a true Public Private Partnership, has a strong commitment from the public administration. The latter provides access to any existing telecom infrastructure, if available (poles, dark fiber, conduits), and eases as much as possible the provision of rights of way needed to deploy the network. On the other hand, the city council gets involved in the demand aggregation process by stimulating residents to subscribe, thereby reaching the minimum pre-subscription-foreseen level to deploy fiber into the neighborhood, and in return gets a fiber connection to some schools, churches, hospitals or other public buildings in the fiber-hood from Google for free.

4.2.3.a A PPP under the Market Economy Investors Principle in Amsterdam

Although the FTTH deployment in the Netherlands is now mainly driven by Reggefiber, a passive infrastructure provider set up by an investment company (Reggeborgh), the first Dutch FTTH initiatives were taken by municipalities.

In the case of Amsterdam, the city wanted to explore the importance of high-speed connectivity to the economic well-being of the city, and launched a formal investigation into the best way to proceed. Based on the outcome of several studies with and without the collaboration of the national incumbent, KPN, and the local cable operator, UPC, the municipality decided to create a public-private partnership (PPP) to invest in a passive fiber infrastructure. This PPP, GNA (Glasvezelnet Amsterdam BV) was incorporated with three groups of investors — the municipality itself, the housing associations and the private sector— each investing €6 million in return for a one third stake in the company. Another €12 million in funding was provided as debt financing, bringing the total investment to €30 million. Although GNA was taken to court multiple times by the cable operators, the public investment was eventually allowed under the Market Economy Investor Principle:

- All shareholders should invest under the same conditions in a profitable business with an acceptable risk/reward ratio.
- The network should be operated using the ‘open network’ concept, meaning that the wholesale specifies that all service providers must be able to purchase transport capacity on non-discriminatory conditions.

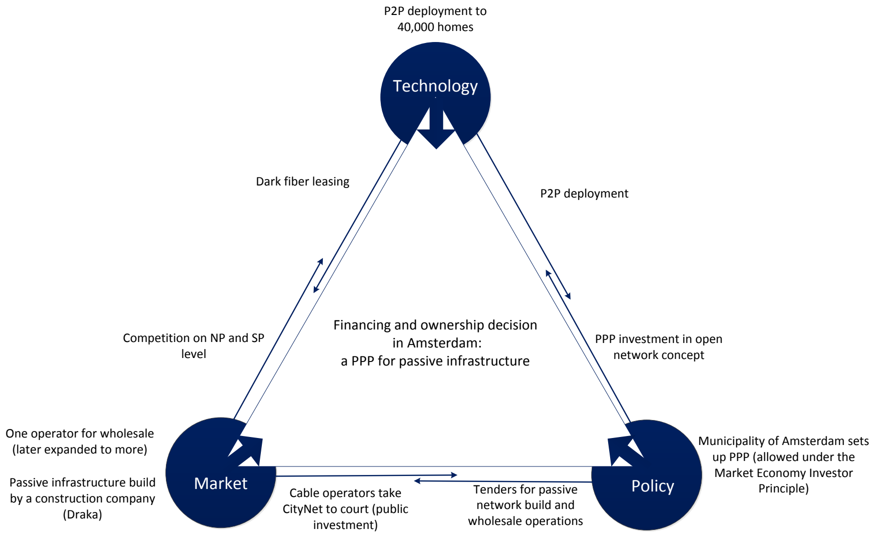

Figure 4-6: TPM interaction for the PPP in Amsterdam

The passive infrastructure was outsourced to a construction company (Draka), while operations are taken up by GNA. Based on a tender procedure, BBNed was chosen to operate the active network (NP responsibility). Services are available from multiple service providers. Since currently, KPN is also active on the network layer, this structure can be seen as an example of PALOM: competition exists on both network and service layer.

The investment fund of €30 million was used to cover about 40,000 homes with fiber access; this process took about 2.5 years and finished in February 2009. Then, GNA announced to connect the remaining parts of the city (420,000 homes in total) by 2013, and estimated an overall budget of €300 million to do so.

Soon, however, the ownership structure in Amsterdam changed, as Reggefiber (the operator deploying fiber networks in the entire country), bought about 70% of the shares, in a partnership with KPN (the Dutch incumbent). The remaining 30% is still owned by the municipality of Amsterdam. This evolution makes tracking the actual process of the initial project hard, as parts are now integrated with the plans of Reggefiber.

4.2.4 Portugal: private investment driven by cable competition

Although most European FTTH initiatives are based on some form of PPP, exceptional examples of other financing structures can be found. The main example for a private investment is to be found in Portugal, where the national incumbent, Portugal Telecom (PT), started a GPON rollout to face the fierce competition by the cable operator which could offer more attractive video-based offers using its HFC network. At the end of 2011, PT had passed 1.6 million homes [4.35], in comparison to Vodafone Portugal, who has currently covered more than 700,000 homes with FTTH, while aiming for the 1.5 million target by mid-2015 [4.36].

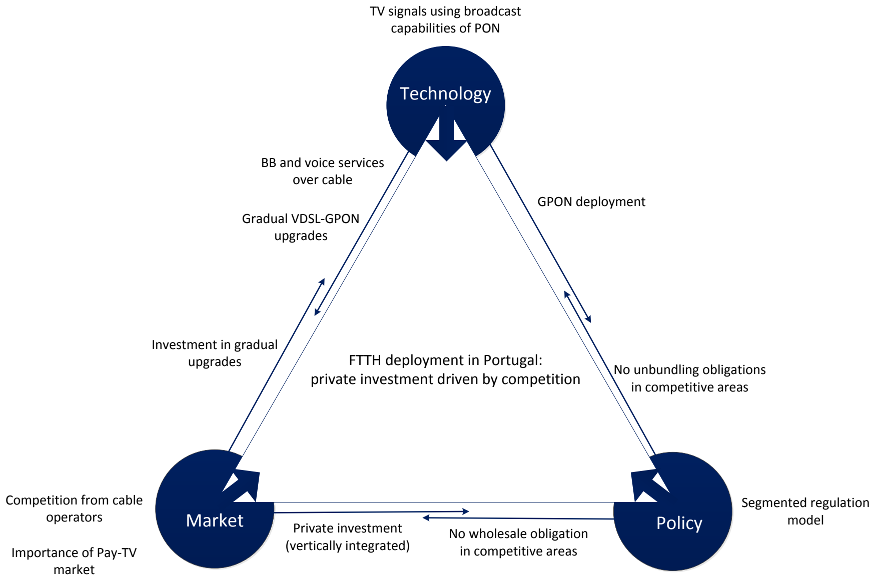

Figure 4-7: TPM interaction for the private investment driven by competition in Portugal

This decision to upgrade to FTTH was backed by the decision of the National Regulatory Authority ANACOM, who adopted a segmented regulation after a market analysis in 2008. The decision determined that access to ducts and associated infrastructure (so-called market 4) should be an obligation for all infrastructures (DSL, DOCSIS and FTTH), but that a wholesale offer (bitstream access, market 5) should only be regulated in non-competitive areas. In areas with sufficient competition (defined as areas where the percentage of passed homes by the main competitor – the cable operator ZON – is larger than 60%), there is as such no SMP, and according to European guidelines, no need for access regulation [4.37]. In that type of areas, Portugal Telecom is therefore deploying in a vertically integrated business model, providing all technical layers themselves. In most of these competitive regions, the combined market shares of ZON and PT currently exceeds 85%.

The upgrade of Portugal Telecom's network started in 2007 and was a gradual process. First, the network was quickly upgraded to DSL and later the twisted copper pair loop was shortened by Fiber-to-the-Node installations, with the final step deploying fiber to the actual homes with the GPON technology. The choice for GPON was largely based on its capability for broadcasting, as many Portuguese homes have multiple TV-sets and thus require enough signals (the analogue TV signals could be carried over a third wavelength in the GPON system (RF overlay)).

Installing FTTH furthermore allowed to easily and cost-efficiently upgrade the mobile network to LTE, providing Portugal Telecom with the opportunity of offering quadruple-play for competitive prices.

4.3 Comparing FTTH deployments worldwide

In this final section, we include more FTTH deployments worldwide, which are characterized using the parameters defined in section 4.1, thereby aiming at drawing general conclusions about these cases. It becomes evident (Table 4-2) that urban regions are characterized by the presence of alternative networks, like DSL and DOCSIS networks, that were already in place long before one started deploying FTTH. In the rural areas on the other hand, FTTH networks are sometimes the first broadband networks to be installed, which can result in different marketing strategies to be applied by the operators. There is a strong difference in who initiated the project and their strategies used, as well as what drove them to start deploying an FTTH network. Furthermore, four cases described in the table deal with large-scale deployments (on a country-wide level in Portugal, Italy, Norway, New Zealand, the USA and Japan), which makes it harder to categorize the case in purely urban or purely rural. For these reasons, we will divide our analysis into three parts: urban cases, rural cases and large-scale deployments, and discuss the different characteristics for each of them.

Table 4-2: Overview and characterization of a variety of FTTH deployment cases

CASE	Region	Scale of deployment	Competitive Infrastructure	Business Model	Initiator	Other important actors	Key drivers	Deployment strategy
Stokab Stockholm (Sweden) [4.28]-[4.29]	Dense urban	City-level	DSL and DOCSIS	PALOM	City of Stockholm	Housing corporations, enterprises	Societal value: competitiveness of region	Business and public users first
Amsterdam CityNet (the Netherlands) [4.26]-[4.27]	Dense urban	City-level	DSL and DOCSIS	PALOM	City of Amsterdam	Housing corporations, private investors	Societal value: promote local economy and integration	-
Reggefiber (the Netherlands)	(Dense) urban	City-level	DSL and DOCSIS	PALOM	Reggeborgh (investment company)	-	Market power	Demand aggregation by Reggefiber
Google Fiber (USA)	(Dense) urban	City-level (city per city)	DSL and DOCSIS	Vertically integrated	Google, private company	The city, by connecting its buildings	Competition and market power	Demand aggregation
Reykjavik Fiber Network (Iceland) [4.38]	Urban	City-level	DSL	ALOM	Reykjavik Energy, public utility company	Municipalities	Societal value: competitiveness, horizontal integration: synergies	-
OnsNet Neunen (the Netherlands) [4.39]	Urban	City-level	DSL and DOCSIS	Vertically integrated (although not intended)	Cooperative OnsNet, founded by inhabitants	€800 government subsidy per HH, later Reggefiber	Societal value: increase ICT services development	Direct involvement from end-users in investment
Fastweb (Italy) [4.40]	Mainly urban	7 cities (e.g. Rome, Milan etc.)	Dial-up Internet, some DSL, no DOCSIS	Vertically integrated	Fastweb, a private company	Partnership with electricity firm in Milan	Societal value: digital divide	-
Portugal Telecom (Portugal) [4.35]-[4.37]	Mainly urban	Country-wide (1mln homes passed as of 2009)	Cable operators	Vertically integrated	Portugal Telecom, the incumbent	N.A.	Competition from cable on Pay-TV market	Deployment so far only in competitive areas

Altibox, subsidiary of Lyse Energi (Norway) [4.41]	Both urban & rural	Country-wide (360k homes passed as of 2011)	7 telecom operators across the country	Vertically integrated multi-utility (different roles in subsidiaries)	Lyse Energi (regional energy supplier)	N.A.	Horizontal integration	-
New Zealand [4.30]-[4.33]	Mainly urban	Country-wide (75% of population)	DSL (and limited DOCSIS)	ALOM	Government	Local Fiber Companies	Public contract by election promise	-
Australia [4.42]	Mainly urban	Country-wide (but mainly FTTN)	DSL	Vertically integrated	Government	Telstra, by selling their legacy copper	Public contract	-
Verizon FiOS (USA) [4.43]-[4.44]	Mainly urban	Country-wide (mainly FTTB in MDUs)	DOCSIS	Vertically integrated	Verizon, private company	N.A.	Competition from cable (video), lower operational costs	Replace legacy cables with fiber
NTT (Japan) [4.45]-[4.46]	Mainly urban	Country-wide (no FTTH in rural areas)	DSL (mainly OLOs) and DOCSIs	Vertically integrated with limited unbundling obligations	NTT, private company with government shareholder	N.A.	Competition from OLOs	Replace legacy cables with fiber
Pau-Pyrenées (France) [4.47]	Rural	Pau + 13 neighboring municipalities	DSL, but not everywhere	ALOM	Municipal authority of Pau-Pyrenées	N.A.	Societal value: promote local economy	-
SEIPC, Pays Chartrain (France) [4.48]	Rural	Regional (71 municipalities)	No alternative infrastructures everywhere	PALOM	SEIPC, the regional electricity provider	N.A.	Societal value: digital divide	-
Ruhrnet, Stadtwerke Schwerte (Germany) [4.49]	Rural	Municipality-level	DSL, but not everywhere	Vertically integrated	Stadtwerke Schwerte	N.A.	Horizontal integration: multi-utility; “one face to the customer”	-

Urban regions

Urban regions are characterized by the presence of other broadband networks, like the DSL network of the incumbent and/or an alternative network owned by a cable operator. This might be one of the reasons why we see here a clear preference towards an open business model, allowing room for competition resulting in a reduction of prices charged.

In four out of the six urban cases under study, it was the city (or a publicly owned utility company) that recognized the need for a fiber network and initiated the venture. In general, the main reason for deploying the network comes down to boosting the local economy and the ICT market, as well as increasing competition. Apart from the public entity (city or utility), housing corporations and private investors seem to have a rather big influence, both financially and in aggregation of demand. In Amsterdam for instance, the housing companies took up 1/3rd of the initial investment (1/3rd was taken up by the city of Amsterdam, 1/3rd by private banks), meanwhile ensuring a certain take-up rate from the start, as all their homes got connected. Key motivations for the housing corporations to invest in FTTH networks were two-fold: being able to offer a fast and reliable FTTH connection to their residents, which in turn increases the value of their real-estate property.

The remaining two cases were driven by private companies: Reggefiber in the Netherlands and Google Fiber in Kansas and other cities in the USA. Noticeable here is that they both use the deployment strategy of demand aggregation prior to rollout, this to ensure sufficient income from the start of the project. Although being privately initiated, the city did play an important role. In the Netherlands, Reggefiber used the deployment in Amsterdam as an example for their model, while part of the demand aggregation process in the USA is led by public buildings convincing their neighbors to subscribe, thereby ensuring their own connection (see section 4.2.3).

Large-scale deployments

The second category of European cases under consideration is that of large-scale (country-wide) deployments. Seven examples are given here: Portugal, Italy, Norway, New Zealand, Australia, Japan and the deployment by Verizon in the USA.

In Portugal, it was the incumbent itself that decided to start rolling out FTTH, in order to stay competitive vis-à-vis the cable operator in the digital television market. This case leads to interesting conclusions, as it is often said that the only application that truly needs FTTH networks, is video. Cable operators are ahead because their networks are built to transmit video services, and they can more cost-efficiently upgrade their network bandwidth as well. Clearly this illustrates that there is no such thing as a "killer app", but the use of multiple high-quality video-related services simultaneously is a good motivation to begin to deploy

FTTH. Note that the case in Portugal is very similar to what is happening in many Eastern European countries where incumbents are starting with FTTH rollouts due to a lack of good infrastructure.

In Italy, a new company was set up: Fastweb. They saw opportunities in connecting the residents in seven municipalities (cities like Milan, Rome, etc. and their environments), where the Internet conditions were rather rudimentary. Formulating a partnership with AEM, the electricity company in Milan, they were able to save costs on digging, and in turn gained additional subscribers for the network.

The third large-scale deployment listed in the table was initiated and fully deployed by Altibox, a subsidiary of the regional Norwegian energy supplier Lyse Energi. This again is a completely different case, with a utility company opting for a "multi-utility" strategy, offering both energy and broadband.

The two following large-scale deployments were all initiated by the public authorities, being in the form of a PPP in New Zealand and a public procurement model in Australia.

Finally, the two last large-scale deployments listed in the table are privately initiated: the incumbent NTT in Japan and the private company Verizon in the USA. An important similarity here is that they both use their existing customer base (former DSL clients) to ensure sufficient revenues for the FTTH (mainly FTTB for Verizon) deployment. By removing the legacy cabling when passing with fiber, both operators "oblige" the customers to switch to the fiber offer.

Note that, although the initiators for the large-scale deployments under study are very diverse, all business models have one company that is responsible for both the passive and the active infrastructure, whereas the provisioning of the services is taken up by the same company (in case of a private initiative), or left to the market (in case of a public initiative). It is further remarkable that the real large-scale deployments are to be found outside of Europe, where the regulation is not as strict in prohibiting public involvement or obliging unbundling on private operators.

Rural regions

As mentioned before, rural areas are characterized by rudimentary access to the Internet, and broadband DSL or DOCSIS networks are not available everywhere. One could conclude that rural areas form good markets to start deploying FTTH, wouldn't it be that the upfront costs are much higher than in urban areas (because the distances to be bridged in between two homes are much higher, see Table 4-1). Because of this high upfront investment, and lack of interest from the incumbents to invest, the initiative to deploy the network was always taken by a public institution: a public utility firm or the municipality itself.

Furthermore, it is important to mention that rural areas with no other broadband infrastructure available are the only areas where public funding is allowed (the so-called white areas, as defined in the European Regulatory framework [24]).

General remarks

Finally, all cases are put together to verify if other conclusions can be taken, independent from the type of region. A relationship can be found between the key drivers and the business model applied. If the goal of the initiator is to promote the local economy, encourage competition or a similar reason related to public interest and the advantage for the end-customer, the business model used is more open. On the other hand, if the initiative is taken by a private company that aims at maximizing its ROI, the business model is Vertically Integrated, not allowing any competition.

4.4 Summarizing the impact of policy and the market on the viability of FTTH deployment

By giving an overview of ongoing FTTH deployments worldwide, this chapter aimed at analyzing the impact of the policy and market pillar on the business case for FTTH deployment. The different cases were analyzed based on six characteristics: the region type and scale of deployment, the policy conditions, the initiator and key drivers, the financing structure, the applied business model and existing competition, both inter- and intra-platform.

The region type (dense urban, urban or rural) proved to be an indicator for the existing competitive infrastructure, whereas the scale of deployment could be linked to the available regulation. The European policy rules (basically coming down to only allowing state aid in rural areas or in some specific exceptions) are therefore of major importance to take into account when quantitatively evaluating the business case for FTTH deployment in Europe (see chapter 5). The absence of state aid rules in Oceania allows direct public funding, while the absence of access regulation in the United States does not inhibit private initiatives such as Verizon FiOS or Google fiber to deploy a Vertically Integrated model (these private initiatives are of course not prohibited in Europe, but typically set back by the fear of unbundling or open access obligations).

In almost all cases there is a clear influence from public parties. There are exceptions, e.g. Portugal, where the incumbent was motivated to deploy FTTH as a result of competitive pressure from the cable operator. This competitive pressure was not found elsewhere as deployed DSL networks generally meet the needs of currently offered TV-services. The public actor is the municipality itself or a utility firm, and its role varies among the cases: from active deployment of the network, to investment of public money where the municipality acts as a genuine market player or to the aggregation of demand where the municipality

ensures a certain take up rate from the start of the project (public administrative buildings, schools, hospitals and so on). Another conclusion involves the relationship between the actor who takes the initiative and the business model applied. A public actor tends to opt for a more open business model (ALOM or PALOM), while a private actor will try to minimize the threat of entry by applying a Vertically Integrated model. A similar link can be found between the initiator and the key driver: a public actor will deploy the network because of the advantages for the end users (both in the matter of public interest – access for all – as to force a reduction of prices stimulated by enhanced competition), while a private actor will try to maximize ROI. Two approaches to ensuring sufficient revenue (for ROI maximization) were found: demand aggregation, which lets users pre-subscribe before deployment, and replacing of legacy cabling, thereby forcing the migration of the existing subscriber base to the fiber network.
In general, our analysis showed the importance of the policy pillar in all types of deployment, be it as full investment, participation in a PPP or indirect aid in the form of regulatory holidays. The policy pillar furthermore showed to impact the technological pillar significantly, in obliging open access on a dark fiber or bitstream layer. The impact of the market pillar is limited in case of a public investment or PPP, but significant in the case of a private deployment, as there, the competitive threat provided a driver for investment.

Following the conclusions of this chapter, it becomes evident that a thorough analysis of the business case for Fiber-to-the-Home deployment requires more than standard economic evaluation techniques. First, it is clear from the different cases studied, that multiple actors take up different roles, while having various drivers or key targets to reach them. The business case for FTTH deployment and operations should therefore be divided into separate segments, allowing for the evaluation of the different separate roles in open access business models. The cost-benefit models and results for the roles of Physical Infrastructure Provider (PIP) and Network Provider (NP) are therefore the subject of the next chapter. Second, as the key drivers vary along with the initiator of the analyzed case projects, it makes sense to not only evaluate the targets of private investors, i.e. maximizing the financial ROI, but also investigate the key goals of public actors, who focus on reducing digital divide and increasing efficiency of the economy in general. A quantification model for these indirect benefits is explained and applied on two exemplary cities in chapter 6. Finally, although having the main advantage of reducing the investment in FTTH by sharing lower layers of the network, the open access business models also entail an extra cost of cooperation. This cost for open access consists of equipment, process and business related sub-items and is further detailed and calculated in chapter 7. In the end, this PhD book thus gives an overview of the evaluation of a Social (i.e.

including indirect effects) Cost-Benefit Analysis for Multi-Actor (i.e. evaluation of both individual business cases and cost of cooperation) deployment of FTTH.

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5
Cost-benefit analysis for FTTH

"If they started by saying you have to prove to me this has a 90 percent chance of success, they'd never invest in anything"
– Guy Hamel

In the previous chapters, the conditions on technological, political and market domains were specified. These settings define the context for the quantitative techno-economic analysis, which will be executed in this and the following two chapters.

Leaning on the identified trend of open networks, in which the responsibilities are shifted from one company operating in a vertically integrated model, to multiple firms each taking up separate layers in an open access model, a first step in analyzing this business trend therefore consists of evaluating the business case for the layers separately (the subject of this chapter). The relevant cost and revenue models will be explained (section 5.1 and 5.2), after which a business case analysis will be dedicated to the evaluation of the investment of the physical infrastructure provider (PIP, section 5.3) and the network provider (NP, section 5.4) respectively. Here, a business case analysis refers to evaluating the economic viability of the investment by comparing costs with potential revenues. Please note that we do not devote any attention to the business case of the service provider, as their core business focuses on the application, rather than the network layer, which is, as been mentioned before, beyond the scope of this

research. The results of this chapter are based on the work described in [5.1]-[5.7].
In the following chapters, the elementary business cases will be extended towards broader cost and revenue models, which respectively include indirect benefits, especially important for public actors, and cooperation costs, focusing on the extra equipment, processes and transactions needed to be able to share the infrastructure and networks in the open access business model.

5.1 Generic cost modeling

The first step in evaluating the economics of an FTTH network for possible future scenarios is to make a good estimation of all costs incurred. In order to do this, we start from a project lifecycle – planning, deployment, migration, operations and teardown – as shown in Figure 5-1, and combine this with a zooming approach in which we increase the detail of the largest or most risky/unknown cost components first. The figure already gives an indication of the importance of the different cost components, by means of stronger and darker text and lines, in the total cost of the exploitation and upgrade of an FTTH network. Following this approach, the total cost of the network over its entire lifetime can be calculated, also referred to as the Total Cost of Ownership (TCO).

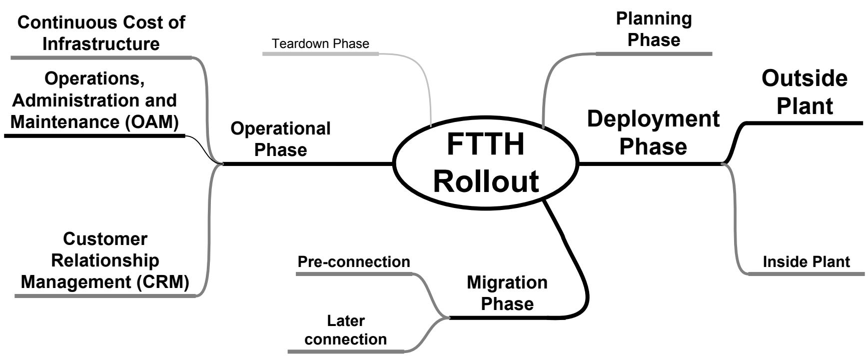


Figure 5-1: Network lifecycle model for an FTTH rollout

As mentioned with the zooming approach, we delve into more detail in the largest subcomponents (or influences) of the final cost. An example of this is shown in the deployment phase, where it will be important to make a distinction between outside plant and inside plant. We further split this cost to come up with detailed cost components for which both input and calculation are easier to make. The outside plant deployment, for instance, consists of rolling out the physical network: digging the trenches and laying the ducts, micro-ducts and fibers (in case of the most common buried deployment that is). The inside plant,

on the other hand, consists mainly of equipment (both passive: e.g. racks and shelves, and active, such as OLTs and ONTs) that need to be installed and maintained. As cost calculations for network deployment in the streets are clearly different to equipment installations in central offices or customers' homes, different cost models (or cost modeling languages) should be developed. The first section of this chapter gives an overview (including dedicated, though basic examples) of three modeling languages designed for evaluating (1) the cost of network deployment (PNMN: Physical Network Modeling Notation), (2) the cost of equipment installation, possibly including maintenance (ECMN: Equipment Coupling Modeling Notation) and (3) the cost of operational processes (BPMN: Business Process Modeling Notation).
Before diving into the detailed explanation of the separate modeling languages, we will first give a short overview of their structure: all three languages consist of a graphical user interface (GUI), which is used for visualization of the model. It allows to graphically represent the links between different types of equipment (ECMN) or activities (BPMN), which in turn simplifies discussions about the models. The backend of the GUI is then linked to a calculator, which uses specified input data to perform the needed calculations for obtaining the total cost of the network deployment, equipment installation or operational process.

5.1.1 PNMN: Physical Network Modeling Notation: fast estimation of infrastructure deployment costs based on analytical approximations

When deploying a new infrastructure, the largest part of the investment cost is taken up by the installation of the outside plant, i.e. the manual labor for trenching and installation of the cables. Although real deployments need a detailed rollout plan indicating the exact amount of cables and trench distance, in the business modeling phase, a fast, yet reliable estimation is preferable in the strategic investment analysis. In this phase many alternative installations will be compared to each other in search for a set of scenarios for instance in which costs are reduced, revenues increased, risks contained.
The Physical Network Modeling Notation (or PNMN) aims at drawing the infrastructure layout of a physical network (e.g. a buried cable network used for telecommunications purposes). By depicting the surface of the area to be covered, the number of connection points to be addressed and by choosing an analytical calculation model from a selected list, the total trenching and cable length will be calculated by the model. This amount can then be used to estimate the total cost of deployment of the network infrastructure. Within the model, the topology of the network can be added as a parameter, thereby allowing to choose between Point-to-Point (P2P) and Point-to-Multipoint (P2MP).

PNMN is built up in a hierarchical manner, allowing to calculate different levels of infrastructure deployment (e.g. from Central Office to Street Cabinets in a first level, from Street Cabinets to individual houses in a second level). As the model is structured hierarchically, it is possible to use different deployment models for different parts of the network (see example below), and the level of hierarchies is unlimited.

Building this hierarchical structure can be done top-down or bottom-up, depending on whether you start by dividing the entire area into smaller pieces, or by grouping the lowest level connection points into groups, respectively.

- Top-down: by specifying, for each level of connection points, what area size they should cover or how many connection points will be linked, the area can be divided into smaller pieces, which each can have its own dedicated analytical calculation model.
- Bottom-up: by specifying, for each level of connection points, how many of these connection points should be served by the higher level, groups can be formed. Each group can have its own dedicated analytical model.

The different analytical models have been specified in [5.8] and are visualized in Figure 5-2: simplified street length (a), street length (b), double street length (c), diagonal tree (d) and simplified Steiner tree (e).

