Aalto University
School of Electrical Engineering

Aalto University
School of Electrical Engineering
Degree program in Communications Engineering

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Techno-economic Model for Broadband Copper Access Life-cycle

Master's Thesis
Helsinki, 16.1.2013

Supervisor: Professor Heikki Hämmäinen
Instructor: Johan Laxén M. Sc.

AALTO UNIVERSITY | Abstract of the Master's Thesis

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Subject of the thesis:
Techno-Economic Model for Broadband Copper Access Life-Cycle

Number of pages: 96	Date: 16.1.2013	Library location:
Professorship: Networking Business		Code of professorship: S-38

Supervisor: Prof. Heikki Hämmäinen

Instructor: Johan Laxén, M.Sc. (Tech.)

Broadband network is constantly improved with faster connections, advanced technology and equipment. The broadband access network in Finland consists of combination of multiple different technologies. The main technologies in use are copper, optical fiber and wireless radio signal. A copper network offers required speeds for limited distances but is a rather old technology for a broadband connection. A perished copper access line can cause a lot of failures in a network. Wires can be maintained by installing amplifiers and shortening loop lengths, but costs of maintaining the wires are soon as expensive as installing new access lines.

The purpose of this thesis is to study the profitability and suitability of copper network as a broadband access media in Finland in areas where it is still in use. Techno-economic calculations are applied in the copper network life-cycle analysis in this study. The life-cycle is assumed to be different in different types of areas and therefore the analysis is divided to urban, sub-urban and rural areas. As a result, this thesis presents a reasonable definition for copper based network's life-cycle.

The life-cycle modeling is conducted by comparing competitive technologies in different competition areas. Copper access competes with existing fiber access in urban areas, with future fiber access in sub-urban areas and with mobile broadband solutions in rural areas. The results of this study show that copper network is able to compete with fiber access only at short loop lengths. Fiber is a profitable investment if the number of installation meters stays below eight meters per household, and it could then replace copper. The radio capacity of 3G in the rural areas is 1.5 users per square kilometer and it is able to compete with copper network at data rates below 8 Mbps. 4G could compete with 24 Mbps copper access connections in the future if the user density is below 3.2 users per square kilometer.

Keywords: copper network, DSL, life-cycle, techno-economic modeling

Publishing language: English

AALTO-YLIOPISTO Diplomityön tiivistelmä

Tekijä: Jasmine Holmström		
Työn nimi: Teknistaloudellinen malli kuparipääsyverkon elinkaarelle		
Sivumäärä: 96	Päivämäärä: 16.1.2013	Työn sijainti:
Professuuri: Tietoverkkoliiketoiminta		Koodi: S-38
Valvoja: Prof. Heikki Hämmäinen		
Ohjaaja: DI Johan Laxén		

Laajakaistaverkkoa kehitetään jatkuvasti tukemaan suurempia nopeuksia, kehittyneempää teknologiaa ja uusia laitteita. Suomessa laajakaistaverkko on toteutettu useamman eri teknologian yhdistelmänä. Käytetyt siirtotieteknologiat ovat karkeasti kupari, optinen valokuitu ja liikkuva langaton laajakaista. Kupariverkko kykenee tarjoamaan tarvittavia nopeuksia tiettyyn asiakasjohtopituuteen saakka, mutta on laajakaistayhteyden siirtotienä jokseenkin vanha teknologia. Haurastuneet kuparikaapelit voivat aiheuttaa paljonkin vikoja verkossa. Kaapeleita voidaan kuitenkin tekohengittää vahvistimia lisäämällä tai kuparijohdon pituutta lyhentämällä, mutta jossain pisteessä kuparikaapeleiden korjauskustannukset alkavat maksaa yhtä paljon kuin uusien asiakasjohtojen asentaminen.

Tämän diplomityön tarkoituksena on tutkia kupariverkon kannattavuutta ja soveltuvuutta laajakaistapääsyverkkotekniikkana Suomessa niillä alueilla, joilla se on vielä käytössä. Kupariverkon elinkaari määritellään teknoekonomista laskentaa hyväksi käyttäen. Tämän elinkaaren oletetaan poikkeavan eri alueiden kesken ja siksi elinkaaren mallinnus tehdään erikseen kaupunkialueille, esikaupunkialueille ja haja-asutusalueille. Työ tarjoaa perustellun määritelmän kupariverkon elinkaareksi.

Elinkaarta mallinnetaan vertaamalla kupariverkkoa kilpaileviin laajakaistateknologioihin erityyppisillä alueilla. Kupari kilpailee kaupunkialueilla olemassa olevan kuituverkon kanssa, esikaupunkialueilla tulevaisuuden kuituverkon kanssa ja haja-asutusalueilla langattomien laajakaistatekniikoiden kanssa. Tulokset näyttävät, että kupariverkko on kilpailukykyinen kuituverkon kanssa vain lyhyillä asiakasjohtopituuksilla. Kuituverkkoon on kannattava investoida, jos kaivumetrit kotitaloutta kohden ovat alle kahdeksan metriä. 3G verkon radiokapasiteetti on 1,5 käyttäjää neliökilometrillä. 3G on kilpailukykyinen kupariverkon kanssa alle 8 Mb/s kuparinopeuksilla. Tulevaisuudessa 4G olisi kilpailukykyinen kupariverkon 24 Mb/s nopeuksille, jos käyttäjämäärä jää alle 3,2 käyttäjää neliökilometrillä.

Avainsanat: kupariverkko, DSL, elinkaari, teknoekonominen mallinnus	Julkaisukieli: Englanti

Preface

This Master's Thesis completes my studies for Master of Science degree at Aalto University School of Electrical engineering. The work was carried out at TeliaSonera Oyj under the guidance of Johan Laxén. Supervisor from Aalto University was Heikki Hämmäinen.

I am very grateful for this opportunity to work in supervision of such skilled professionals and of this really interesting topic. I appreciate the work contribution that my instructor Johan Laxén has made for my thesis. Not only he guided me through this work but also taught me critical and precise thinking. I also appreciate the valuable advices and effort that Professor Heikki Hämmäinen has given for this work.

Special commendations I want to state to my fellow workers Meerit Rantanen and Matti Palosuo who have been really kindly helping with providing material for this thesis. Thanks for the interviewees and all the other parties that have given their time and knowledge.

I want to express particular thanks to my friends and family who has supported me throughout my studies. Finally, greatest compliments to my boyfriend Olli for his loving support.

Helsinki, January 2013
Jasmine Holmström

Contents

List of abbreviations

ADSL	Asymmetric Digital Subscriber Line
ARPU	Average Revenue per User
CATV	Cable Television
CAPEX	Capital Expenditure
CDMA	Code Division Multiple Access
CLEC	Competitive Local Exchange Carrier
CO	Central Office
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DOCSIS	Data over Cable Service Interface Specifications
EDGE	Enhanced Data Rates for GSM Evolution
EPON	Ethernet Passive Optical Network
Flash	Fast Low-latency Access with Seamless Handoff
FTTB	Fiber to the Building
FTTH	Fiber to the House
GPON	Gigabit Passive Optical Network
HDSL	High bit-rate Digital Subscriber Line
HFC	Hybrid Fiber Coax
HSPA	High-Speed Packet Access
ILEC	Incumbent Local Exchange Carrier
IPTV	Internet Protocol Television

IRR	Internal Rate of Return
ISDN	Integrated Services Digital Network
ISP	Internet Service Provider
LOS	Line-of-Sight
LTE	Long Term Evolution
MDF	Main Distribution Frame
MIMO	Multiple-Input Multiple-Output
NMT	Nordic Mobile Telephone
NPV	Net Present Value
OA&M	Operations, Administration and Management
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operational Expenditure
PON	Passive Optical Network
POP	Place of Presence
SHDSL	Single pair High bit-rate Digital Subscriber Line
SHDSL.bis	SHDSL bonding interface standard
SMP	Significant Market Power
UMTS	Universal Mobile Telecommunications System
VDSL	Very High Speed Subscriber Line
VoIP	Voice over Internet Protocol
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network

1 Introduction

1.1 Motivation and background

In the field of telecommunications the development of new technologies is rapid. For example, broadband network is constantly improved with faster connections, advanced technology and equipment. (Fijnvandraat & Bouwman 2006) Broadband is a part of the universal service in Finland since July 2010 which means that everyone should have a possibility for an Internet access. The universal service obligation is currently 1 Mbps and it is raised as broadband technologies evolve. Broadband network is expected to be able to offer qualifications that are set by the Ministry of Transport and Communications. (Ministry of transport and communications 2008)

The broadband access network in Finland consists of a combination of multiple different technologies. The main technologies in use are copper, optical fiber and wireless mobile broadband technologies. A Copper network offers required speeds for limited distances but is a rather old technology for a broadband connection. On the other hand, rolling out fiber is expensive due to digging costs and long investment pay-back periods. Wireless solutions could offer a temporary solution, but it is going to run out of capacity at some point (Interview 26.6.2012).

Reduction in subscriptions has led to the decision of pulling out copper network in certain very sparsely populated areas. The reduction in subscriptions correlates with regional population decrease as people have moved from rural areas to population centers. The revenues from broadband business in rural areas have decreased notably compared to the expenses. When the yield and cost curves cross, business is no longer profitable. Cost reductions are usually done by optimizing the network. Optimization means closing the unprofitable parts of the network and replacing them with alternative solutions e.g. with wireless broadband.

Ageing of a copper cable causes failures in subscriber connection. It can also reduce connection data rate. Costs of maintaining a network increase due to failures. Copper cables are maintained in some business areas but copper is not used anymore in building new networks. In population centers and very densely populated areas the fixed access line business is still profitable because there are enough customers. (Interview 22.8.2012)

The purpose of this thesis is to study the profitability and suitability of copper network as a broadband access media in Finland in areas where it is still in use. Techno-economic calculations are applied in the copper network life-cycle analysis in this study. The model takes into account copper network's physical capabilities, competition, cost of maintenance and revenues, and it compares copper to alternative technologies. In addition to scaling technical capabilities and limitations, profitability calculations are also performed. As a result, this thesis presents a reasonable definition for copper based network's life-cycle.

1.2 Research objective and research questions

Objective of this study is to use techno-economic modeling to define a life-cycle for copper access network that is used in broadband business in Finland. The study includes defining different geographical business areas and alternative technologies for copper based broadband network. In addition, characteristics of broadband business in general are studied. The main research question is as follows:

How can the life-cycle of copper broadband access network in Finland be defined with techno-economic modeling? What is the life-cycle according to the model?

Basics for the techno-economic model are gathered through interviews and literature reviews which try to answer to following questions:

- What are the possible alternative technologies for copper broadband access technology?
- What are the main characteristics that affect to profitability and capability of a broadband network in general?

- How techno-economic modeling can be carried out and what are the proper methods to perform sensitivity analysis?

1.3 Scope of the study

Research question is about creating a model to define copper access network life-cycle. Copper network offers multiple different services such as broadband, voice and television services. In this study the focus is on the broadband service side, not voice or television services directly. Nevertheless, because Internet Protocol Television (IPTV) and Voice over Internet Protocol (VoIP) services are offered through a broadband connection, the bandwidth requirements are taken into account in the study.

There are two types of copper wires in use in the Finnish broadband network: twisted pair and coaxial cable. Basically coaxial cable is used in offering a cable television service, but later it has also been used in broadband as well. Coaxial cable and twisted copper pair are two different technologies. Copper network in this thesis refer to twisted pair copper network. However, coaxial cable is taken into account as an alternative broadband solution for twisted copper.

Copper cables are in use in different parts of the network in Finland. This study examines copper cables life-cycle in the access part of the network. Copper cables in core and metro parts of the network are excluded from the life-cycle model. The in-house network of a house is usually made of copper cables and it is maintained by either housing companies or house owners instead of broadband network operators. Therefore, copper cables in in-house networks are excluded from the model too.

Geographically this study focuses on Finland and Finnish access network. Finland is divided to approximately five thousand network areas according to the serving area of an exchange. This study is made from the perspective of a network operator. An operator categorizes network areas in Finland as their own Incumbent Local Exchange Carrier (ILEC) areas and competitor's Competitive Local Exchange (CLEC) areas.

1.4 Research methods

The techno-economic model for copper access network life-cycle is comprised based on Smura (2012) and ECOSYS (2006). Inputs to the model are gathered through a literature review and expert interviews. The life-cycle modeling is carried out by comparing the different technologies as scenarios. Comparison takes into account technical and economic characteristics.

Techno-economic modeling is performed in Microsoft Office Excel®. Basic profitability indicators, such as Discounted Cash Flow (DCF), Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PP), are calculated. The sensitivity analysis is carried out by varying inputs from the most probable values and the risk analysis is carried out by the Monte Carlo method.

1.5 Outline of the thesis

The structure of this thesis is illustrated in the Figure 1 below. Technical parameters refer to an overview of the broadband access technologies in Finland. This overview is performed in chapter 2. Economic parameters refer to an overview of broadband business in Finland in general. Broadband business parameters are introduced in chapter 3. Techno-economic modeling is defined in chapter 4. Information and methods of the previous chapters are deployed in the life-cycle model, its sensitivity and risk analysis in chapter 5. In chapter 6, conclusion and future research are provided.

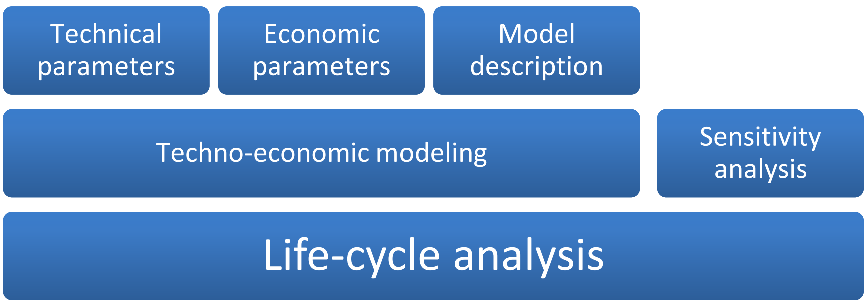

Figure 1 Structure of the thesis

2 Broadband access networks

This chapter introduces characteristics of the universal service obligation in Finland and defines an overall structure of a broadband network. Alternative broadband access network technologies are introduced. Those are divided into fixed and wireless technologies. Finally, services that a broadband access should offer are discussed in this chapter.

2.1 Broadband network in Finland

In 2008, the Finnish Communications Regulatory Authority started a project (together with the Finnish government and the Ministry of Transport and Communication) that would bring 100 Mbps network to no further than two kilometers from 99 % of the permanent places of residence, business and public administration in Finland by the end of 2015. The statute sets its own challenges for a broadband network. In 2010, BBC wrote an article about Finland being the first country to make broadband a legal right for all the citizens. Universal service obligation has been 1 Mbps since 2010 (this data rate limitation implicate to the downstream data connection speed). (Ministry of transport and communications 2008 and 2012)

In agreement with the Ministry of Transport and Communication (2008), the purpose and use of a broadband connection has changed from reading e-mails to downloading pictures, music and video clips. Moreover, the Internet is used for services and applications that are offered either by the society or a private party. Voice, data and video are all delivered through a single connection and therefore demand for more bandwidth has increased. (Corning white paper 2005) At the moment of writing, operators in Finland offer only services for broadband and IPTV. Voice services are not productized by operators but those can be used over Internet by the aid of other companies such as Skype™.

Broadband network consists of core, metropolitan area (metro) and access network parts. In the core network, routers are connected by fiber links creating the core of the network. Core routers are usually located in the biggest cities. Metro and edge network creates a connection between the core and the access network by fiber, radio and copper links. These copper-based trunks are going to be wholly replaced by optical fiber in the near future. While, access subscriber lines are mainly built on copper cables. Metro and edge part of the network consists of routers distributing connectivity to access network Digital Subscriber Line Access Multiplexer (DSLAM) or Optical Line Terminals (OLT) depending on the access network technology. Purpose of the access network is to connect a subscriber in the network. Schematic illustration of the broadband network is shown in the Figure 2. (Baliga, Ayre, Hinton, Sorin and Tucker 2009) This study investigates the access part of the network.

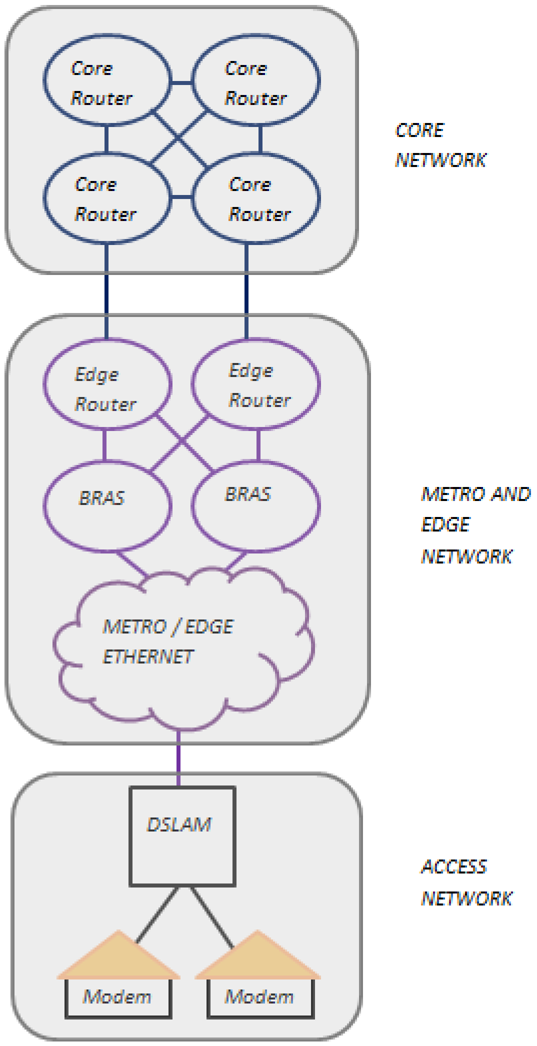

Figure 2 Schematic structure of the broadband DSL network

As mentioned before, fixed broadband access network is mainly based on copper lines. Copper lines were originally built for a fixed telephone network. Since the purpose of the network changed development of transmission technologies begun. Broadband traffic requires more efficient bandwidth usage than voice signals. (Gagnaire 1997) Broadband is a universal service and there are 1 614 600 fixed broadband subscriptions in Finland. (Viestintävirasto 2012) These subscriptions are distributed to different technologies according to Figure 3 below. "Property in connection" consists mainly of FTTB subscriptions and "Other" includes fixed wireless broadband.

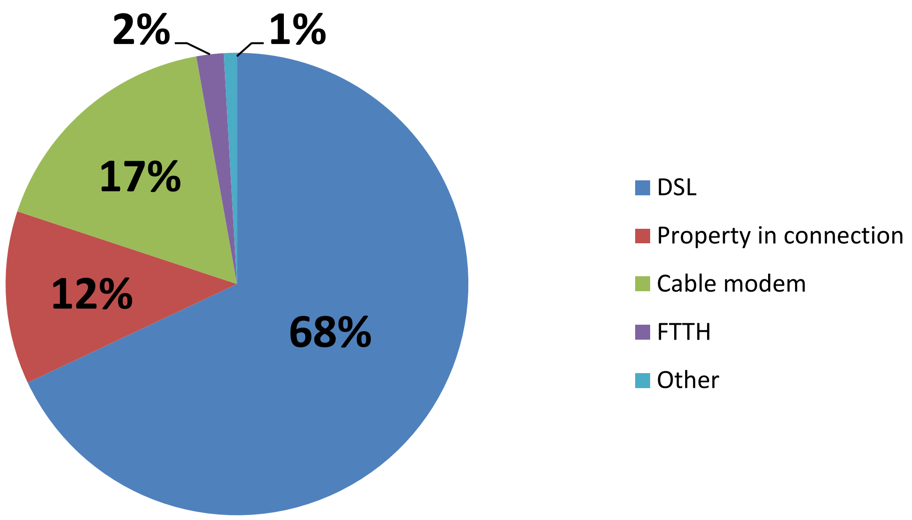

Figure 3 Share of different technologies for fixed broadband

According to Fijnvandraat and Bouwman (2006) if an operator wants to compete in broadband business, it can choose from multiple options of actions, such as upgrade copper line connections, install optical fiber lines, roll out wireless networks or apply hybrid transmission solutions. Furthermore, a new transmission line has to meet the increased requirements for data rate, be cost effective and allow operator a competitive advantage. Operators want to invest in the technology that is interoperable, economically viable and low risk. (Fijnvandraat & Bouwman 2006) For broadband quality, there should be enough signal power carried through and signal to noise ratio of the signal must be acceptable.

In the following sections, broadband access technologies that are used in Finland are being introduced. These technologies are split into categories of fixed and wireless.

2.2 Fixed technologies

There are three different fixed broadband technologies in use in the Finnish network at the moment i.e. twisted copper pair, coaxial cable and optical fiber based technologies. This section gives a brief introduction to these technologies.

2.2.1 Twisted copper pair

The copper network in Finland was originally built for telephony services and construction of the network was done during many decades. Twisted copper pair cables connect almost all the permanent places of residence in Finland, which makes it a really significant access media for a service that should reach the whole population. With the aid of Digital Subscriber Line (DSL) technologies twisted copper pair lines can be used as high speed broadband network medium. (Corning white paper 2005) DSL is the most widely penetrated broadband access technology in Finland.

Twisted copper pair lines are used also for telephone services. Plain Old Telephone Signal (POTS) splitter separates voice signals from data signals. Use of POTS services is declining 15 % every year and Finnish telecom operators have decided to eventually dismantle POTS services. At the moment of writing, POTS service is in use in great part of Finland. (Interview 7.6.2012) Voice services are not taken into account in the copper access network life-cycle model.

Finnish copper access network consist of different types of copper wires varying from 0.4 mm to 0.5 mm twisted pair cables (Interviews 6.6.2012 and 11.6.2012). The 0.4 mm wire offers 70 % of what the 0.5 mm wire is capable of. Connection is worse with a narrower wire. (Cioffi, Silverman and Starr 1999) Bad connection attenuates more and it is more sensitive to external stress. There are two types of installation technologies for a copper cable line i.e.

ground cables and aerial cables where the wire is installed into poles. Copper pole cable lines are more sensitive to external stress and especially to hard weather conditions than copper ground cable lines.

Attenuation depends on a used transmission frequency as well as thickness and shielding of a cable. Maximum data rate of a copper access connection change at different loop lengths. Loop length is defined as a distance from an Internet Service Providers (ISPs) Place of Presence (POP) or Central Office (CO) to customer's premises. (Corning white paper 2005) There is an individual twisted pair for every subscriber and therefore sufficiency of copper capacity is stable. (Cioffi, Silverman and Starr 1999)

Copper cable lines connect DSLAMs to main distribution frame (MDF) that serves a connection to an individual subscriber. DSL technology increases broadband performance at the physical level. There are a number of different DSL technologies. DSL technology family consists of Asymmetric DSL (ADSL), Single-pair High-Bitrate DSL (SHDSL) and Very high speed DSL (VDSL) technologies.

First copper based internet service was Integrated Services Digital Network (ISDN) that deployed copper lines to offer symmetric 144 kbps connection. It was used for voice and data services. ISDN was built on top of the Public Switched Telephone Network (PSTN). (Cioffi, Silverman and Starr 1999) Soon after the first fast broadband technique HDSL was developed. It allowed 2 Mbps symmetric connection. (Starr, Cioffi and Silverman 1999) Current DSL technologies have been developed in process of time. Most common DSL technologies are versions of HDSL, ADSL and VDSL. Next, different DSL technologies are introduced.

HDSL/SHDSL

HDSL uses two twisted copper pairs to create one symmetrical connection. Achieved data rate approximately 2 Mbps over two copper twisted pairs with a reach of 3.6 km. (Goralski 2002) SHDSL can be called as the next generation HDSL which is also a symmetric connection. It can deliver up to 2.3 Mbps on single wire pair. The data rate is reached for 3.7 km loop lengths and for 7.5 km distance data rate is decreased to 192 kbps. (Broadband Forum 2008) SHDSL is not compatible with POTS. SHDSL subscriptions are usually used by account customers because of the symmetry characteristic. Symmetry feature is advantageous when e.g. uploading data to a server. (Goralski 2002)

SHDSL bonding interface standard (SHDSL.bis) deploys multiple streams to create one connection. Bonding multiple twisted pairs for one subscription allow significantly higher data rates. For example, if one twisted pair throughput is 5 Mbps, two pairs throughput is then 10 Mbps. Advantage of SHDSL.bis is its reliability. If some of the used lines broke, the connection itself remains unbroken. (Pan 2008)

ADSL

ADSL can provide up to 8 Mbps downstream and 0.8 Mbps upstream data rates. As a disadvantage, ADSL maximum data rate is limited for 5.4 km loops. (Cioffi, Silverman and Starr 1999) (Corning white paper 2005) Early versions of ADSL suffer from crosstalk in adjacent lines. Crosstalk avoidance has improved in advanced version ADSL2.

ADSL2 provides 12 Mbps downstream and 1 Mbps upstream data rates. As a result of efficient framing, symmetrically 50 kbps more data rate is used for payload traffic instead of overhead. ADSL2 enables bonding multiple wires, but bonding is very rarely used. Energy consumption is decreased by enabling traffic load based power saving over ADSL line. (DSL Forum white paper 2005) ADSL2 has not been in use in Finland as it was considered only an intermediate step to ADSL2+.

ADSL2+ is an advanced version of ADSL and ADSL2 technologies. It is able to deploy double the bandwidth compared to ADSL2. Maximum data rate is 24/1 Mbps up to 2 km loops. Crosstalk is reduced even more in ADSL2+. (DSL Forum white paper 2005)

VDSL

The most advanced DSL technology is VDSL and first version allows up to 55 Mbps downstream and 15 Mbps upstream connections. This early version has not been deployed in Finland as the second version was already available i.e. VDSL2. It better utilizes available bandwidth and can provide up to 100 Mbit symmetric connections for 350 m. Bandwidth utilization differ from 12 MHz to 30 MHz and similarly data rate differ from 55/30 Mbps to 100 Mbps. Also, VDSL2 is fully interoperable with ADSL technologies which make it cost effective to install. (Broadband Forum 2008)

VDSL2 is most likely to be used as an asymmetric access technology because of its characteristic of high bit rate for short distances only. VDSL2 is used from 0.3 km to 2.4 km loops depending on a preferred data rate. VDSL2 is more or less used in conjunction with optical fiber network (FTTB or FTTC). Thus, last mile access of FTTB is usually VDSL2. In practice, a DSLAM is brought to a basement and the in-house network is the last mile.

Crosstalk in adjacent wire pairs it is eliminated by vectoring in VDLS2. Available bandwidth is deployed really efficiently. (DSL Forum 2001) (Eriksson and Odenhammar 2006) VDSL2 can offer very high bit rates if vectoring and bonding are used together. According to Cota and Pavicic (2011) six (thickness 0.5 mm and loop length 0.5 km) copper twisted pair wires is capable to 550 Mbps data rate with vectoring and bonding.

Copper cable ageing

Even if DSL technologies would develop, fixed copper wires are physically getting old. In many cases, existing wires in Finland are over 50 years old. Aged cables cause more failures. To prevent failures, old cables should be replaced or loop lengths should be shortened. Highest expenditure of a cable installation is digging. (Interview 11.6.2012) Digging could be prevented if cables are installed to ground in pipes. Then old cable can be pulled out while new one is pushed in. A pipe not only protects cables in ground but also makes it possible to replace or install a cable without digging all the way.

Copper cable's quality deteriorates at some point. This point depends on type, age and material of a cable. Nevertheless, it is not unambiguous that age or type of a copper wire would define its real state of function. Attenuation of a cable must be defined by monitoring received signal strengths. Different frequencies attenuate differently. Signal loss is noticed to be greater above 1 MHz frequencies. (Hashim, Abdullah, Yunus, Abidin and Ramli 2010) Differences between used frequencies cause inconsistency in defining conditions of a copper cable. Slightly damaged copper twisted pair may work fine for voice services but is causing failures for data transmission. Failures can be decreased also by dropping maximum data rate of a subscription or by shortening loop length.

Summary

Distances from 2 to 2.4 km ADSL2+ would be optimal but for shorter loop lengths VDSL2 could offer better data rates. (Eriksson and Odenhammar 2006) SHDSL.bis is optimal for symmetric connections if voice services are not used. DSLAMs can be furnished with all of these technologies simultaneously. Characteristics of the most popular DSL technologies are shown in Table 1 below. (Fijnvandraat and Bowman 2006)

Table 1 Summary of DSL technologies

	SHDSL	ADSL	ADSL2+	VDSL2
Max speed up (bps)	2M	512k	1M	100M
Max speed down (bps)	2M	2M	24M	100M
Max distance at max speed (km)	3.7	5	2	0.3
Max distance (km)	7	6.5	5.4	2.4
Type	Symmetr.	Asymmetr.	Asymmetr.	Both

Comparison between ADSL2+, VDSL (12 MHz) and VDSL2 (30 MHz) is shown in the Figure 4. Maximum data rates (Mbps) are shown as a function of distance (meters) from an exchange. VDSL2 can offer two times greater data rate compared to VDSL. VDSL technologies are deploying short copper loops efficiently. ADSL2+ data rate is more stable and can be seen as good option for broadband technology at longer distances. In the article of Lightwave (Rigby 2012) fiber-copper combination access solutions are expected to grow and dominate still five years from now.

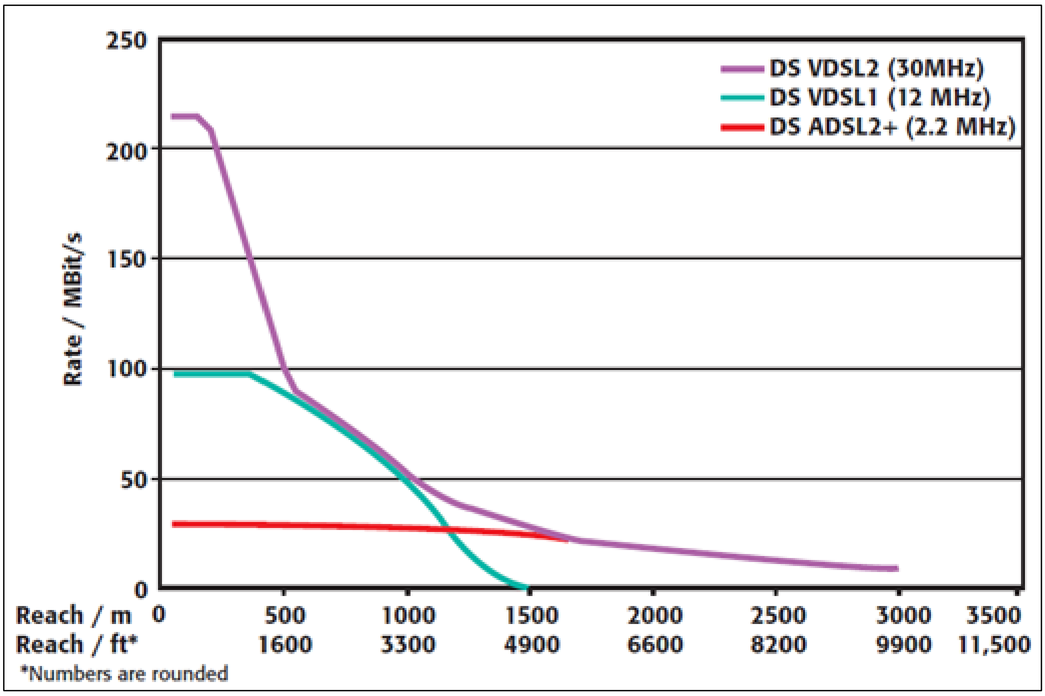

Figure 4 Comparison of the DSL capacities as a function of distance (Walko 2005)

2.2.2 Coaxial cable

Coaxial cable is originally used for Cable TV (CATV) service which is designed for one way traffic. By the aid of Data over Cable Service Interface Specifications (DOCSIS) technology asymmetric bi-directional traffic is possible in coaxial cable. Achieved broadband data rate with DOCSIS 3.0 is 10 to 100 Mbps and with Multiple-Input Multiple-Output (MIMO) technology data rate up to 200 Mbps (requires CAT5 in-house network cabling). To be able to support two way communications, coaxial cable network requires an upgraded. Disadvantage of coaxial cable is limited capacity. Capacity in a coaxial cable is shared with all the end users at the cable area. (Vesala 2012) Sometimes CATV networks are fiber and coaxial combinations i.e. Hybrid Fiber Coax (HFC) which increases capacity. (Eriksson and Odenhammar 2006)

According to World Broadband Statistics (Vanier 2011), cable modem is the second most penetrated broadband technology in the world. Coaxial cables are located in residential areas, whereas DSL connections are built to business regions as well. (Cioffi, Silverman and Starr 1999) Nonetheless, over 50 % of the Finnish households are covered by CATV network and 17 % of the households are covered by DOCSIS 3.0 technology. (Vesala 2012) (Viestintävirasto 2012)

2.2.3 Optical fiber

Optical fiber infrastructures are named by fiber location in regarding to a subscriber. Fiber to the Curb (FTTC), Fiber to the Building (FTTB) and Fiber to the House (FTTH) infrastructures are used in Finland, which from FTTB is the most common (Rigby 2012). A common term for an optical fiber access is FTTx. As mentioned in section 2.2.1, FTTC and FTTB are extended with copper. FTTH is fiber all the way to a customer. Capacity of optical fiber network is almost infinite. (Corning white paper 2005) Therefore, it is considered to have a potential to adjust to future changes.