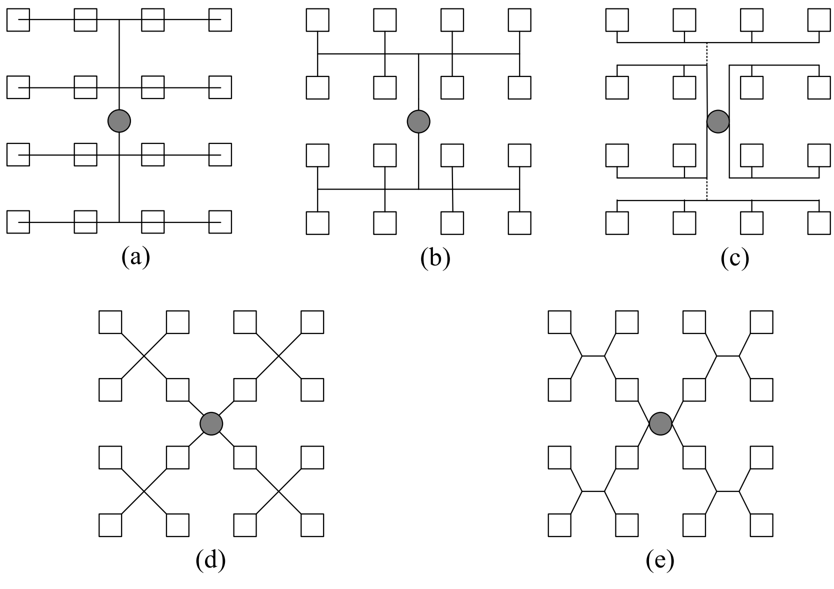


Figure 5-2: Graphical representation of the different analytical models for PNMN

The calculator uses the chosen layout to calculate the installation (trenching) length, as well as the fiber length, based on two parameters:

- n: the number of connection points on one side of the square
- l: the distance between two connection points

The higher-level connection point (grey circle) is always located in the middle of the square.

For the simplified street model, the installation length I and fiber length F can then be determined:

$$I = (n^2 - 1) * l$$

$$F = 4 * l * \sum_{i=1}^{n-1} [\min(i, n - i) * (n - i)]$$

An analogous reasoning can be followed for the other analytical models, for which we refer to [5.9].

In the example given below (Figure 5-3), an FTTH access network with two levels of hierarchy is schematically represented. On the left side of the figure, the feeder section (in between central office and street cabinet) is modeled using direct connections, analytically approached as a diagonal tree structure, while the right hand side indicates the distribution section from the street cabinet to individual houses, which will typically follow the sidewalks and is analytically approached as a uniform double street length model.

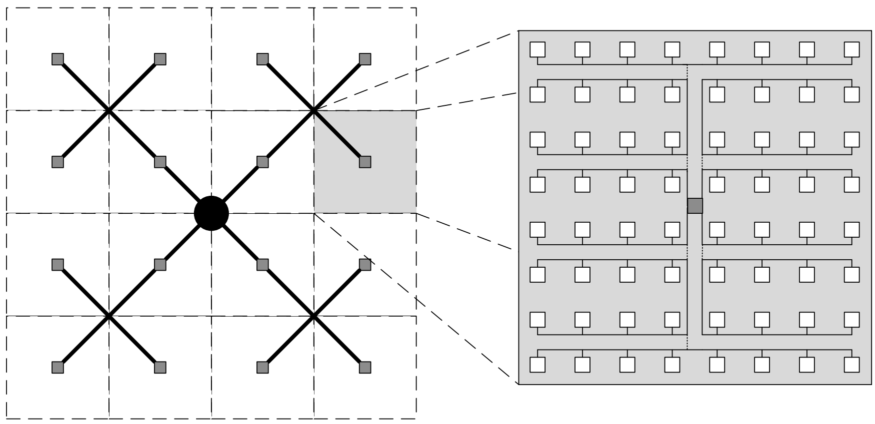


Figure 5-3: Schematic representation of an FTTH access network: direct feeder section from central office to street cabinet (left), double street model distribution section from street cabinet to houses (right).

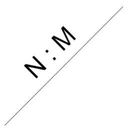
5.1.2 ECMN: Equipment Coupling Modeling Notation: modeling granular equipment placement over time

When tackling the problem of how to dimension a central office, a street cabinet, a server room, etc., one is repetitively having the same discussions and making very comparable calculations. For instance a central office of a telecom operator

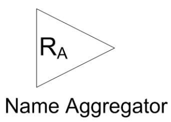
contains ODF racks and System racks in there. A System rack contains at max 3 (sometimes 4) shelves and each of those shelves can be equipped with a predefined amount of OLT cards. Finally this amount of line cards will be directly correlated to the amount of customers to serve via this central office. Calculations of the dimensioning are as such clearly hierarchical in nature. For instance the amount of shelves will depend on the amount of OLT cards which is in turn dependent on the amount of customers to connect.
ECMN draws from this hierarchical structure and allows determining the amount and cost of equipment to be installed. By installing only the equipment that is needed at each point in time (based on the amounts of drivers), the costs of equipment are spread out and the investing firm receives a direct payoff that can be used to pay back the investment in equipment.
The model is built up of four types of elements: drivers, equipment blocks, connectors and aggregators:

The driver serves as the input for the model, and is as such coupled to the "leaves" of the tree structure. Drivers, as their name indicates, drive the amount of equipment that will be installed. They are linked to equipment blocks by the use of connectors.

The equipment block identifies a type of equipment for which the needed amount (and cost) over time needs to be calculated. Apart from their cost, they can contain other operational parameters such as energy consumption, maintenance, etc.



The connector connects drivers, equipment and aggregators to each other. The granularity factor links the different levels of equipment types, by indicating the maximum number of equipment of the lower type (children - N) that is needed before a new equipment of the higher type (down flow parent - M) is to be installed.



An aggregator will combine multiple constraints into one new constraint to link to blocks further in the calculations (down flow parent), thereby linking multiple children to one parent. Additionally aggregators can define how the combination of constraints should be performed by means of a flexible rule set (R_A, e.g. summation, multiplication) indicated directly into the symbol.

Going back to our simplified example of the central office with which we started this paragraph, we can now apply the ECMN to it (Figure 5-4).

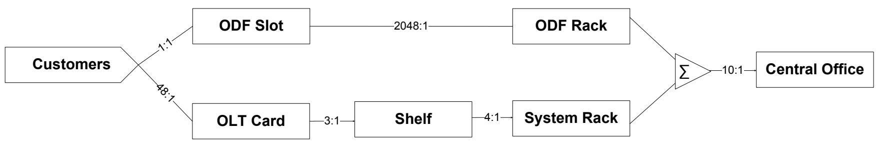


Figure 5-4: Example of an ECMN tree for installation of a central office in an FTTH network

In a first step, a tree structure is graphically drawn indicating the equipment that needs to be installed in the central office, while linking them using granularity factors. In this case, a central office consists of maximum 10 racks (both ODF and System racks), which in turn consist of a number of ODF slots (ODF rack) and shelves with OLT cards (System rack). The lowest level of the tree (typically most left in the GUI) are then linked to drivers, in this case the customers.
In a second step, the needed input parameters are defined per equipment (cost, maintenance, failure rate, power consumption, etc.) and on the entire model (time functions for the drivers initiating the calculation, e.g. the amount of customers that will need to be served in each year). As these drivers are linked to the lowest equipment types in the graphical tree (customers drive the amount of ODF slots and OLT cards), they serve as such as drivers for the higher branches, thereby allowing calculations of the entire tree bottom-up, for the amounts of each equipment type and their costs, both initial investment (Capital Expenditures - CapEx) and continuous costs (Operational Expenditures - OpEx).
The output of the model then indicates the total cost for equipment deployment over time. Figure 5-5 gives an example of an ECMN output for a linearly increasing number of customers.

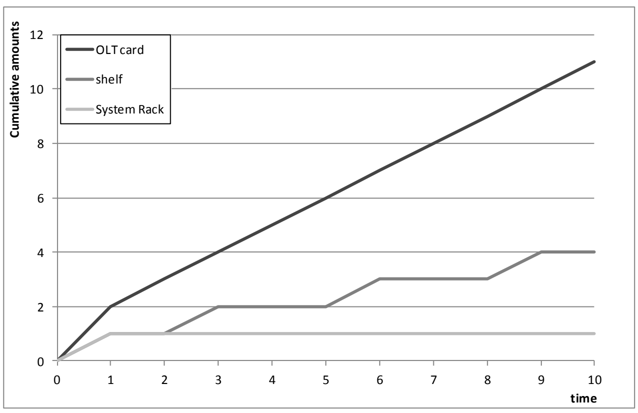


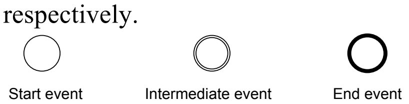
Figure 5-5: Example of ECMN output (amounts of equipment)

ECMN can of course be applied for more and different types of equipment modeling, e.g. the ratio of the different parts needed for assembling a new product based on different requirements, the equipment installed in computer rooms in schools based on the number of students, etc. Additional features allow easy identification of minimal installation sizes, switchover of equipment types over time, aggregation rules based on summation (as shown in Figure 5-4), maximum, average, etc. The calculations render the amounts to install in time, but also the expected cost, energy consumption, space requirements, etc. when the specifications for the equipment are completely filled. For a more detailed description of the modeling and calculation, as well as more detailed examples, we refer to [5.2].

5.1.3 BPMN: Business Process Modeling Notation: using flows to determine the cost of automated or manual processes

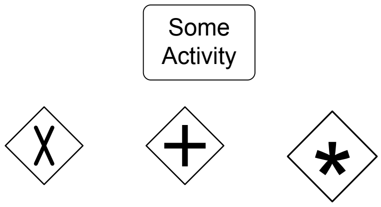
Finally, this section includes a third and final specific cost modeling language for the modeling of processes. When tackling the problem of how to dimension and estimate the costs of executing operational processes such as physical repair processes, installation procedures, etc., one is repetitively performing the same tasks. Although many approaches exist for visualizing the flow of a process, typically by means of some flowchart based modeling language, the link of this flowchart towards estimation of future new costs is not straightforward. There are several tools which allow the user to perform such operational modeling for their current organization with the focus on allocation of the costs to the different departments and predict the effect of small changes in these models.
BPMN (Business Process Modeling Notation) is a well-developed standard [5.10] based on flowchart structures. Processes can easily be translated into flowcharts and BPMN contains a rich set of modeling elements allowing to model even the more arcane process structures. Linking these flowcharts to the right cost parameters (e.g. cost per hour of manual labor), and using activity based costing [5.11]-[5.12], allows for a clear, statistical calculation of the operational process cost for a specific time horizon.

A process model in BPMN is built around three basic building blocks: events, activities and gateways, indicated by circles, rectangles and diamonds respectively.



Events indicate the start, intermediate and end points of the process.

Activities indicate the actions taking place in the execution of the process. They will contain a descriptive name and



can contain parameters for the calculation of the costs.

Gateways indicate splits or joins in the process. Those splits can either be conditional or unconditional and can have multiple incoming and outgoing execution paths of which more than one can be chosen at the same time.

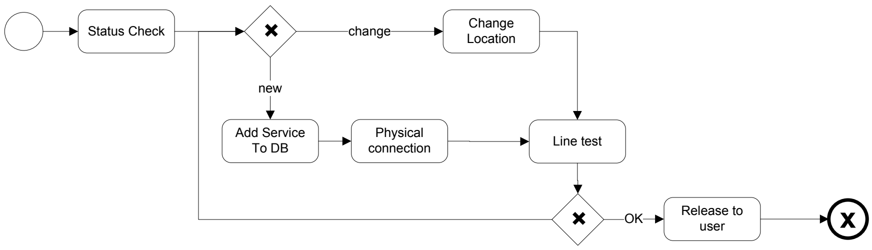


Figure 5-6: Example of a BPMN process for the connection of a (new or existing) customer to an FTTH access network

An example of a BPMN process model is given in Figure 5-6. This is a simplified example of a customer provisioning process, in which the customer wants to connect to the network, or change his existing connection. This process details the different steps that need to be executed in order to complete his request. BPMN already provides all flexibility to incorporate decisions and conditions by exclusive gateways (change/new customer, succeeded or failed line test (OK/NOK)) and fork or join gateways (the line test will only be started if the location has been changed or the physical connection has been formed). By inserting the right information at the different events (time to execute, needed man power, etc.), at the gateways (probability of each paths) and at the start events (number of events per time), the cost for execution of the entire process can be calculated using the activity based costing approach.
Again operational processes are not limited to telecommunication networks and can be used for modeling any kind of process-based work (with manual and/or automated tasks).

5.2 Direct revenue modeling

Once the full network, the equipment and the operational expenditures are modeled, all costs of the business model can be calculated. Still, this is only part of the analysis and should be complemented with a modeling of the revenues for each activity in the business model. Given the costs and the number of paying customers, in combination with a desired profit margin or break-even point, the revenue model will calculate the needed charge per user. As such it has a notion of a fixed pricing scheme but also of an adaptive scheme aiming at break-even or a profit over break-even (cost-plus pricing) with an adjustable timing on when to get up to this point, or a revenue scheme that is adjusted to the yearly costs (running cost-plus pricing).

5.2.1 Fixed pricing

In a fixed pricing scheme the provider directly indicates the price for the customers to pay. There are no additional parameters and calculations. Clearly the fixed pricing scheme can also make use of a timed predefined price.

5.2.2 Cost-based pricing (=cost-plus pricing)

In cost-based pricing the price the provider will charge, will be based on an intended profit margin over the time horizon. This profit margin can be fixed or changing over the time horizon.
The parameters in this pricing scheme are

- P expected profit margin (%)
- N time horizon, expected lifetime of the project

The inputs of this pricing scheme are

- TCO the costs per year, summed and discounted to TCO over N years
- A(i) the customers per year, or the absolute adoption in year i, determined following theoretical adoption curves, such as Rogers [5.13], Bass [5.14] or Fisher-Pry [5.15]
- r the discount rate, typically ranging between 5% and 10% in telecom network investments

For example, we can calculate the revenues needed (per subscriber and per month) based on the known TCO. The following formula is used:

$$\sum_{i=1}^{N} 12 * X * A(i) * \frac{1}{(1+r)^{i}} = (1+P) * \text{TCO over N years}$$

The formula takes into account a monthly average revenue per user (ARPU) of X (multiplied by 12 to arrive at a yearly ARPU), the absolute uptake (adoption) of customers and a discounting factor to incorporate the time value of money. By equating this revenue potential to the above calculated TCO, the needed monthly ARPU can be derived.

Figure 5-7 underneath gives an overview of this pricing scheme, based on a decreasing cost function and a desired profit of 10% after a time horizon of 20 years.

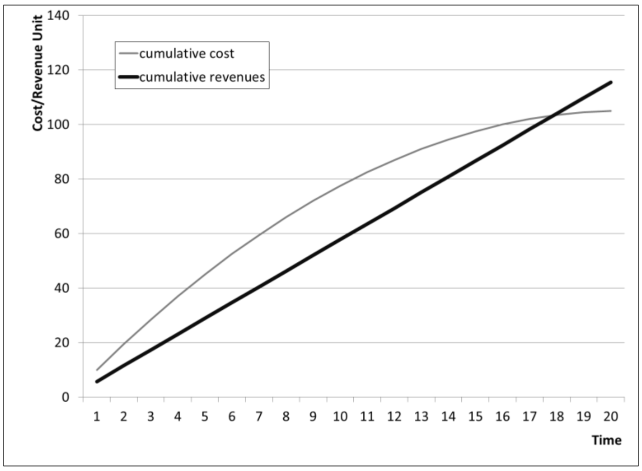


Figure 5-7: Cumulative costs and revenues for a cost-based pricing scheme with 10% profit expected after 20 years

Note that this profit margin can be set to zero for a break-even calculation, or that it can vary over time (e.g. in an early stage, one wants to attract customers by setting a low price – low profit margin – which is then increased after a certain customer threshold is reached).

5.2.3 Running cost-plus pricing

In running cost-plus pricing the price will be based on a short term part of the total costs. It can be mimicked by a repetitive cost based pricing over the short term and with the repetition ending at the total time horizon. Typically the provider would want to have its costs of this year repaid by the customers of the same year taking into account an intended profit margin.

The parameters in this pricing scheme are

- P_i expected profit margin (%) per year
- N time horizon, expected lifetime of the project (in this case infrastructure

The inputs of this pricing scheme are

- C_i the costs per year (which, when summed and discounted, amount to TCO over N years)

- A(i) the customers per year, or the absolute adoption in year i, determined following theoretical adoption curves, such as Rogers [5.13], Bass [5.14] or Fisher-Pry [5.15]
- r the discount rate, typically ranging between 5% and 10% in telecom network investments

The formula is thus adjusted to calculate a varying ARPU (per subscriber and per month) based on the known yearly costs:

$$\text{for year } i = 1..N: 12 * X_i * A(i) = (1 + P_i) * C_i$$

Figure 5-8 underneath gives an overview of this pricing scheme for a decreasing cost function as input, wanting to achieve a yearly running profit of 10% (thus having each year a profit of 10%).

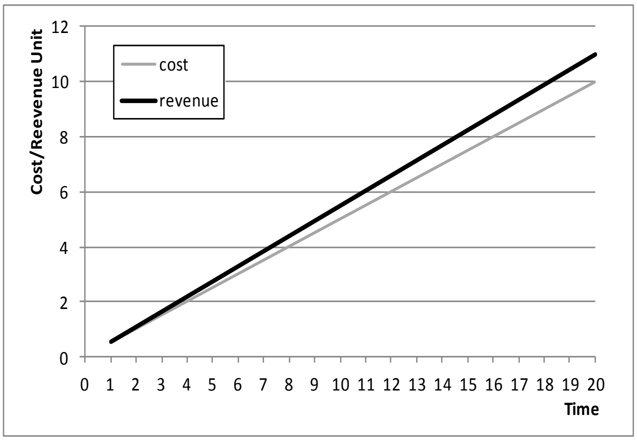


Figure 5-8: Yearly costs and revenues for a running cost pricing scheme with a yearly 10% profit, for a time horizon of 20 years

Additionally the revenue model allows switching between revenue schemes at a given time or condition (e.g. critical customer mass reached). This revenue model allows answering questions on the main economic indicators such as profitability, minimal and advised pricing or payback period.

5.3 Business case analysis for the Physical Infrastructure Provider

Having introduced the cost and revenue modeling specifics, the next section will apply them on the business cases for the Physical Infrastructure Provider (PIP). Deploying the passive infrastructure requires a huge initial investment that consists of manual labor cost for trenching and costs for fiber cables, ducts and micro-ducts. The combination of this outside plant cost with the upfront cost for

installing the necessary passive equipment in the central office and street cabinets (e.g. Optical Distribution Frame (ODF) racks), results in the total Capital Expenditure (CapEx) for the PIP (Figure 5-9). Note that we only take into account the cost for the access network; we do not calculate the in-house cabling and deployment. Typically, this in-house cabling is done by the house owner (in case of single houses), or outsourced and paid by the housing organization (in case of multi-dwelling units). Furthermore, note that all calculations throughout this section are based on a P2P access network topology, because this technology allows more flexibility in terms of unbundling and open access (see also chapter 3 and 7). Although this chapter analyzes P2P infrastructure, it has to be mentioned that the cost of deploying a P2MP network will not differ significantly, as the main part of the cost for physical infrastructure deployment (up to 80%) is spent on civil works [5.16], which are similar for both topologies.
Apart from the upfront investments, there are also costs during the lifetime of the infrastructure: a cable may break, which requires digging and splicing to repair, and renting costs for the floor space in the central office have to be paid every year. These yearly recurring costs are grouped as Operational Expenditures (OpEx).

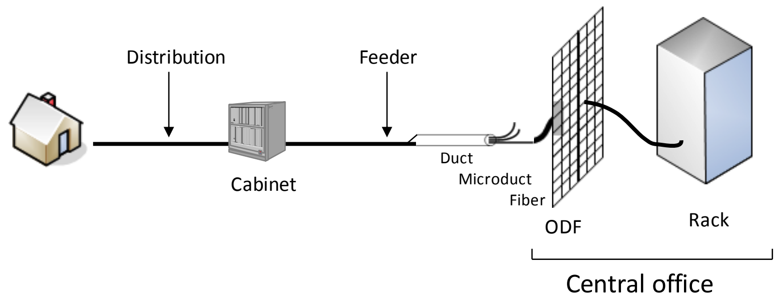


Figure 5-9: Overview of the passive infrastructure in an FTTH network

The summation of both the upfront investment (CapEx) and the costs for keeping the network up and running (OpEx) results in the Total Cost of Ownership (TCO) of the passive infrastructure, which was modeled in more detail in [5.17]. The main parameters are summarized in Table 5-1. Please note that the values of these parameters, as well as the financial parameters that will be introduced later, were verified by European telecom operators and vendors, and checked with main sources in literature. They therefore are reliable for evaluation of FTTH deployment in Europe, but should be revisited when analyzing other deployments abroad. This can either be done using other input sources, or by following a more general sensitivity approach.

Table 5-1: Unit costs for different parameters, possibly varying over area types

Parameter	Dense urban	Urban	Rural
Trenching (per m)	€50	€35	€20
Duct (per m) – depending on diameter	€3 – 6		
Fiber cable (per m) – depending on number of fibers per cable	€0.3 - €1.7		
Outdoor Cabinet	€7500		
Floor space (per m^2 per year)	€220	€110	€170
Labor cost (per hour)	€45		

The evaluation will be done for three area types: dense urban, urban and rural (for a detailed description we refer to section 4.1.1) and three adoption types: conservative, likely and aggressive, that reflect the uncertainty in uptake of customers over time. To model different levels of generic curves, input values for three countries were chosen, because they represent typical deployment and uptake status in Europe (Figure 5-10). The likely curve represents an average adoption uptake and speed, and is modeled based on the forecast for the Netherlands (where some fiber networks are already present). The aggressive curve models a fast uptake of a large-scale deployment and uptake, as forecasted for Slovakia, while the conservative curve is based on the forecast for Germany, which has a lower speed of adoption than average.

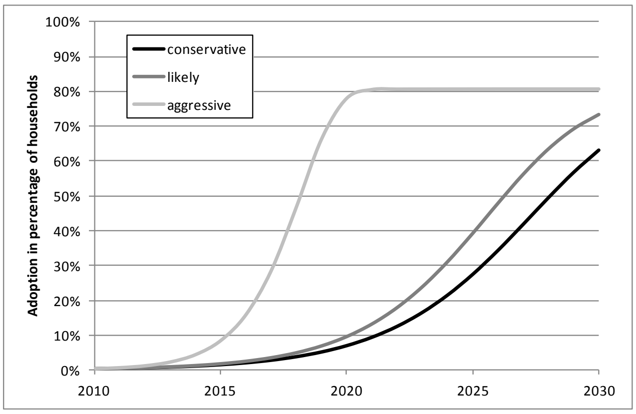


Figure 5-10: The adoption curves for the scenario studies

5.3.1 Total Cost of Ownership for the PIP

When calculating the TCO of the physical infrastructure for the three areas, the differences in number of users and average distance covered per user are clearly reflected (Figure 5-11). For the reference scenario, we use a planning horizon of 20 years (based on the typical estimated lifetime of the passive network [5.18]-[5.19]), and a discount rate of 5%, which is based on the reference discount rate for a low-risk investment [5.20]. As the PIP cost is nearly entirely driven by upfront distance-based trenching cost, there is negligible impact from the adoption curves, therefore only the results for the likely curve are shown here. When considering the cost for the physical infrastructure spread over all potential customers (cost/HP = cost/ home passed), we clearly see that this is growing with a decreasing household density and therefore increasing trenching cost per household. Note that the cost/HP in the dense urban area (572 euro) is doubled in the urban area (1094 euro) and tripled in the rural area (1764 euro). On the other hand, the TCO for the physical infrastructure also reflects the overall surface and total amount of customers per area. Here, we observe that the overall cost for the rural area (5.40 million euro) is significantly smaller than that for the urban area (9.45 million euro), which is only based on the significantly lower amount of customers. The cost for the dense urban (8.92 million euro) is only slightly smaller than for the urban area.

As the initial investment for the trenching takes up the highest part of the deployment cost, this is also reflected in the ratio of CapEx versus OpEx. As mentioned before, the CapEx consists of the upfront investment in trenching, cabling and passive equipment, while the OpEx denotes the maintenance, repair and floor space costs, which is considerably lower.

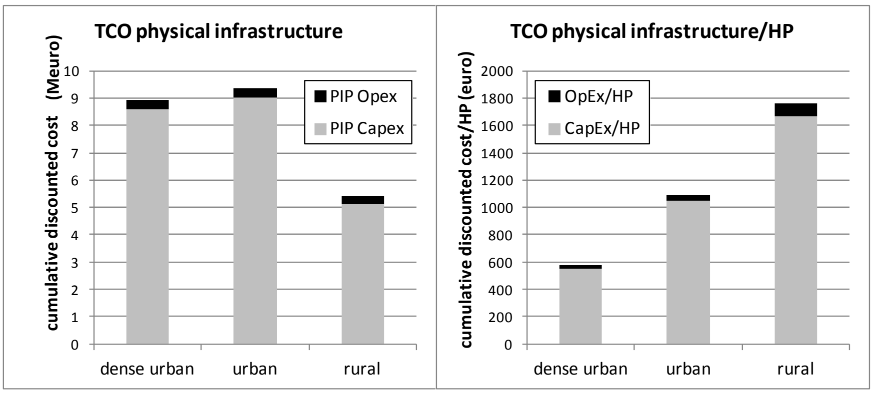


Figure 5-11: Total Cost of Ownership for the PIP, cumulative and discounted over 20 years (for the likely adoption curve)

5.3.2 PIP business case over 20 years

When using the revenue model explained in section 5.2.2 to calculate the needed monthly ARPU for break-even after 20 years, we notice a large spread over the different areas and adoption curves (Figure 5-12): from €8.6 for the dense urban area to €26.5 in the rural area, for the same aggressive adoption curve. When comparing the areas on the likely and conservative adoption curves, the difference only gets bigger.

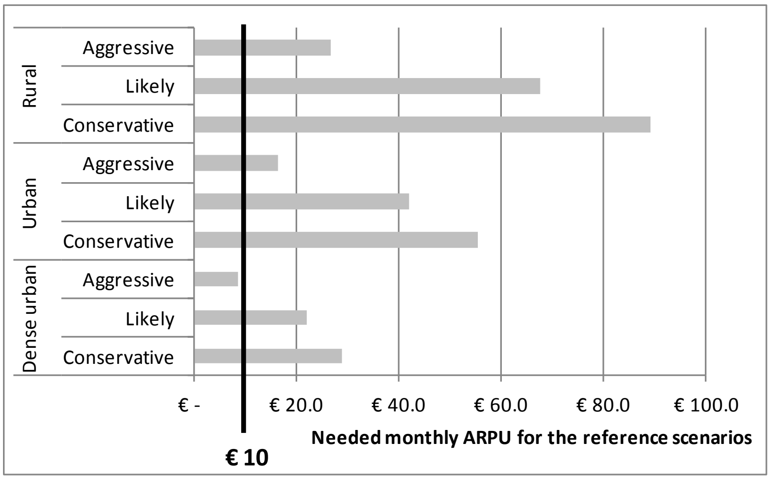


Figure 5-12: Revenues needed per subscriber per month for the physical infrastructure for the reference scenarios

Although this range proves a relevant outcome, comparing the results to realistic values is needed to provide a good benchmark. Despite massive changes in the telecommunications offer (from voice and analogue TV to Voice over IP, digital TV and fixed and mobile broadband), the total household spend on communications services, as well as the allocation of this amount over the different types of services, remains static over time [5.21]. Revenue models for funding the physical infrastructure can therefore be based on (i) regulated DSL or fiber unbundling offers, or (ii) on revenues from existing cases. Please note that the revenues mentioned below are values found at the moment of executing the study (mid 2013), and could therefore slightly have changed.

In the first case, we can expect the PIP revenues to fall in the same range as the current DSL unbundling offers, since new fiber alternatives should be able to compete with existing DSL offers, especially in (dense) urban areas. We therefore compare revenues for an FTTH infrastructure provider with the charges OLOs (Other Licensed Operators) currently pay to the incumbent for unbundling of the local loop (LLU) in DSL networks. These regulated prices vary amongst

EU Member States, but the average OLO pays between €7 and €10 per customer per month for the use of the unbundled DSL local loop [5.22], [5.23].
Secondly, real-life case studies exist that apply the open access business model with different actors on different layers. Stokab, the PIP in Stockholm for example, charges €5 to €7 per customer per month for dark fiber access in the inner city [5.24]. Another example can be found in the large-scale deployment of fiber in the Netherlands by Reggefiber, which agreed with OPTA (the Dutch National Regulatory Authority) on prices for ODF access on a regulatory basis [5.25]. These prices varied between €7.39 and €25.39, depending on the number of individual fiber pairs and the CapEx per household. However, Reggefiber has recently adjusted its fiber tariffs, stepping away from different pricing schemes for different regions. As of January 1st, 2013, the operator can choose to apply the varying tariff or to use the average national charge of €16.39 [5.26], [5.27].
Averaging these different sources, we can assume that a future PIP can expect around €10 per customer per month. This value will be used as a reference for the remainder of our calculations of this section. Comparing this €10 average to the needed revenues (Figure 5-12), learns that only in the dense urban area with aggressive adoption curve this €10 suffices to achieve a viable business case over 20 years.

This means that in all other cases the monthly revenue of 10 euro for the PIP does not suffice to cover for the costs (Figure 5-13). This observation can be interpreted in two ways. Either the observed time frame of 20 years (or the combination of the time frame of 20 years and the used discount rate of 5%) is not appropriate for the evaluation of an infrastructure project as considered here; or 20 years is the right timeframe indeed and the business case simply does not fly based on the current regulatory prices. As such, high investments in fiber access infrastructure can be considered unlikely.
However, referring back to the real-life deployments operational today (e.g. Reggefiber, Stockholm, etc.), we see that the responsible companies are successful and even expanding their rollouts. We will therefore investigate how the business case could be improved in the next section.

One important remark that should be made at this point, deals with the focus of the model. Although the model was built using a bottom-up approach, thereby ensuring that all relevant parts of the technical calculations are included, the model does not take into account business related and management costs, which are also referred to as transaction costs. These transaction costs are part of the cooperation costs that follow an open access model, and will be evaluated as part of chapter 7. Furthermore, recent literature [5.28] has shown that in 90% of investigated large transportation projects, actual costs are higher than estimated costs, on average 27.6%. Since telecommunication access network deployment can be categorized as a large infrastructural project, like roads and railways, it is likely to experience the same effect. Taking these two remarks into account when analyzing the results of the business case leads to a risk that obtaining a zero-NPV in an upfront modeling, fed with realistic data, could still not be economically viable in real-life.

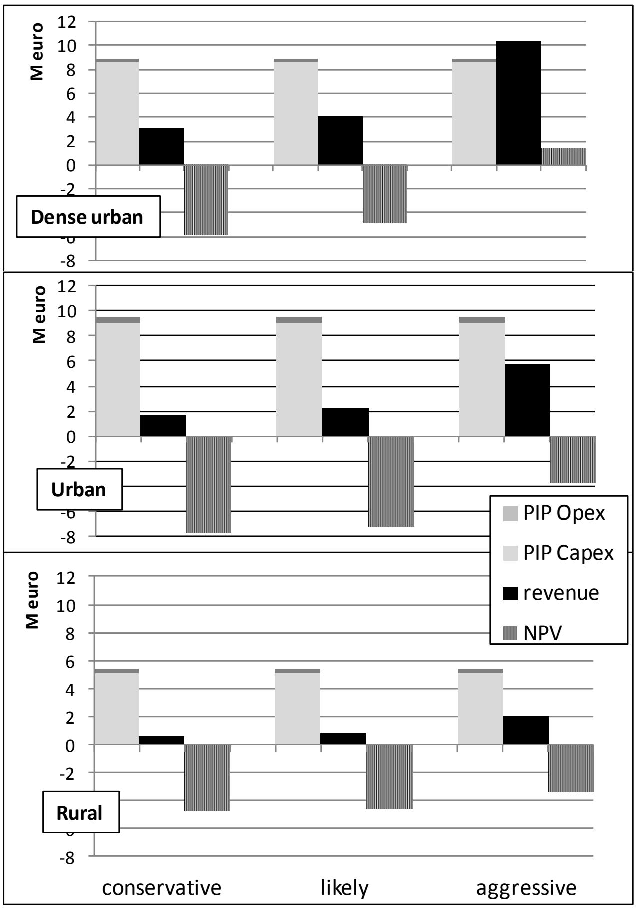


Figure 5-13: Cumulative costs, revenues and NPV for the physical infrastructure for the reference scenarios

5.3.3 How to improve the business case?

Although the results above are based on benchmarked input data, the results indicate rather negative business cases. When comparing these results with existing deployment cases, among which successful ones (see chapter 4), we can identify a number of differences in market, infrastructural and regulatory parameters. The cost of deployment can for instance be decreased by reusing existing ducts, while the uptake rate can be influenced by demand aggregation. In order to better predict the outcome of future business cases, these types of improvement measures should be taken into account in our cost-benefit analysis as well, which is the subject of this section.

5.3.3.a Impact of demand aggregation

The business case for the PIP is especially difficult because of the combination of a high upfront investment with revenues that have a very slow uptake. One solution could be to have high revenues sooner in the project lifetime. Demand aggregation is a process in which interested customers sign a cooperation agreement before the deployment is started. In this way, areas can be chosen in which there will be a guaranteed uptake from the start. For example, Reggefiber (the Netherlands) requires, depending on the cost for the envisaged area, a level of 30-40% demand aggregation before starting the deployment (see section 4.2.3.a and [5.29]). Google Fiber also applies this strategy in promoting their offers in the specific cities in the United States (see section 4.2.3).

Based on these realistic assumptions, we have modeled the impact of demand aggregation of 20 or 40% on the aggressive adoption curve, by adding this percentage to the expected adoption (see Figure 5-14). We assume however that the curve does not exceed the original maximum adoption percentage.
In the dense urban case, the original aggressive curve already led to a positive business case, which is clearly strengthened by an additional demand aggregation. For the urban area, we see that the negative NPV of minus 4 million euro is halved by demand aggregation of 20% and nearly equaled out by a level of demand aggregation of 40%. The rural case remains difficult though.
Of course, aggregating demand requires extra costs for marketing your offer, and going door-to-door for customer's agreements. This cost however is low compared to the overall gain, and can - to some extent- replace the cost of marketing in a later stage. Another advantage of demand aggregation is a lower uncertainty and a reduction in the cost of upfront revenue estimation.

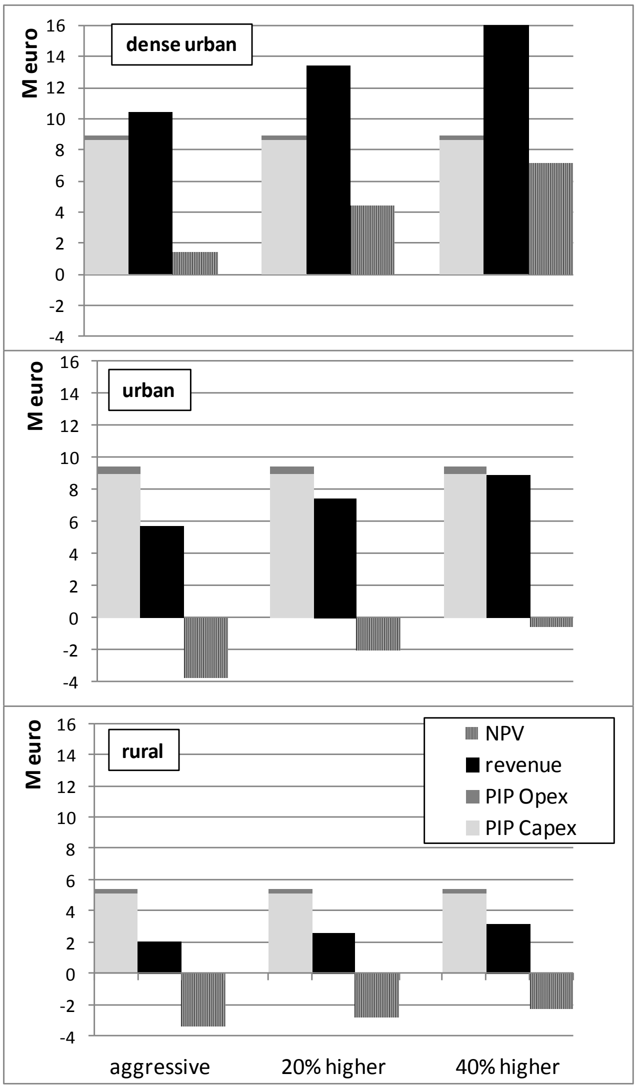


Figure 5-14: Cumulative costs, revenues and NPV for demand aggregation of 20% and 40% on top of the aggressive adoption curve

5.3.3.b Impact of duct reuse

It is clear from Figure 5-11 that the majority of the PIP costs, and by extension of the entire FTTH deployment cost, is in the CapEx. More specifically it is in the trenching and ducting cost (because we consider only buried deployments), which is significantly higher than the cost for the fiber itself [5.30]. In case some parts of the ducts can be reused, this will therefore lead to a significant cost benefit. Actual duct reuse can take different forms. Of course, "old" telecom ducts used in the DSL network can be an option, but for example in Paris, fiber was deployed in sewer systems [5.31].

To quantify the effect of possible duct reuse on the business case for the PIP, we compared three scenarios (the percentages differ for the areas under study and are based on discussions with the project partners of the European FP7 research project OASE [5.32]):

- a greenfield deployment, where no ducts can be reused,
- a “small” scenario, in which between 25% and 70% of the ducts in the feeder fiber section can be reused, and 15 to 20% in the distribution cable section of the network (Figure 2),
- a “large” scenario, with a duct reuse of 35 to 80% in the feeder fiber section, and about 20 to 40% in the distribution cable section.

The variances in duct reuse are explained by a different estimation of the available ducts in the different areas: the availability of ducts will be much higher in a dense urban region, where most probably, an existing telecom network is already present, while the availability and/or quality of current telecom network in rural areas might be much lower.

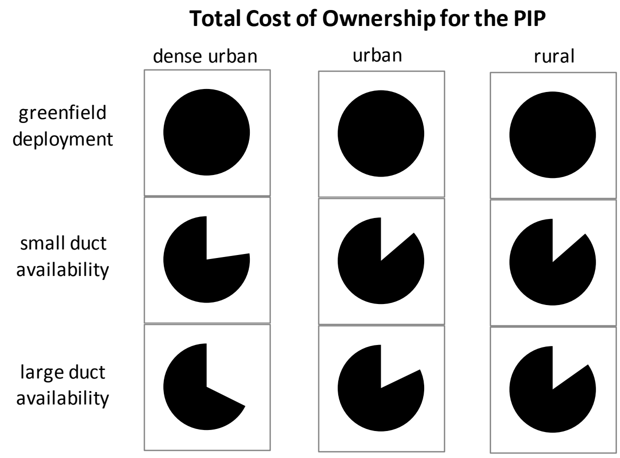


Figure 5-15: Impact of small and large reuse of available ducts on the TCO of the PIP

Figure 5-15 shows the impact of the three levels of duct reuse on the TCO, which clearly is significant. It should be noted that this duct reuse does not always come at zero cost, as owners of the ducts (other operators, utility companies) can charge for their use. In the case an incumbent deploys the fibers in ducts previously used for legacy cables, the costs can be assumed negligible (this is the assumption used here, which follows the views by OpenReach, UK, which report a charge per annum of less than €1 [5.33]). It should furthermore be noted that, when evaluating P2MP topologies, the duct reuse in the feeder fiber section might be higher, as this topology uses a lower number of feeder fibers than P2P, and as such requires less spare capacity in existing ducts [5.34].

Because of the higher duct reuse in the dense urban area, the savings that can be achieved are also higher (savings up to 32% compared to 15% in the rural area). Although reusing ducts proves a significant reduction in the deployment cost, this measure on its own does not make the business case in an urban or rural region.

Reusing available ducts is only one option to reduce the overall trenching costs. These costs can also be lowered by using other techniques, like for example, micro-trenching, which installs the cables in a very narrow trench [5.35]. In the Netherlands, this deployment, immediately in the road, was considered. Aerial deployment using poles or facades is another, cheaper option for deployment [5.36], which has been successfully applied in Cornwall, United Kingdom [5.37]. However, in some countries, aerial deployment is not allowed under regional legislation (e.g. certain regions in New Zealand) or there is, as for example in the Netherlands, “a silent assumption among permitting local governments that new FTTH outside plant will be trenched” [5.38].

Finally, the deployment of FTTH can be combined with other utility network rollouts (e.g. water, gas, electricity, etc.), which can entail cost savings up to 21% [5.39]. The disadvantages of this latter approach are clearly the cost of needed coordination: joint rollout requires synchronized planning amongst all utilities, as well as synchronized operations and repair of the cables. Research [5.40] has furthermore proven that it is not always clear where existing ducts lie exactly, neither is it a foregone conclusion on who owns them. The European Union follows this line of thoughts, as they specify in their guidelines [5.41]: “Member States may decide in accordance with the EU regulatory framework for electronic communications, for instance, to facilitate the acquisition process of rights of ways, to require that network operators coordinate their civil engineering works and/or that they share part of their infrastructure. In the same vein, Member States may also require that for any new constructions (including new water, energy, transport or sewage networks) and/or buildings a connection suitable for NGA should be in place”. These guidelines were made stricter in 2014, as all network operators are now obliged to share details about their ongoing or planned civil works and even meet “any reasonable request to coordinate civil works on transparent and non-discriminatory conditions” [5.42].

5.3.3.c Prolonging the planning horizon

Since the passive infrastructure that is currently providing Internet, the incumbent’s DSL network or the cable operator’s HFC network, has been deployed decades ago, and still has not reached the end of its lifetime (if there would be no need for higher speeds, the copper networks could still be used much longer), it is likely to expect that the same holds for the dark fiber cables (current operators also expect lifetimes of up to 50 years [5.19]). It thus makes sense to prolong the planning horizon, since it is very likely that the dark fiber infrastructure will generate revenues for more than 20 years. Furthermore, prolonging the business case will also extend the adoption curve, leading to a higher adoption potential in a later stage of the project (Figure 5-10). These revenues are not captured in the initial business case with a lifetime of 20 years.

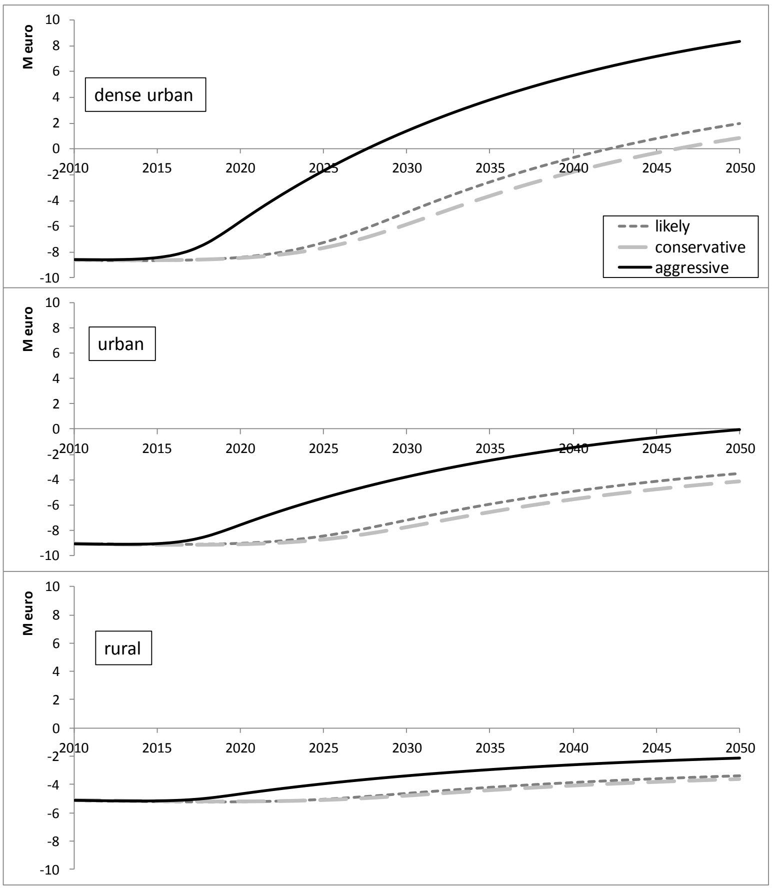


Figure 5-16: NPV curves for a prolonged planning horizon of up to 40 years show a positive business case for dense urban and urban areas

On the other hand, the current economic investment climate is reluctant towards granting loans for long-term payback periods. The argumentation for the long lifetime of the fiber infrastructure should therefore be assured, as some now do by comparing broadband infrastructure to other network infrastructures, such as electricity or water, roads or railways [5.43].

When considering discounted cash flows over a period of 40 years (2010-2050, Figure 5-16), we observe a discounted payback time of less than 40 years in the dense urban scenario, independent from the adoption curve. Also for an aggressive adoption in the urban scenario, we see a positive case in less than 40 years. The rural case, however, never breaks even within the observed time span. The difference between the business case for 20 years and 30 years is much higher than going from 30 to 40 years. This can be explained by two effects. First, in 2030, the adoption curve hasn't reached its maximum potential, so more customers will subscribe in 2030-2040 (while the number of new subscribers between 2040 and 2050 is negligible). Secondly, the further in the future the revenues are paid, the higher the effect of discounting, and thus the lower the impact on the cumulative revenue. Therefore, we decided not to look beyond a business case of 40 years.

5.3.3.d Additional revenue sources

Results up till now have assumed PIP revenues based on a per customer fee (of maximum 10 euro), in some cases differentiated based on the associated cost (Reggefiber model) combined with an expected adoption for advanced broadband services. We can however imagine additional revenues for a physical infrastructure provider, as the dark fiber he deploys could also be of interest to non-telecom customers. These revenues can be significant, as Stokab reported they can add up to 50% of their total revenue [5.44].
Possible additional revenues can come from large businesses or public institutions (like administrations, hospitals, schools, etc.) that want to rent an end-to-end dark fiber connection, and use their own active equipment for lighting it up. This ensures a safe and secure connection between multiple establishments of one enterprise (e.g. a bank). If an FTTH network is present, it can also be used as a backhaul network for Next-Generation wireless offerings, such as Long-Term Evolution (LTE) networks. The base stations of these networks can be connected to the fixed fiber network, and the wireless operators pay their fair part of the lease.
As these extra revenue sources are very diverse and case-dependent, the quantification of these effects falls outside the scope of this research.

5.3.3.e Combining improvements

Although all separate improvements clearly benefit the economic outcome of the business case, they will most probably not be applied in isolation in real-life cases. Furthermore, the analysis still shows scenarios (especially in the urban and rural region) that do not find a positive outcome. It therefore makes sense to combine the improvements to verify whether positive business cases for those areas can be reached. We chose here to implement a selection of combined scenarios: small or large duct availability, a demand aggregation of 20 or 40%

and a planning horizon of 40 years. These combined improvements were compared to the reference case (which is the aggressive adoption curve, no duct availability, no demand aggregation and a planning horizon of 20 years). Figure 5-17 shows the results for the three regions under study.

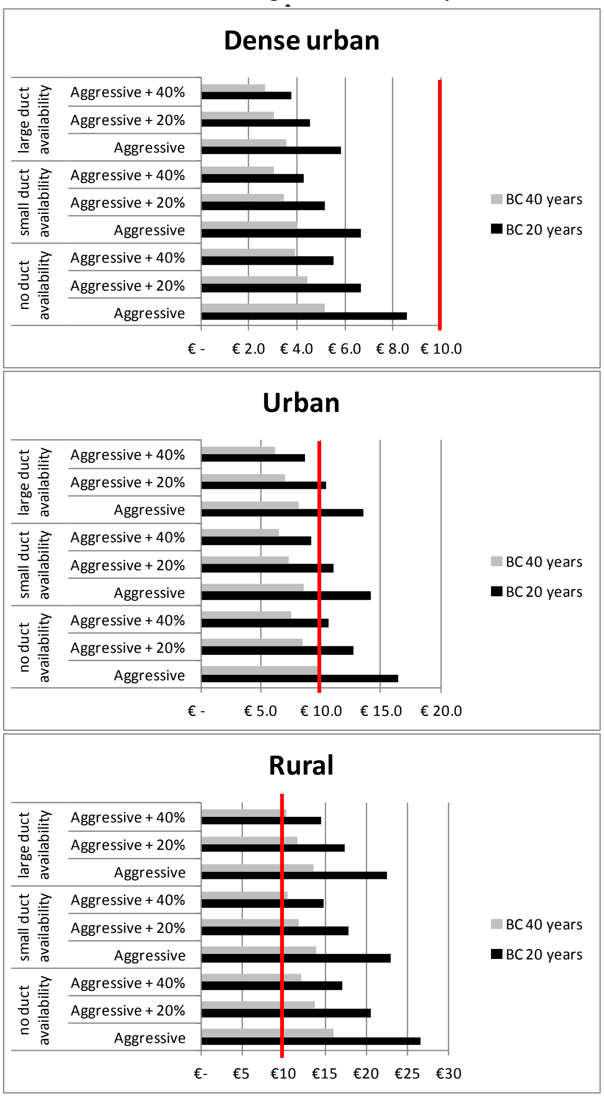


Figure 5-17: Needed revenues per home connected for different combinations of combined improvements for the business case for the PIP

Taking into account the assumed ARPU of €10 per month (red bold vertical lines in Figure 5-17) we see that the business case in a dense urban region is actually very positive, with all scenarios remaining well below this threshold. For the urban area, we see that especially the longer planning horizon proves a significant improvement to the business case. The combination of this longer planning horizon with one other measure (at least 20% demand aggregation or small duct availability) is sufficient to arrive at an interesting economic case. In the rural area, however, these conclusions do not hold and the business case will never prove to be economically viable. Even when being able to reuse about 50% of ducts (large availability, which is a rather unlikely scenario due to the low overall availability of “old” infrastructure in rural areas), attracting 40% of households from the start, and amortize the investment over a time-span of 40 years, the business case still need more than the assumed €10 monthly ARPU.

5.3.3.f Use of State Aid or other public funds

In the previous sections we have indicated that, even when implementing improvement measures, the business case for the physical infrastructure provider remains very difficult, especially in rural areas. Despite of the potential additional revenues from e.g. non-telecom customers, the cost reduction based on duct reuse and the positive impact of demand aggregation on the timing of the revenues, it is clear that there will remain scenarios (combinations of areas and adoption curves) that will not result in a positive business case.

In case the provision of a broadband network is regarded as a service of general economic interest ("SGEI") [5.41], state funding might fall outside the scope of State Aid and therefore could be a solution to make the case economically viable. Otherwise, in case the physical infrastructure is deployed by some undertaking, state funding might still be involved (e.g. in a Public Private Partnership) when the capital placed by the State - directly or indirectly- is at the disposal of an undertaking in circumstances which correspond to normal market conditions. A third option allows Member states to call upon the Universal Service Directive to fund underserved regions. This directive specifies that: “Member States must ensure that the electronic communications services detailed in the Directive are made available to all users in their territory, regardless of their geographical location, at a specified quality level and an affordable price” [5.45]. Finally, when assigning Right-of-Way privileges to operators for densely populated areas, obligations to serve other remote regions can be coupled (cross-subsidizing).

5.3.4 Conclusions on the PIP business case

This section investigated the business case for the physical infrastructure provider in a buried deployment, as previous research has shown that the civil works needed for deploying this infrastructure take up to 70% of the total investment. Different scenarios were calculated, based on reference areas (urban, dense urban and rural), as well as likely, aggressive and conservative adoption

curves. Based on an average monthly ARPU of max 10 euro, the case is only profitable in a dense urban area with aggressive adoption. In the other scenarios, the estimated payback time clearly exceeds the considered 20 years, thereby fiercely increasing the investment risk.
Different improvements to the business case were hence proposed. Demand aggregation ensures a significant market share and therefore revenue immediately after deployment by having interested customers sign a cooperation agreement upfront. A level of demand aggregation of 40% can nearly make all scenarios in urban and dense urban areas profitable. Taking advantage of duct reuse has an important impact on the cost base; and leads to significant decreases of the trenching costs. Reusing ducts results in a very positive business case for a dense urban region, and makes the required investment pit for the urban and rural regions less deep, but does not result in a positive business case. Another option is to look for other types of customers than the pure residential ones: additional revenues from public institutions or businesses (large, medium and small enterprises) can help to improve the case. Furthermore, as we are considering an infrastructure investment here, it might make sense to prolong the planning horizon beyond 20 years. A discounted payback time of less than 40 years was observed in the dense urban scenario, independent from the adoption curve. Also for an aggressive adoption in the urban scenario, we see a positive case in less than 40 years.
Since in real-life projects, these proposed improvement measures will not be implemented in isolation, but combined where possible, this section investigated this combined improvements' impact too. When using more than one improvement measure, the business case for the dense urban area proves to be successful in almost all scenarios; for the urban areas, not all scenarios result in a positive outcome, but successful business cases can definitely be found when directing the market parameters right. We therefore suggest that Member State plans should comprise a balanced set of policy actions to incentivize and supplement private-sector action, with targeted measures for different region types. Private investment should be encouraged by appropriate coordination of planning and rules for sharing physical infrastructure and by targeted financing measures to reduce risk and promote new open infrastructures.

Despite all measures discussed above, even if combined, the business case for the physical infrastructure provider in rural areas seems not to fly. The use of public funds might be the only way out. If the Member State considers the provision of a broadband network should be regarded as a service of general economic interest, state funding might fall outside the scope of State Aid and could therefore be feasible. The same holds when the capital placed by the State is at the disposal of an undertaking in circumstances which correspond to normal market conditions.

The Recommendation on regulated access to Next Generation Access (NGA) networks suggests enabling attractive and fair profits for investors. If implemented, regulated prices for access to fiber networks should therefore fully reflect investment risk for the investing companies. Regulated fiber access prices are only available in a few Member States now (like the Netherlands), however, based on the discussion above we can assume that they will or should on average be clearly higher than the 10 euro assumed throughout this chapter. Furthermore, in order to remove risk for the PIP, fiber access prices can reflect costs in some way, e.g. taking into account distances or area types.

5.4 Business case for the network provider

In this section, we will investigate the business case for a network provider, who is responsible for deploying, activating and operating the active equipment on top of the passive infrastructure. We make the distinction between the traditional architectures and a selection of NGA architectures. For the traditional architectures, we consider a planning horizon of 10 years (from 2010 to 2020), since this corresponds more or less to the typical lifetime of active equipment [5.18]-[5.19]. For the NGOA architectures, we take a planning horizon of 20 years, and consider migration from the traditional ones to the NGOA in 2020 (so that each architecture covers a lifetime of about 10 years).
This section deals with the business case of one NP, meaning that we make abstraction of open access possibilities and competition on NP layer for now (this will be taken up in chapter 7). We therefore only consider service provisioning costs for new customers (as customers cannot change NPs): churn (number of switching end users, see chapter 7.2.3) on the NP layer is set to zero.

5.4.1 Traditional architecture

In this first section, we will focus on the evaluation for the business case for the NP for traditional architectures (P2P Ethernet, in which each end-customer is served by a dedicated fiber from the central office) over a planning horizon of 10 years. We will calculate the NPV and needed revenues per customer for the NP for the nine combinations of regions and adoption curves (dense urban/urban/rural x conservative/likely/aggressive) as described in section 4.1.1 and Figure 5-10**.** Furthermore, we investigate the impact of the Customer Premises Equipment (CPE) cost (which includes the cost for in-house cabling and the ONT and its installation), and look for alternatives to improve the business case. So depending on the scenario under study, the total NP cost contains NP CapEx (Central Office equipment and installation), NP OpEx (operations and recurring costs like energy, maintenance and fault management), Service Provisioning (actual connection of the customers) and CPE costs (in-building infrastructure and ONT, as well as operational expenditures related to those). We will first give an overview of the TCO for an NP, to continue with the evaluation of the NPV and needed revenues for multiple scenarios.

5.4.1.a TCO for the NP

When evaluating the TCO for the NP (Figure 5-18), it becomes clear that this cost is much lower than the cost for the PIP (see Figure 5-11). It is furthermore much more influenced by the actual customer uptake, which can be explained by the fact that the NP only installs new equipment the moment it is needed (i.e. when new customers subscribe), while the PIP deploys everything in the beginning of the planning horizon.

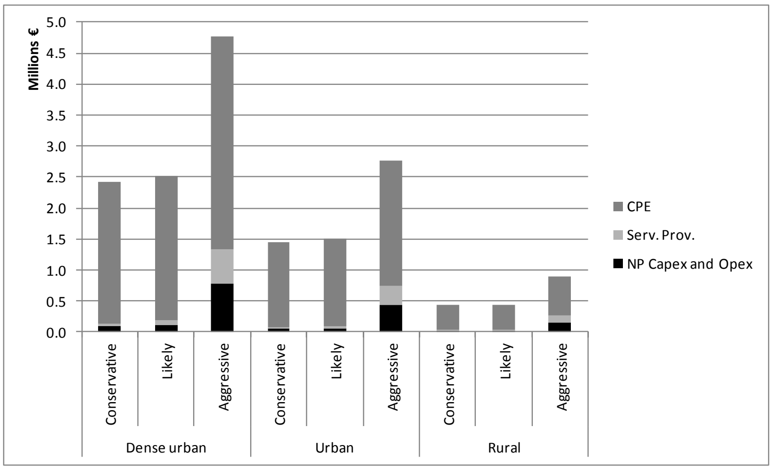


Figure 5-18: TCO for the NP, including NP, CPE and Serv. Prov. cost (cumulative and discounted with 10% after 10 years)

The share each of the three costs takes up is also interesting to evaluate in more detail: the CPE cost is definitely the highest, and doesn't vary too much with the adoption curve, while this impact is more visible in the NP and Service Provisioning cost.