There are multiple different optical fiber network technologies. Passive Optical Network (PON) solutions are Ethernet PON (EPON), Gigabit PON (GPON) 1G-EPON and 10G-EPON. Advantage of PON is low energy consumption and low upholding cost per user. There is no need for active devices in between Optical Line Terminal (OLT) and Optical Network Unit (ONU) in PON (see Figure 5). (Kramer, De Andrade, Roy and Chowdhury 2012) Another optical fiber technology is Active Ethernet, also called Point-to-Point (P2P). Unlike PON, P2P technology can be used in conjunction with copper cables. Nevertheless, there are more active devices compared to PON. Fiber network structure is illustrated in Figure 5.

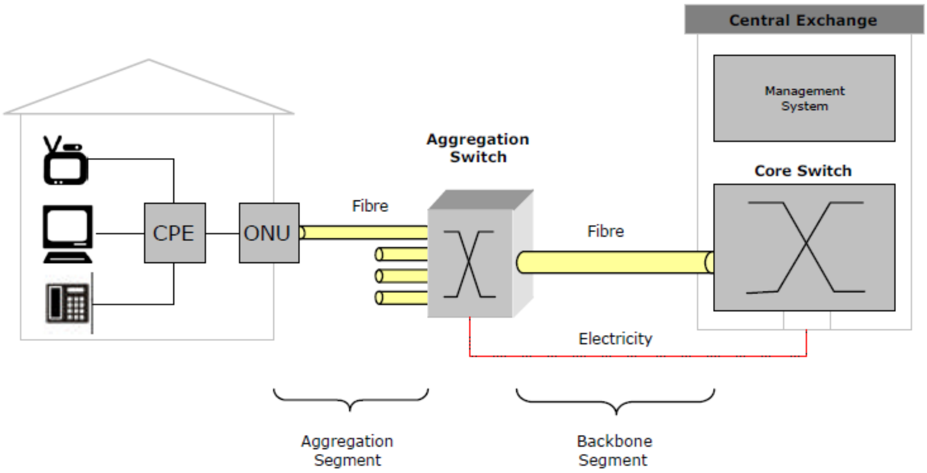

Figure 5 FTTH network infrastructure (BREAD 2006)

Installation costs of optical lines are high because of digging and expensive equipment. However, these costs can be reduced by intelligent network topology planning and advanced digging techniques. (Song, Byoung-Whi and Biswanath 2010)

2.3 Wireless technologies

There are a number of wireless access technologies. Wireless access allows mobility but it may not be as reliable as fixed access. Radio signals are sometimes affected weather and terrain issues. Wireless signal attenuates as a function of distance from a transmitter. Attenuation depends on a frequency and used signal power. Also, capacity of a radio link station is limited. Previously mentioned factors must be taken into account in wireless network design. Radio networks are usually designed to cover as many places possible. (Interview 26.6.2012)

Radio signals are transmitted over frequency bands. There are a finite number of available frequencies. Therefore, the frequencies are shared among Finnish telecom operators. The Finnish state arranges a frequency auction to share free frequencies. Different types of wireless technologies are designed for certain frequencies. State may regulate the purpose of use of a frequency band. For example, auction for 800 MHz frequency band is meant for 4G use.

There are four main wireless broadband access technologies in Finland; 3G (UTMS), 4G (LTE), @450 and satellite broadband. In addition, Wireless Local Area Network (WLAN) is used indoors as extension for fixed access. This section gives a brief introduction to these technologies in use considering their suitability as fixed broadband connection and technical characteristics.

2.3.1 Universal Mobile Telecommunication System

Third generation (3G) network is deployed almost all around the world and in Finland 3G can be said to have a nationwide coverage. Strength of a signal depends on a receiver location in relation to a nearest link station as well as characteristics of a mobile device's receiver. Higher speeds are achieved by stationary users. 3G network is suitable for low data transmission with portable mobile devices. Nowadays most of the portable devices have 3G receiver integrated in them. 3G network may run out of capacity if a large amount of data is transferred over it. 3G is suitable for light internet browsing and reading emails, but e.g. playing games over 3G is rather objectionable. Usually web sites have their web pages as a lighter version for mobility use. Lighter versions are made to reduce network load but also to save battery of a handheld device. (Corning white paper 2005)

First wireless data transmission technology was Enhanced Data Rates for GSM Evolution (EDGE) that is considered as 2.75G network. It can provide a speed up to 384 kbps. The first 3G network was Universal Mobile Telecommunications System (UMTS). In UMTS, used radio technology is 3G/WCDMA (Wideband Code Division Multiple Access) with peak throughput of 384 kbps. For 3GPP release 1999 theoretical maximum data rate is 2 Mbps. As demand for a faster connection increased, better radio technologies were developed. High Speed Packet Access (HSPA) was created to use existing UMTS network which better exploited available bandwidth. (Rysavy research white paper 2008)

HSPA is the most commonly used 3G technology. It comprises components of uplink and downlink HSPA's and was originally referred to as 3.5G network. Theoretical maximum downlink data rate is 14 Mbps and uplink data rate is 5.5

Mbps with 5MHz bandwidth. (Furuskär, Rao, Blomgren and Skillermark 2011) An advanced version HSPA+ is currently the leading 3G technology in Finland. It is referred to as 3.9 G network and it offers 21/11 Mbps maximum speeds. HSPA+ uses 64QAM downlink modulation and 16QAM uplink modulation both with Multiple-Input Multiple-Output (MIMO) technology that use multiple (usually two) antennas to send and receive a signal. (Zellmer 2012) It is possible to achieve data rated up to 42/23 Mbps by using two adjacent 5 MHz downlink carriers. HSPA+ technology that use two carriers is called HSPA+ dual carrier (or DC-HSPA+). (Johansson, Bergman, Gerstenberger, Blomgren and Wallen 2009) (Zellmer 2012)

In Finland, UMTS with HSPA technology is used at 2100 and 900 MHz frequency bands. DC-HSPA+ is used only at 2100 MHz band. Higher frequency covers smaller area and therefore there is more capacity available per square kilometer. Lower frequency has a greater coverage area but less capacity per square kilometer. In Finland, 2100 MHz frequency band is used in densely populated areas whereas 900 MHz band is used in less populated areas. In addition to used frequency band, type of a link station and amount of transmit power effect on coverage area. The most rurally populated areas in Finland are not geographically completely covered with 3G. (Sonera Kuuluvuuskartta 2012)

Previously introduced 3G radio technologies are overlapping and used simultaneously. Complete migration from EDGE to UMTS to HSPA takes time. Regionally there are spots where there is a reception from only some of these networks. HSPA is backward compatible with both EDGE and UMTS which benefits a customer when HSPA network is not reached or data rate drops too low. (Rysavy research white paper 2008)

2.3.2 Long Term Evolution

Currently the most advanced wireless mobile broadband technology is Long Term Evolution (LTE). It is able to use 20 MHz of bandwidth allowing peak data rate up to 100 Mbps in downlink and 50 Mbps in uplink. (Furuskär et al 2011) Due to its high data rates, LTE is considered as 4G network. It is able to use higher frequency bands than 3G which are ranging from 800 MHz to 3.5 GHz. However, with higher frequency cell size is smaller. LTE bandwidths range from 5 to 20 MHz's.

LTE differ from 3G infrastructure. Where 3G network processes data from core network via controller to a link station, LTE sends signal from core network straight to a node. This allows faster handover and also speeds set-up time, which is a crucial phenomenon for real time services. Round trip latency is reduced from HSPA+'s 50ms to LTE's 10ms. (www.3gpp.org/lte) Difference of 3G and LTE networks is seen in the Figure 6 below.

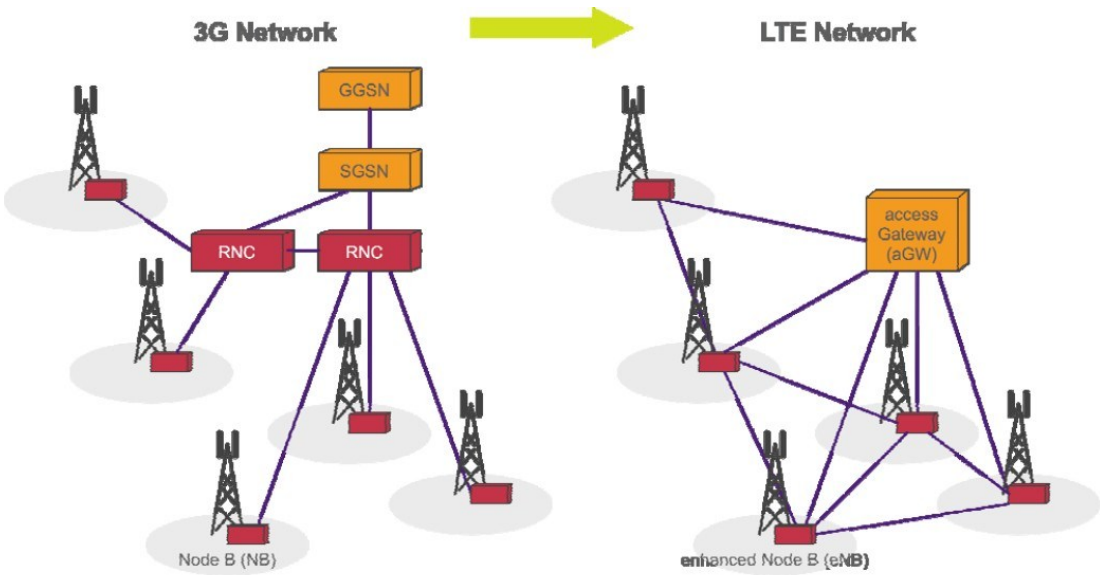

Figure 6 Wireless network infrastructures

Currently used frequency band for LTE in Finland is 2600 MHz's. Range of such a high frequency is short. LTE network in Finland covers only biggest population centers. However, the network is expanding. Frequency band 800MHz is allocated for LTE but it is not yet in use. As current 3G network use 900 and 2100 MHz bands, using the same links with LTE 800 and 2600 MHz bands, similar coverage area would be achieved. (Interview 26.6.2012) LTE capacity is not enough to offer a broadband connection for everyone in most densely populated areas but in sparsely populated areas available capacity is most likely to be sufficient enough. (Tareen, Saeed and Rafique 2011)

2.3.3 @450

NMT (Nordic Mobile Telephone) frequencies are being used to offer broadband network in Finland. This network is called @450 wireless broadband and it works at 450 MHz frequency band. It has been based on Flash OFDM (Fast Low-latency Access with Seamless Handoff, Orthogonal Frequency Division Multiplexing) technology. Characteristics of Flash OFDM are low latency and great mobility. (Ministry of transport and communications 2008) @450 network is able to offer up to 2 Mbps downlink and 512 Mbps uplink data rates. (Datame 2013)

Disadvantage of @450 network is expensive Customer Premises Equipment (CPE). As utilization rate of @450 technology is quite low, equipment prices stays at their price level. Flash OFDM uses very narrow bandwidth that limits its capability. Used bandwidth is 1.25 MHz, which allows data rates up to 1 Mbps and with two of these frequency bands the data rates is doubled. @450 data rate is enough to fulfill universal service obligation in Finland.

Flash OFDM is standardized loosely which does not predict any development on this technology. (Ministry of transport and communications 2008) Manufacturer has stopped producing equipment for Flash OFDM. Therefore, @450 changes to Code Division Multiple Access (CDMA) technology in the beginning of 2013. Theoretical maximum speed of CDMA is 14 Mbps and practically 9 Mbps data rates could be achieved. (YLE 2012) Nevertheless, at maximum 3 Mbps data rate @450 subscriptions are offered. (Datame 2013) @450 network is most probably used as an additional choice for the areas where there is no coverage for any other network. This network is not considered as a competitive technology for DSL but is mentioned because it could compensate possibly missing 3G coverage. (Digitoday 2012)

2.3.4 Satellite broadband

Satellite solutions have been primarily used for one way TV broadcasting but new technologies allow also two way communications with high speeds. One drawback is the round trip latency of 500ms to 700ms. The latency is a result of a long distance to the satellite from the Earth. Lower latencies could be achieved by improved network technology or shorter distance. (Corning white paper 2005)

According to the Sonera web pages (2012) a satellite broadband subscription includes limited amount of data. The limit is set to avoid overload and to guarantee enough capacity for a single user. Currently offered data rate on a satellite connection is 10 Mbps downstream and 2 Mbps upstream. Unlike other wireless broadband solutions, data rate of satellite broadband is stable as it requires a fixed position receiver. A satellite access could be sensitive to weather condition changes. Satellite coverage is nationwide if terrain conditions allow a Line-of-Sight to the satellite. The most northern places are more sensitive to terrain conditions because of a relative location to the satellite. The satellite is located in the equator and direction of a parabolic antenna is a rather horizontal. (Interview 23.8.2012)

Advantages of a satellite broadband are the already existing network and a large coverage area. Nevertheless, due to satellite broadband low penetration in Finland, CPE's are costly. User needs a parabolic antenna, a modem and an installation of an antenna. (Morelli and Petrone 2011)

Satellite broadband technology is a viable solution for a broadband connection. Compared to UMTS technologies, satellite broadband has quite similar data rate but it has more capacity. However, satellite broadband is not as mobile as UMTS technology is. A life time of a satellite is approximately 15 years, which after a new satellite must be shot in to the sky. (Interview 23.8.2012) In satellite broadband, network operator and service operator are two different operators. A satellite broadband access subscription is rented from a network operator which increases customer tariffs. This wireless broadband solution is not considered as a rival technology for DSL but it is considered as completing the network in the areas where a broadband connection is not otherwise available.

2.3.5 Wireless Local Area Network

Wireless Local Area Network (WLAN) is a common name for IEEE 802.11 standard family. It is an extension for a fixed access used to enable wireless connection inside a building or at a small range. It can offer high bandwidth and high data rates but with a signal radius of only few hundred meters. Data rates are basically similar to fixed line data rates depending on a version of WLAN used (there are variations of IEEE 802.11 standard that support different data rates). Advantages of WLAN are its simplicity and robustness against failures. (Perahia 2008) (Liangshan and Dongyan 2006) (Gu and Zhang 2003)

WLAN enables wireless connection for fixed broadband access. WLAN uses a free frequency band of 2.4 GHz. These frequencies are not regulated and network can be set up by a user with suitable equipment. As the frequencies are free and other WLANs use the same frequencies as well, a connection is easily disrupted by neighboring WLANs and also other signals. Used with weak encryption, WLAN could be easy to break into and the network itself is usually visible to everyone. Data packets in a WLAN network are easy to collect by an unwanted party. Security of WLAN is weaker to 3G and 4G. (Crow, Widjaja, Kim and Sakai 1997) (Gu and Zhang 2003)

Use of WLAN is increasing as there is a need for connecting multiple devices to the Internet. Almost all the mobile handsets, such as mobile phones and tablets, support WLAN technology. In this thesis, WLAN brings competitive advantage to fixed broadband accesses. Even if DSL is considered as fixed network there is a possibility to connect wirelessly.

2.4 Broadband services

In addition to the universal service obligation set by the Ministry of Transport and communications (Viestintävirasto 2010) there are also other factors that are calling for an increased performance. Even more services are available for a customer over the Internet. Services are not only offered by an ISP but other quarters as well. This section discusses about the services offered in the

Internet and through a broadband access line and what these services require from an access line.

The biggest operators in Finland offer IPTV service on top of a broadband connection. Technologically it is possible to be implemented by unicast stream service or multicast stream service. Difference between these technologies is that multicast utilizes less bandwidth per user but has a higher network construction cost, whereas unicast creates a single connection between source and receiver which creates more load on a network. Unicast IPTV can be used in a network without reforming it to support multicast if there is enough capacity available. In Finland, IPTV services are only offered for over 24 Mbps subscriptions. Traditional television service is a live streaming type of a service where content is time dependent. However, operators also offer on-demand contents for their customers such as video renting services. On demand service requires a single stream and cannot be realized with a multicast. Use of an on demand content is becoming general. Catch-up and recording services are popular which also implicate to that customers call for on-demand services and freedom to choose when to watch television content.

In addition to the services offered by an operator there are number of other similar types of services offered through the Internet. Movies and television series can be watched whenever at a specific web pages. In Finland, many television programs can be post-watched from content provider's web pages. In addition, worldwide video-on-demand services (HBO Nordic, Netflix, YouTube) are offering wide repertoire of movies, series and other videos in the Internet. Video streaming requires higher data rates and it easily increases average data traffic. Smart video streaming services vary video quality according to available bandwidth. A little less bandwidth utilizing services used are radio and voice services such as Spotify, Skype, Grooveshark. (Sonera web pages 2012)

IPTV services are currently only available for a fixed broadband subscription and most of them are receiving multicast stream. In wireless broadband connections, IPTV services would be affected by capacity limitations and multicast is not yet possible. Nevertheless, on demand video stream services work through wireless mobile broadband as well if watched on small screen hand held devices with decreased video quality.