This can be explained by investigating the cost breakdown in more detail. As mentioned before, the CPE cost consists of the cost for the in-house cabling and the cost for the ONT (including installation). While the ONT cost is incurred only when the end-customer actually subscribes, the cost for in-house cabling (better understood as in-building cabling: providing the cables between households in Multi-Dwelling Units) is largely upfront (e.g. when one house organization decides to fiber up all its buildings). The ONT related costs in the CPE will therefore be more impacted by the adoption, while the upfront in-house cabling installation is to a large extent independent of the adoption curve (Figure 5-19).

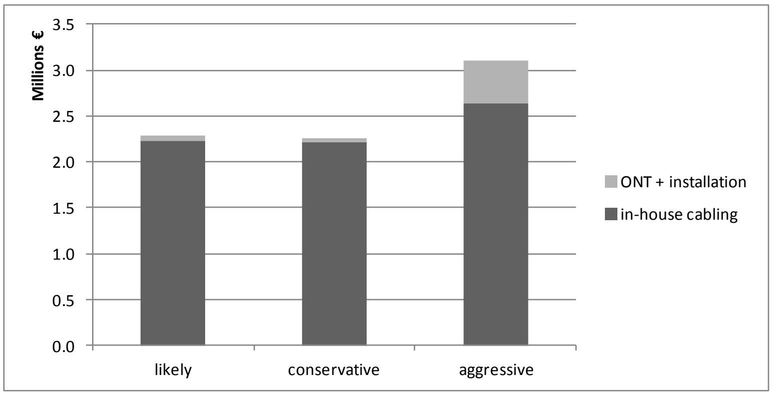


Figure 5-19: Cumulative and discounted CPE cost for the dense urban region (10 years period, discount rate of 10%)

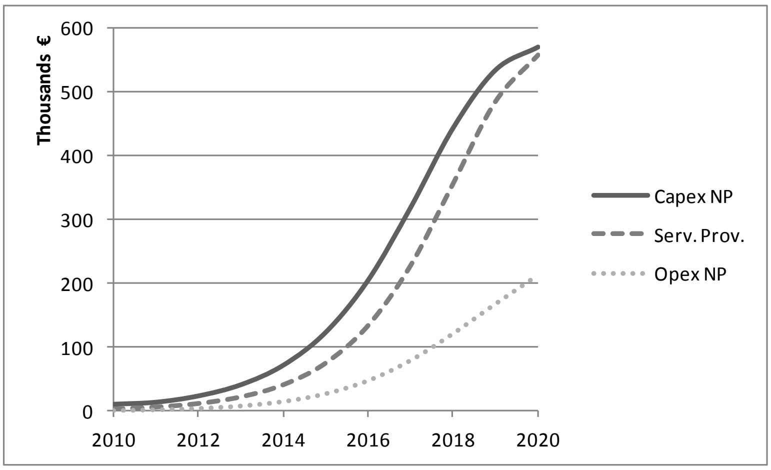


Figure 5-20: Cumulative and discounted NP and service provisioning cost for the dense urban area, aggressive adoption curve

The impact of the adoption curve on both CapEx and OpEx costs of the NP, as well as on the service provisioning is shown in Figure 5-20 (an example for the dense urban area and aggressive adoption curve). The S-shaped adoption curve can be clearly deducted from this graph and thus reflects the time-dependent expenses of the NP. It is exactly this time- or customer-dependency that differentiates the business case of the NP from that of the PIP: for a large part, the NP costs will only be made from the moment the NP has ensured revenue, while the PIP has to hope for a high subscription rate to recoup its huge upfront investments. This leads to a higher uncertainty for the PIP business case, which therefore is subject to higher risk.

5.4.1.b Evaluating the business case for the NP

Keeping the cost analysis as described above in mind, this paragraph will investigate the business case for the NP by comparing the costs with the expected revenues.

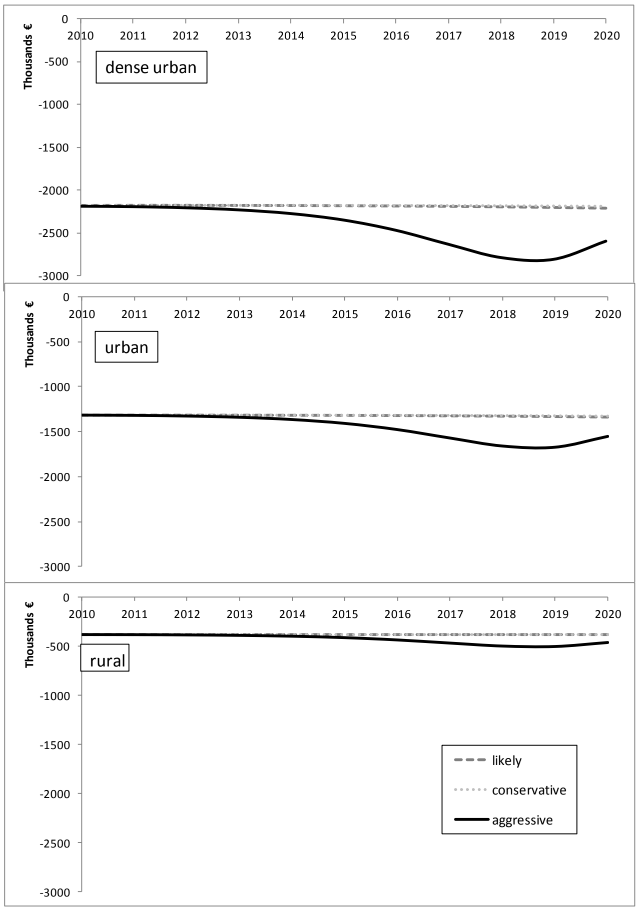


Figure 5-21: NPV curves for the NP business case (likely and conservative curves are coinciding)

When using the estimated monthly customer revenue of €10 (as a first assumption, the NP revenues cannot exceed the monthly revenues for the PIP, given the comparison of needed investment in both layers), Figure 5-21 shows that the business case for the NP is not economically viable. The NPV is negative in all scenarios, and doesn't seem to improve in the long run. This can be explained when returning to the cost breakdown described in the previous paragraph: the large investment pit in the beginning of the planning period is due to the in-house cabling cost that the NP makes upfront, while the extra costs incurred later in the planning period are due to the ONT costs and installation. Although amelioration is seen at the end, it doesn't cover for the high initial pit. The curves are quite similar for the different areas and adoption forecasts (Figure 5-21), it is only the debt of the curve that is different. As will be concluded later is this paragraph, this can be explained by the dependency of the overall NP cost on the number of subscribers.

It is clear that €10 per customer per month will not suffice to cover the business case for the NP (with the forecasted adoption curves and planning horizon), but what is then a realistic price? Figure 5-22 provides the answer: in the aggressive adoption scenario at least about €21 per customer per month, in the likely adoption €75-90 and in the conservative even €90-110! It is thus clear that the business case for the NP in these economic conditions does not fly!

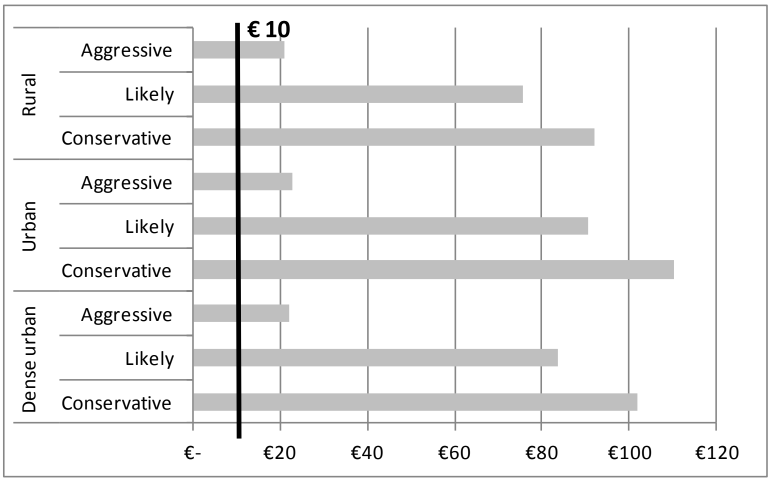


Figure 5-22: Needed revenues (per customer per month) to arrive at a positive business case for the NP after 10 years, including CPE cost

5.4.1.c Possibilities to improve the business case for the NP

From the previous analysis, it has become clear that in the assumed conditions, the NP will never have a positive business case. Other paths should therefore be explored to verify what can be done to better reflect the reality (the business case for the NP is never seen as truly economically unviable). This paragraph will discuss several possibilities, like charging the customer an upfront fee to cover for the high CPE cost, prolonging the planning horizon, ensuring a higher adoption uptake by demand aggregation, etc.

Recouping the CPE cost by charging an upfront fee

From Figure 5-18, it is clear that it is the high CPE cost that makes the business case so negative. This paragraph will therefore focus on finding other ways to recoup these high costs. As shown in Figure 5-19, the CPE cost mainly consists of two parts: the in-house cabling on the one side, and the ONT including installation on the other. Both also incur some operational expenses for fault management and energy consumption (but those are only minor).

How to recoup the in-house cabling cost?

As described above, the in-house cabling is mainly done upfront, when a group of building owners or housing organizations decide to wire their buildings with fiber. This wiring can be done by the PIP, by the housing organization itself, or by the NP. It therefore can be the responsibility of the NP, but this is not necessary. Furthermore, this responsibility is only applicable for multi-dwelling units, since for single houses, the fiber will most likely end at the front door of the customer's premises.

In this case, we assume that the in-house cabling is asked for by the housing organizations, and consequently paid by them. The housing organizations themselves can then recoup the costs by increasing the rent for the apartments with a couple of euro a month.

If we assume 50% of the people living in MDUs, the housing organizations would have to increase their monthly rent with €3-€4.50 (for all inhabitants, independent of their actual subscription to the FTTH network), depending on the area, which is a marginal increase when compared to the average monthly rentals for apartments across Europe.

How to recoup the cost for the ONT and its installation?

When a customer decides to subscribe, a socket and ONT should be installed in his home to ensure the end-to-end connectivity. When comparing to current VDSL or DOCSIS installations, operators frequently charge the customers a one-off installation fee. It thus makes sense to investigate how much this fee would need to be in the case of FTTH ONT installation.

When taking into account that this upfront cost should cover for the ONT, its installation and the possible operational expenditures over a period of 10 years, an upfront charge of about €50 - €55 should be charged to each customer, which is reasonable and comparable to the upfront fees charged by DSL or DOCSIS operators nowadays. It furthermore is not too high, because this fee is charged in the same time period (year) in which the cost for it is made. If costs are only recouped in a later stage, the impact of discounting makes that a much higher fee should be paid then.

What is the impact of excluding CPE costs on the business case for the NP? Following the results of the extra upfront charge and monthly rental increase, which can be assumed as reasonable, we decide now to leave them out when calculating the business case for the NP. The updated NPV curves, which now only include "true" NP and service provisioning costs, are shown in Figure 5-23 (for a monthly customer revenue of €10). It is clear that this evaluation is definitely better from an economic point of view, the business case is positive in every scenario.

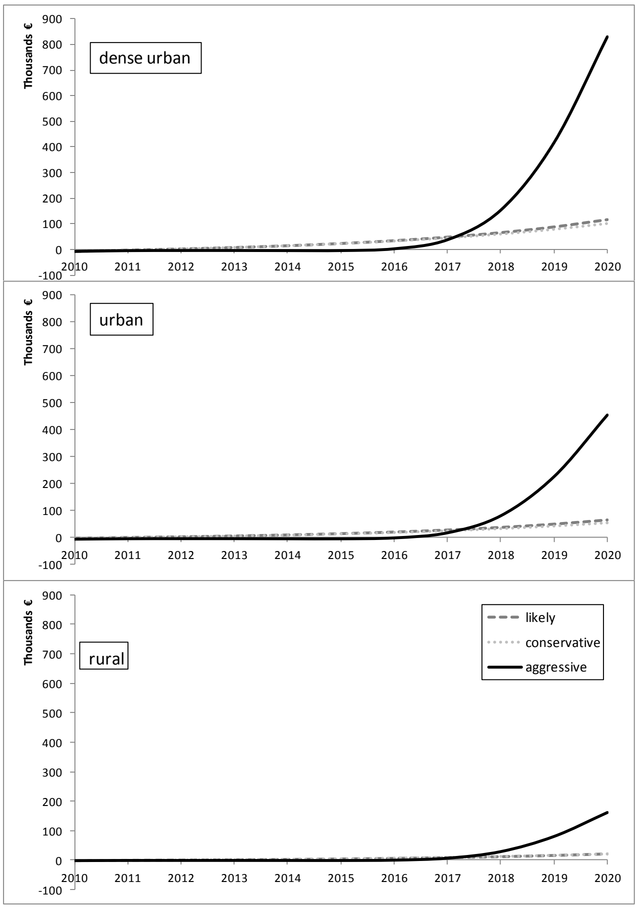


Figure 5-23: NPV curves for the NP business case, excluding the CPE costs, show positive results for all cases (likely and conservative curves are coinciding)

Using estimated monthly revenue of €10 per customer, the results are positive, but how many revenues are now exactly needed? The answer is given in Figure 5-24: €5.75 - €7.50 per user per month, depending on the area and the adoption curve. Although the difference in between area types and uptakes are much smaller than for the PIP results (even invisible in the figure), there is a trend in these dependencies on area type and adoption curve. Similar to the PIP, the cost for deploying active end-to-end connectivity in a dense urban area is cheaper than in a rural area, and thus the needed revenues there will be lower. When looking at the adoption curve on the other hand, we see a different trend: the higher the uptake, the higher the needed revenue. This can be explained by the impact of discounting: in case of the aggressive curve, customers are connected earlier on, so that, although the absolute cost is the same, the discounted cost is higher.

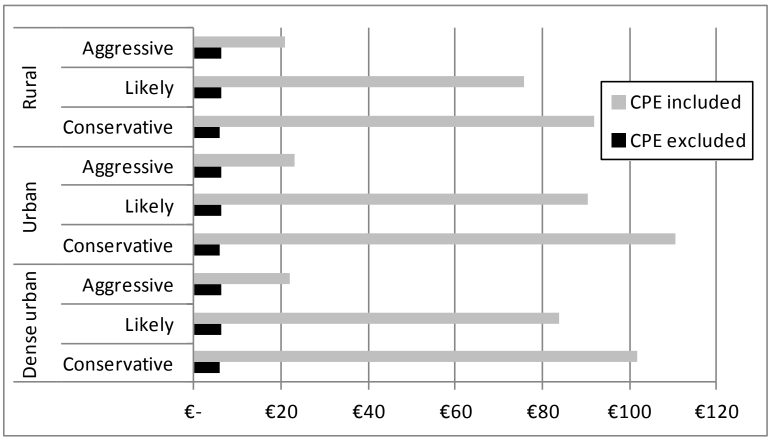


Figure 5-24: Needed revenues (per customer per month) to arrive at a positive business case for the NP after 10 years, for the case including CPE costs and excluding CPE costs

Why are these charges so much lower than the one presented in the business case for the NP including the CPE costs? An explanation can be found in the way the costs are recouped:

- The upfront in-house cabling is recouped by letting ALL households pay a higher rent if the MDU is fibered up, even if the household itself doesn't subscribe to the network (and thus decides not to take an Internet subscription). Dividing the high in-house cabling cost by all residents leads to a very low extra fee (a couple of euro per month), in comparison to a very high fee for the few FTTH subscribers.
- The ONT cost is recouped at quasi the same moment as it is made, which filters out the impact of discounting (i.e. if fees are paid during a later period in time, they are less worth because the value of money decreases over time).

Demand aggregation to ensure take-up from the beginning

Although recouping the CPE costs in one or another way is the most likely option to improve the business case for the NP, we also investigate the impact of demand aggregation: what is the impact on the business case if there is an ensured take-up of 20% or 40% from the beginning of the project?

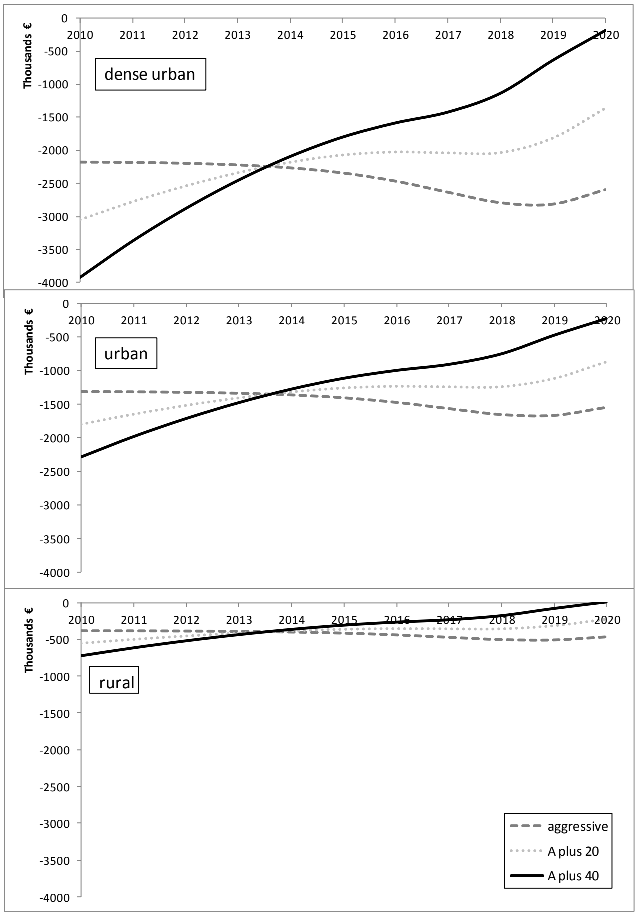


Figure 5-25: NPV curves for the NP business case (including CPE costs) show that demand aggregation improves the business case, but does not make it viable

Figure 5-25 (example of the aggressive adoption curve) shows that there is clearly an improvement to the business case if there is a demand aggregation of 20% or 40%. In the case of 40%, the NPV is almost positive after 10 years for the dense urban and urban regions, and even absolutely positive for the rural regions. The difference in between regions can be explained by the fact that, for the rural region, there is less in-house cabling needed since there are not so many MDUs.

The revenues needed per customer per month shrink sharply to about €13 for the aggressive adoption curve with 20% demand aggregation, and even to about the assumed €10 per customer per month for 40% aggregation of demand from the start.

5.4.1.d Conclusion on the NP business case for traditional architectures

Following the results of the paragraphs above, we can conclude that the business case for the network provider for recouping the investment in traditional architectures (the results follow the example of a P2P Ethernet) is viable, on the conditions that the cost for in-building and ONT (including installation) is recouped in an alternative way. We proposed to recoup the in-building wiring through the housing companies, which in turn can slightly increase their rent, and recoup the ONT cost by charging a small upfront fee to new users.

5.4.2 Business case over 20 years: migration to Next Generation architectures

As mentioned above, the active equipment (network layer) has a far shorter lifetime than the physical infrastructure (10 years on average compared to 20-50 years). If comparing the investment for the PIP with the investment case for the NP, the planning horizon is therefore an important parameter to take into account.

While the previous section calculated the NP business case for a shorter planning horizon (10 years), this section will approximate the planning horizon of the physical infrastructure, therefore taking into account the migration step to Next Generation (NG) architectures in the middle of the planning period (year 10).

Two architectures will be compared: Next generation AON (NG-AON), migration from AON, and time and wavelength division multiplexing (TWDM) PON, migration from GPON [5.46]. For an explanation about AON and TDM/WDM PONs, we refer to section 3.2.2.

5.4.2.a NG-AON and TWDM-PON

NG-AON (Figure 5-26a) is the natural evolution of an AON, active star architecture in which the customer has already been connected by means of Ethernet switches (32 ports switches are used in the study) from the central office (CO) via an intermediate aggregation point at a remote node/cabinet. One of the NG-AON variations is to adopt WDM-PON technology which can be used to backhaul the existing AON active star architecture. In a migration towards a node consolidation strategy [5.47], the first level of (or legacy) COs in the current FTTH network will be closed down, and hence, the OLTs and other equipment in the CO must be relocated further to an aggregated central access node (CAN). In relation to the NG-AON solution, arrayed waveguide gratings (AWG, 1:40) are placed in the legacy CO locations to backhaul all the traffic and forward them to the CAN. In total, this NG-AON can serve up to 32x40 (1280) customers from one feeder fiber. The migration from the existing AON active star to NG-AON (WDM PON backhauling) architecture can be deployed smoothly without changing the fiber infrastructure in the existing distribution network. Some NP equipment in the existing AON architecture (e.g. optical network terminals (ONTs) and Ethernet switches) can be reused in the NG-AON.

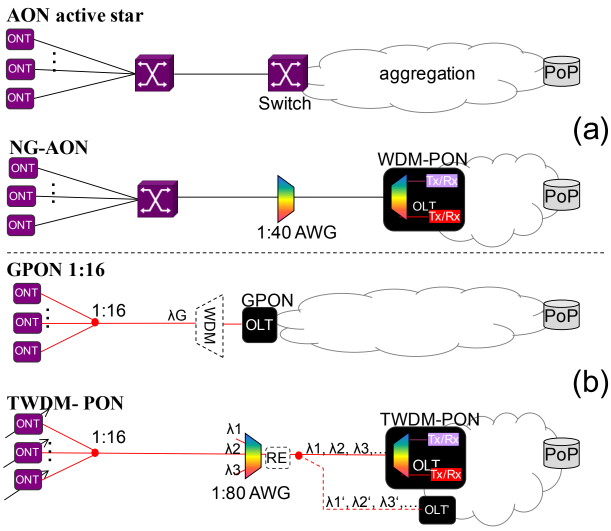


Figure 5-26: Architecture changes for (a) migration from active star AON to NG-AON, and (b) migration from GPON 1:16 to TWDM-PON

TWDM-PON (Figure 5-26b) is a natural evolution of a TDM-PON in which the customer is connected to the CO by means of a power splitter (1:16) (see also section 3.2.2.a). As TWDM-PON solution, we assume that 80 of the existing 1:16 TDM-PONs are gathered further in the network by means of a 1:80 AWG. In this way each TDM-PON has its own wavelength and serves in turn 16 customers in a TDM manner. In total, a TWDM-PON80x16 will serve up to 1280 customers from one feeder fiber.
This chapter will compare the migration costs of NG-AON and TWDM-PON, and indicate how they can be made competitive.

5.4.2.b TCO for both migration paths

The Total Cost of Ownership (TCO) includes both upfront and operational costs, and makes the distinction between general capital and operational expenditures (CapEx, OpEx), service provisioning and customer premises equipment (CPE -

installation and maintenance of the ONT). CapEx include the purchase and installation cost of the equipment in the CO and remote nodes, while OpEx refer to maintenance and energy consumption of this equipment. Patching and administrative costs related to a new subscription are grouped under service provisioning. When calculating the TCO for both migrations, and taking into account a payback of investment within 10 years, it is possible to determine the needed ARPU for the NP for each reference scenario (Figure 5-27). Since we consider two technologies that result from a natural evolution of typical, current deployments (Active Ethernet AON and TDM-PON), we assume a migration towards the new technologies in 2020 (hard migration of all connected customers in one year), as this provides a fair basis for the cost comparison. We will therefore only study the business case from 2020-2030 (a planning horizon of 10 years), and make abstraction of the costs incurred in previous periods.

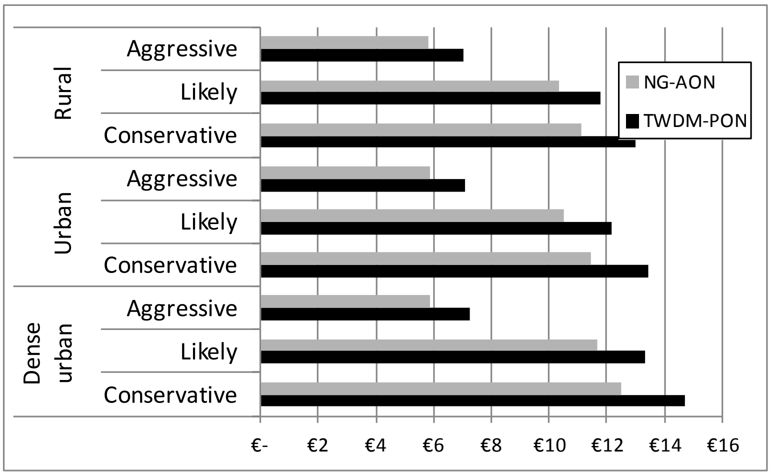


Figure 5-27: Needed monthly ARPU to turn break-even after 10 years, for both migration steps

From this analysis, it is clear that the TCO for migrating from GPON to TWDM-PON is higher than the migration from AON to NG-AON. This can mainly be explained by the need for replacement of the GPON ONTs, while the original AON ONT can be reused. The AON ONT will also need replacement somewhere in the lifetime, but this exchange should not be performed at once.

The CPE CapEx and OpEx (replacement of ONTs for existing customers, new ONTs for new users and in-house installation, maintenance and energy consumption for both) therefore takes up a much higher share of total cost in TWDM-PON than in NG-AON (30-50% versus 10-40% respectively, depending on the adoption curve).

The impact of the adoption curve is also interesting: the higher the initial adoption in time of migration, the lower the needed ARPU, which can be justified by the higher number of subscribers sharing part of the upfront investment (NP CapEx – purchase and installation of CO equipment, as well as CPE CapEx – sharing of in-building installations, see Figure 5-28). The results for the likely and conservative curve show less difference than likely and aggressive, but this can be easily explained by a smaller difference between those adoption curves (see Figure 5-10).

Finally, we see a higher service provisioning cost per customer in NG-AON, which can be explained by the higher cost of physical provisioning required at remote nodes.

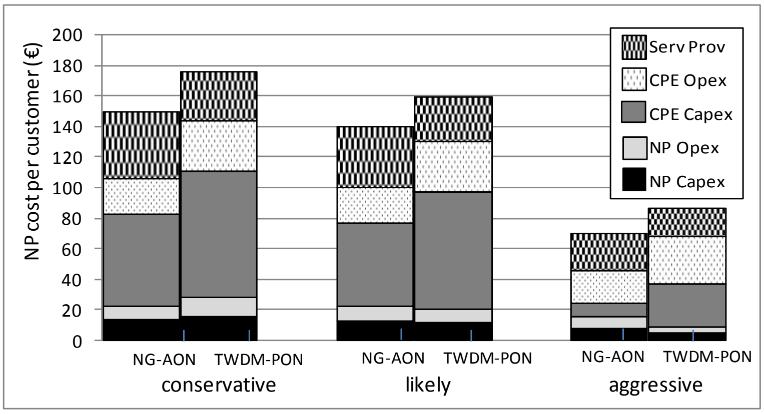


Figure 5-28: Breakdown of the yearly cost per customer for a network provider (Dense Urban area)

5.4.2.c How to improve the business case for TWDM-PON

When comparing the ARPU found above with current FTTH offer prices, we can conclude that the business case for TWDM-PON migration will most probably not hold. It is therefore appropriate to search for improvements.

Since a large part of the TCO can be attributed to the necessary replacement of the ONTs in the PON migration case, recouping these costs in another way might help to reduce the monthly needed ARPU. One option is to charge an upfront fee, marketed as a necessary installation fee for upgrading the customer's subscription.

Charging customers €100 installation fee (which corresponds in order of magnitude to the cost of a TWDM-PON ONT), reduces the needed monthly ARPU to €6 - 12 (in line with NG-AON).

A second option to improve the business case is to spread the cost of migration over time (referred to as 'soft migration'). In this case, all new customers are connected directly to the new technology, while the existing customers are left with the choice for upgrading. In this way, the investment is spread out over a number of 'soft migration years', after which a forced migration upgrades the remaining customers on the old technology. In order to avoid parallel operations of two technology generations, the soft migration period should be kept limited in time. However, for the TWDM-PON architecture under study here, the extra cost of this co-existence is limited (introduction of a migration specific WDM coupler per TDM-PON during the maintenance window), so we study the impact of soft migration over the entire planning horizon (1-10 years) for the exemplary case of an urban area with aggressive adoption (Figure 5-29). The impact of the soft migration is clearly shown as a shift (and reduction, due to the effect of discounting) of the cost migration peak to a later stage. This may lead to savings on cumulative CPE CapEx of 3% for a 5-years-, and even 5% for a 10-years- soft migration period.