A broadband connection must be able to adapt to increased bandwidth demand caused by services that are offered across the Internet. Data traffic has increased notably since 2006 (Stordahl 2010). Even greater files are transferred over the Internet such as HD video streams and large application files. For example in USA 30 % of the total network traffic is caused by video rental services that work through the Internet such as Netflix. As Netflix landed to Finland on October 2012, a clear increase in total data traffic took place. According to Sonera's statistics, the increase was on average 5 GB per user compared to previous month data traffic. Final affection on the average data traffic is seen only after the service trial time has ended in the end of 2012.

3 Broadband business

Traditionally broadband business has been based on offering a possibility to transfer data over the Internet. A user paid based on a time spent on the Internet. After an increase in data traffic due to heavier applications and more available information in the Internet, pricing was changed be monthly fixed price. Price was set according to available data rate regardless of the amount of transferred data. However, tariffs change along different geographical areas because of a higher cost of maintenance per customer and a lack of competition. Nowadays, an offered service is not just a physical access but also set of services, such as IPTV or video rental services, alarm systems, special services for elderly etc.

Broadband access as a service product is dependent on a location. In the most densely populated areas broadband business is more profitable than in the less densely populated areas. New broadband technologies are first implemented in to cities where risk is smaller due to high demand. To ensure connectivity also in the most rurally populated areas the Finnish state participates on network construction costs. States involvement makes an investment for rural areas more attractive, yet still risky for an operator.

This section describes the economic factors of a broadband business. It includes broadband business competition and nature in Finland. Also, how broadband as a service differ from other services. Customer segmenting and importance of marketing are discussed as well as commonly used revenue models. Finally, cost components of a broadband network are presented.

3.1 Competition in Finland

In Finland, competition in broadband business exists mainly between three major players; Elisa, DNA and TeliaSonera. Finnet and other operators usually have their networks in rurally populated areas where competition is very minimal. An operator wants as many customers as possible. Therefore, rival areas are more likely to offer better services than areas with minimal competition. Robert Atkinson (2007) claims that competition makes operators lower their prices, improve their networks and give overall better customer service. Customers do not necessarily see the difference between used broadband technologies but they rather want to know if the services they are using works through the connection they have. (Corning white paper 2005) According to Sonera (2011) an average residential customer does not know the differences between broadband access media technologies. A customer values data rate, connection reliability and ease of use. Still a majority does not really know their internet connection speed. This unawareness could be a result of a limited set of subscriptions in the area (there may be only one type of a subscription available) or lack of interest in technology.

Competition is about getting the most customers by competing with price, services and technology. Market shares of different operators in fixed broadband business in Finland are illustrated in the Figure 7 below (Viestintävirasto 2012). Elisa and DNA fixed broadband networks are mainly located in the densest city areas where competition is harder. TeliaSonera have a fixed network also in a little less densely populated rural areas. Other operators are local network operators and they have their networks in smaller towns.

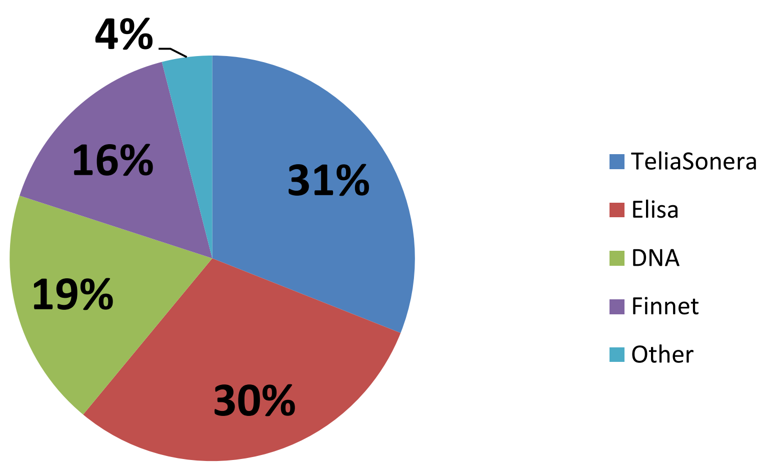

Figure 7 Operators market share at fixed broadband business in Finland

In Finland, broadband is a regulated industry where products are sold and produced as much as they got demand. Similar to municipal water and electricity, broadband service is a universal service where the service must reach all the permanent residences in Finland. Ministry of Transport and communication regulates telecommunication services with Universal Service Obligation (USO). In Finland, USO areas are defined according to incumbent operator areas (incumbent operator is defined according to ownership of a copper access network). An operator, who owns most of fixed access lines and has a significant market power (SMP) in an area, has an obligation to offer service according to requirements. (Viestintävirasto 2010) Thus, a universal broadband service for all the permanent residences is guaranteed. (Ministry of transport and communications 2008)

Investments in broadband business are permanent and cannot be easily sold further. Therefore, competition is different from normal industries, such as banking or airlines. Competition increases development of a network but it also makes operators waste resources (nature and society resources). Every operator builds their own access lines to a house, when less money and energy is spent if they would use the same line together. Fiber access line would have enough capacity for both. Of course there are situations where operators are co-operating and they share digging costs but they still install their own access lines. Competition must be maintained to keep operators continuously developing their services. (Atkinson 2007)

The Finnish state regulates competition by legislating access line leasing and limiting maximum prices. By leasing an access line, competition is enabled in any area. Competition keeps broadband subscription prices low for a customer. Currently only DSL access lines are leased as fiber access line leasing prices are too high. (Ministry of transport and communications 2012)

Network investments are done only if those could cause additional revenues. Possible situations where an investment is profitable for an incumbent operator are e.g. if a competitor enters to market with a better service or if there are additional revenues gained from an additional service that requires investments in a network. At non rival areas, a monopoly operator decides for new investments without any external stress. Usually it is more profitable to stretch existing infrastructure as long as there is no competition and network is profitable. In business portfolio, these kinds of products are called "cash-cows" as they do not require any investments anymore but those are still bringing revenues. When revenues are secured and there is no competition, driver to renew a network can be increased maintenance costs and overlapping network or changed regulation that requires improved network capabilities. Other reasons to renew a network are; totally perishing transmission medium, customer's demand and/or competition. (Interview 7.6.2012)

Formerly in broadband business, who invested in a network infrastructure the most won the competition. Nowadays, operators are rather competing with efficient and focused marketing instead of better coverage. An operator tries to win customers by offering additional services, focusing on marketing and keeping the prices low. Of course improved network technologies tempt customers but it is also about how it is advertised. For example, a customer does not necessarily see technological difference between e.g. 4G speeds (3G dual carrier) and 4G (LTE) but rather chooses a subscription on the basis of a more attractive marketing. (Interview 11.6.2012)

3.2 Market segments and demand

Because broadband is based on a fixed infrastructure, business market segments are mainly geographical but also based on characteristics of an end user. Geographically Finland can be divided into different market segments by many ways. Commonly division is made according to population densities and also according to different competition areas in broadband business. Operators tend to separate their own incumbent network areas from competitors. Even if broadband business is based on a location, marketing could be focused to different customer groups based on their needs.

In the United States, the traditional monopoly operator is called as Incumbent Local Exchange Carrier (ILEC). Rival operator is thereby called as Competitive Local Exchange Carrier (CLEC). Division is made based on copper network ownership and location. ILEC and CLEC areas depend on a perspective; competitive operator's ILEC areas are always operator's own CLEC. The main idea in the division is that the ILEC operator owns and operates a network and CLEC leases it. (Pindyck 2004) In this study, division to ILEC and CLEC is relevant in the sense of costs and competition. Profitability of an investment could be unprofitable in ILEC area but due to higher OPEX of leased lines a similar investment could be profitable in CLEC area.

In addition to ILEC and CLEC area division, Finland is divided into network areas. Every operator decides how network area division is made at their incumbent areas. Most common division criterion is a serving area of an exchange (DSLAM). However, as new technologies (FTTx) are being deployed and new construction areas are being built, operators create new network areas inside to a network area.

Operators categorize their network areas according to population density and number of potential customers (including account, residential and operator customers). Population density (or permanent household's density) can be used as a criterion for an investment. Sonera statistics proofs this proposition as the correlation between fiber access houses and household density is 53 % (which is considered as a reasonable correlation, nearly notable). Correlation is negatively affected by fiber installations to the most rural areas and densely populated areas that are not yet fibered.

Urban, sub-urban and rural is a common area classification based on a population density. Sometimes additional categories, remote and dense urban, are used. Dense urban and urban areas could be said to consist of apartment buildings. Sub-urban area consists of detached houses. Rural areas are mainly scattered settlements and at a remote area there are really few houses here and there. Niemi (2004) defines different areas according to population and density concentration inside a city area. For example, urban area is defined as population over a certain limit and 60% of the population is living in city areas. Monath, Elnegaard, Cadro, Katsianis and Varoutas (2003) used access line loop lengths as a categorization criterion, as central offices are usually located near population centers. In this study, geographical categorization is made according to technological competition setting in different types of areas. All five area categories (dense-urban, urban, sub-urban, rural and remote) are defined but only three of them are used in copper life-cycle model. Population density is defined according to a suitability of different technologies. This division is discussed further in this thesis.

Finland is a large country as its surface area. Problem in building a nationwide network in Finland is that population density is truly heterogeneous. Every fourth person lives in the Helsinki metropolitan area which is geographically only 0.2 % of the whole country area[1]. Most of the people live in biggest cities. Not even biggest cities population densities are close to e.g. United States urban area population densities. Nationwide network coverage is easier to build in countries where people live evenly. For example, an average population density in France is ~115 inhabitants/km^2 whereas this number in Finland is ~18 inhabitants/km^2 (Ulkoasiainministeriö 2012). Despite these limitations in Finland, 99 % of the population is covered with broadband network and 79 % has a broadband subscription. (FiCom 2012)

Migration from less densely populated areas to densely populated city centers is constantly ongoing. Population of the Finnish cities is growing while population of smaller municipalities is decreasing. This is due to migration but also due to natural causes. Expected change in population in different municipalities in percentages from 2003 to 2030 is shown in the right side of the Figure 8. Red areas indicate to population growth areas. Current number of households per municipality region is shown on the left in the very same figure. Red areas are

[1] Population of the Helsinki metropolitan area is approximately 1.32 million (www.helsinginseutu.fi). Population of Finland is 5.41 million. (www.vaestorekisterikeskus.fi). Finland's ground area is 303 893 square kilometers and metropolitan area is 3 697 square kilometers. (http://tietopalvelu.uudenmaanliitto.fi/alue/pinta_ala/)

areas with over 25 000 households and green ones are areas below that value. It is easily seen that population growth is stronger in biggest cities in Finland and decrease is stronger in rurally populated municipalities and areas. This could effect on broadband access network in such a way that dismantling of copper access network spreads to a wider area while demand increase in the cities. There is a slight difference in these maps area divisions due to municipality renewal in 2012. Some areas were tied together during the renewal. (SVT 2004/1)(TSF 2012)

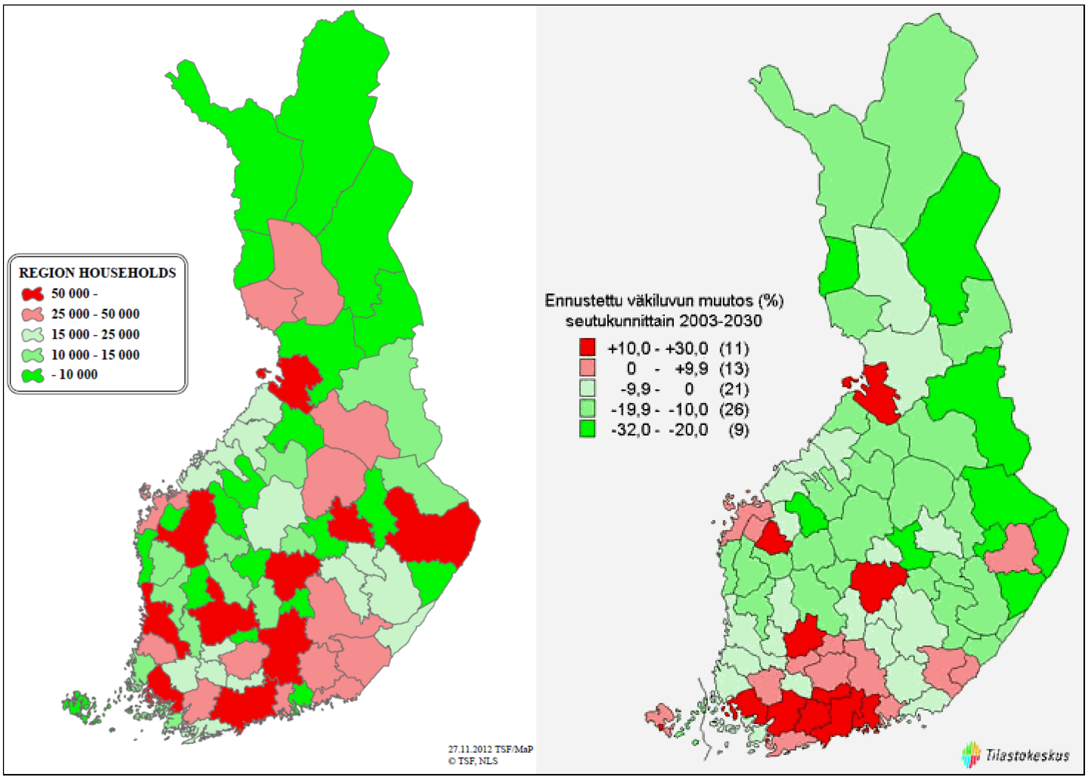

Figure 8 Current households per municipality region (TSF 2012) and expected change (%) in population by municipality regions 2003 – 2030 (SVT 2004/1)

Population growth rate is assumed to be approximately 0.2 % a year (OECD Stat Extracts 2010). This assumption is approximately equivalent to the predictions in STV 2004/2. Migration and normal reduction as a result from natural causes is taken into account in this analysis at every competition area. Change in population is calculated according to (SVT 2012/2) where population evolution is estimated for each municipality.

As in many products, segmentation in broadband services is done based on characteristics of a customer. As seen in Finnish operator's web pages (Sonera, Elisa and DNA) they separate their product categorization for residential, account and operator customers. In all of these categories, there are different service level agreements (SLAs), tariffs and subscription types. Account subscriptions usually require symmetrical connections, constant reliable connectivity and possibly additional services. Account customers pay more for their service. Residential subscriptions are usually asymmetrical and priced according to maximum down link data rate. Fault correction is not prioritized as for account subscriptions. Operator subscriptions are rented cable, carrier and site spots that are priced according to revenue marginal set by Ministry of Transport and Communications.

Age may also be a valuable categorization criterion. The time when the first generation of internet users is the oldest in Finland could be the time when all Finnish inhabitants use the Internet. Prediction curve of broadband penetration in Finland is exponentially increasing as population renews. (Malkki 2011) Figure 9 illustrates the frequency of internet usage in different age groups in Finland from 2009 to 2012. Last line indicates to whole Finland ages from 16 to 74. Share of people who daily connect to the Internet is approaching to 80 %. People that use internet less than daily is about 85 %. As now 25 to 34 age people get older and elderly people pop off, the internet usage grow and most probably a broadband access begin to resemble water and electricity as its importance to people. (SVT 2012)

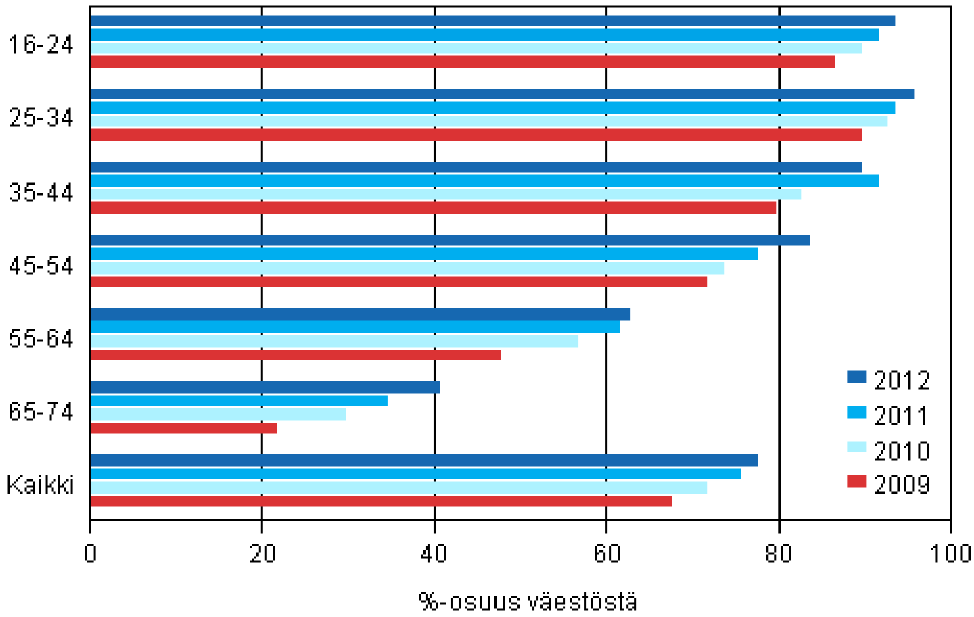

Figure 9 Percentage of different age groups in Finland that use the internet daily 2009 - 2011 (SVT 2012)

As discussed before, demand for greater data rates and connectivity is increasing and needs of a customer must be recognized. According to FiCom (2012) customers want a cheap, reliable subscription that works fast everywhere. However, customer must make a compromise somewhere when choosing the most suitable internet connection. Even if 80 % of households in Finland could choose 100 Mbps data rate subscription only 5 % has it. Wireless mobile broadband is usually the cheapest broadband access connection and it can offer compatible or good enough data rates. Nevertheless, even if it is not as reliable as fixed access, customers tend to choose it over fixed option. Rather than selling an internet access defined as maximum data rates, customer could be more interested in the information about what can be done with that data rate. For example, subscription for IPTV user or subscription for a person who only want to read e-mails.

3.3 Revenue modeling

Broadband operators live by the prices customers pay for a broadband connection, additional services and spin-offs. In this section a common pricing is introduced based on Finnish Ministry of Communication (2011) statistics and the main Finnish telecom operator's web pages.

Currently fixed broadband connection pricing is flat rate according to maximum data rate and geographical location. A subscription at rurally populated non rival area is more expensive than similar subscription in densely populated rival area. Difference result from a higher maintenance cost per subscription and lack of competition in the rurally populated area. However, subscriptions are priced according to maximum data rates and in less densely populated areas, fewer subscription types and usually lower data rates are available. Prices in densely populated areas have fallen due to competition and price per Mbps can differ notably between different areas.

Wireless mobile broadband technologies UMTS (3G) and LTE (4G) are priced according to amount of prioritized data with a maximum available data rate. Wireless access subscription is usually cheaper to fixed broadband access. Wireless broadband data rate can vary greatly depending on a number of simultaneous users and maximum capacity.

As mentioned before, a broadband connection is productized for three categories: residential, account and operator products. All of these products are priced differently. Residential customer pricing is the most sensitive to competition. Account customers pricing is set according to SLA and they value quality and reliability more than affordability. Operator customer’s prices are usually set as high as possible within Return on Equity (ROE) limit set by the Finnish Ministry of Transport and Communications.

Mean prices of wireless broadband access subscriptions for residential customers are calculated according to Finnish telecom operator’s tariffs in September 2012. 3G subscription is on average 19.90 euros per month whereas 4G subscription is 42.9 euros per month. Satellite broadband subscription is 69.90 euros per month. @450 broadband connections have not been sold for a while but the price was approximately 50 euros per month. Of course, these prices vary by required amount of data transferred. In addition, initial fees are quite high in satellite and @450 broadband subscriptions. Rokkas, Katsianis and Varoutas (2010) estimate that account customers pay approximately 20 % more than residential customers.

Prices vary according to competition and time. Prices are high during low demand and along a demand growth prices decrease. If newer technologies are being introduced, prices of an old technology could be set higher to force customers to change. Rokkas, Katsianis and Varoutas (2010) assume a yearly price decrease of 2 % and Krizanovic, Zagar, and Grgic (2011) assume this decrease is 5 %. Price evolution (2009–2012) of different types of fixed broadband connections is illustrated in the Figure 10. Note that Ficora's way of calculating average prizes was changed in November 2011, which causes some failure in the statistic. These prices are list prices that are regulated by the Finnish state and subscriptions are usually sold with a discount campaign prices that are assumed to be about 30 % less than list prices.

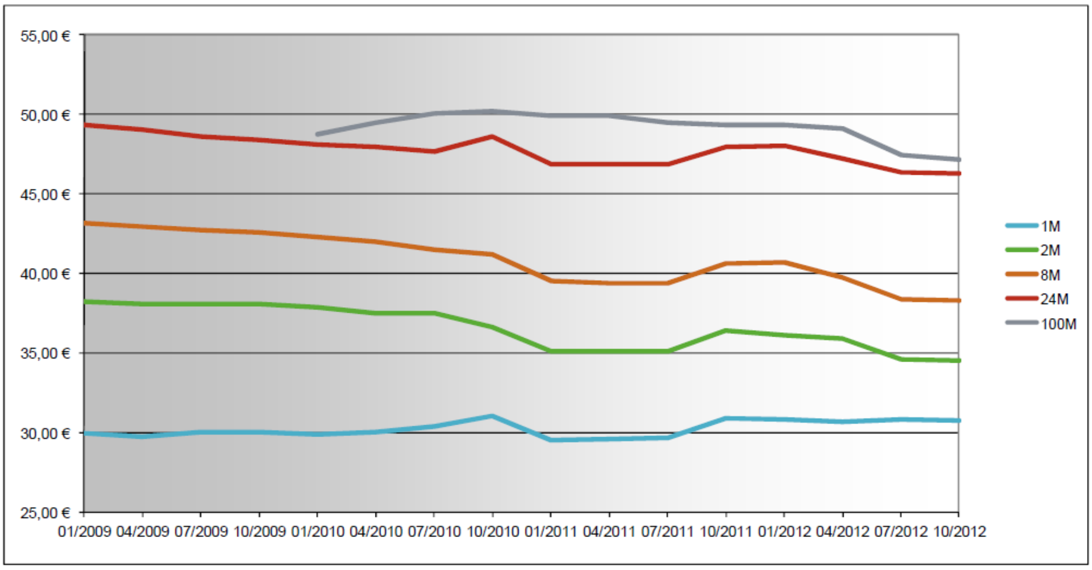

Figure 10 Price evolution of a broadband connection in Finland (Ficora 2012/2)

Revenues are also gained from additional services that are offered through a broadband access line. Currently, operators offer IPTV, alarm and security systems, cloud services and other services. However, transmission media is not limited by an operator and anyone can use the Internet as their business channel. Internet services such as Google, Spotify™ and Netflix are services that are offered through internet without an operator getting any revenues from them. These services use a lot of bandwidth and those could be considered as a threat to operators. For example, Netflix high quality video stream use up to 2.3 GB/hour with HD quality (http://support.netflix.com/en/node/87). AT&T tries to solve this problem by limiting bandwidth usage. Data gaps vary from 150 GB to 250 GB depending on the subscription type. (AT&T 2012) In the future, operators are most probably changed their pricing based on transferred data.

Common value used for measuring revenues from a telecommunications subscription service is Average Revenue per User (ARPU) which indicates to the revenue that a customer brings to a company. This value takes into account revenues from subscriptions tariffs, additional services and also spin-offs. It is calculated by dividing total revenue by number of customers. It can be calculated to meet wanted time interval. (Krizanovic et al 2011)

According to Capgemini (2011) revenue model comprise of three things: type of a customer relationship, distribution channel and payment structure. At every access network coverage area there is a base of potential customers and existing customers. The aim is to get the potential customers interested in available products and to get the existing customers to keep the product. Revenue modeling thereby includes a prediction of customer penetration, which is a relationship of existing and potential customers.

3.4 Cost components

Expenditures in broadband business can be divided in to two different categories: costs that are occasional one-time investments and costs that are repetitive maintenance expenses. In this study, relevant costs are related to broadband business and especially expenditures that change if used broadband technology is changed.

Energy consumption creates costs but it is also an environmental question in the field of ICT and telecommunications. By the aid of Broadband Equipment Code of Conduct (2011) contract the European Union tries to limit used energy per user. The whole Internet is said to consume 0.4 % of all the energy consumption in broadband-enabled countries and this value is going to increase to 1 % when broadband access data rates increase. (Baliga et al 2009) Access part of a network is said to be most energy consuming. Access network comprise of many active devices. DSL access equipment is assumed to consume from 0.3 W to 1.7 W per user depending on state of a device. Optical fiber network energy consumption in Point to Point (P2P) network varies from 0.3 W to 4 W per user at 1 Gbps data rates. Wireless UMTS/HSPA base station should consume energy from 570 W to 800 W and LTE base station is 100 W more than that. Watts per user value depends on a number of users in range of one cell. These numbers are guidelines and not always actual values. (Broadband Equipment Code of Conduct 2011) Energy savings can be done by smart topology planning (which minimizes number of active equipment) that is advantageous also when considering costs of building of a network. Smart topology planning reduce installation costs because of distances could be optimized and more customers could be covered by less effort. (Kramer, De Andrade, Roy and Chowdhury 2012)

Timing effects on costs. Not only because of possible competitive advantage but also because installation costs and equipment prices decrease in process of time. An example of a technology that would decrease installation costs is micro trenching. Micro trenching creates a shallow groove instead of a large hole for cable installation. This would reduce costs of digging. In addition, risk is smaller once standardization is detailed and developed. New technologies and innovations are a risk because they might not succeed if the standardization is loose or if somehow better technologies come in. First in the market advantage of a situation of being the first, but second in the market has an advantage in learning from the first's mistakes.

According to Lannoo et al (Lannoo, Casier, Ooteghem, Wouters, Verbugge, Colle, Pickavet and Demeester 2009) income from an investment is more valuable the sooner it is received from the time calculated. Costs are greater in fast rollouts than in slow rollouts. Cost per subscriber in the US varies between $1000 and

$1800 but in Finland this number can be much higher in the rural areas as Finland is not evenly populated. (Eriksson and Odenhammar 2006)

Costs are commonly divided into two groups: Operational Expenditures and Capital Expenditures. Both of these cost groups are to be defined next.

3.4.1 OPEX

Operational Expenditure (OPEX) is a cost related to operational, maintenance and administration. OPEX is a cost that is necessary in keeping a service active and running. These costs consist of maintaining a network i.e. operational administration, electricity, rent and repairing of a network. OPEX is a repetitive cost by nature and it is never deprecated. (Verbugge et al 2005)

Repetitive costs are employee salaries, customer relationship costs, marketing and maintenance cost of a network. Common costs of activities, such as salaries and marketing, are directed to products. In copper based network, direct OPEX costs are: electricity, repairing and maintenance. Fault repairing may be the biggest cost portion in a copper network. The amount of failures is increasing as network components and cables get older. Costs in coaxial cable network consist of similar types of components than costs of a copper network. However, cable broadband network requires active amplifiers at every few hundred meters. Many active devices may cause failures in a network too even if wires would be in a good condition. Optical fiber maintenance costs are smaller than in copper-based solutions (both coaxial cable and copper twisted pair networks) due to fewer failures but also due to less energy consuming devices in network. Mobile wireless broadband technologies costs comprise of cell site leases, energy consumption and cost of maintenance. Power consumed per customer is dependent on the amount of customers in range of one link station coverage area. Energy consumption per site is somewhat constant.

OPEX breakdown structure is important when trying to determine cost savings in dismantling a network. According to NSN White paper (2009) wireless network OPEX breakdown structure directed OA&M costs are 70% of total

OPEX. These costs are directed to this service product. In copper access network portion of OA&M is assumed to be less as direct technical costs are bigger. Let's assume that direct technical costs are 45 %. There are more active devices per subscription and more failures in a copper access line. If a copper access network would be dismantled made cost saving is not the whole directed OPEX but only direct maintenance costs.

Costs differ between ILEC and CLEC areas. Incumbent operator's network maintenance costs consist of electricity, heating and directed Operation, Administration and Maintenance (OA&M) costs. For a competitive operator, OPEX costs consist of site rents, leased lines and also directed OA&M costs. Rents of sites and lines are kept as high as possible within the limits of state regulations. OA&M costs are always somehow directed to products, in this case to sites or subscriptions. These costs are quite constant but if a number of products (e.g. DSLAM sites) are reduced, these costs are directed to other products.

3.4.2 CAPEX

Capital expenditures (CAPEX) are costs related to investments. CAPEX is always depreciated over time. To define precisely, also work of an installation that is related to investment is considered as CAPEX. Definition and what is considered as CAPEX differs between organizations.

In this study, investments refer to installation of a new technology or expanding a network. For example, upgrading a network component to support newer technology and rolling out fiber are both CAPEX. Installation of fiber or any other fixed infrastructure that is placed in ground is quite expensive because digging is expensive. Digging costs differ are different for different types of ground coating materials. Wireless links station extensions require backhauling to a link station. Backhauling is fiber installation as well, but CAPEX per subscription is smaller because a larger area is covered. Fiber broadband access must be pulled into each basement or house separately. (Weingarten and Stuck 2004) CAPEX in broadband fixed network installation depend on a distance from Central Office (CO) to a DSLAM or to a house, number of used equipment and network topology design. In this study, network topology is assumed to be similar to existing copper network.

Economies of scale stand for decrease in cost of equipment. Cost of equipment will decrease when production volume increase. (Lannoo et al 2006) For example cost of FTTx equipment decrease when fiber access rollouts get more popular. Price evolution of telecommunications network equipment can be said to decrease 15% every year.

4 Techno-economic modeling

In this chapter I am going to define the concept of techno-economic modeling. Usually it is used to analyze feasibility of a new technology. (Salminen 2008) Yet I am going to exploit the modeling to explore a feasibility of an old technology. The reliability and sensitivity analysis is also being introduced in this chapter.

Techno-economic modeling is trying to determine economic feasibility of a complex technology or a system. It is a simulation-based model for optimizing system solutions in different environments. (Hoikkanen 2007) Model can be based on pure profitability analysis, comparing different scenarios or comparing alternative technologies. Profitability is almost always measured as Discounted Cash Flow (DCF) which is said to be the best practice for valuing corporate assets. (Smura 2012) This chapter follows a structure of the techno-economic modeling process created by Smura (2012) but also ECOSYS (2006) techno-economic evaluation –methodology.

Figure 11 illustrates the main principles of techno-economic methodology of the ECOSYS too. Inputs, modeling and outputs of the analysis are clearly illustrated in the figure. Inputs are categorized in to three classes: costs components, services and architecture inputs, and revenue components. Financial calculations combine these inputs to understandable financial results for each year under examination which from critical profitability indicators can be calculated from with sensitivity analysis. Black arrows in the left hand side indicate information flows and sources. There is also a real option calculation choice shown in the figure. A real option is sort of a flexibility analysis, partly complementary for DCF analysis. (Lähteenoja et al 2006) Most of work in techno-economic modeling is done determining components, background information, technological limitations and input values for the model.

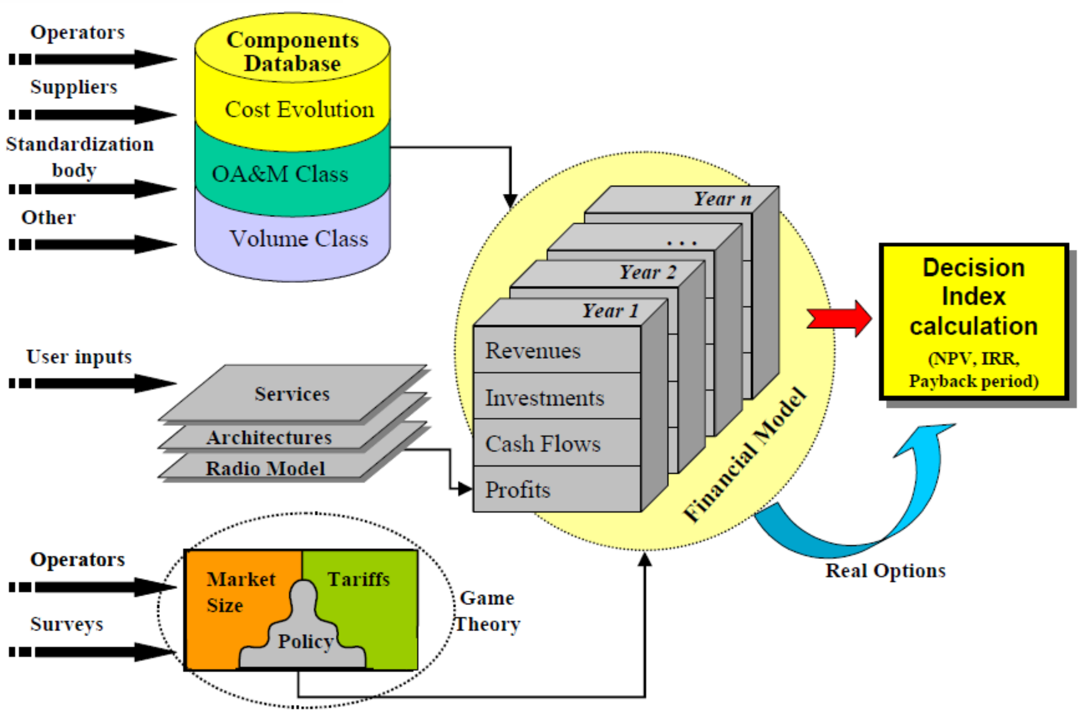

Figure 11 Techno-economic methodology (Lähteenoja et al 2006)

4.1 Inputs to the analysis

As techno-economic modeling is based on profitability analysis of an examined technology, inputs are mainly costs and revenues predictions. Also technical capabilities are taken into account as a limiting input. Hoikkanen (2007) divides input values into two categories. First category includes factors that define and effect on revenues i.e. service penetration, demand, tariffs, coverage area characteristics such as loop lengths, etc. Second category includes factors that define and effect on cost elements i.e. network architecture, costs of network devices, network scale and so forth. Cost elements are usually divided into OPEX and CAPEX cost elements as described in chapter 3.4. Input parameters divided into cost and revenue categories shown in the Figure 12. Used input parameters must be chosen in a way that those are relevant considering the question to be answered with a techno-economic model.