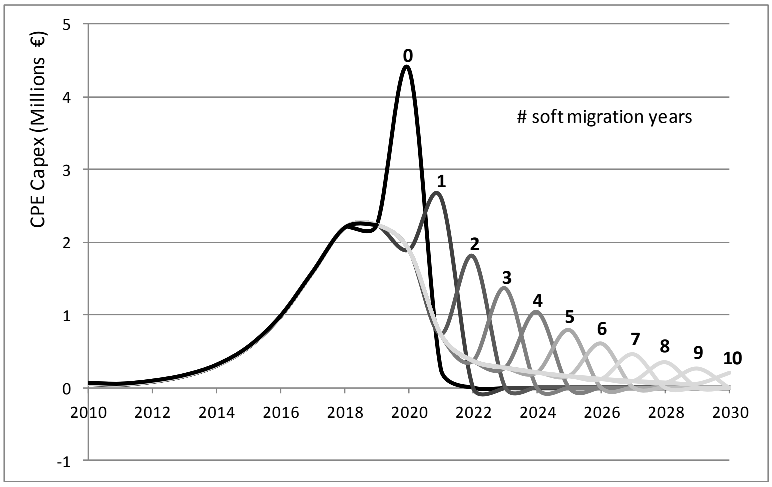


Figure 5-29: Prolonging the soft migration period shifts and lowers the investment peak for the CPE CapEx

5.4.2.d Conclusions of the migration business case

Although the initial CapEx investment in AON infrastructure might be higher than the investment in PON, this analysis clearly shows that upgrading AONs is cheaper than upgrading PONs. On the other hand, if the costs for CPE equipment (ONT, optical socket and installation) can be recouped in another way or spread out over time, this significantly ameliorates the business case for PON upgrade and makes it again competitive to AON.

5.5 Summary and conclusions

The previous chapters showed, by exploring technological, policy and market conditions, that the business case for FTTH investment is difficult. Therefore, before starting the actual production or rollout, a need arises for a detailed modeling and understanding of the different costs that are included, and this for the different partners involved. The business model shows which partners to contact and which cost factors to take into account, but this is merely a starting point. A detailed cost modeling is required in order to get a good estimation of the costs, but also get a look at the potential risks, alternative scenarios, etc. It is important to build such cost models based on expert knowledge and translate this into a model everybody can intuitively understand and which naturally follows the actual cost structure. As such several domain specific cost modeling languages should be used and combined into one overarching model. In a first part of this chapter, we detailed both the cost and revenue modeling languages that can be used in evaluating the business case for FTTH deployment. The first language allows modeling the trenching and cable distance for newly-to-deploy networks, and is based on a set of analytical models. ECMN, the second language, allows calculating the amount and cost of equipment placement by setting up a granular tree structure. BPMN uses process flowcharts to estimate the cost of specific processes. Finally, different approaches for revenue modeling were proposed.

This explanation of the used models was followed by a quantitative evaluation section, which provided the business case results for a physical infrastructure deployment. By calculating different scenarios, based on reference areas (urban, dense urban and rural) and adoption curves (likely, aggressive and conservative), the conclusion was made that the business case is only profitable in a dense urban area with aggressive adoption. In the other scenarios, the needed revenues are much higher than the assumed monthly ARPU of €10, which followed from realistic case studies. It thus made sense to take a closer look at the business case assumptions, and identify potential refinements that can improve the case and hence reduce the economic risk: demand aggregation, reusing available ducts, additional revenues from public institutions or businesses, prolonging the planning horizon, etc. Following these improvements, the business case could be made viable in dense urban and urban areas, but for rural areas, subsidies or state aid measures seem the only way out.

A third and final part of the chapter investigated the business case for the network provider. Although the NP's investment only constitutes 30% of the overall deployment costs, the active equipment has a shorter lifetime (in the order of 10 years), which is also an important factor in the analysis. Two approaches were taken to include the notion of a shorter lifetime: a business case for only the traditional architectures on a 10-year planning period on the one hand, and a business case over 20 years including a migration to NG architectures on the other.

In the analysis of the traditional architectures, the conclusion was made that the business case is viable, on the condition that the CPE costs are not taken into account when calculating the needed monthly ARPU. The cost for in-building networks can be recouped through the housing organizations, while the cost for the ONT (and its installation) are easiest taken into account by charging an upfront fee to new subscribers.

The business case over 20 years compared a migration scenario for two architectures: NG-AON (upgrade from AON) and TWDM-PON (upgrade form GPON). Although the initial CapEx investment in AON infrastructure might be higher than the investment in PON, this chapter clearly shows that upgrading AONs is cheaper than upgrading PONs. On the other hand, if the costs for CPE equipment (ONT, optical socket and installation) can be recouped in another way or spread out over time, this significantly ameliorates the business case for PON upgrade and makes it again competitive to AON.

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6

Modeling for public partners: extension to social cost-benefit analysis

"The Gross National Product does not include the beauty of our poetry
or the intelligence of our public debate.
It measures neither our wit nor our courage, neither our wisdom
nor our learning, neither our compassion nor our devotion.
It measures everything, in short,
except that which makes life worthwhile"
- Robert F. Kennedy

As mentioned already in chapter 2, deploying an FTTH network is not only a technological matter. Following the results of the cost-benefit analysis for the different layers in the FTTH network (sections 5.3 and 5.4), it is clear that, especially for the deployment of the physical infrastructure, the business case is not viable in many areas. Furthermore, the market and policy analysis of several FTTH deployments showed that, in many cases, other actors will be involved in the FTTH network rollout and operations (see chapter 4). Although technical and economical improvements were already suggested and evaluated in the previous chapter, this involvement of especially public actors, such as governments, municipalities or other authorities, makes room for evaluating other benefits an

FTTH network would entail, thereby affecting many, if not all, sectors of the economy and society. Despite an increasing growth of broadband networks combined with a rising number of studies calculating in great detail the direct costs and benefits of these deployments, less attention has been paid to the indirect effects resulting from those emerging applications. This chapter will therefore rely on the results of [6.1] and [6.2] to investigate the field of indirect benefits by both identifying and quantifying them. As these effects have proven to contribute to economic growth, this chapter argues for including indirect benefits in the techno-economic analysis, thereby extending it to a social cost-benefit analysis (SCBA).

After this introduction paragraph, section 6.1 defines indirect benefits, lists the sectors under study, and gives an overview of existing studies. A model for conceptualization, measurement and quantification is proposed in section 6.2, and is applied to the areas of eGovernment (related in particular to savings on travel and waiting time by introducing an e-counter) and eBusiness (related to reducing traffic jams by allowing employees to work at home) in section 6.3. In a bottom up manner, section 6.4 quantifies the indirect benefits in these two sectors by studying two cities: Ghent (Belgium) and Eindhoven (the Netherlands), chosen based on comparability regarding number of inhabitants and information-intensive enterprises, size, presence of university, etc. By quantifying these benefits per actor, we show that the indirect benefits would provide large businesses and local authorities additional incentives to stimulate investment in broadband networks. The results are benchmarked to the results of previous studies in section 6.5, and linked to regulations and investment decisions in section 6.6. Finally, section 6.7 concludes this chapter.

6.1 Indirect benefits: what, and more importantly: why?

Conventionally, investment in broadband access networks has been evaluated using the narrow focus of cost-benefit analyses (CBAs), which indicate that investments needed to upgrade current networks are huge and can hardly be covered by customers' incremental monthly subscription fees [6.3]-[6.4], but which insufficiently identify indirect effects generated by e-services emerging in sectors outside of telecom. Based on the Bresnahan and Trajtenberg's concept of general purpose technologies [6.5], however, it has been shown that broadband infrastructure can act as an enabler supporting an endless variety of applications using the Internet as a platform [6.6]. As such, broadband access networks are pervasive technologies affecting different sectors of the economy in providing opportunities for growth of new e-services in a complementary manner. If these complementarities are taken into account, CBAs have to focus in great detail on the conceptualization, measurement and quantification of indirect effects [6.7].

We argue that indirect effects of broadband infrastructure should be taken into account in the evaluation of broadband deployment projects as these effects are responsible for economic growth and thus necessary to account for the full impact of broadband deployment and uptake. Since Aschauer's original argument [6.8] that there may be substantial discrepancies between the results of conventional CBAs and the ultimate effects of such investments on welfare, research in the public choice tradition has increasingly focused on the existence and the quantification of indirect effects. Furthermore, the "Guide to Cost Benefit Analysis of Investment Projects" [6.9] stresses the need for incorporating the socio-economic benefits in the project objective and evaluation, but acknowledges the difficulties in predicting and quantifying all impacts of the project[6].

6.1.1 Many terms, one definition?

Indirect effects, social benefits, induced effects, uncaptured value, etc.: there are many terms to indicate the extension of a traditional cost-benefit analysis to a social cost-benefit analysis. Before explaining the model used for identification, categorization and quantification, let us first start by giving a definition of indirect effects.

Forzati et al [6.12] write about *uncaptured values* and identify them as "an important portion of benefits which are not necessarily internalized and represented by the end-user willingness to pay for specific services". In a study by Eijgenraam et al. [6.13], *indirect effects* are effects that are not a direct consequence of the project, but which follow from the direct effects. Common examples they mention are re-distribution effects, cluster effects, welfare effects and efficiency improvements. An investment in infrastructure (road or railway) could on the one hand lead to a higher clustering of certain activities, which induces higher economies of scale (e.g. production of certain regions is grouped), but on the other lead to a higher spread of other activities, which in turn induces a reduction in traffic costs. As such, they argue that the indirect effects should always be evaluated case-by-case, as they frequently involve trade-offs. They furthermore mention the notion of *external effects*, which are defined as unwanted, non-priced effects on the welfare of those who will not directly be a consumer of the project. Good examples here are consequences of infrastructure projects for the environment and nature.

[6] It should be noted though that the context and historical developments strongly affect these effects. Recent work (e.g. [6.10]-[6.11]) suggests that ICTs do not always lead to productive uses by people. For more details, we refer to section 6.5.2.

The “Guide to Cost Benefit Analysis of Investment Projects” [6.9] makes the distinction between indirect effects and indirect network effects. *Indirect effects* are “effects outside the transport market as the result of a transport initiative, typically including changes in output, employment and residential population at particular locations”. They mention the example of people moving because of better connections to their work due to new infrastructure. *Indirect network effects* are “effects on the transport network of choices made in other markets (land and property markets, the labor market, product markets and the capital market), as a result of changes in generalized costs brought about by a transport initiative”. For instance, they mention a change in the way traffic flows due to the moving of many households because of the installation of a new infrastructure.

In this work, we will use an intermediate, more generalized definition, stating that *indirect benefits are benefits for one actor, caused by actions of another actor. Indirect effects from a network deployment are not limited to the telecommunications sector only, but spread out to the entire economic, social and cultural environment.* Examples include savings that can be made from keeping elderly longer at home, benefits from e-learning and possibilities for businesses and their employees (teleworking, cloud computing etc.).

6.1.2 Impact on sectors outside of telecommunications

Introducing broadband or more specifically, Fiber-to-the-Home (FTTH) networks will entail new services in many sectors outside the telecommunications domain Figure 6-1.

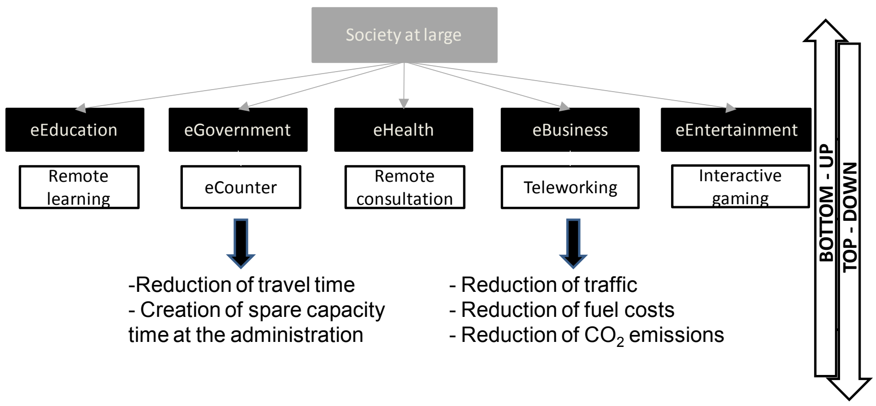

Figure 6-1: Overview of sectors influenced by indirect effects of broadband

Reliable eHealth services, for instance, can reduce the amount and length of hospital stays and home visits. Another example is the effect of videoconferencing on both eEducation and eBusiness, which allows following courses or working from home, thereby significantly reducing transport needs and time. Also in other sectors, such as eGovernment and eGaming, similar savings effects can be found. In investigating a number of sectors, [6.14] concluded that the cost savings in just four sectors of the economy (particularly transport, health, electricity and education) would justify the construction of a nationwide FTTH network. Although having looked at different sectors of the society, this chapter will only focus on two specific sectors where most indirect benefits can be expected in the near future [6.15]: eBusiness and eGovernment.

6.1.3 Evaluating indirect benefits

Literature has just started to provide conceptual frameworks to examine these indirect benefits. In the discussion on the "real" benefits of broadband infrastructure for economic growth [6.16]-[6.17], rarely any agreement has been reached with respect to common methodologies and appropriate data sources to measure and evaluate these benefits. Although there have been a few studies focusing on the value of these indirect benefits, they have not been consistent and frequently not transparent in describing their methodologies. It is furthermore not always clear if the baseline for comparison is a low-speed connection (e.g. dial-up), broadband (e.g. ADSL) or no Internet connection at all. The authors are aware of the fact that this study is not the first in its sort, but do however believe that the identification, categorization and quantification processes used overcome some pitfalls of previous research. This section will therefore shortly compare with previously published models, which are divided into two categories: bottom-up (the approach used later in this chapter) and top-down. Top-down models use statistical methods on macro-economic data to draw conclusions about trends and causal effects. A bottom-up model, on the other hand, starts from the added value of individual effects, which are later summed to get an overall effect on society. Although this paragraph will focus mostly on the benefits of the bottom-up model that will be introduced in this chapter, we admit that both bottom-up and top-down models can be complementary in evaluating the value of indirect benefits.

6.1.3.a Top-down

First of all, the comparison with top-down approaches should be made. Top-down approaches are models which use macro-economic input data in statistical evaluation models, such as regression or input-output analysis. Katz et al. [6.18], for example, investigated the impact of broadband on the German economy, using input-output analysis on two investment scenarios: a national broadband strategy (50 Mbps for all by 2014), and an ultra-broadband strategy (at least 50 Mbps on VDSL, 100 Mbps on fiber by 2020). Another recent study calculates the effects of FTTH-FTTx on employment and population evolution in Sweden [6.19]. They apply a multivariate regression analysis, but only use a limited number of time periods (2007-2010). Finally, we refer to the research of Ida et al. [6.20], who use a mixed logic econometric model on the results of a large-scale survey to estimate the willingness to pay for services over FTTH in Japan. Here, the main drawback is, as mentioned in [6.21], that “people often don’t know what their willingness to pay for a product is, until they are required to make a purchase”.

The main advantage of using top-down approaches is the theoretical underpinning of the models themselves, which improves the reliability of the results. However, since most models experience a large degree of complexity, they are frequently misused and results are often wrongly interpreted. Furthermore, statistical models only indicate a correlation in between parameters, but do not procure causal insights of individual effects and benefits. A final, and perhaps most important, drawback of these types of methods is the use of macro-economic data, which allow only for ex-post evaluation. Of course, predictions of future behavior can be asked for in surveys (as was partly done in [6.20]), but these data are rather subjective and can be biased.

6.1.3.b Bottom-up

Following the argumentation described above, we opted for a bottom-up quantification, because (i) the possibility of forecasting, (ii) the (causal) relationship of individual effects and their subsequently generated benefits. This paragraph will describe some previously published bottom-up studies and indicate where they are different from the methodology used in this research.

The methodology of the New Zealand Institute [6.22] is comparable to the methodology used in this chapter: they also start from a number of sectors, for which they expect indirect benefits. Evidence and values for these indirect effects are gathered from national and international sources. The main difference is that they quantified the value for each effect at once, and did not start from the value per individual or unit, as will be done in this chapter. The methodology is therefore less detailed, and risks double-counting effects by grouping them.

The study of Columbia Telecommunications [6.23] is less transparent in its methodology, the main similarities with our study are that they also used a categorization tree, they only quantified actual monetary savings, and they used interviews with experts on the field to identify the effects and gather input data. This study claims to evaluate the benefits of high-speed broadband on top of traditional broadband, but a meta-study by Hayes [6.15] shows that these assumptions do not hold.

The study that matches best with our study in methodology used is the study by Price Waterhouse Coopers [6.21]. They also investigated the effects of different specific applications using the bottom-up approach, and made the distinction between adoption of broadband in general and the adoption rate of the different applications. While in that study, only an overall economic benefit was calculated, this study adds the allocation of the benefits to the different actors. They furthermore included the quantification of subjective and large environmental effects (e.g. opportunity cost of time involved in commuting related to salary, the cost of traffic congestion and the effect on the climate change), which we did not consider. Finally, the willingness to pay (WTP), which was estimated as the current subscription revenues, was attributed to the direct benefits in the overall economic total. We however believe that this WTP of customers does not necessary equal the current average revenue per user (ARPU); in a lot of European countries where there is a lack of competition, broadband subscription rates are sometimes said to be kept artificially high by incumbents, as regulatory authorities see the need for setting price caps and defining access regulation [6.24].

The final study we want to mention is The Guide to Cost Benefit Analysis of Investment Projects [6.9], which acknowledges the importance of including both direct and indirect effects, and applies quasi the same monetization methodology to reflect social opportunity and market value cost for indirect effects. The main difference with our study is that they do not attribute these costs to the actors.

Having identified the clear need for the identification and quantification of these effects, as well as the discrepancy in previous evaluation studies, this chapter investigates the indirect benefits using a bottom-up approach, which allows to more clearly link the monetary results to the individual effects [6.25], while top-down methods only evaluate the overall effect using aggregated macro-economic data. It therefore provides more detailed results compared to top-down approaches [6.26]-[6.27]. Furthermore, since no macro-economic data comparing ante- and post-deployment situations are needed, our model allows forecasting the value of the effects whereas top-down models only allow for evaluating ex-post of deployment. The main disadvantage of bottom-up approaches is its sensitivity to input assumptions: since calculations are based on a range of input parameters, multiplications of a large number of small deviations could have a significant impact on the output. Careful and well-founded estimation of input data is therefore an absolute requirement of a bottom-up approach.

6.2 Identification, categorization and quantification of indirect benefits: a description of a bottom-up model

As described above, this chapter will focus on modeling the indirect effects using a bottom-up approach. This section will describe the identification and categorization process, give some more details on the practical approach of data gathering and explain the evaluation model. As mentioned in the previous section, the advantages of bottom-up modeling are a clearer link between results and individual effects, more detailed results and a possibility of forecasting. Despite some criticism of cost modeling exercises for infrastructure planning [6.28], an objective method for quantifying indirect social benefits of broadband networks should be used by decision-makers to think about "real" solutions to municipal problems, such as savings achieved by telecommuting or e-government services.

6.2.1 Identification process is defined in a tree structure, categorization is performed along three dimensions

The identification process takes the form of a tree structure, starting from the different sectors that can be influenced, to identifying specific services (and subservices) that are deployed, to finally arrive at the actual effects. Figure 6-2 gives a graphical representation of this identification tree structure, both in general (a), as well as applied to the concrete example of teleworking (b). Using this tree structure for the identification process allowed structuring the different effects, and ensured completeness.

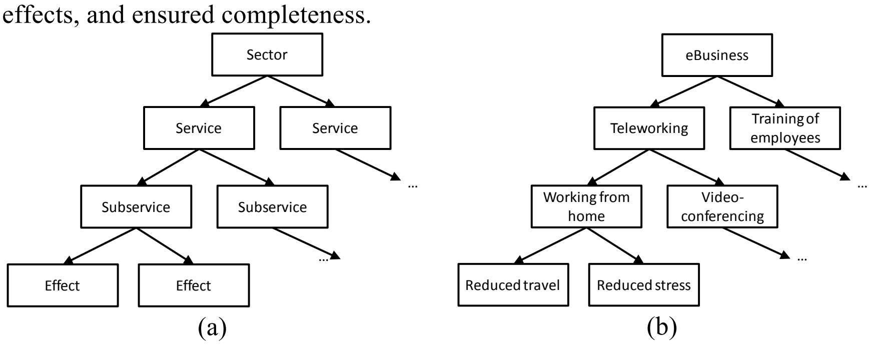

Figure 6-2: Generic example of identification tree

The individual effects are subsequently categorized along three dimensions: measurability, term and actor (Table 6-1).

Table 6-1: Abbreviations used for categorization

Measurability	S	Subjective
	O	Objective
Term	LT	Long term
	ST	Short term
Actor influenced	G	Government and local authorities
	C	Companies
	I	Individuals
	S	Society

The dimension measurability indicates whether the value of the effect can easily be transformed into a monetary value. There is a distinction between subjective (cannot be converted in a monetary value) and objective (can be more easily converted into a monetary value).
The second dimension is the term: here the effects are grouped on basis of the period in which the underlying services reach the minimal adoption rate, meaning that 50% of the target audience uses the specific service and will therefore be impacted by the effect. An arbitrary distinction is made between short term (operational within 2 years after deployment) and long term (more than 2 years are needed to reach 50% adoption).
The third and last dimension of categorization refers to who benefits from the effects. The distinction is made between "government" (all local and national authorities), "companies" (all private entities, both SME's and larger firms), "individuals" (inhabitants of the region under study) and "society" (a more general actor that accounts for e.g. environmental effects).

6.2.2 Practical approach and data gathering process

The process of building up the tree's structure was done iteratively, based on a combination of desk research in literature and interviews with several experts in the field to validate and comment. The literature studied included publications in national and international journals, consultancy reports, presentations, press releases and websites (concrete sources are referred to further). Interviews were conducted with representatives of cities, ICT responsibles of universities and some smaller companies, head of a telecom company, etc. It should be noted that the list of identified effects is not exhaustive, but aims at capturing the most important ones.
Geographical, demographical and statistical data were gathered using national and regional databases, while sector-specific data were collected from measurements at the departments of the city and some companies, respectively. An overview of all data used can be found in Appendix A of this book.

6.2.3 A bottom-up quantification model

The quantification model, consisting of three calculation steps per effect, was developed by the authors. The first calculation step quantifies the Total Value Potential (TVP) per service, which indicates the maximum monetary value a certain service or effect could entail, independent of the market that adopts it. Secondly, since the goal is to allocate the right monetary benefit to the right actor, we calculate the Total Value per actor (TVP_a) per time period by taking into account the share of the actor and the adoption curve of the service. The actor's share represents the portion of the total effect that can be contributed to the respective actor, determined according to a statistical allocation key, while

the adoption curve represents how fast the service is taken up by the customers. Finally, the effect of adoption of the technology, broadband or FTTH, is taken into account, resulting in the Total Value for all effects for broadband or FTTH, respectively. These different calculation steps are shortly explained and clarified by means of exemplary figures for the specific case of teleworking below. Note that all formulas detail the benefits per year, and that a multi-period analysis should include discounting before final summation.
As mentioned above, one should first calculate the TVP per service. This is a simple multiplication of four parameters: the *population group* experiencing influence of the effect (e.g. the labor force), the *benefit expressed in units U* (e.g. amount of km saved by avoiding commuting), the *conversion factor* (e.g. 1 km equals €0.5, taking into account the fuel and insurance costs of the vehicle ([6.29]-[6.30]), and the *occurrence* (in case of teleworking, we assume that people work 1 day per working week from home, which leads to 44 days a year).

$$TVP_i(t) = population\ group_i \times unit\ benefit\ [U] \times conversion\ [€/U] \times\ occurence\ (t)$$

To calculate the TVP per actor (TVP_a), the TVP for each service is multiplied with the *share* of the respective actor (e.g. about 90% of the cars are privately owned, so 90% of the benefits are assigned to "individuals") and the *Adoption Curve (AC)* of the specific service, which reflects how fast the service is adopted over time (e.g. a Bass adoption curve with innovation coefficient equal to 0.03, imitation coefficient equal to 0.38 and maximum market potential set to 32% ([6.21], [6.31]).

$$TVP_a(t) = \sum_i TVP_i(t) \times \frac{share_{ia}}{\sum_k share_{ik}} \times AC_i(t)$$

Finally, the Total Value (TV) for Broadband (BB) and Fiber-to-the-Home (FTTH) can then be calculated by summing all TVP_a, multiplied with the *adoption curves* and the *share* taken up by broadband (i.e. traditional broadband including wireless, up to 20 Mbps) and FTTH respectively. The adoption curves for broadband (consisting of DSL and DOCSIS technologies) and FTTH were determined using an extension of the model developed by Norton and Bass [6.32], which allows for calculating the adoption of successive technologies in one market divided amongst three platforms (a DSL-based network, a DOCSIS-driven coaxial cable network and an FTTH network). The parameters for the model (model coefficients and technology introduction years) were derived according to [6.33]. The shares taken up by broadband and FTTH were determined based on needed bandwidth per service[7].

$$TV^{BB}(t) = \sum_a share_a^{BB} \times AC^{BB}(t) \times TVP_a(t)$$

$$TV^{FTTH}(t) = \sum_a share_a^{FTTH} \times AC^{BB}(t) \times TVP_a(t)$$

6.3 Identifying and categorizing the effects for eGovernment and eBusiness

After having introduced the methodology, this section will apply it to eGovernment and eBusiness, because these sectors conceal the most important effects for the near future [6.15]. Electronic Government utilizes the ICT environment in an integrated manner to offer public services to all, at any moment of the day. Using eGovernment will improve the quality and speed of those services and enhance the support of the government policy and the democratic process [6.34]-[6.36]. eBusiness on the other hand is typically defined as the application of ICT for the support of all kinds of business activities [6.37]. Using ICT in the working environment improves the efficiency of employees, helps to improve the productivity of companies and allows flexibility in working hours and location [6.38]-[6.39].

6.3.1 eGovernment: from physical contact to electronic forms

Within eGovernment, the effects of two main services have been identified (Table 6-2), depicting all applications for which the citizen needs to contact the administrative center (e.g. extraction of birth certificate, application for a driver's license, etc.). The discussion on eGovernment services has been driven by the assumption that these services generate increasing and proportional cost-savings [6.40]. In literature, there is some agreement [6.35]-[6.36] that the introduction of interactive services (like the e-counter in the Netherlands and Belgium) provides a major step in cost savings of government services. For example, transforming this physical contact into an electronic format, saves the citizens (at least some) travelling to the city hall. For (local) authorities, this effect entails a huge amount of savings on paper and letters to be sent. One typical example of this electronic format is the online submission of taxes, which is now already

[7] Note that the parameters for the Bass curve are based on reference values from literature [6.21], [6.33], and that varying these parameters will undoubtedly affect results. This kind of sensitivity analysis however falls beyond the scope of this chapter.

used by a fair amount of the population in both Ghent and Eindhoven (the cities under study in this chapter, see further) [6.41]-[6.42].

Table 6-2: Identified services and effects for eGovernment

eGovernment						
Service	Subservice	Effect	Meas.	Term	Actor	Quantified?
Government -citizen transactions	Switching from personal contact to electronic contact (income tax preparation and return, applying for licenses, paying for tickets, etc.)	Reallocation of the time of the administrative personnel (capacity can be used for other services, like back office)	O	LT	G	Yes
		Time gain	O	ST	I	Yes
		Travel cost saving, both fuel and parking costs	O	ST	I, C	Yes
		Decreased consumption of paper (e.g. sending letters)	O	ST	G	Yes
		Decreased traffic jams and road accidents	O	LT	S	Yes
		Less stress	S	LT	I	No
		Reduced CO_2 emission (and other harmful gasses)	O	LT	S	Yes
	Providing information and resources for citizens online (e.g. e-newsletters, city information, personal profile, etc.)	Time gain	O	ST	I, G	No
		Reallocation of the time of the administrative personnel	O	LT	G	Yes
		Travel cost saving	O	ST	I, G	No
		Decreased consumption of paper (e.g. brochures)	O	ST	G	No
		Retrieving information outside office hours	S	LT	I	No

6.3.2 eBusiness: travel savings from teleworking and distance training

In eBusiness, the most important services that create indirect effects are teleworking and (distance) training of employees, see Table 6-3. A high-speed broadband connection (preferably over fiber) will allow people to access their files at home as quickly as at the office, or enable employees to discuss with colleagues all over the world through real-time HD videoconferencing. These options permit employees to work (partly) from home, reducing their commuting time and cost, give the companies the opportunity to cut back on their operational expenditures (e.g. rental fees for office space), while videoconferencing decreases the necessity of business travel [6.43].