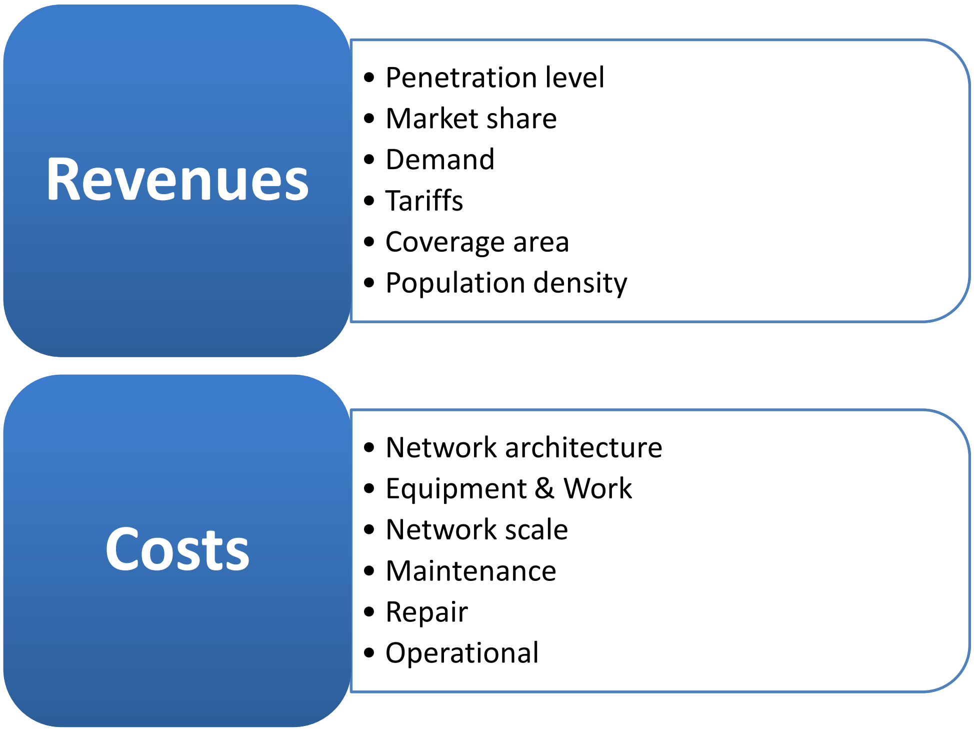

Figure 12 Inputs to the techno-economic model

In addition to cost and revenues relationship, technical capabilities and feasibility is used in techno-economic modeling as a limiting input. In this study, scenarios are defined according to technological capabilities. Technological factors are communications service descriptions such as: data rate, capacity and architecture. Architecture includes network coverage and location. (Lähteenoja et al 2006)

Input parameters may change along the time and some evolution expectations must be made to predict the future. Cost and revenue evolution modeling is discussed and defined in the section 5.3 further in this thesis.

4.2 Modeling

Basic purpose of techno-economic modeling is to convert inputs to a form that creates a financial model. Discounted Cash Flow (DCF) and Net Present Value (NPV) are the most commonly used financial profitability indicators. Cost and revenue components are modeled as a function of time. Basic idea is to reveal those markets and services that have the greatest revenue potential in contrast to investments. (Nagar 2002)

Modeling could be technology oriented or business model oriented. Choosing main focus is important. Techno-economic model is easily too complicated if all the possible affecting forces are taken into account. However, it is also possible to focus on too narrow by evaluating only financial profitability and not taking into account any technological factors. In this study, techno-economic modeling concentrates mainly on financial profitability. Technological capabilities are taken into account in defining scenarios. Sensitivity analysis gives a final result.

4.3 Outputs from the analysis

This section presents key profitability indicators for an investment in a complex system. Model outputs are results from techno-economic model. Basic idea in a profitability calculation is that cash flows during a certain period of time must be positive. (Olsen, Henden, Hansen and Lähteenoja 2009) This statement is represented in equation 1.

$$CF(t) = Revenue - CAPEX - OPEX \tag{1}$$

Discounted Cash Flow (DFC) estimates future cash flows of an investment taking into account time value and discounts. (Rokkas, Katsianis and Varoutas 2010) It is usually expressed as a curve of cash flows as a function of time. The lowest point of a cash flow curve indicates the funding needed for a project and point where cash flows turn positive is the Payback Period (PP) for a project. Time value of money has been taken into account. This curve usually shows negative in the beginning of a project because of an investment. (Mitjana, Wisely, Canu and Loizillon 2002). Cash Flow analysis seeks for an answer to the question of how much and when we are going to get back from an investment in the future. Profitability of an investment can be measured in two ways; NPV and IRR. (Nagar 2002)

Net Present Value (NPV) is the current value of an investment. Basically it is a sum of DCFs during a predefined study period as seen in the equation 2. A firm should invest if NPV > 0. Though, it compares investing on something today with the situation of never investing. Correct comparison would be between investing, investing later, investing after a waiting time. This indicator tells if some investment is going to be profitable or not. (Salminen 2008)

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \tag{2}$$

$Where\ C_t = \ cash\ flow, r = discount\ rate, T = study\ period$

Internal Rate of Return (IRR) indicates to the point where the money used on an investment and cumulative cash flows gained from it are equal. It is an indicator to an achieved value in respect to invested amount of money. Investment is said to be profitable if value of IRR is greater than a discount value used in calculating NPV. (Mitjana et al 2002)

4.4 Risk and sensitivity analysis

Input values are estimations of future demand, price and cost evolutions. Used values are not necessarily definite and possible variations should be taken into account. Variations in input values are modeled with the aid of probability distribution curves and deviation levels. Sensitivity analysis is used in evaluating input value variation affection on overall profitability i.e. project sensitivity on an input factor. A variable which has the strongest influence on output is a risk factor. Risk factor is important to recognize to be able to monitor its evolution during a project and know its effect on overall profitability. Sensitivity analysis is also been used to define optimal values for certain factors that could be predefined but overall affection on an outcome in not yet known. (Frey and Patil 2002)

Previously described sensitivity analysis method is quite simple and does not necessarily give an overall picture as only one parameter is varied at a time. An efficient method is scenario based analysis where two or more factors are taken into account simultaneously. At least the best and the worst case scenarios are calculated with a scenario analysis. An advanced version of scenario analysis is

Monte Carlo method which generates a number of scenarios by combining all the possible input value combination within a given range. It varies input parameters by chosen distribution multipliers and limits. Monte Carlo simulation is possible to run by setting probability distributions for all the inputs separately when results give also achievable absolute values in addition to the relative impact. (Frey and Patil 2002) Monte Carlo simulation tools are many. One known simulation tool is Crystal Ball™ –tool. In this thesis a freeware Monte Carlo simulation tool, MCSim, is used.

Monte Carlo simulation is used to examine the risk of an investment. Parameters under examination must be given a probability distribution range. Depending on a nature of an examined value, probability distribution type is chosen. Triangular distribution is useful if maximum and minimum values are known in addition to most probable value. Normal distribution is useful scale when there is a possibility to an outlier. Nevertheless, triangular distribution is not used in this thesis because there is no function for that in Excel®.

5 Copper network life-cycle analysis

This chapter encompasses the techno-economic analysis used to model copper network life-cycle. It includes constructing of the model, using it and testing its reliability.

The purpose is to figure out how long copper network is compatible in a constantly evolving industry. Copper compatibility is defined by examining its technical capabilities, cost components and revenues. These factors are then compared to possible alternative broadband access technologies. A comparison between alternatives is made to be able to predict possibly replacing technology for copper access. The most suitable option is cost efficient but also it has to bring additional value to a customer. Competitive technologies and their characteristics vary between different geographical areas. Therefore, copper access life-cycle modeling is examined for different environments. As a result, different life-cycle analysis is produced for each area.

5.1 Techno-economic model

Life-cycle model is constructed examining different possible alternative access technologies profitability and capabilities. Profitability and suitability of a technology differ between different types of areas depending on area household density, competition and currently offered broadband access service characteristics (data rate and reliability). In this study, a business model oriented techno-economic evaluation is used. Focus is on gaining more revenues and performing cost savings. Technical parameters are simplified but taken into account as realistic values.

Techno-economic logic (Figure 13) is composed based on Smura (2012). Model is simplified as its technological input parameters. OPEX costs are quite fixed apart from repairing costs that are dependent on an experience of a given technology (e.g. 4G and fiber immaturity) but also age and quality of a network (e.g. DSL access attenuation). OPEX efficiency could be compared as well.

DSLAMs are more or less underutilized in rural areas. CAPEX is greater for technologies that are not yet matured. Fiber installation CAPEX can be defined as cost per digging meter. 4G installation CAPEX is defined as cost per link station. Revenues are fully dependent on a number of customers and service types. However, customers choose a subscription type and an operator according to technical capabilities and price. Number of customers is also dependent on population density and penetration rate. Techno-economic model is constructed in Microsoft Office Excel®.

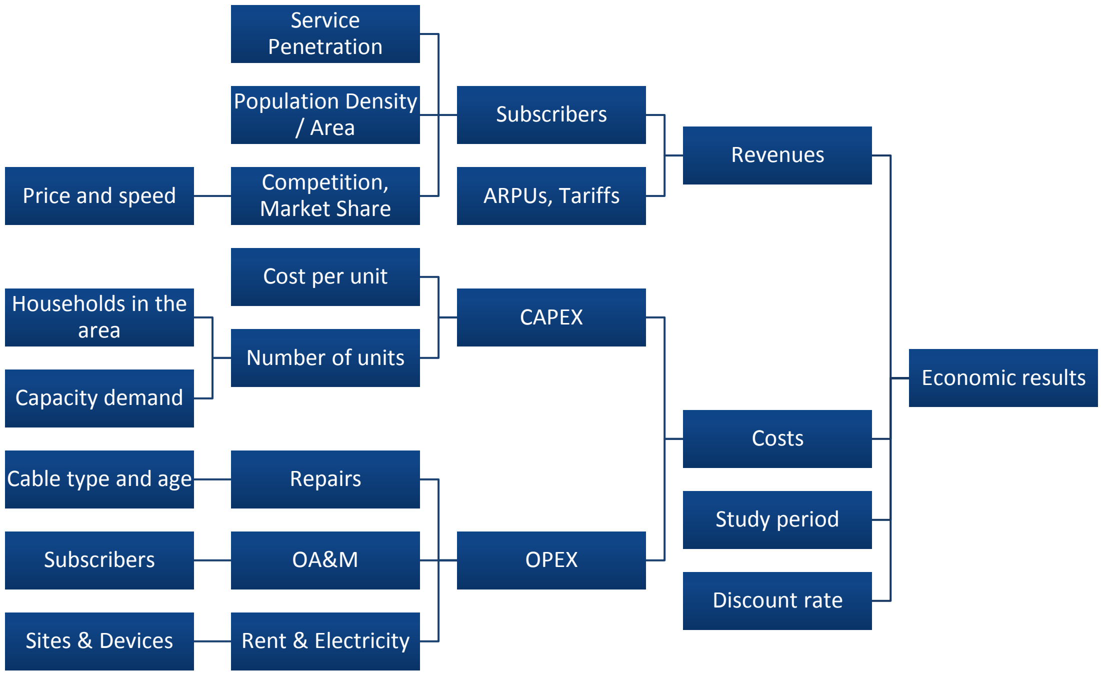

Figure 13 Techno-economic model logic

5.2 Life-cycle modeling

Physically copper network can be maintained as long as needed by fixing defects. New copper lines could be installed to replace broken parts. Maintenance costs are increasing and technological capability of copper access may not be sufficient enough for future demand. Any business is given up if it turns unprofitable. However, there may be unprofitable parts in a network if it makes a complete picture somehow profitable. Such situations could be a remote area broadband subscription for an important business customer that has multiple subscriptions also somewhere else.

Possible scenarios for a DSL access network to turn unprofitable are: when repairing costs (faults) increase too much and/or when number of customers decrease. The latter is a consequence of a situation where customers change to a competing technology or to be a competitor's customer. In addition, migration can decrease number of customers in an area as a number of potential customers in the area decrease too. Alternative access technologies are compared from a customer's perspective as well as from an operator's perspective. Life-cycle of copper access network depends on its competitiveness and profitability.

Copper access network life-cycle differs between areas with different population densities where appropriate technological solutions and competition differ too. In this sort of business area, where service is considered as a universal service, there must be taken into account a situation of replacing dismantled service with a substitute. This means that a substitutive technology must be at least as good as a replaced one. Competition areas are defined on the strength of currently existing network capabilities and also by suitability of an alternative access network technology in that milieu.

5.2.1 Modeling history

If we look at copper network life-cycle so far, it is the only fixed network to cover whole Finland and the network has been constructed during many decades. Copper network was originally built for voice services (POTS) and nowadays it is used for both voice and data transmission. Newly developed wireless voice services (NMT in use in Finland from 1982 and nationwide network on 1990, GSM in use in Finland from 1991(Laukkanen 2001) started to overlap with some parts of copper Public Switched Telephone Network (PSTN) reducing its utilization rate. Wireless services offered a voice service which quality was good enough compared to fixed line voice.

When wireless mobile phones were just becoming general people had both mobile phone and fixed phone subscriptions. As people got used to the situation that they were available anywhere at all times, for most of the people, wired phone did not have any function anymore. Fixed PSTN offered limited functionality compared to NMT/GSM. In addition, operators started to use copper lines for broadband ISDN connections which disabled a voice service while connected to Internet. POTS service has been slowly reduced in Finland and customers have been changed to use wireless voice services. Nevertheless, some delaying factors were met. Some special services that were offered through PSTN could not be transferred through a wireless network at first. Also, some PSTN users think that they do not need newer technology as the old one has worked just fine. Illustration of voice services development can be seen in the Figure 14. Transition phase could take a long time not only because a construction of a nationwide network takes time but also because some users do not want to renew.

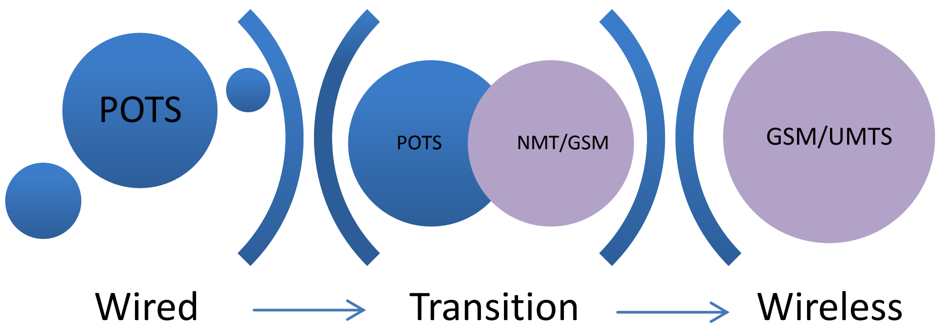

Figure 14 Illustration of the life-cycle of voice services

There are always people who rage against reformations. To persuade customers to switch, operators raise subscription tariffs. Also, similar appearance substitutes are offered such as fixed position phones that use GSM network but look like an old fixed landline telephone. There are still many subscriptions in POTS network but the number of customers is continuously decreasing.

During a transition phase, both (old and new) networks may bring revenues as both of the networks are being used in tandem. An old network could bring quite a lot of revenues due to subscription tariff increase (which is made to eject customers). Finally when there are few enough customers in a network, it can be dismantled. To be able to displace a technology there must be at least similar function and maybe something better to offer.

Even if dismantling of POTS service is still ongoing, dismantling of copper broadband access lines has already begun. In the most rural areas DSL broadband access network is to be dismantled as there are not enough customers to cover the expenses that result from upholding a network. Migration from rural to urban has decreased potential customer base but customers have also changed to use other broadband technologies. Wireless broadband solutions are able to offer better quality and data rates in the areas where DSL loop lengths are long. In addition, copper cables in rural areas are very often located in poles that are very sensitive to external disturbances. Pole cables are usually old and attenuate more than ground cables.

Life-cycle modeling of DSL access network is a bit more complicated, as broadband service can be offered in many forms varying from its data rates and additional services offered. Basic idea is that there must be a financial reason why an operator would want to replace a network. Phases of evolution of copper cables in remote areas have been similar to phases in dismantling of POTS services; there is an overlapping media offering identical service with better features and quality. At the same time, subscriptions are decreasing due to migration to population centers. As a result, it is making copper network unable to compete and expensive to be maintained.

5.2.2 Modeling future

It is assumed that copper network have different life-cycle at different types of areas. As mentioned before, commonly used division is to divide inspection area to urban, sub-urban and rural areas. To illustrate the whole picture, also dense urban and remote areas are defined. A division to areas differs by purpose of use and, in this study all five mentioned areas are defined but only three of them are used in calculations.

DSL access network is dismantled if there is a potentially replacing technology available and there are few enough customers in the area. Possible scenario for copper access network life-cycle could be that its living space is narrowed from two directions. Wireless 3G and 4G expands from the most rural areas towards the densest areas in Finland and fiber access solutions expand from dense urban areas towards sparsely populated areas.

Other broadband access networks would overthrow copper access network if those are able to offer better service from a customer's point of view (i.e. lower price level, additional features and better data rate). From operator's point of view, increase of failures in copper network would force them to replace it with an alternative. (Interview 31.8.2012) Demand for higher data rates is increasing. Fiber access is able to offer greater data rates but mobile broadband has a limited capacity. However, mobile broadband access technologies are continuously developing to be able to offer even higher bit rates. One driver for copper network dismantling is capability limitations; DSL will not able to answer to demand of increased data rates (Interview 31.8.2012) or at least coverage area for higher data rates is small.

Network traffic increase as there are even more applications and services offered over internet. True values for busy hour traffic with different technologies during 2006 - 2010 can be seen in the Figure 15. Forecasted traffic increase from 2010 to 2018 is also shown in the very same figure. It can be seen that traffic varies greatly between technologies as bandwidth and data rate vary. In the figure, FWA (Fixed Wireless Access) subscriptions traffic is far less than DSL traffic. However in this study, when considering wireless mobile broadband as a substitute to DSL, it is assumed that former DSL user continue transferring data similarly as before even if forced to change to mobile broadband.

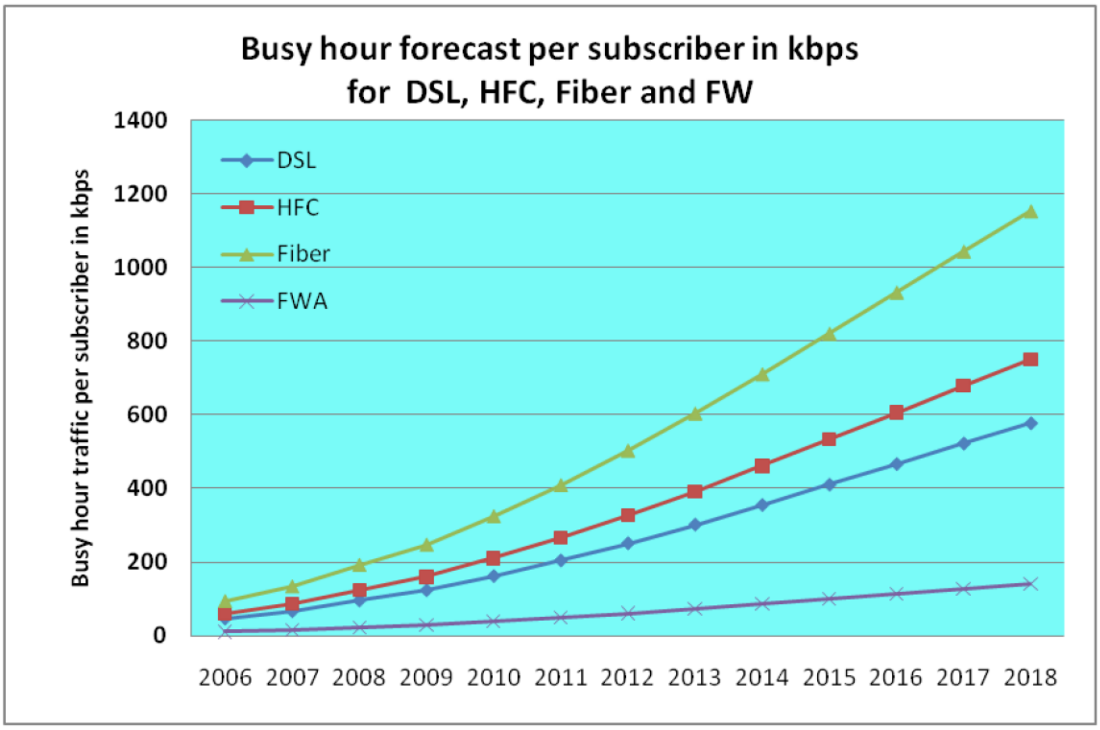

Figure 15 Busy hour traffic forecasts for different technologies (Stordahl 2010)

In the area where optical fiber would replace DSL, there should be enough potential customers who want to pay for increased capacity. Approximately 20 % of all the households in Finland are covered by fiber access. It has been installed only to the places where there is a great demand i.e. population density is high (dense urban and urban areas). The biggest city centers are completely fibered but smaller ones only partly. Half of the Finnish population lives in the cities.

Sub-urban areas are currently covered with DSL and mobile broadband networks. I examine fiber potentiality to expand to sub-urban areas. Fiber installations are quite expensive and network operators invest in them if it would bring enough customers i.e. revenues. Fiber installation cost can be defined as cost per meter and average amount of digging required per building or customer defines potential future fiber areas. Installation cost of a fiber connection depends on distance to the nearest fiber line, type of ground coating and soil.

At rural areas, potential competitive technology for DSL is wireless mobile broadband. Mobile broadband technologies are many but in this study, only UMTS (3G) and LTE (4G) technologies are examined. To be able to clearly define a situation where 3G or 4G with current characteristics could replace DSL, maximum capacities of these technologies must be defined. According to NSN (white paper 2010) the capacity of a mobile link station coverage area can be estimated with the following equation 3.

$$N = \frac{Cell\ Capacity}{Data\ usage} \cdot Sectors \cdot Time \cdot \frac{Max\ load}{Busy\ hour} \qquad (3)$$

Where, N refers to the maximum number of subscriptions in a link station coverage area. Cell Capacity means the maximum capacity (data rate) of one cell. Data usage is the estimated amount of transferred downlink data during a certain time period (usually limited by an operator per month). Max load refer to a portion of cell maximum capacity that is the actual data rate for each user and busy hour means a traffic share of the busiest hour from the whole day traffic. Note that this model does not take into account fading in a wireless media as moving further from the transmitting link station. A coverage area of one cell must be defined to be able to outcome a population density value. Coverage area depends on the height of the link station, transmitting power and frequency band. For three sectors, coverage area of one link station can be assumed as hexagon as illustrated in Figure 16.

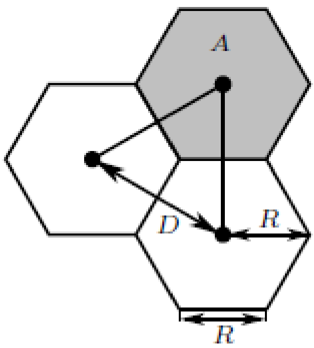

Figure 16 Geometrical illustration of coverage area calculation (Fehske, Richter and Fettweis 2012)

Where, D stands for inter-site distance (ISD) and R is a radius of a sector. Hexagonal area formula is $A = \frac{3\sqrt{3}}{2} R^2$ where $R = \frac{D}{\sqrt{3}}$. D is known so the coverage area is calculated with the following equation 4.

$$A = \frac{\sqrt{3} \cdot D^2}{2} \tag{4}$$

It is assumed that there is one subscription per household. Equation 4 is giving an approximate number for a link station capacity. A precise capacity depends on a location of receiver and terrain conditions which are case specific.

4G (LTE) is a relatively new technology and it yet covers only some cities in Finland. A nationwide coverage is not achieved immediately. Technology rollouts are usually made in low risk areas. 4G is first installed in the most densely populated areas because risk is lower due to high number of potential customers. As mentioned before, 3G network is already nationwide and can be considered as a compensatory technology for DSL also in the most rural areas. Mobile broadband is able to replace a copper network if

1. The population density in the area is small enough and
2. Mobile broadband data rates are as high as or higher than data rates of a copper network.

Life-cycle modeling in this study is based on a comparison of alternative technologies. Different broadband technologies were presented in chapter 2. Possible broadband scenarios are chosen according to area characteristic and technology suitability features, such as architectural suitability, existing infrastructure and cost efficiency. Fiber access installation costs increase as population density gets smaller. Fiber has a better chance to be profitable if the installation cost per household is small and there are enough potential customers. Wireless broadband capacity suits better for low population density areas. In population centers simultaneous users in a wireless network are too many for a network to be sufficient as a broadband access. Comparison in the life-cycle analysis is always made between copper network and an alternative technology. Living space of copper access network is narrowed from two directions; fiber access expands from dense population centers towards sub-urban settlements and wireless mobile access expands from rurally populated areas towards denser areas.

5.3 Basic assumptions

In this section, inputs to the techno-economic model are presented as basic assumptions. Assumptions are based on real information about technology capabilities and price regulation in Finland.

5.3.1 Radio capacity

AT&T (2012) claims that an average high speed internet customer use approximately 21 GB data per month. Sonera's statistics about data usage per customer per month is approximately 40 GB without IPTV. With IPTV this number could be multiplied. Data transmission is not dependent on a time spent in the Internet, it is rather dependent on the activity and applications used and available bandwidth. Newly deployed video services (Netflix, HBO) are just an example of the applications that increase the Internet traffic in a network. Currently operators do not limit data transmission for fixed broadband subscriptions. Only bandwidth is limited due to technical reasons. Wireless mobile broadband subscription's prioritized data transmission is limited varying from 1GB to 50GB. In this study, 40 GB downlink data transmission is used in radio capacity calculations.

Wireless radio capacity is evaluated by calculating maximum users according to equations 3 and 4 (presented in chapter 5.2.2). Number of maximum users is calculated with similar service characteristics for wireless broadband than copper access is able to offer. LTE is assumed to apply 10 to 20 MHz bandwidth and UMTS technologies 5 to 10 MHz bandwidth with down link cell capacities of according to Table 2. Note that the 800 MHz spectrum license has not yet being sold in Finland.

Table 2 Assumed downlink capacities of 3G and 4G networks

Technology	Bandwidth (MHz)	Cell capacity (Mbps)
3G: 900 MHz	5	21
3G: 2100 MHz	5	21
3G-DC: 2100 MHz	10	42
4G: 800 MHz	10	50
4G: 2600 MHz	20	100

Higher frequency bands offer smaller coverage area which is directly proportional to the greater capacity per square kilometer. Higher frequencies are used in the urban areas and lower frequencies in the rural areas. It is assumed that 3G 900 MHz and 4G 800 MHz transmitters are located in masts or poles and 3G 2100 MHz and 4G 2600 MHz transmitters are located in buildings. Calculations are made with monthly data transmission per user values of 14, 20, 28, 30, 40 and 80 GB. Calculating capacity for multiple data transmission values its sensitivity to data traffic is also examined. ISD are set according to 2 Mbps cell edge data rates. Busy hour, max load and number of sectors are assumed to be according to NSN (white paper 2010) i.e. busy hour share is 7 %, maximum load 50 % and it is assumed approximately 3 sectors per link (suits fine in the rural areas and is used in the other areas as well to simplify the model). 50% max load means that from the total cell capacity user can receive only half of it in practice. Approximate values calculated for maximum radio capacities are shown in the Table 3.

Table 3 Maximum number of users for mobile broadband

	3G 900 (rural)	3G 900 (sub)	3G 2100 (sub)	3G-DC (urban)	4G (rural)	4G (sub)	4G (urban)
ISD (km)	10.84	2.31	1.655	0.673	11.244	2.391	0.528
80GB							
Users/site	74	74	74	148	177	177	353
Users /km^2	0.73	16.1	31.2	378.1	1.6	35.7	1462.6
40GB							
Users/site	148	148	148	297	353	353	706
Users / km^2	1.5	32.1	62.5	756.2	3.2	71.3	2925.3
30GB							
Users/site	198	198	198	396	471	471	942
Users / km^2	1.9	42.8	83.4	1008.3	4.3	95.1	3900.4
28GB							
Users/site	212	212	212	424	504	504	1009
Users / km^2	2.1	45.9	89.32	1080.3	4.61	101.89	4179
20GB							
Users/site	297	297	297	593	706	706	1413
Users / km^2	2.9	64.2	125.1	1512.5	6.5	142.7	5850.6
14GB							
Users/site	242	242	242	848	1009	1009	2018
Users / km^2	4.16	91.7	178.6	2160.7	9.22	203.8	8358

5.3.2 Fixed broadband capability

Data rates differ slightly depending on type of a copper cable. Maximum data rates of a copper access network were introduced in chapter 2.2.1. If 0.5 mm cable is able to offer 24 Mbps a 0.4 mm cable can offer only about 17 Mbps (i.e. 70% of the 0.5 mm cable data rate) on the same distance. FTTx is able to offer 100 Mbps or 1Gbps. VDSL2 and FTTx are competing with same commercial speeds. Cable broadband offer data rates from 10 Mbps to 100 Mbps.

It is assumed that all the existing customers are changed to fiber if fiber installations are made and the increase in the customer base is assumed to be 10 %. The fiber installation penetration rate is assumed to be 40% in both ILEC and CLEC assuming that competing technology is DSL.

5.3.3 Used technologies

Evolution of different broadband technologies penetrations are presented in the Figure 17 below. Both consumer and account customers are taken into account in this statistic. (Viestintävirasto 2012) Total number of broadband subscriptions is linearly growing as is the number of mobile broadband subscriptions as well. Number of copper access subscriptions is decreasing. In Figure 17 statistic VDSL subscriptions are also calculated in to number of DSL subscriptions. VDSL subscriptions are 84 000 from total of 1 097 700 DSL subscriptions in June 2012. VDSL subscriptions increased 30 % from the previous year. Thus, ADSL subscriptions decreased 4 % during 2011-2012. Number of DSL subscriptions has been decreasing since 2008 and for first three years this decrease was about 9 %. Availability of a substitutive technology and operator's marketing effects on the churn of copper access subscriptions. Number of customers in mobile broadband increased 8 % from 2011 to 2012.

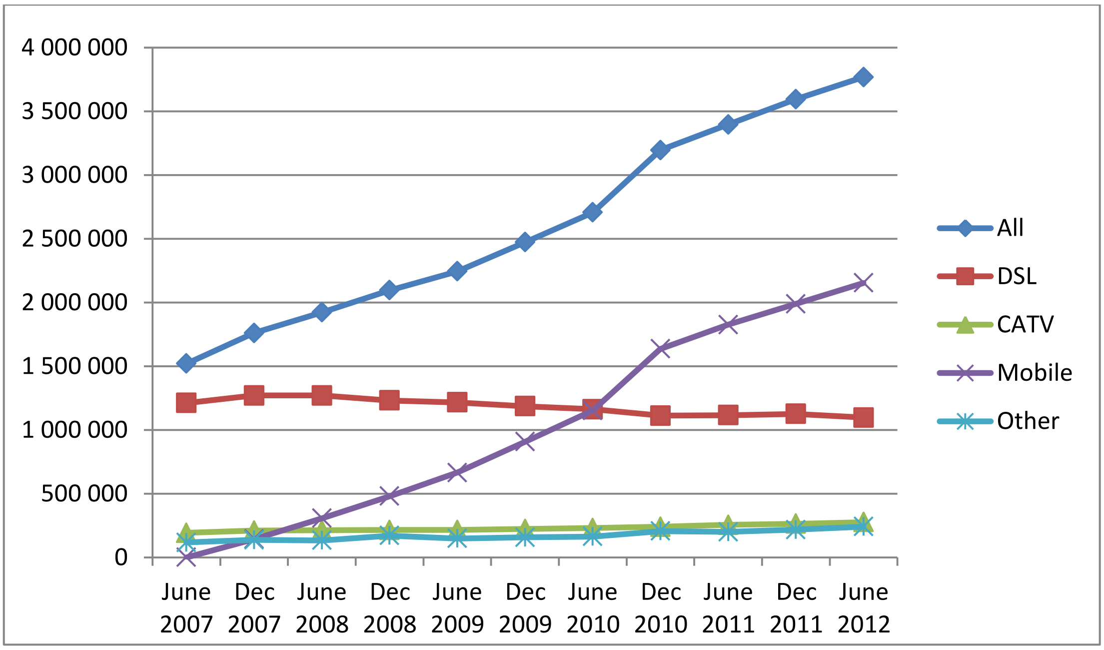

Figure 17 Number of broadband subscriptions in Finland from 2007 to 2012

Fixed and wireless broadband technologies are overlapping and multiple choices are available for a customer. Fiber access overlaps with DSL in other than new construction houses. An incumbent operator uses their fiber access and still leases copper lines for a competitor. SMP regulations are valid even if fiber access is installed and operator customers may choose between renting a copper access line and renting a fiber line. Fiber installations are usually made for a smaller area than a network area. Therefore, fiber access installation does not necessarily decrease upholding costs of a copper network but can somewhat decrease cost of failures in a network.