Table 6-3: Identified services and effects for eBusiness

eBusiness						
Service	Subservice	Effect	Meas.	Term	Actor	Quantified?
Teleworking	Working from home	Reduced travel (time and costs for both fuel and parking)	O	ST	I, C	Yes
		Decreased traffic jams and road accidents	O	LT	S	Yes
		Reduced emission of CO_2 (and other harmful gasses)	O	LT	S	Yes
		Reduced stress	S	LT	I, C	No
		Decreased number of absenteeism by illness	O	LT	C, G	Yes
		Reduced office space and operational expenditures	O	LT	C, G	Yes
		Higher independency and flexibility for the employee	S	ST	I	No
		Reduced spending on human resources	O	LT	C, G	Yes
	Videoconferencing	Less business trips	O	LT	C	Yes
Training of employees	Grouped management of ICT infrastructure for clustered companies	Reallocation of the time of the support staff	O	LT	C	No
		More efficient use of network- and ICT services	O	LT	C	Yes
	Online training (possibly from home)	Reduced travel (time and costs for both fuel and parking)	O	ST	C, I	No
		Reduced training expenses	O	ST	G, C	Yes
		Reduced stress	S	LY	C, I	No
		Reduced emission of CO_2 (and other harmful gasses)	O	LT	S	No
		Decreased traffic jams and road accidents	O	LT	S	No

6.3.3 Not only positive effects

Although both tables above clearly focused on the identification of the benefits of broadband, the authors are well aware of possible negative sides. This paragraph will shortly describe some of the disadvantages (as for the positive effects, the list is not, and will most probably never be, exhaustive), but these will not be used further down in the actual calculations.

A common critique on working at home is the transfer of electricity consumption from the employer to the employee [6.17]. This is of course true, but this part of the cost is small compared to the other operational savings (like office space rents and furniture). Furthermore, these operational savings free money at the employer's side to fund, for example, the employee's Internet subscription. Secondly, there is the logical possibility that allowing people to work from home, will make them move further away from work (since commuting is no longer necessary every day). It is however a question whether this effect is really negative, since it can also be looked at from the opposite side: working at home allows people to keep on living in remote or smaller villages, and liquidates the necessity to migrate to the larger cities [6.19]. Although it has been stated that "households may redistribute non-work travel among their members on workdays to take advantage of telecommuters' additional flexibility or location at home, […] the net effect is still a reduction in trips per household on workdays" [6.44].
On eGovernment, there has been less criticism, but there the main question deals with the necessity of all-fiber networks – does basic broadband not suffice to offer an e-counter? This is indeed true to some extent, as will be shown later.

6.4 Calculating the indirect effects for Ghent and Eindhoven

The model will be applied to two case studies: Ghent, an urban city in Belgium with a well-developed xDSL and cable network (but no FTTH yet), and Eindhoven in the Netherlands that owns a well-established FTTH network, deployed in 2007, but which doesn't cover the whole city yet.
These two cases were selected because of comparability on demographical, geographical, economic and cultural basis. Both cities can be categorized as urban, house a university with comparable number of students, as well as a business campus where lots of smaller high-tech enterprises are settled. Exactly this combination of a high degree of comparability with the difference in telecom offerings, will allow evaluating the impact of FTTH on the effects that have been identified.

6.4.1 Overview of the input parameters

Table 6-4 gives an overview of the input parameters used. In order to fairly compare both cases, the economic parameters are kept the same. The calculation period is limited to 2012-2030, and the discount rate set at 10% (based on the rate of the Belgian incumbent, Proximus (former Belgacom) (9.61%) [6.45], and the Dutch incumbent, KPN (10%) [6.46].

For similar reasons, the parameters determining the adoption curve for the services will be kept the same (which can be justified by the comparable economic and cultural background), only the introduction years of the services vary. The adoption curves of the technologies (traditional and FTTH) were based on existing data where possible, and extrapolated into the future. The penetration curves of traditional broadband could therefore be based on existing data for both cases. For FTTH, the introduction year for Eindhoven was set at 2007 (the year of the deployment of FTTH there [6.47]), while in Ghent, we assume a deployment at the start of the business case analysis, which means that first FTTH effects will be visible in 2014. Note that this assumption was made when the study was made (2012). If the study would be re-executed now, this FTTH deployment date in Ghent should be shifted in time.

Table 6-4: Comparison of regional data for both case studies: Ghent and Eindhoven [6.48]-[6.49]

Parameter	Ghent	Eindhoven
Number of inhabitants	246,719	217,223
Number of households	106,805	97,523
Number of SMEs	7,289	6,513
Number of students at the university	31,445	21,743
Commuting population	138,597	143,100

Before we elaborate on the output of our model, we would like to discuss the significant difference in the penetration rates of both municipalities. The penetration of FTTH (homes connected) in the municipality of Eindhoven is about 17% [6.50]. The total Internet penetration is 92%, which is in line with the Dutch average. The fiber penetration is significantly higher than the country's average, which is 4.19% [6.51]. At the time of this analysis (mid-2013), there is no FTTH rolled-out in the municipality of Ghent. The total broadband penetration is similar to the Dutch situation though. In the outcomes, this will have a clear impact on the results, since the effects of fiber will be present from the start in the case of Eindhoven.

6.4.2 Results from the bottom-up methodology: comparison of Ghent and Eindhoven

After having described the model, input parameters and identified effects, this section focuses on the results of the actual bottom-up calculation. We will first discuss the total value of the indirect effects for both sectors, identify the most important effects, to finally evaluate the value per actor.

6.4.2.a Total value

The total value represents the combination of the effects due to current broadband and the effects of fiber, and sums to €930 million for Ghent and €1140 million for Eindhoven (discounted and cumulative up to 2030). The higher value for Eindhoven in comparison to Ghent can be explained by the influence of the presence of the FTTH network there (see further for more details).

Calculating this total value is of course relevant, but digging deeper down to the value per inhabitant (for eGovernment) or per company (eBusiness) might give a better insight. These values are shown in Figure 6-3 (cumulative and discounted over 18 years), where a distinction is made between the value obtained by customers that have "normal" broadband, and those who are subscribed to fiber. It is clear that the portion taken up by fiber is much higher in Eindhoven than in Ghent, which can easily be explained by the fact that there are already more FTTH subscribers.

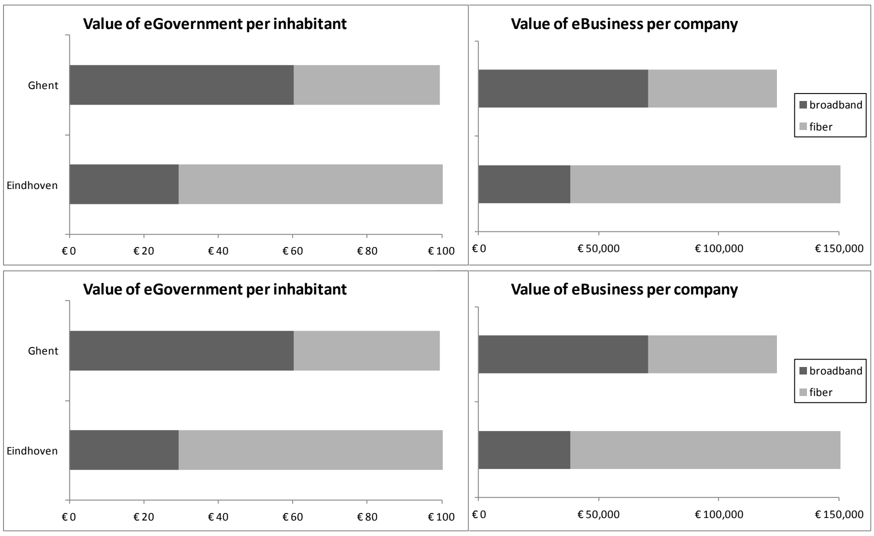

Figure 6-3: Value of the indirect effects for eGovernment per individual, and eBusiness per company

From this graph, it can be concluded that there is a clear advantage of FTTH for the eBusiness sector, since the value per company for Eindhoven is significantly higher than that for Ghent, and the portion taken up by fiber is also significantly larger. For eGovernment on the other hand, the additional value that fiber brings is only limited. This can be explained by the services that were identified for eGovernment: most of them can also easily be used on "normal" broadband (for more details on these services, see Table 6-2). The value of eGovernment is only

€100 spread out over 18 years, so this value might not provide an incentive to invest in fiber infrastructure. The value of about €150 000 per company, on the other hand, is significant.

6.4.2.b Most important effects

To identify the most important effects, we step away from the technology and its adoption, but only look into the maximum potential of the service itself, adjusted with its adoption curve (TVP_i x AC_i). We opted to exclude the impact of adoption of the technology, so that we can compare both cities on a fair basis.

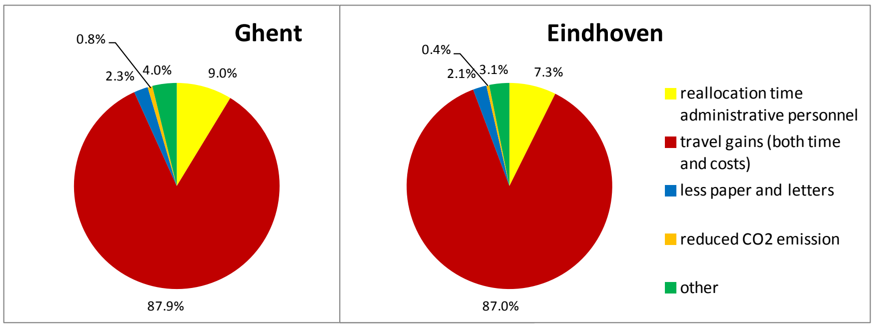

Figure 6-4: Indication of the most important effects for eGovernment

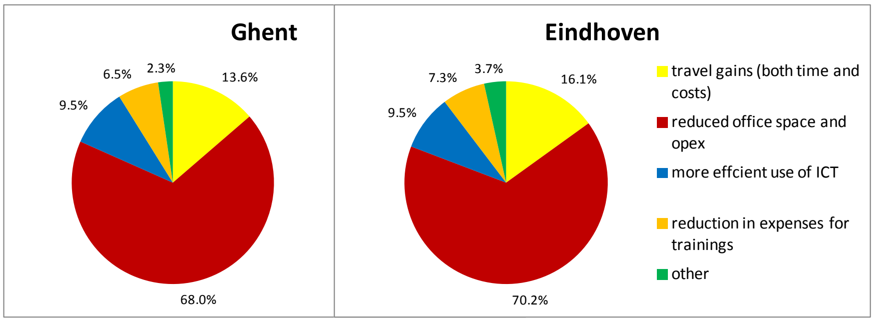

Figure 6-5: Indication of most important effects for eBusiness

The comparison for eGovernment is made in Figure 6-4. We see similar results for both cases: the travel savings take up the largest part (88% for Ghent, 87% for Eindhoven, respectively). These savings include savings on time, fuel costs, parking costs and other costs related to automobiles, like insurance. It has to be mentioned that these costs only apply to inhabitants that visit the administrative center of the city hall by car. We didn't take public transport or biking into account, so this value could even be higher. The other effects are much smaller, but not negligible.

The same analysis can be performed for the eBusiness sector (Figure 6-5). Here, about 80% is taken up by savings in travel and office space (about €103 000 per company in Ghent, €120 000 in Eindhoven). Allowing people to work from home, can on the long term reduce the amount of office space needed. On a shorter term, these effects are already translated in operational savings (for e.g. lightning, electricity, cleaning staff, etc.).
The same reasoning holds for a more efficient use of ICT: if a fast broadband connection is present, companies can centralize their ICT infrastructure (servers etc.), which allows sharing this infrastructure among different locations.
Although not included in the eGovernment sector (we assumed one administrative center location in each city), this sharing of ICT infrastructure could also entail large savings for the authorities, and should be kept in mind when evaluating public investment in fiber infrastructure.

6.4.2.c Value per actor

To conclude this results section, we give an overview of the results per actor (Figure 6-6). The spreading of the results do not differ much between Eindhoven and Ghent, and this can mainly be explained by the value of the shares contributed to each actor type, which were comparable for both cities.

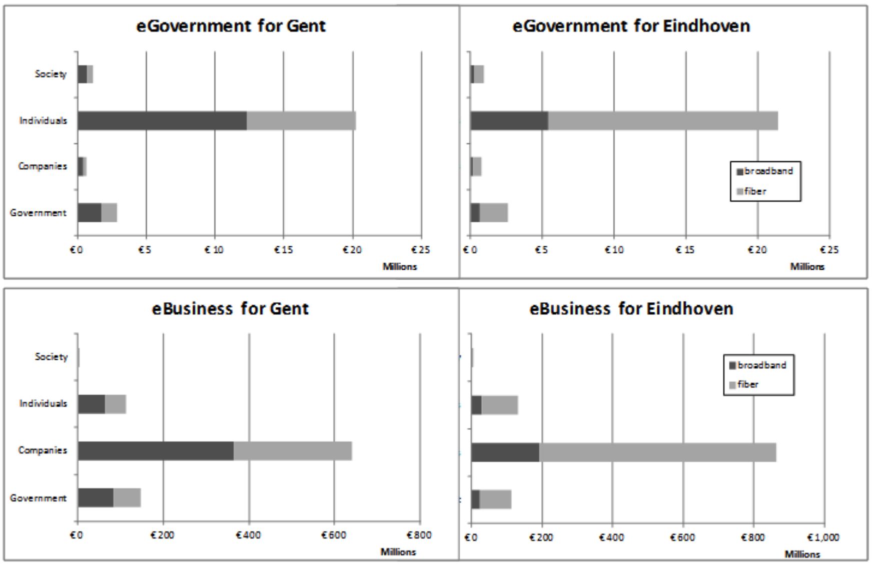

Figure 6-6: Overview of the value of the indirect effects per sector and per actor

Clearly, the largest part of the savings for eGovernment can be allocated to the individuals. This can be easily explained by comparing Figure 6-4 and Figure 6-6: the largest effect: travel savings, is of course an advantage for the inhabitants of the city.

The same reasoning holds for eBusiness: the largest part is taken up by savings in operational expenditures and office space, which is of course a saving for the companies. The individuals primarily benefit from the savings in travel time and costs. Surprisingly, the government also gains a fair share of the savings of eBusiness. This is due to the split in types of businesses: private and public enterprises, whereas the advantage for the public enterprises is allocated to the actor "government".

6.5 Benchmarking our results: comparison to other studies

To benchmark our results, we will compare them with other studies available in literature. Based on transparency and degree of comparability, three studies were selected, among which two of them also used the bottom-up approach ([6.22], [6.23]); the third study opted for a top-down methodology ([6.18]).

6.5.1 Comparison with other bottom-up studies

Both studies ([6.22], [6.23]) identify different types of effects, but chose to only quantify the more objective effects (similar to the strategy followed in this chapter). Furthermore, they both claim to quantify the incremental effects of high-speed broadband on top of existing infrastructures. Although this seems to be the case for New Zealand, the meta-study of Hayes showed that the baseline for Seattle is no broadband at all [6.15]. We will therefore compare the results of New Zealand with the incremental effects of FTTH found in this study, and the results for Seattle with the total effects of this study (from traditional broadband and FTTH combined). Note that these incremental effects are different from the results described in section 6.4, as that section also included the effects for "normal" broadband for the fiber customers (so that Ghent and Eindhoven could easily be compared). For a methodological analysis of all studies, we refer to section 6.1.3.

6.5.1.a Comparison with New Zealand for eBusiness effects

Unfortunately, the New Zealand Institute did not quantify the effects for eGovernment, so there is no basis for comparison here. They did quantify the effects for eBusiness extensively, allowing us to make a detailed comparison. Table 6-5 gives the value per individual and per year for the three cases: Ghent, Eindhoven and New Zealand.

The results for New Zealand and Ghent are very comparable, while the value for Eindhoven is more than double. This can be explained by a higher fiber adoption in Eindhoven (already 16.5% in 2012), but also in the higher benefits from fiber for eBusiness. The highest benefits for eBusiness for New Zealand were also found in remote working (or teleworking) and reduced travel costs in general.

Table 6-5: Comparison of the monetary value of the incremental effects of FTTH, per capita and per year, for eBusiness

	This study - Ghent	This study - Eindhoven	New Zealand
eBusiness	€15	€38	€12

6.5.1.b Comparison with Seattle

Comparing the results of our study with the study of Columbia Telecommunications is less straightforward than the comparison with the study for New Zealand, because the report is not very transparent in explaining its methodology. The positive point is that they did calculate values for eGovernment. Table 6-6 shows that the results are in same order of magnitude, but show some variation. Note that the values are significantly higher than those of Table 6-5, since these take into account the combined effect of broadband and FTTH.

When comparing eBusiness, it is clear that the value found in Seattle is higher than the results of this study (about double). This can however be explained by the type of effects that were taken into account in both studies: in Seattle, more than two third of this value can be accounted to a reduction in traffic congestion, an effect that we did not quantify (because of subjectivity, and a lack of available input data).

The same, almost tripled, result is found for the eGovernment sector. Again, this value can be explained by the fact that our study did not take an effect into account that was rather important for Seattle: the more efficient use of ICT by sharing infrastructure amongst governmental buildings. As mentioned before, we did not take this value into account because we started from the assumption of one administrative center per city.

Table 6-6: Comparison of the monetary value of the total effects of broadband and FTTH, per capita and per year, for both eBusiness and eGovernment

	This study - Ghent	This study - Eindhoven	Seattle
eBusiness	€193	€270	€547
eGovernment	€5	€7	€15

6.5.1.c Comparison with a top-down study for the impact of broadband on the German economy

Katz et al. [6.18] investigated the impact of broadband on the German economy, using input-output analysis on two investment scenarios (see section 6.1.3.a for more information on the methodology). The results of this study predict that the German GDP (Gross Domestic Product) will grow with €170.9 billion between 2010 and 2020.

This total value counts both direct and indirect effects, and includes all sectors (so does not limit to eBusiness and eGovernment). The direct effects include the direct economic activity related to the deployment of the network (job creation and the purchasing of expensive equipment), the indirect effects consist of a faster innovation process and the creation of new business activities.

It is of course far from straightforward to compare a macro-economic analysis starting from general economic indicators with a bottom-up analysis that identifies the value for the different effects separately. We opted for an estimation of the importance of eBusiness and eGovernment compared to other sectors (such as eHealth, eEntertainment etc.), and used this percentage to calculate the macro-economic value of eBusiness and eGovernment, as found by Katz et al.

Based on a more extensive, internal study including also other sectors, the combined share of eGovernment and eBusiness in the total share of possible indirect effects, is 59%. Applying this percentage to the value found by Katz et al. (who calculated the effect for the entire economy, while this study focused only on eBusiness and eGovernment), leads us to the conclusion that these values are very similar (Table 6-7). The value for Eindhoven is again higher due to the extra benefits already perceived for eBusiness on fiber.

Table 6-7: Comparison of bottom-up (this study) to top-down [6.18] (yearly basis)

	Total value per capita	Percentage allocated to eBusiness and eGovernment	Result: value per capita for eBusiness and eGovernment
This study (Ghent)	€198	100%	€198
This study (Eindhoven)	€277	100%	€276
Katz et al. (Germany)	€333	59%	€196

6.5.2 Impact of regional differences

The results of this and the previous section show that indirect benefits are clearly present, but the comparison of studies however showed significant differences in order of magnitude. Part of this difference can of course be explained by the used methodology and included effects, but part can be allocated to the size of the region, population density, industry sector, etc.

Not only can we see a regional impact by comparing quantitative results of earlier studies, previous literature also indicates this. In [6.52], for instance, the authors found that "broadband alone is not responsible for increased levels of productivity, but rather the availability of both broadband and high-quality human capital is key to broadband-related productivity increases" (p. 18). That paper also argues that faster broadband only proves its use when people are trained enough to apply it effectively to their daily work. Geographical location and population density are furthermore noteworthy characteristics to address in the future, as they not only affect the magnitude of the benefits, but can also induce extra costs (adopting a more complex Internet technology can require significant co-invention costs [6.53]). Finally, linkages of companies within particular broadband regions have proven that there are industry effects of broadband [6.54]-[6.55] and agglomeration effects fostered by broadband [6.56]-[6.57].

Although the goal of this work was to compare the two regions under study (Ghent, Eindhoven), future work should account for these regional differences by extending this study towards including regions with other characteristics.

6.6 Impact on the investment decision and guidelines for the specific actors

Within the discussion on Next Generation Access (NGA) networks in Europe [6.58]-[6.59], fiber technologies have been considered as the most future proof technology. Compared to other broadband technologies like xDSL and Cable Modem technologies, fiber infrastructure providers face high sunk costs and demand uncertainty (see section 5.3 and [6.6]). Based on current uptake predictions [6.60] and expected Willingness to Pay [6.61], investors face payback periods of 20 to 40 years (see section 5.3.3.c and [6.62]-[6.63]), which are too long to be justified in the current economic climate. However, these investments are necessary to reach the goals set out by the European Union in its Digital Agenda: "By 2020, all Europeans should have access to Internet of above 30 Mbps and 50% or more of European households have subscriptions above 100 Mbps" [6.64].

Although the key question for investment in broadband infrastructure has been to choose projects which "have the longest lifespan, highest efficiencies and strongest social benefits" [6.7], these benefits are not taken into account in most techno-economic analysis of investments in NGA infrastructures. This chapter calculated that these indirect benefits are significant (in comparison to a deployment cost of €550 - €1750 per home, depending on the type of infrastructure and the region – see section 5.3.1), especially for individuals and companies, and to a lesser extent for the government. If these indirect benefits could be internalized in the willingness to pay of the respective actors or externalized to other market parties in the business or government sector, they could provide a significant boost to the business case of broadband deployment. They can further prove useful in drafting national broadband plans [6.65].

If the indirect effects are included in conventional Cost-Benefit Analysis, a better case for local government involvement in municipal networks can be achieved. This methodology can be useful in specifying the conditions for the application of the Service of General Economic Interest (SGEI) principle with respect to NGA networks [6.58], which allows addressing the "real" problems persisting in local communities such as digital inequality issues, restructuring of deprived areas and industrial parks to solutions provided by NGA networks and new broadband services.

Furthermore, there are other options to incentivize the right actors to help stimulating the investment. Authorities on all levels should promote the deployment of new and faster broadband networks. Apart from intervening financially, this chapter learns that this can also be done qualitatively, by making e.g. the companies aware of the potential savings that could be obtained in operational expenditures. These companies could then decide to compensate their employees by paying for their home Internet subscription as an extra non-statuary benefit. On the other hand quantitative measures taken by the authorities are also possible, by using benefits in kind for targeted households (as is done in other sectors such as health, education, etc. [6.66]). Past initiatives such as the Private PC initiative (a legislation that provided tax benefits for companies that equip their employees with a home computer and Internet connection [6.67]), could be extended towards low-income households in the future. Concrete actions like this do not interfere with European State Aid regulations, as their primary goal is to reduce the digital divide by including those targeted households in the digital society. By indirectly increasing the willingness to pay of those specific households, however, those initiatives could stimulate investment at the same time.

6.7 Conclusions and future work

Following the tricky investment case for FTTH deployment (section 5.3), linked to the identified positive effects of stable, reliable and fast broadband for society, this chapter argued for investigating the indirect benefits of NGA networks and internalizing them in the investment decision of the involved actors, thereby extending traditional cost-benefit analysis to social cost-benefit analysis. Indirect effects are benefits for one actor, caused by actions of another actor. Indirect effects from a network deployment are not limited to the telecommunications sector only, but spread out to the entire economic, social and cultural environment. Since existing studies about these indirect benefits are rare and unclear about the used methodology for quantification, this chapter introduced an identification, categorization and quantification model for indirect benefits. The first step of the model relies on a tree structure, in which sectors, services and sub-services lead to the identification of the individual effects. These latter are categorized along three dimensions (measurability, term and actor) in a second step, and finally quantified using a bottom-up model. In this research, we opted for a bottom-up methodology because it allows modeling the effects separately, and in more detail. Although this model is more influenced by the values of the input parameters than a top-down approach (which uses statistical data in regression analyses), it gives a clear causal relationship between the input parameters and the final result. Bottom-up models furthermore allow forecasting the effects, while top-down statistical calculations require ex-post macro-economic data.

Although benefits will become apparent in multiple sectors, such as eHealth and eEducation, literature showed that the sectors of eGovernment and eBusiness conceal most effect in the near future. Therefore, the model was applied to these sectors, for two specific, comparable cities: Ghent and Eindhoven.

Within the sectors eGovernment and eBusiness, the most important effects (leading to the highest monetary value), are travel gains from reduced physical contact in the administrative center, and operational savings for companies by introducing teleworking. From the comparison of Ghent (without FTTH) and Eindhoven (with a well-established FTTH network), it became clear that some services, like teleworking, clearly benefit from the presence of fiber all the way to consumers' homes, while for others (e.g. the e-counter for eGovernment) traditional broadband through DSL suffices. To benchmark our results, they were compared to earlier studies found in literature. In general, the results of this study are in line with the outcome of previous investigations.

Finally, the chapter indicated how and where the quantification results could be used to improve the business case for NGA deployment. Not only was shown that the value of the indirect benefits is significant when compared to the investment needed for FTTH deployment, also some recommendations were formulated about how to steer these savings into the investment case. Two main recommendations focus on non-statuary benefits for employees in the form of broadband subscription fees, and benefits in kind for targeted households, granted by local authorities.

Future work in this domain includes the extension of the study to other sectors, like the health and entertainment industry, as well as the extension of the study to include regional differences (size, population density, labor force, industry sector, etc.), as indicated in section 6.5.2. Furthermore, we should evaluate the different services separately, to see which bandwidth speeds they actually need and which kind of limitations they have, so that a more accurate calculation can be performed.

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7

Sharing infrastructure and cooperating does not come for free: extension to multi-actor analysis

"Most economic fallacies derive from the tendency to assume that there is a fixed pie, that one party can gain only at the expense of another" – Milton Friedman

The previous chapters clearly showed the shift in responsibilities for network deployment and operations. While in the past, telecommunications access networks (PSTN, CA-TV) were in the hands of one, vertically integrated, operator, new deployments observe a range of parties active on different layers, thereby sharing the underlying infrastructure. New business models arise, which focus on the sharing of this infrastructure, preferably in an open and non-discriminatory way. When the non-discrimination rule is enforced through restricting each operating firm to one dedicated layer of the deployment (physical infrastructure, active equipment or services only), an open access network is achieved. In the case that lower-layer actors are also allowed to act and compete on higher layers, the scenario is referred to as unbundling, whereas the network should be shared among competitors, although the actor that owns the underlying infrastructure can be favored and should be regulated.

Sharing of underlying infrastructure may avoid duplicating huge investments; it also entails some extra costs. Extra equipment needs to be installed to allow for competition on higher layers, additional processes need to be executed to permit collaboration and transactions in between different business entities and also entail an extra cost. This chapter builds on the results of [7.1] and [7.2] to describe these costs in a cost breakdown and to quantify them for the different types of open access.

7.1 Sharing infrastructure requires collaboration

The previous chapters argued that moving towards an FTTH access network in which an optical fiber is running all the way from the central office to the customer, is from a technological point of view the best solution as an optical fiber has superior properties in comparison to a twisted copper pair or a coaxial cable. However, the deployment of this fiber network requires a high initial investment, and this investment cost holds back the installation of fiber in those regions where twisted-pair copper and/or coaxial cable networks are available. Clearly these investments will only be made when there is sufficient certainty of a payback over a limited period. As the installation of the outside plant takes over 70% of the total network cost [7.3], increasing the amount of customers on the infrastructure will also increase the chances of payback considerably. This can be achieved by opening up (renting) the physical infrastructure or a higher network layer to be used by different competing operators in a so-called open access network, thereby maximizing the use of the underlying network infrastructure.

Sharing the infrastructure avoids duplication of what is often perceived as a natural monopoly, however it does not come for free. Allowing competing operators on top of one infrastructure entails extra costs in terms of equipment, processes and transactions. The open access network will require additional equipment for providing isolated network interfaces towards the different operators operating over it, hence ensuring equal and non-discriminatory access. Connecting new operators and new customers will require additional operational handling steps. Especially the cost of connecting and disconnecting customers might become an important cost taking into account typical customer churn in highly volatile markets. Thirdly, the presence of multiple operators will induce additional administration for contract negotiations, subscription, follow-up and termination procedures, all of which are not needed when the entire network (PIP-NP-SP) is operated by one single, vertically integrated operator.

Opening up the network can technically be done in three basic ways: on dark fiber level (layer 1, allowing multiple NPs), wavelength level (layer 1.5, allowing multiple NPs, though with the restriction that they need to deploy the same technology) and bitstream level (layer 2, allowing competition on SP level). However, as wavelength division multiplexing (WDM) is only used on a very small scale in the access, this technical option has been described (section 3.3.2), but will not be evaluated. The other options: fiber open access (on both P2P and P2MP networks) and bitstream open access are shown in Figure 7-1.

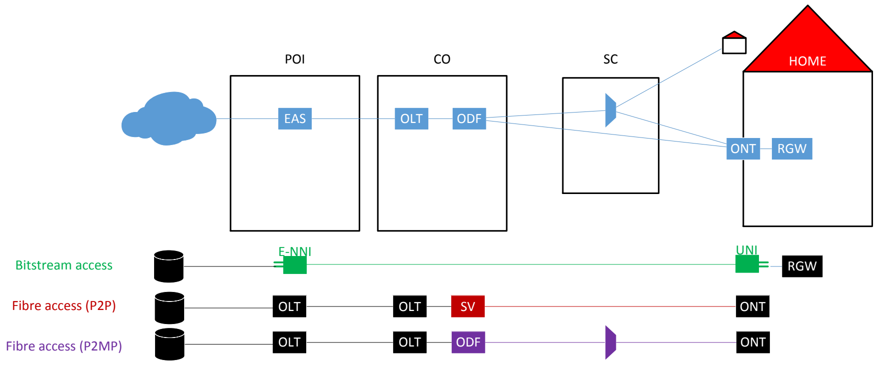

Figure 7-1: FTTH open access types

Opening up the network on layer 2 (bitstream) provides the access seeker with end-to-end connectivity. The service provider links in through the E-NNI (= External Network-Network Interface) at the network side (Point of Interconnect - POI), and connects its Residential Gateways (RGW) to one port on the ONT, located in the home. This connection opportunity is also referred to as the UNI (User Network Interface). The layout and technology used in the network is of no interest to the SP, as only connectivity is offered, i.e. a certain guaranteed upload and download bandwidth speed.

In the case of fiber open access, a point-to-point fiber cable is offered in between the central office and the end customer's premises. Depending on the underlying network topology, the link can be direct for each user separately (in case of a P2P network, then the connection happens at the splice vault (SV) or cross-connect ODF), or direct for each NP (P2MP layout). In this latter case, the PIP should provide an extra splitter in the field (street cabinet – SC) per connected NP. For a detailed technical description on how open access is offered on both levels, we refer to section 3.3.

7.2 Procedures that entail extra costs

As explained above, offering open access entails extra costs related to the collaboration of multiple actors. These extra costs are especially seen when executing certain procedures, such as (1) connecting a new provider (NP in case of fiber open access, SP in case of bitstream), (2) connecting a new end user and (3) when an end user decides to switch provider (procedure of churn). This section will shortly detail the different steps that need to be undertaken for each procedure, thereby indicating potential sources of extra cost.

7.2.1 Connecting a new provider

The first procedure depicts the connection of a new provider: an NP in the case of fiber open access, an SP in the case of bitstream. Figure 7-2 shows the different steps that need to be taken.

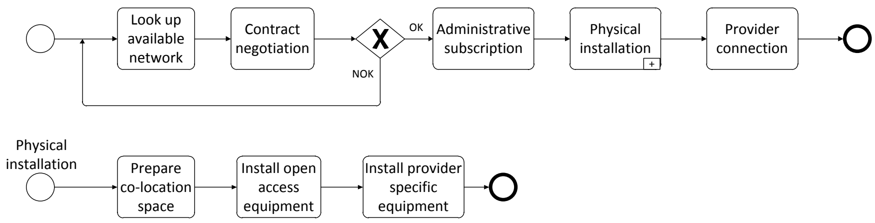

Figure 7-2: Flowchart representation of the different steps for the procedure of connecting a new provider

In a first step, the provider needs to search if the network infrastructure is available, i.e. if there is enough dark fiber in case of an NP connecting, or enough spare connectivity in case of an SP. Secondly, the provider needs to negotiate the terms of the contract with the lower-level operator. If they do not reach an agreement, the procedure starts again and the provider can look for another network to connect to, if available. After the contract terms have been agreed upon, the new provider should be subscribed to the network, which encompasses administrative procedures such as sharing contact information, setting up billing, etc. All these administrative actions can be categorized as transaction costs (see further).

Subsequently, the needed equipment can be installed in the provided co-location space. This step, as well as the physical connection depends on the type of open access offered.

In case of fiber open access on top of a P2P topology, the PIP should install a cross-connect ODF (patch panel) in the central office, while the NP installs its own ODF there. The cost for the cross-connect ODF scales with the number of connected end users in the area, as for every end user, an ODF slot must be provided. The ODF of the NP will need to be connected to the cross-connect ODF for all existing users, which will induce patching costs. In our model, we assume that no end users are subscribed upfront, thus that the installation of the NP specific equipment is postponed and will therefore be counted in the procedure for connecting new end users (see section 7.3.2).

In case of a P2MP topology, fiber open access is offered by placing an extra splitter per NP in each street cabinet. The NP's users should be connected to that splitter, as should the NP's feeder fiber. In the central office, a co-location space is provided by the PIP, in which the NP installs its ODF. The PIP then connects this ODF to the NP's feeder fiber.

The handover point for bitstream open access is offered at the POI, where the SP connects its router to the assigned E-NNI port of the NP's EAS. Furthermore, a CVC is set up between the POI and the different COs.
After the provider is physically and logically connected, users can subscribe to this provider, which is the subject of the following section.

7.2.2 Connecting a new end user

When an end user wants to subscribe to a broadband service, he will always contact an SP that is offering services in his area. A contract is "negotiated" between the end user and the SP, which in most cases comes down to the end user choosing one of the broadband offers of the SP (specified data rate and monthly download volume). The SP receives this offer and negotiates the right Quality of Service (QoS) agreement with the NP he is connected to. This QoS denotes the requested best-effort bandwidth and the so-called Committed Information Rate (CIR – the minimum bandwidth that is available to the end user's OVC at all times). If the contracts are settled, an administrative procedure will be set up for the actual subscription, after which the CPE needs to be installed and connected: an ONU to terminate the end-to-end connection of the NP and a RGW to send and receive service-specific data (of the SP). The installation of this CPE can be executed by the provider(s) or by the end user itself in case the fibers are pre-connectorized and don't need to be patched. In fiber open access, the NP should install additional equipment (OLT-shelf-rack, according to the equipment trees described in [7.4]) in the central office, if needed.

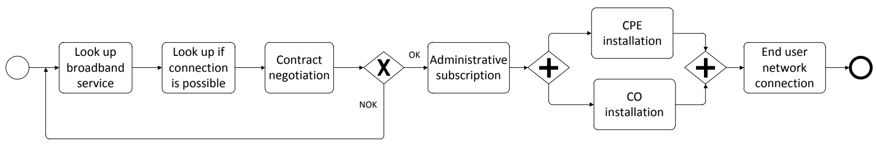

Figure 7-3: Flowchart representation of the different steps for the procedure of connecting a new end user

As a last step, the user needs to be connected to the network. In case of bitstream open access, this connection is only a logical connection: the NP should assign the right OVC to the link in between the end user and the SP's router. In case of fiber open access, the right distribution fiber needs to be terminated at the NP's splitter (P2MP topology) or a fiber needs to be patched from the cross-connect ODF to the NP's ODF (P2P topology). After the physical connection, the NP should connect the user also logically: this is a software cost. The different steps for the process of connecting a new end user are summarized in Figure 7-3.

7.2.3 Churn of an end user

When an end user decides to switch provider, be it SP or NP, he is said to churn. Because the steps for churning SPs are different from churning NPs, the procedures will be handled separately.

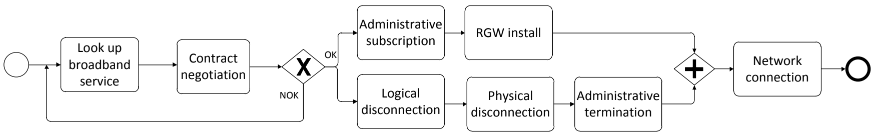

Figure 7-4: Flowchart representation of the different steps for an end user churning SPs

When an end user wants to switch SP (Figure 7-4), he first has to search for an alternative offer (SP_2). He places an order with this SP_2 and the contract is negotiated, after which an administrative subscription is started. Simultaneously, the end user notifies his original SP (SP_1) about terminating his contract. The original RGW is disconnected, the OVC is terminated (including logical disconnection) and SP_1 sets up a final billing. The new RGW is installed (by SP_2 or by the user itself) and a new OVC is set up between the SP_2's router and the end user's RGW.

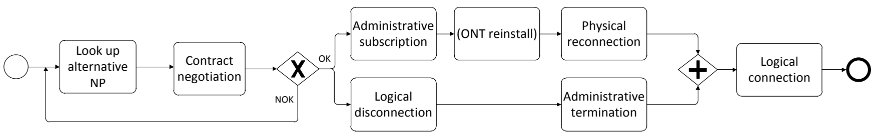

Figure 7-5: Flowchart representation of the different steps for an end user churning NPs

In case an end user wants to switch NPs, which can be triggered by the request to be connected to a new SP (business-wise linked to a new NP) or by the opportunity of cost savings (cheaper NP, this will most likely be triggered by a range of end users living in the same geographical area switching), he looks for an alternative NP and contracts are negotiated. If positive, the end user's SP will be subscribed to the new NP, while the original NP disconnects the end-to-end connectivity and prepares the administrative termination (final billing). The new NP requests the PIP for a reconnection of the end user's fiber to his splitter (in case of P2MP topology) or a reconnection at the cross-connect ODF in the CO (P2P topology). If the original and new NP use non-compatible technologies, ONUs might have to be replaced. As a final step, the new NP sets up the logical connection so that end-to-end connectivity is achieved and the SP can continue offering its service to the end user. The different steps are visualized in Figure 7-5.

7.3 Evaluating the cost of cooperation

In order to investigate the cost impact of open access, we must be able to identify and classify the different costs. The total cost is subdivided in three categories: equipment related costs, process related costs and business or transaction related costs (Figure 7-6).

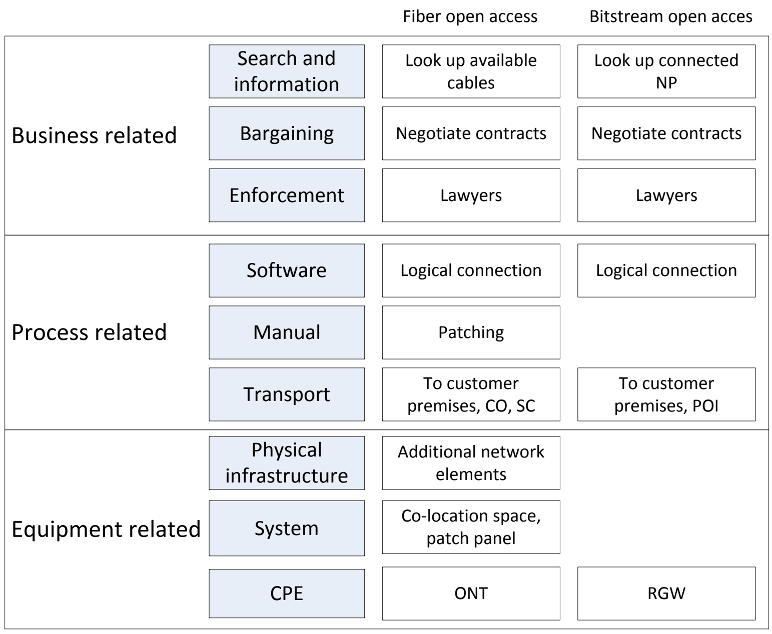

Figure 7-6: Conceptual cost breakdown

The equipment related costs are further detailed in costs related to (1) the physical infrastructure, which corresponds to all extra equipment that needs to be installed in the outside plant, both active and passive; (2) the extra equipment in the central office, also referred to as system side and (3) the CPE side: Customer Premises Equipment, such as adjustments to the ONT or RGW.

Secondly, process related costs consist of software costs and manual processes, the latter being split up in manual interventions such as patching, and transportation.

Finally, there are business related costs, also referred to as transaction costs. They represent the extra costs related to interactions between the different actors and are further categorized following the framework proposed by Williamson [7.5]. Search and information costs aim at reducing information asymmetry and include costs for planning, standardization and research. Bargaining costs are all costs related to the negotiation and administration of contracts. Enforcement costs are costs required for making sure everything works as agreed upon, and include for instance the enforcement of Service Level Agreements (SLAs).

Table 7-1: Overview of input values for open access cost calculations, applicable on a European urban access network setting

Equipment related costs	
RGW	€50
ONT (including installation)	€80
1:32 Splitter	€330
Ethernet Aggregation Switch (Layer 2)	€650
SP Router (Layer 3)	€180,000
ODF slot	€20
ODF Rack	€800
Floor space per ODF Rack	$1.40m^2$
OLT card (P2P)	€600
OLT card (P2MP)	€2000
Shelf with switching fabric (P2P)	€5900
Shelf with switching fabric (P2MP)	€5375
System Rack	€600
Floor space per System Rack	$0.78m^2$
Floor space cost	€150/m^2/year
Process and transaction times	
Look up	0.5h
Contract negotiation between providers	1h
Contract negotiation user-provider	0.25h
Administrative subscription new provider	4.2h
Administrative subscription new user	1.7h
Administrative termination user	1.7h
Logical Connection	0.5h
OVC Connection	1.3h
Logical Disconnection	0.4h
Cost per patch in CO	€19.5
Cost per patch in SC	€17
Labor costs	
Customer service desk	€45 per h
Technician	€52 per h
Network Operating Center	€58 per h
Transport Costs	
Transport to CO (round trip time)	€14
Transport to SC (round trip time)	€28
Transport to household (round trip time)	€36

Equipment related costs are calculated based on the purchasing cost of the equipment itself, which includes a maintenance contract, as well as the cost for floor space. Process and transaction costs are calculated based on the time consumed to execute the process (e.g. make the connection) or the transaction (time needed for the administrative subscription or termination for instance), and the labor cost per hour. Please note here that contract handling between providers includes contract negotiation for connecting to a new region (we assume well-established, operational providers) and the procedure of administrative subscription (setting up a new account, assignment of costs, distribution of bill and verification of payment). Contract handling between a user and a provider includes the administrative subscription (create account, assign cost, distribute bill), as well as the cost for customer helpdesk (requesting information and handling administrative issues, typically clustered at the beginning and the end of a contract period). Transport costs are calculated taking into account both time and fuel consumption. The input values used for these calculations can be found in Table 7-1. These values were retrieved from a range of reference sources: the equipment related costs were found in [7.4], [7.6]-[7.8], the process and transaction times were based on [7.9] and [7.10], the labor costs were retrieved from [7.10] and the transport costs were calculated based on own estimations of distance and fuel costs.

This conceptual cost breakdown can now further be used to quantitatively evaluate the extra cost for the different procedures introduced in section III, for both fiber and bitstream open access.

7.3.1 Connecting a new provider

The first procedure that will be evaluated is also the first chronological procedure: a provider (NP in case of fiber open access, SP in case of bitstream open access) needs to be present before end users can subscribe.

Figure 7-7 shows the open access cost for connecting a new provider in the three scenarios under study. The additional cost open access adds for connecting a new SP is almost negligible and only consists of the establishing of the handover point and limited transaction costs. No real upfront investment is needed here, as no open access-specific equipment must be installed. This stands in great contrast to both fiber open access flavors, which both have transactions costs similar to bitstream open access, but incur significant upfront investment in the installation of additional equipment.

To verify whether it is useful to offer open access, the cost for connecting a new provider to an existing infrastructure should compared to the cost of deploying a second, parallel infrastructure. Hereby, it makes sense to compare the cost of passing a house (deploying passive infrastructure in the streets, €570 to €1750 per home, depending on the region under study, see section 5.3.1), to the cost calculated here, which comes down to €10-12 per household for fiber open access, and less than €0.5 per household for bitstream open access (assuming 20,000 households per CO or POI).

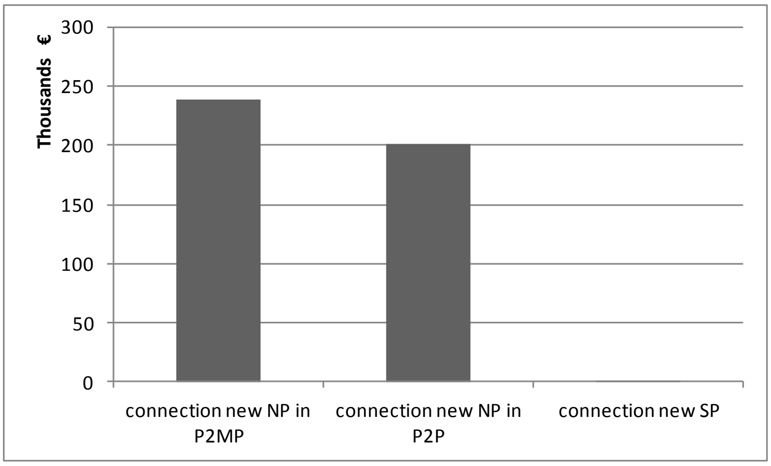

Figure 7-7: Open access cost for connecting a new provider, for fiber (P2MP and P2P) and bitstream open access

When investigating the difference between P2P and P2MP fiber open access, we see a clear influence of varying the number of NPs on the open access cost per provider (Figure 7-8). Note that, theoretically, there is no upper limit to the number of competing NPs in fiber open access but, following the study of existing fiber deployments (chapter 4 and [7.11]), the assumption was made that never more than five network providers will be active in the same geographical area at the same point in time. In P2P fiber open access, the main part of the cost can be attributed to the installation of the patch panel in the central office (equipment – system), which has to be installed only once, independent of the number of connected NPs. Please note that, although indicated here as an extra cost, a single, vertically integrated provider might also need an ODF for flexibility purposes. In P2MP, on the other hand, an extra splitter for each new NP has to be installed in each street cabinet, thus explaining both the equipment cost (cost for splitters) as well as the process cost (transport to all SCs and connecting the fibers to the splitters). Transaction costs are very low (in the order of €300 per provider) and, as they mainly constitute of administrative actions, they are equal for each new provider, independent of the total number of providers in the region. Process costs for a new NP in P2P are close to negligible, as they only comprise one transport to the CO.

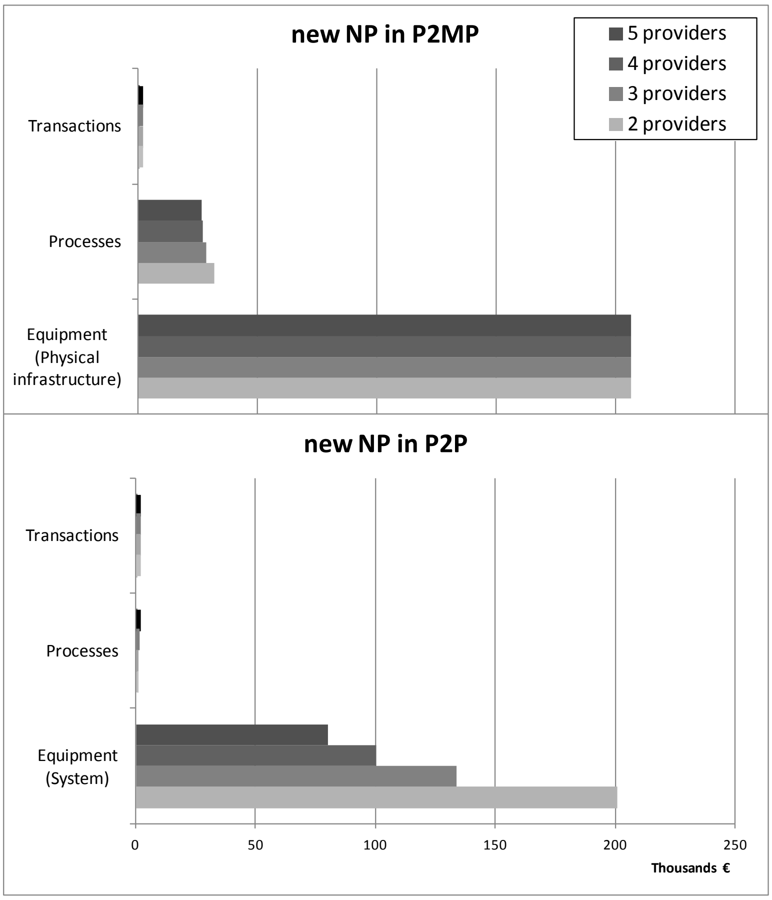

Figure 7-8: Varying the number of NPs has a clear influence on the open access cost per provider

As both equipment and process costs for P2MP fiber open access are significant, it makes sense to investigate whether they can be reduced by enlarging the street cabinets. Compared to the reference split ratio of 1:32, huge savings can be made by grouping more users in one street cabinet (Figure 7-9).

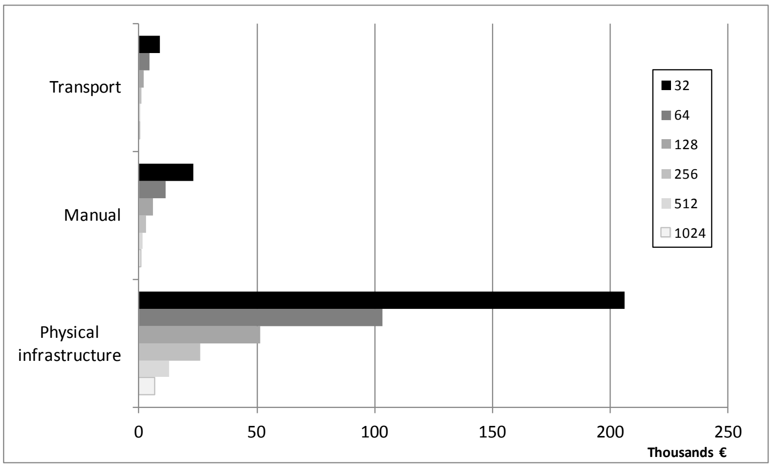

Figure 7-9: The influence of the number of users per street cabinet on the cost for connecting a new provider in P2MP fiber open access

7.3.2 Connecting a new end user

The cost for connecting a new end user is significantly more expensive in case of an open access network, as can be seen from Figure 7-10. Connecting a new end user on P2MP open access is 60% more expensive than connecting a new end user in a vertically integrated scenario. For P2P fiber open access and bitstream open access, the cost is 42% and 45% more expensive, respectively.

To recoup this connecting cost using the recurring monthly fees a provider receives from its end user over a contract period of 24 months, an extra monthly fee of €5.2, €4.6 and €3.1 needs to be charged to the end user in case of fiber open access P2MP, fiber open access P2P and bitstream open access, respectively.

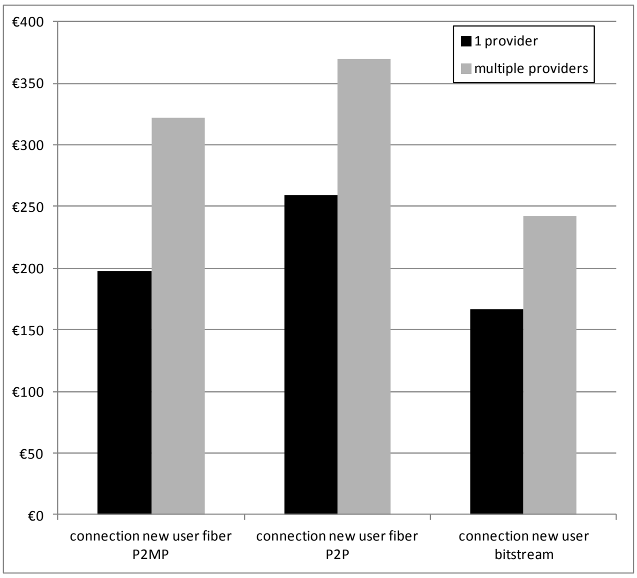

Figure 7-10: Cost for connecting a new user is more expensive in an open access network

In case of fiber open access, we see a significant increase in bargain costs, as now, contracts need to be handled between the end user and the SP, SP and NP, as well as NP and PIP. In the case of a vertically integrated operator, there is only one operator, so there is no need for contracts between SP, NP and PIP. A second difference can be found in the cost for transport and manual process, which can be explained by the need for re-patching of the user's fiber, at the CO for P2P fiber open access and at the SC for P2MP fiber open access. A small difference can be seen in the Equipment System costs, which consist of the NP specific equipment installed in the central office. In the case of 2 providers, the OLTs, shelves and racks are used less efficiently, thereby explaining the minor increase in cost. This difference is higher for P2MP fiber open access as users located on different splitters need to be connected to different OLTs.

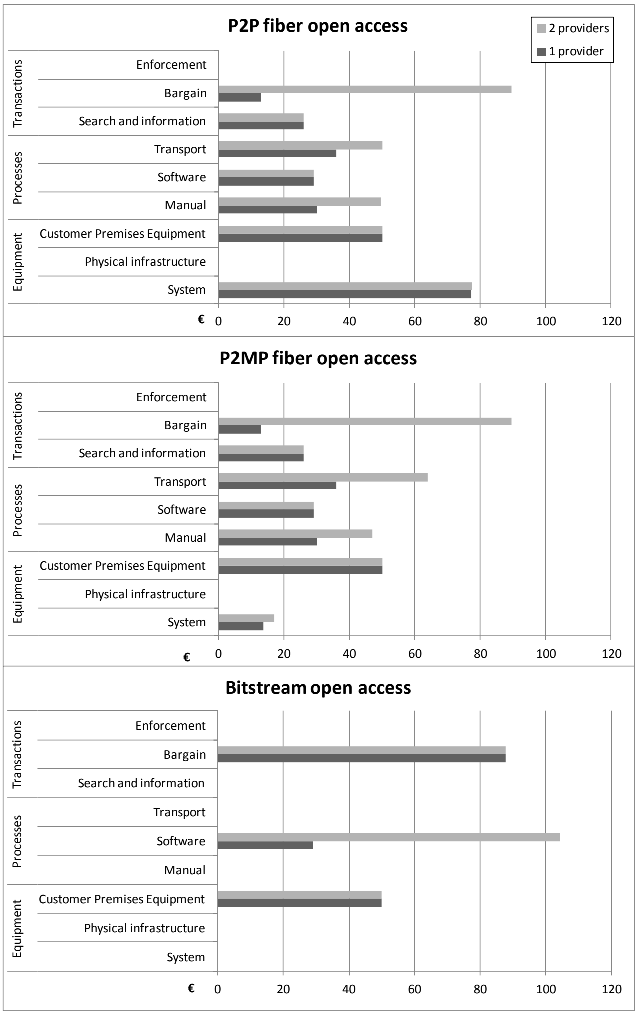

Figure 7-11: Cost split for connecting a new end user, for the three open access types

The cost for connecting a new user in a bitstream open access network only includes an increase in software cost for setting up the SP-specific operator virtual circuit. Here, bargaining costs are not increased vis-à-vis the vertically integrated scenario as there is only contact needed between the end user and the SP. This contact includes contract information and administrative subscription of the user with the provider and is independent of the number of providers, since the contract between the end user and the provider needs to be established anyway. This is different from the fiber open access case, where no

administrative subscription with NP and PIP is needed in case of a vertically integrated operator (SP, NP, and PIP roles are taken up by one single firm).
Note that, although the values for contract handling (bargain) are based on other research, precise estimation of these costs strongly depends on the specific contract and providers involved, and hence is difficult. Nonetheless, the results in Figure 7-11 show that the impact of transaction costs is significant.

7.3.3 Churn of an end user

The last procedure under study is the churn of an end user, in which an end user decides to switch provider. As can be seen from Figure 7-12, this cost is about €400 per churn process (for P2MP fiber open access, 3% and 12% cheaper for P2P fiber and bitstream open access, respectively) and thus comparable for all three cases.

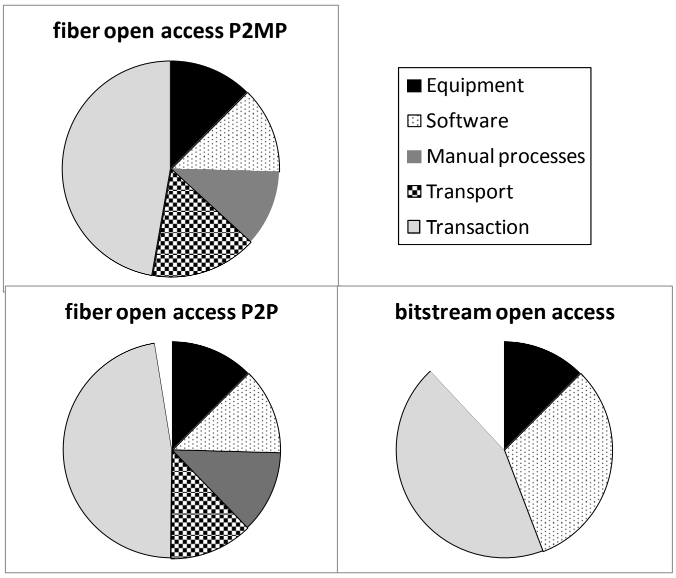

Figure 7-12: The cost for churn is comparable for all three open access cases (fiber open access P2P and bitstream open access are presented relative to fiber open access P2MP, which is the most expensive option)

Around half of the total churn cost is taken up by transaction costs, which include the administrative termination with the original provider (assign final cost, distribute bill, check payment, close account and helpdesk, 53% of transaction costs) and the administrative subscription with the new one (create customer account, assign cost, distribute bill, 47%). Smaller parts are taken up by equipment costs (new RGW – in case of SP churn, new ONT for NP churn),

transport and process costs (for re-patching the fibers at the CO or SC) and software costs for setting the right logical connection.
Similar to the connection of a new user, the note about the difficulty in estimating the exact cost of administrative subscription, termination and customer helpdesk, also holds in this case of estimating the cost for customer churn.
The cost for churn for fiber open access could be reduced by standardizing the ONU, so that no replacement is needed. By grouping churning end users in time, the transport cost can be shared among those, thereby reducing the transport cost per end user significantly. Note that this especially holds for P2P fiber open access, as the reconnection of the fiber has to be done in the central office for all users, whereas for P2MP fiber open access, only churning users in the same geographical area (connection located in the same street cabinet) will be able to benefit from the sharing of transport cost.
In case of bitstream open access, the main saving that can be achieved is by standardizing the RGW, again avoiding replacement. Although this is definitely possible, it will be more difficult than standardizing the ONU, due to the specifics of the service of each service provider (e.g. Internet and digital TV bundles). The total cost reduction is represented in Figure 7-13.

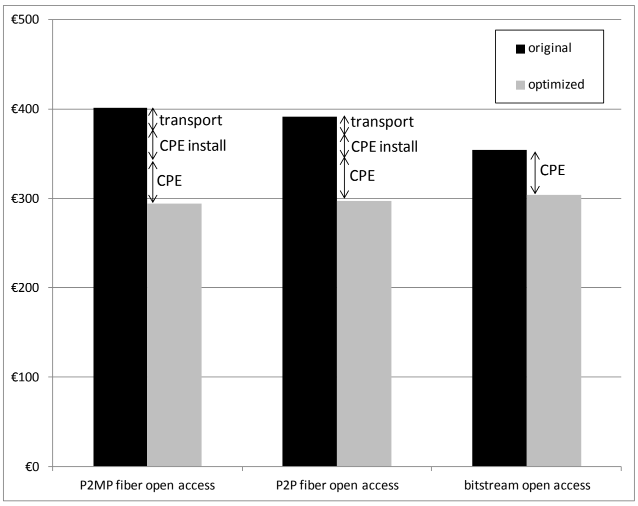

Figure 7-13: Optimizing the cost per churning end user by standardizing the CPE and sharing transport costs provides significant reductions

7.3.4 Optimizing the cost of cooperation

As the results show that the additional costs for offering open access are not negligible, it is worthwhile searching for how to reduce them. Some possible optimizations were already mentioned: increasing the number of users per street cabinet in a P2MP network, standardizing the CPE equipment or sharing transport among end users. Another option is to replace the cross-connect patch panel in P2P fiber open access with an automated switch. The purchasing cost for this type of equipment will of course be significantly higher than the manual patch panel we implemented in the reference scenario, but it will induce savings in the churning process, as the re-connection of end users can be done automatically instead of manually. This results in a trade-off question between upfront investment and operational expenditures, and will heavily depend on the amount of churn. Quantitative calculations for this optimization can however not be included in this paper, as such an automated cross-connect switch is not commercially available yet (so no reliable cost estimates can be found).

Apart from optimizations in equipment and process costs, the transaction costs could also be optimized. One way to reduce transaction costs is by reducing the uncertainty that is coupled with the transaction. Uncertainty can be reduced by increasing the level of information sharing. A greater degree of information sharing will lower the information asymmetries and as such the search and information costs, which will in turn lead to a reduction in transaction costs. An example of information sharing is the use of integrated databases.

A second factor influencing the transaction costs is the frequency of the transaction. Here, both economies of scale and scope, as well as learning curves can reduce the cost for the transaction over time.

Finally, a third factor impacting transaction costs is the ease of measurement. By automating billing and payment checking processes, the administrative bargaining costs can be significantly reduced.

Although described here shortly, the quantitative evaluation of these impacting factors on the total transaction cost for the three procedures described here, requires extended modeling and practical testing of these possible reductions, which falls beyond the scope of this dissertation.

7.4 Conclusion

Following the huge investments that installing an FTTH network brings, it is unlikely that these investments will be duplicated by two separate operators deploying parallel networks in the same geographical region. Still, as competition in service offerings for end users is desirable, another option to this unlikely infrastructure-based competition is allowing competing operators using the same underlying infrastructure. By sharing the infrastructure among multiple operators, the use of this underlying infrastructure can be maximized, thereby reducing the investment risk. However, opening up the network in an open access scenario also entails additional competition and collaboration costs.

This chapter investigated the cost for offering open access on top of a Fiber-to-the-Home network, thereby comparing open access on fiber and bitstream layer. The additional cost for opening up the network was evaluated for three procedures: the connection of a new provider (network provider in case of fiber open access, service provider for bitstream open access), the connection of a new end user and the churning process of end users. The results show that the additional open access cost for connecting a new provider is significant for fiber open access, but negligible for bitstream open access. The main chunk of this additional cost is taken up by the installation of extra equipment, in the central office for a P2P network, in the street cabinets in case of a P2MP network. The cost per provider could be reduced by increasing the number of providers in a P2P access network, and by increasing the number of end users per street cabinet in case of a P2MP topology.
The additional cost for connecting a new end user in an open access network can mainly be found in setting up the physical or logical link between the provider and the end user: manual patching of fibers in case of fiber open access, establishing an isolated virtual circuit in case of bitstream open access. A significant increase in transaction costs is furthermore noted for fiber open access, as multiple contracts need to be signed.
The final procedure, the churn of end users, is dominated by transaction costs needed for administrative termination of the original contract and the administrative subscription of the new one. Other significant parts are the cost for renewing of the CPE equipment, which can be avoided when standardized, and the cost for making a new provider-to-end user link (physical re-patching in case of fiber open access, logical setting up of a new OVC in case of bitstream).

In general, findings in this chapter show that open access can be a viable alternative for telecom operators in regions where infrastructure-based competition is not economically profitable. This chapter can furthermore also provide insights for public actors (such as governments and municipalities) on the additional cost for the different types of open access, especially when choosing the network topology (P2P – P2MP) and the layer of opening (on top of PIP or on top of PIP+NP).

Future work in this domain can include investigating the cost for wavelength open access, as next-generation access networks will most probably be supported by wavelength division multiplexing. Furthermore, optimizations for reducing the open access costs could be found by investigating more ways to standardize equipment and automate processes, while the impact of reducing uncertainty, increasing the frequency and enhancing the ease of measurement should be quantitatively calculated to estimate the possible optimizations in transaction costs.

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8
Conclusion

"I think and think for months and years.
Ninety-nine times, the conclusion is false.
The hundredth time I am right."
– Albert Einstein

The ever increasing bandwidth demand generated by new and enhanced services asks for continuous upgrades of telecommunications networks. These upgrades can be tackled by installing higher performing signaling equipment, but also includes replacing the former twisted copper pair or coaxial cables with optical fiber. A few decades ago, fiber cables were introduced in the core networks, connecting continents and larger cities. Gradually, optical fiber was deployed further down in the network (metro, access), eventually reaching the end customer: Fiber-to-the-Home. The closer the fiber is brought to the end user, the more expensive the investment gets, as the fiber is shared by less users. This makes current operators frequently postpone the investment in an all-fiber access network, as they do not clearly see sufficient revenue potential from this network upgrade.

This dissertation investigated the strategic decision in FTTH investment, by performing detailed techno-economic analysis taking into account the important boundary settings. This final chapter will provide the main conclusions of the performed research, and will give directions for future work.

8.1 Summary and conclusion

Following the exploration of historical and recent developments in FTTH networks worldwide, we conclude that techno-economic analysis of strategic network decisions should be taken with respect to the technological, policy and market characteristics that are different for each investment case.

Studying the layered structure of the telecommunications network (according to the Internet protocol stack), allows subdividing the responsibilities in deploying and operating an (access) network in three general roles: the physical infrastructure provider (PIP – physical layer), the network provider (NP – data link, network and transport layer) and the service provider (SP – application layer). The PIP determines the topology of the network: point-to-point versus point-to-multipoint. The NP is responsible for the architecture decisions, where the choice depends on the presence of active equipment in the field (active versus passive optical networks). The SP, finally, contracts with the end customer and offers different services and applications. This observed trend of splitting up responsibilities amongst different entities requires evaluating their business cases separately, though not independently.

Evaluation of physical infrastructure investment learned that it can be made profitable in most (dense) urban areas, given the right conditions and improvements on both cost and revenue side. Deployment of dark fiber infrastructure in rural areas will most probably not be economically viable without financial support (from public authorities). Investment in active network equipment should be evaluated using shorter time horizons or by including technology and equipment migrations, given its limited lifetime.

Sharing the infrastructure investment among multiple actors avoids duplication of investment in infrastructure that is often perceived as a natural monopoly, but requires additional equipment, process and transaction costs for connecting a new provider and connecting a new or churning end user.

Following this general summary, the remainder of this section gives an overview of the most important take-aways and recommendations of this dissertation (Figure 8-1).

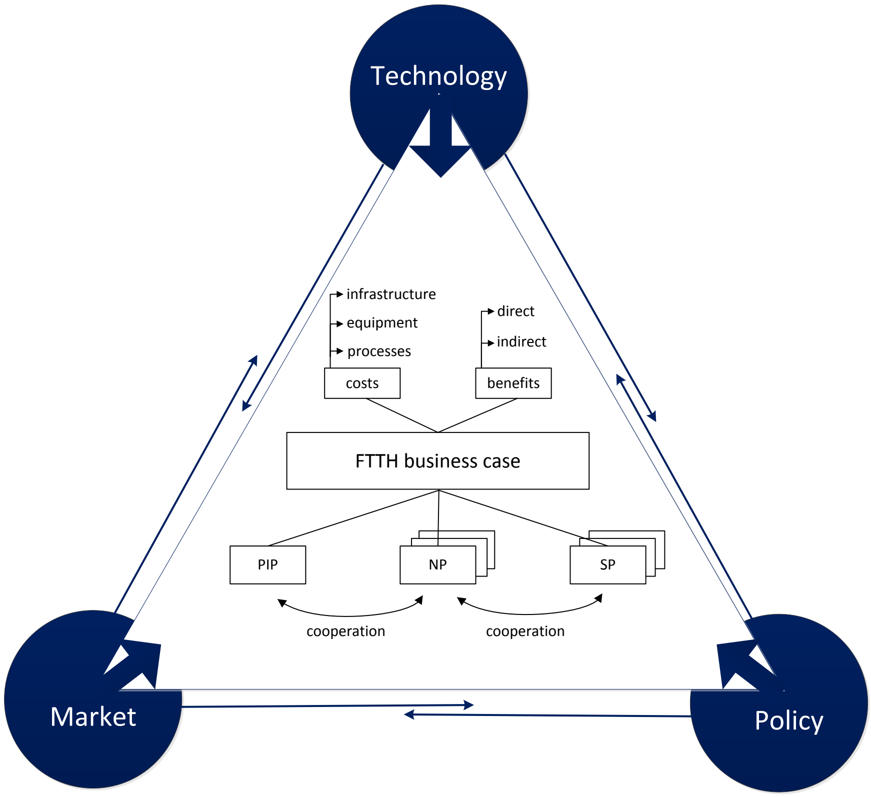

Figure 8-1: Overview of this dissertation

Sharing the infrastructure and allowing competition amongst multiple network and service providers avoids duplication of infrastructure investment and can be achieved by opening up the network at fiber, wavelength or bitstream layer. When the underlying network layer is opened up, multiple operators can compete on a higher layer. A PIP can allow multiple NPs on top of its physical infrastructure by providing fiber or wavelength access. When opening on the fiber layer, each NP receives dedicated fibers to reach its end customers. This is done by a dedicated fiber per end user connected to the NP's equipment via a patch panel in case of a P2P topology, while a splitter per NP connects the distribution fiber to the NP-specific feeder fiber in a P2MP network. In case of opening at wavelength layer, each user is served through a dedicated wavelength, which can be patched manually to the right NP in the central office or automatically through the use of an AWG in the street cabinet. Competition amongst SPs can be achieved through opening at bitstream layer. Through the use of an isolated, virtual connection in between the NP's aggregation switch and the end user's ONT, the SP is offered dedicated end-to-end connectivity, which can be used to provide dedicated services to its subscribers.

Many current FTTH deployments are initiated by a combination of public and private actors, driven by distinct goals and taking up separate responsibilities in different business models. For investigating the conditions set by the market and policy pillar, a variety of operational FTTH deployment cases was studied on six characteristics: the region type and scale of deployment, the policy conditions, the initiator and key drivers, the financing structure, the applied business model and existing competition, both inter- and intra-platform. A clear link could be found between the region type (dense urban, urban or rural) and the existing competitive infrastructure. Rural areas are in general less interesting for high return on investment from broadband deployment, hence the most public involvement was seen there. Although more explicit in rural regions, public involvement was noticed in almost every case, thereby ranging in both level of institution (national government, local municipality, regional public utility owner), as well as in degree of involvement (granting Right of Way, aggregating demand, financial support, direct investment). Public involvement is mostly driven by socio-economic advantages (universal access for all citizens, reduced prices due to enhanced competition) and linked to an open access business model, whereas private players want to maximize return on investment, preferably by prohibiting intra-platform competition as a vertically integrated operator. Competitive pressure is regarded as the stimulus for private initiative in FTTH investment.

Evaluating strategic network decisions in FTTH deployment requires a detailed and reliable estimation of both costs and revenues, and thus asks for the development of novel techno-economic models. As different actors take up different roles in the network, their business case must be evaluated separately. Specific cost and revenue models were developed for analyzing both the PIP and NP business case. On the cost side, three modeling languages were built. Analytical models for different street topologies allow for a fast estimation of physical infrastructure deployment costs (PNMN). Granularity-driven trees calculate the amount of equipment to be installed, as well as their associated cost for energy and maintenance (ECMN). Process flowcharts, finally, generate the statistical cost of operational processes (BPMN). On the revenue side, different pricing schemes allow for matching the estimated willingness to pay to the forecasted adoption curve.

The business case for physical infrastructure investment is very difficult, especially for less populated areas, and thus requires measures for improvement or even public funds. Evaluating the business case for physical infrastructure investment showed that, under the conditions of a monthly ARPU of 10 euro and a time horizon of 20 years, profits are only made in the dense urban area under an aggressive take-up rate. Measures for improving the business case were thus proposed. Demand aggregation, as already applied by Reggefiber in the Netherlands and Google Fiber in the USA, can make nearly all dense urban and urban deployments profitable. Reusing existing ducts (from legacy twisted copper pair or coaxial cable networks, or other utility infrastructures) can significantly reduce the trenching costs. Prolonging the time horizon to 40 years can make a positive business case in the urban area with aggressive adoption. Despite these improvements, even if combined, the business case for FTTH deployment in a rural area remains difficult. Here, using public funds might be the only way out.

As the lifetime of equipment and their related technologies is shorter than that of the physical infrastructure, business case analysis for network provider investment should be done on shorter time spans or include migration. The investment part for the network provider only constitutes 30% of total upfront investment, but its active equipment will not last as long as the buried physical infrastructure. When evaluating the business case for the NP on a 10-year period, profits can be made on the condition that the CPE and in-building wiring is recouped separately from monthly customer fees. If a longer time horizon needs to be considered (to make a fair comparison to the business case of the physical infrastructure), technology and equipment migration needs to be taken into account. The analysis here concludes that, although the upfront equipment investment for active optical networks may be higher, upgrading AONs is significantly cheaper than upgrading PONs, mainly because of compatibility of ONT equipment.

Including the value of indirect benefits as an additional revenue source from FTTH investment can convince public partners to get involved. Public and private partners have different goals when getting involved in FTTH deployment cases. Whereas private partners strive to maximize their financial profits, public entities are mainly driven by socio-economic goals. Internalizing these so-called indirect benefits of broadband networks in the investment decision of the public actors might therefore improve their business case prognosis. In this research, the indirect benefits were identified, categorized and quantified using a bottom-up approach. The advantages of this approach are (1) that it allows modeling the benefits separately, thereby holding on to a cause-effect relationship, and (2) that it provides the possibility of forecasting the added value of the effects. Top-down modeling is less influenced by input parameter values, but it is less accurate in determining the causal relationship and can only be applied ex-post. The developed bottom-up model was applied to two sectors: eGovernment and eBusiness, for two cities: Ghent and Eindhoven. The main added value was found in the travel gains (for both commuting and traveling to the city's administrative center), as well as operational savings (in office space and electricity). The value of these indirect benefits was shown to be significant when compared to the investment needed for FTTH deployment, and could be steered into the business case by granting broadband subscription fees as non-statutory benefits for employees or by local authorities providing benefits in kind to targeted households.

Although open access entails additional equipment, processes and transaction costs for connecting a new provider or connecting a new or churning end user, this extra cost is very low compared to the investment needed to deploy a parallel infrastructure. The business case analysis for both the physical infrastructure and the network equipment learned that FTTH investment is not easy. However, if the infrastructure can be shared amongst multiple operators (NPs or SPs), the investment risk can significantly be decreased. Although open access allows this sharing, it does not come for free, but entails extra equipment, processes and transaction costs. Connecting a new NP in fiber open access entails a significant upfront equipment and process cost in the installation of a patch panel in the central office (P2P network) or a splitter per new NP in each street cabinet (P2MP topology). The cost for connecting a new SP on bitstream open access is negligible as it comes down to a very limited transaction cost. Connecting a new end user is driven by the process costs for setting up a physical (fiber open access) or virtual (bitstream open access) link. The cost for churning end users is mainly driven by extra administrative transactions, whereas the cost for replacing the CPE can be reduced by standardization.

8.2 Future work

Future work to this research mostly focuses on extending the work to other domains and sectors.

Extension to other regions. The cases studied in this research were all situated in developed countries, as their historical background provided more means for comparison, especially in terms of economic setting. Recently, however, new FTTH initiatives are rising in the developing world. Operators such as Zuku in Kenya and Vivo in Brazil are starting to deploy fiber in major cities. Since their market settings and policy conditions are significantly different, adding these types of cases to the list will allow for further investigation and generalization of the found conclusions.

Studying the background settings (in terms of economic situation, geographical areas and political environment) will learn if the developed models are generic enough to be applied to those cases, or if adjustments in terms of modeling or parameters (new parameters and/or new values to the existing ones) are needed.

Extension to other sectors. The evaluation of indirect benefits in this work was limited to eGovernment and eBusiness, as literature indicated that these sectors conceal the most indirect effects for the near future. However, other sectors could also entail significant effects worth valuating. The education sector for instance could benefit significantly from distance learning (especially in remote areas), while remote surgery is an example of a service that could generate serious benefits for the health sector. Finally, the hidden value of broadband for the entertainment industry should also not be forgotten: there is significant willingness to pay for e.g. virtual presence in gaming.

Applying the bottom-up methodology used for the monetary evaluation of eGovernment and eBusiness on other sectors influenced by broadband and FTTH (eEducation, eEntertainment, eHealth) can lead to additional potential savings. To do this, the right services, their effects and related input data should be collected by a combination of both desk research, evidence from existing use of those services and interviews with both local and international experts.

Extension to other technologies. As wavelength division multiplexing is not commercially available yet, the additional costs for wavelength open access were not yet taken up in this research. However, the opportunity identified by TWDM could provide a flexible and affordable solution on existing PONs, and should hence be explored further. As technology evolves further, the cost of this type of open access should be evaluated and compared, together with its advantages and disadvantages, to the already discussed options of fiber and bitstream open access. Furthermore, the current cost and revenue models should be applied to longer-term evolutions in telecom access networks, which are studied by both industry and academia (e.g. in research projects such as OASE).

The developed cost modeling languages (ECMN, BPMN, and PNMN) and revenue pricing schemes can be applied to model the expected cost evolution and needed revenue estimation for these evolutions in both network architectures and open access types. Furthermore, as all languages are developed in a generic way, they are applicable for the techno-economic modeling of other broadband technologies, such as wireless 4G/5G deployments or in-house broadband wiring installations.

Extension to other players. As this dissertation focused on the deployment of a new access network, based of optical fiber, the business case for the service provider was not tackled explicitly. However, the recent discussions about net

neutrality, including who should be responsible for paying for the Internet traffic, could provide good arguments to investigate the costs and benefits of a service provider in more detail.
Modeling the costs and revenues of a service provider would first require a qualitative identification and categorization of the different cost components, for instance using a lifecycle cost breakdown (planning, deployment, migration, operations and teardown). This breakdown allows for identifying hardware costs (set-up boxes, streamers), operational costs (connection and maintenance processes, but also customer relations and helpdesk), license costs (for video and TV content) and software costs (development of applications and related interfaces). While the modeling of hardware and software costs can be tackled using (a modified version of) ECMN and BPMN, software costs will require a new type of modeling language. On the other hand, as revenues for service providers do not always (only) originate from the end users, but frequently include advertisement income, the pricing schemes developed should be extended to allow for calculating these new types of revenue sources as well.

Extension to other modeling approaches. This research strongly relied on bottom-up approaches for modeling both costs and revenues for the different actors involved in a FTTH deployment. However, if sufficient macro-economic data for sufficient cases is available, the costs found in this research could be benchmarked against the results of top-down approaches. This comparison was already performed in the chapter on indirect benefits, where the results of this bottom-up research were compared to other top-down approaches.
Top-down modeling applies statistical regression and input-output methods on sufficient and reliable trend data. Calculating costs and revenues for FTTH deployments in a top-down manner would therefore have to rely on a much bigger number of cases, such that relationships between geographical, economic, technological and political parameters on the one hand, and deployment and operational costs and revenues on the other, can be used as benchmarks for other regions and guidelines for policy makers.

Extension to other application domains. Although the Social Cost-Benefit models developed in this research were applied to the case of FTTH deployment, the trend towards opening up the value chain and allowing multiple actors to take up separate roles is not only visible in telecom. The separation between infrastructure deployment and maintenance on the one hand, and service offerings on the other, is also applicable to recent trends in the electricity and railroad market, and appears in the split between platform and application developers in sectors such as mobile phones and eHealth applications.
In order to apply the concepts developed in this research on other application domains, similar steps need to be followed. First, the distinct roles need to be

identified, and mapped to the right actors. Next, a cost breakdown for all separate roles needs to be composed, thereby indicating the cost driver and potential cost modeling language for each category. Calculating the costs and matching them to a good pricing scheme for an estimation of the needed revenues is the following step. The last hurdle is the identification and estimation of the cooperation costs, i.e. does splitting up the roles among multiple actors lead to savings or only induces additional costs?

A
Gathered input data for the quantification of indirect benefits

This appendix summarizes the input data used for quantifying the indirect benefits for eGovernment and eBusiness, for the cities of Ghent (Belgium) and Eindhoven (The Netherlands). For more information about the methodology and subsequent results, we kindly refer the reader to sections 6.3 and 6.4.

Table A-1: Input data for eGovernment in Ghent

Subservice	Effect	Population group	Unit benefit [U]	Conversion [€/U]	Occurrence (x/year)	Actor's share (%)			
						G	C	I	S
Switching from personal contact to electronic contact	Reallocation of the time of the administrative personnel	199174	10.4 minutes	0.0272 €/minute	12	100	0	0	0
	Time gain	199174	0.55 hours	10 €/hour	1.911	0	0	100	0
	Travel cost saving - fuel	199174	11.76 km	0.5 €/km	1.911	0	8.75	91.25	0
	Travel cost saving - parking	199174	1 hour	1.8 €/hour	1.911	0	8.75	91.25	0
	Decreased consumption of paper (e.g. sending letters)	199174	0.8114 €	1 €/€	0.50	100	0	0	0
	Decreased traffic jams and road accidents	199174	0.98 €	1 €/€	1.911	0	0	0	100
	Less stress	/	/	/	/	/	/	/	/
	Reduced CO_2 emission (and other harmful gasses)	199174	1.412 kg	0.135 €/kg	1.911	0	0	0	100
Providing information and resources for citizens online	Time gain	/	/	/	/	/	/	/	/
	Reallocation of the time of the administrative personnel	199174	4.5 minutes	0.03 €/minute	4	100	0	0	0
	Travel cost saving	/	/	/	/	/	/	/	/
	Decreased consumption of paper (e.g. brochures)	/	/	/	/	/	/	/	/
	Retrieving information outside office hours	/	/	/	/	/	/	/	/

Table A-2: Input data for eGovernment in Eindhoven

Subservice	Effect	Population group	Unit benefit [U]	Conversion [€/U]	Occurrence (x/year)	Actor's share (%) G	C	I	S
Switching from personal contact to electronic contact	Reallocation of the time of the administrative personnel	148118	10.4 minutes	0.0265 €/minute	12	100	0	0	0
	Time gain	148118	0.79 hours	10 €/hour	1.999	0	0	100	0
	Travel cost saving - fuel	148118	8.51 km	0.5 €/km	1.999	0	12.25	87.75	0
	Travel cost saving - parking	148118	1 hour	3 €/hour	1.999	0	12.25	87.75	0
	Decreased consumption of paper (e.g. sending letters)	148118	0.74 €	1 €/€	0.675	100	0	0	0
	Decreased traffic jams and road accidents	148118	0.98 €	1 €/€	1.999	0	0	0	100
	Less stress	/	/	/	/	/	/	/	/
	Reduced CO_2 emission (and other harmful gasses)	148118	1.021 kg	0.135 €/kg	1.999	0	0	0	100
Providing information and resources for citizens online	Time gain	/	/	/	/	/	/	/	/
	Reallocation of the time of the administrative personnel	148118	4.5 minutes	0.0265 €/minute	4	100	0	0	0
	Travel cost saving	/	/	/	/	/	/	/	/
	Decreased consumption of paper (e.g. brochures)	/	/	/	/	/	/	/	/
	Retrieving information outside office hours	/	/	/	/	/	/	/	/

Table A-3: Input data for eBusiness in Ghent

Subservice	Effect	Population group	Unit benefit [U]	Conversion [€/U]	Occurrence (x/year)	Actor's share (%) G	C	I	S
Working from home	Reduced travel time	138597	1 hour	10 €/hour	44	0	0	100	0
	Reduced travel costs	138597	37.6 km	0.5 €/km	44	0	8.75	91.25	0
	Decreased traffic jams and road accidents	138597	0.98 €	1 €/€	44	0	0	0	100
	Reduced emission of CO_2	138597	4.512 kg	0.135 €/kg	44	0	0	0	100
	Reduced stress	/	/	/	/	/	/	/	/
	Decreased number of absenteeism by illness	138597	0.67 days	68.99 €/day	1	21.61	78.39	0	0
	Reduced office space and opex	138597	357.85 €	1 €/€	12	21.61	78.39	0	0
	Higher independency and flexibility for the employee	/	/	/	/	/	/	/	/
	Reduced spending on human resources	138597	5.007 €	1 €/€	12	21.61	78.39	0	0
Videoconferencing	Less business trips	7289	10 trips	150 €/trip	1	0	100	0	0
Grouped management of ICT infrastructure	Reallocation of the time of the support staff	/	/	/	/	/	/	/	/
	More efficient use of network- and ICT services	61934	429 €	1 €/€	1	0	100	0	0
Online training	Reduced travel (time and costs)	/	/	/	/	/	/	/	/
	Reduced training expenses	138597	12.62 €	1 €/€	12	21.61	78.39	0	0
	Reduced stress	/	/	/	/	/	/	/	/
	Reduced emission of CO_2	/	/	/	/	/	/	/	/
	Decreased traffic jams and road accidents	/	/	/	/	/	/	/	/

Table A-4: Input data for eBusiness in Eindhoven

Subservice	Effect	Population group	Unit benefit [U]	Conversion [€/U]	Occurrence (x/year)	Actor's share (%) G	C	I	S
Working from home	Reduced travel time	143100	1 hour	10 €/hour	44	0	0	100	0
	Reduced travel costs	143100	27.8 km	0.5 €/km	44	0	12.25	87.75	0
	Decreased traffic jams and road accidents	143100	0.98 €	1 €/€	44	0	0	0	100
	Reduced emission of CO_2	143100	3.336 kg	0.135 €/kg	44	0	0	0	100
	Reduced stress	/	/	/	/	/	/	/	/
	Decreased number of absenteeism by illness	143100	0.8 days	160 €/day	1	13.46	86.54	0	0
	Reduced office space and opex	143100	357.85 €	1 €/€	12	13.46	86.54	0	0
	Higher independency and flexibility for the employee	/	/	/	/	/	/	/	/
	Reduced spending on human resources	143100	5.436 €	1 €/€	12	13.46	86.54	0	0
Videoconferencing	Less business trips	6513	10 trips	150 €/trip	1	0	100	0	0
Grouped management of ICT infrastructure	Reallocation of the time of the support staff	/	/	/	/	/	/	/	/
	More efficient use of network- and ICT services	61882	429 €	1 €/€	1	0	100	0	0
Online training	Reduced travel (time and costs)	/	/	/	/	/	/	/	/
	Reduced training expenses	143100	13.71 €	1 €/€	12	13.46	86.54	0	0
	Reduced stress	/	/	/	/	/	/	/	/
	Reduced emission of CO_2	/	/	/	/	/	/	/	/
	Decreased traffic jams and road accidents	/	/	/	/	/	/	/	/