5.3.4 Costs

OPEX inputs are estimations according to NSN white paper (2010) and Ministry of transport and communications (2012). OPEX costs are estimated according to SMP operator's copper access leasing prices. Leasing prices include directed OA&M costs of an access line and 9 % profit margin. Cost difference between rural and urban areas is assumed to be similar to the difference between TeliaSonera price categories in SMP operator's leased line price list. (Ministry of transport and communications 2012) Fiber access OPEX is estimated according to Ericsson FTTx equipment descriptions where the OPEX costs are promised to be at least 40% lower than DSL OPEX costs. Mobile broadband OPEX is highly dependent on a link station upholding costs independent from number of customers. Wireless broadband network OA&M are included in the cost per site a year. Fiber access CAPEX is given as a cost per meter of digging, which is assumed to include the equipment installations as well. This number is set according to interviews (6.6.2012 and 11.6.2012).

DSL churn rate is assumed to be 7% (Sonera statistics from year 2009 to 2010). Common discount rate 10% and 10 years study period are used. Depreciation is assumed to be 20 years for fiber access installations. Tax rate is not taken into account in this analysis. All the costs are shown in the Table 4.

Table 4 Cost estimations for different technologies

Cost component	Price in 2012	Price evolution
	Wireless mobile broadband network	
3G/4G OPEX	8000€/site/year	-
	DSL network	
Total OPEX (rural)	32 €/subs/month	+7%
Total OPEX (sub-urban)	Rented 22 €/subs/month Own 20 €/subs/month	+7%
Total OPEX (urban)	12 €/subs/month	+7%
	FTTx network	
CAPEX	120 €/meter of digging	-
OPEX	12 €/subs/month	-

5.3.5 Revenues

Market penetration, number of potential customers and actual customers of a broadband service are estimated according to population densities and internet usage in Finland from Tilastokeskus (2012) statistics and Sonera's statistics about network area division in Finland.

Fixed broadband subscription prices (considered as ARPU in this study) according to maximum data rates are shown in the Table 5 (Saunalahti, Sonera price lists 2012 and Viestintävirasto 2012/1 & 2012/2). These prices are operator's list prices and they do not take into account discount prices that subscriptions are usually sold with. A common discount rate could be assumed to be 30 % in the calculations (estimated according to current offers in the main operator's web pages). Discounted prices would give more realistic results for operator's revenues from broadband business. Prices are divided into four different pricing categories where number 1 refer to the Finnish capital city area, number 2 prices refer to other cities and number 3 comprise of rural areas. These prices are Business to Consumer (B2C) tariffs and differ between areas because of different upholding cost per customer and lack of competition. Wireless 3G price is currently fixed 19.90 € with 20 GB data packet and every 5 GB costs 1.9 € (Sonera web pages 2012).

Table 5 Fixed broadband subscription prices according to data rate and area type

Area	1		2		3	
Data rate	Price (€)	€/Mbps	Price (€)	€/Mbps	Price (€)	€/Mbps
10 Mbps	23.90-25.90	2.5	33.20-37.90	3.5	49.90	4.9
24 Mbps	29.90-32.90	1.3	43.30-47.90	1.9	59.90	2.5
100 Mbps	39.90-42.90	0.4	43.30	0.4	59.90	0.6
1 Gbps	99.00	0.1	99.00	0.1	99.00	0.1

Tariffs change as a function of time with an assumed price evolution Δ = -2 % and tariff erosion as a function of time is:

$$f(t) = (1 - \Delta)^t \qquad (1)$$

5.4 Competition scenarios

Input scenarios for a techno-economic model are defined in this section. Information about population density, currently existing broadband technologies and amount of customers is gathered. Different competition scenarios take place at different areas. These areas are defined according to:

1. The capability of wireless mobile broadband and
2. The existence of fiber access network.

Both criteria result a population density value. Mobile broadband radio capacity is defined as a maximum user density. Fiber access networks location is correlating with household density. Network area data is being examined to define average types of network areas at each area category.

Finland is divided into approximately five thousand different network areas. Network area division was originally made according to location of an exchange. New network areas are created in new construction areas. As mentioned before, copper cables are not used in building new networks and new construction houses are connected to the Internet by fiber access lines. Therefore, new construction network areas are not built around an exchange.

Copper network in a network area can be divided into zones according to copper access loop lengths. These zones have different maximum data rates. With ADSL2+ 24 Mbps data rate is achieved up to two kilometers and 2 - 8 Mbps data rate until five kilometers. Older ADSL equipment offer only 1 - 8 Mbps up to five kilometers. Maximum commercial and maximum technical speeds are defined for each network area. These data rates are valid only for short distances, and in network area edges the actual data rate is smaller.

Cable television (CATV) is offered in all the Finnish cities[2] in 25 of the cities CATV can be used as a broadband. Together there are 1 537 000 CATV houses which from 276 100 has cable modem installed. (Viestintävirasto 2012) According to network area analysis, household density in the cable broadband areas is on average 1217.84. Cable broadband is able to offer similar data rates than fiber broadband and therefore, cable broadband is counted in to fiber competition scenario.

Next, competition scenarios are being introduced. Five different types of areas were recognized which in three of them there could be clearly defined a competition scenario between copper broadband access and some other broadband access technology. Thereby only these areas are relevant in defining copper access network life-cycle.

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[2] European Union defines cities either by the density of population and number of inhabitants or by function of a municipality. Finnish municipality law 5§ state that a municipality can decide whether to call themselves city. 108 municipalities are called cities in Finland. www.kunnat.net

5.4.1 Remote area

Telephone signal was originally transferred to a customer along a pole line before pole lines were installed to ground. Cable renewing in remote areas is expensive and therefore copper network still consists mostly of pole lines. In this study, remote area comprise of areas where pole lines are dismantled and replaced with wireless solutions. Copper network is going to be wholly dismantled until two years from the moment of writing.

Electricity distribution companies are usually using the same poles than telecommunications companies. A decision of dismantling a pole line is made together with an electricity distributor who installs their cables to ground. From all the five thousand network areas about 1500 are already decided to dismantle from copper pole lines. A life-cycle of copper pole lines is shorter than a life-cycle of copper ground lines. Poles are perishing and air cables attenuate more than ground lines. Operator may choose from four options:

1. Replace poles with new poles,
2. Install copper cables to ground,
3. Install fiber access to ground,
4. Replace access lines with wireless solutions.

In remote areas, options 1 – 3 are unprofitable. Age of a pole is 10 years which after it must be changed and quality of an airline is bad for broadband traffic. Copper and fiber ground line installations are equally expensive and there are too few customers compared to investment cost. Remote network area's average household density per network area is currently 0.7 households/km^2 and maximum household density is about 4 households/km^2. These household densities are getting even smaller due to migration. Wireless solutions offer better quality broadband service than long copper pole lines. Therefore, operators are replacing poles with existing wireless solutions. The dismantled area is about 54 % of Finland's surface area.

5.4.2 Rural area

Rural area can be defined in two different ways. According to areas where 3G or areas where 4G is sufficient for a replacing broadband connection for DSL. Sufficiency is measured as population density where wireless alternative is able to offer similar data rate than copper access lines. Cost savings from dismantling a copper network differ between ILEC and CLEC areas. However, competition is assumed to be very minimal in the low population density areas. Attractiveness of wireless broadband for a customer and possible cost savings for an operator are discussed.

Wireless maximum data rates were presented in Table 2. An actual data rate received by a customer is assumed to be half of the maximum cell capacity. Actual and maximum data rates are presented in Table 6. Theoretical maximum capacities are shown in the column "Cell capacity" and actual data rates are shown in the column "Max load", meaning that 3G mobile broadband max capacity of 21 Mbps offers about 10 Mbps in practice.

Table 6 Customer received data rates during the busy hour

Technology	Cell capacity (Mbps)	Max load (Mbps)
3G: 900 MHz	21	10.5
3G-DC: 2100 MHz	42	21
4G: 2600 MHz	100	50
4G: 800 MHz	50	25

Profitability comparison is made between maintaining two parallel networks and maintaining only one network. Wireless mobile broadband network is maintained in any case because it is used to mobile voice services as well. Dismantling of a copper access network could decrease maintenance costs. There are no investments required in a network because wireless 3G network already exists and for a comparison with 4G, it is assumed that the network is constructed regardless of copper network.

Account customers are not taken into account in the calculation. Those are assumed similar to residential customers in this study. Account customers must be taken into account when doing micro planning of the areas that are really dismantled from a copper network. Account customers may have multiple subscriptions around country. Therefore, keeping an expensive DSLAM could be more profitable than dismantling it, if the dismantling would cause subscription terminations elsewhere.

The first scenario is that everything would continue as it is. Operators maintain two separate networks; wireless (3G, 4G, @450, satellite) and fixed (DSL). Customers choose themselves which technologies they want to use as their internet access. DSL churn is assumed 4% every year since there is a substitutive technology available.

In the second scenario customers are forced to change from fixed to wireless. Fixed copper access network is dismantled. Only wireless network is maintained. It is assumed that all the customers are satisfied with wireless broadband access and there is no competition between other operators. Competition scenarios are presented in the Table 7.

Table 7 Scenarios in rural area

Wireless / Scenario	1. DSL and wireless	2. Only wireless
3G or 4G	3G can compete with only below 8 Mbps DSL access. 4G can compete with only below 24 Mbps DSL access.	
Costs	Maintenance costs of two overlapping networks.	Maintenance cost of only a wireless network.
Revenues	Higher ARPU in fixed copper access than in wireless broadband.	Lower ARPU in wireless broadband.
Technical	Data rate up to 8 Mbps or 24 Mbps in DSL and 21 Mbps (in practice 10 Mbps) in 3G or 50 Mbps (in practice 25 Mbps) in 4G. Fixed feels more reliable.	Data rate up to 21 Mbps (in practice 10 Mbps) or 50 Mbps (in practice 25 Mbps) in 4G. May require additional CPE installations when used as fixed broadband access.

Mobile broadband competition area is defined with a maximum radio capacity that is calculated according to 40 GB average data usage per month. It is assumed that in rural there are only link stations in masts. With these assumptions, rural area is defined as below 1.5 households per square kilometer with 3G 900 MHz frequency band i.e. about 350 network areas. For 4G 800MHz rural area would expand to 3.2 households per square kilometer i.e. about 700 network areas. (See section 5.3 for capacity calculations.) Price evolution is usually decreasing but due to lack of competition, prices could stay at their level. Characteristics of total rural area (according to 3G capability) are shown in the Table 8.

Table 8 Characteristics of the area: rural

Total rural area	Rural
DSLAM sites	144
Wireless link stations	148
Total households	12500
Household density	< 1.5
Current DSL customers of total households	30 %
Current mobile BB customers of total	50 %

5.4.3 Sub-urban area

Sub-urban area is potential fiber access area. Currently operator offers only copper broadband access subscriptions and wireless 3G until a certain limit. However, it is assumed that for a main broadband connection, people choose DSL. Sub-urban area household density is over wireless mobile broadband capacity but below household density of fiber access area. There are two input scenarios for techno-economic model. Both scenarios are examined form ILEC and CLEC operator's perspectives. Operator can decide whether to:

1. Continue without changes (DSL)
2. Install FTTx (or update CATV to support broadband) and migrate customers from DSL.

New network installations are made if they cause additional value or revenues. Additional value is caused e.g. if fiber installations increase the sales of IPTV or if there is a contract made with a whole housing company. In competitor's area fiber installations could bring competitive advantage. In addition, cost of maintaining a leased line is more expensive compared to cost of maintaining an own network regardless of the transmission technique. Competitive operator may freely install fiber in traditional operator's premises.

An average sub-urban network area is defined according to areas that are not part of fiber access area and wireless mobile broadband (3G) capable area. Values that are used in the calculations are shown in the Table 9 below. Portion of customer's form the total number of households is estimated according to common market shares of the main operators (taking into account the internet usage about 85 % and use of mobile broadband in the dense areas as well). "Meters of fiber installation per household" is an initial value which finally defines the sub-urban area. Number of customers and subscription price are assumed to linearly increase when changing from DSL to FTTx.

Table 9 Initial values for the profitability calculations (ILEC and CLEC)

Average sub-urban area	Sub-urban
Non-fibered households	1000
Total households	1500
Household density	200
Current DSL customers of total households	ILEC 40 % CLEC 9 %
Meters of fiber installation per household	10

A decision to invest in a network is affected by a number of factors. Without competition, probability of an operator renewing a network is low. The decision is affected by an investment profitability (NPV, Pay Back period and IRR), demand and current technology suitability if there is no competition.

5.4.4 Urban area

Urban area consists of areas where fiber access lines are installed in parallel with copper access lines. Fiber access lines could be owned by an incumbent operator who owns the copper line too, or fiber access lines could be owned by a competitive operator. Incumbent operator offers 100 Mbps subscriptions for residential and account customers through fiber access lines and for operator customers it rents copper access lines (operator can also rent fiber access lines but it is uncommon due to high tariffs). Copper access lines are not removed even if sites and equipment are removed.

There are two different input scenarios for a techno-economic model. The first scenario is where there are both incumbent fiber access and incumbent copper access. Incumbent operator will dismantle copper access devices and change customers to fiber access. Incumbent operator is still obligated to lease copper lines to a competitor. Copper lines are used as long as tariffs of fiber access lines are relatively higher than tariffs of a copper access line. The second scenario is where there are incumbent copper access lines and competitors fiber access. Copper network is used as long as there are enough customers. Until this point copper access network is a cash cow for an operator.

As mentioned before, customer values connection reliability, price and fast enough data rate. Of course, compromises must be made between these features as reliable and fast service costs more. It is good to notice that the observed fastness of a connection is proportional to the purpose of use.

Copper access is able to offer up to 24 Mbps data rate subscriptions with ADSL2+ and up to 100 Mbps with VDSL2 if access cable is short enough. Note usually FTTB uses VDSL2 as a last mile connection technology. Fiber access can achieve up to 1 Gbps data rate if an in-house network is built with at least CAT5 cable. With older in-house network cables the maximum data rate is 100 Mbps. Urban area characteristics are defined in the Table 10 below. These values are estimated according to network area characteristics having more than 50 % of the households fibered.

Table 10 Characteristics of the area: urban

Average urban area	
Fibered households	1800
Total households	2700
Household density	2000

The Finnish state regulates prices of access subscriptions. An operator may not lease access lines with too high price and they are not allowed to decrease their customer prices below a certain level. Price regulation tries to maintain competition and make it easy to enter to market. Rival operator must attract customers either by better price or better service. However, to be able to cover the expenses a newly built fiber access cannot lower their prices too much. If there are two operators offering similar data rate subscriptions (with different technologies) one with a lower price would attract a price sensitive customer more. A technology oriented customer would choose more reliable and advanced technology over cheaper price. A customer could also make a decision according to marketing and possible brand loyalty.

5.4.5 Dense Urban area

Dense urban area consists of new construction houses where there have never been copper cables installed or areas where there are fibers installed by multiple different operators and copper access network is not used. In this area a copper access network is already useless. There is very keen competition in dense urban and there are usually at least three different operators competing of the customers. These areas consist of capital city center area and other very densely populated areas where there are both account customers and residential customers. City structure is tall apartment houses, shopping centers and office buildings. Note that there is a huge difference between installing an access line to a big apartment house and installing it to a row house or a small apartment house.

In city areas, installation of new cables is very expensive due to ground toppings such as cobblestone that is installed by hand. Customer tariffs are quite low due to high competition in the city areas. However, if there are enough customers investment will pay for itself with low tariffs as well. Copper access capacity is limited and it does not necessarily offer the most reliable connection. Fiber access is installed by multiple operators in these areas because of a number of paying customers and capacity requirements (to be competitive).

This area has already been dismantled from copper. Copper dismantling is assumed to spread from this area to less densely populated areas as the competition there increases due to migration that will further increase population of the denser areas.

5.5 Economic results

This section encompasses profitability calculations and competition between technologies and operators at different competition areas in this study. Economic comparison is made from operator's perspective which is impressed by customer satisfaction as well. Three different types of areas are being evaluated separately: urban, sub-urban and rural (it is assumed that there are no DSL lines in use in the dense urban and remote areas that were introduced before). All of these areas are assumed to define different life-cycles for copper access network.

5.5.1 Results rural

From a customer's perspective wireless mobile network (3G and in the future 4G) has begun to offer as good service (or even better) as copper access lines in rural areas. Wireless mobile broadband technologies have developed a lot, whereas copper access technologies are already deploying copper cable capacity at maximum. Rural areas lack of competition and operators are lazy to renew their networks there. Old copper access devices are in use (ADSL, max data rate 8 Mbps) and loop lengths are long (which could decrease data rate even below 1 Mbps) in rurally populated areas. Wireless mobile broadband popularity can be seen in the increase in wireless mobile broadband subscriptions (seen in the Figure 17 at section 5.3).

From an operator's point of view they are currently maintaining to overlapping broadband technologies; 3G and copper access. Maintenance cost per customer in a fixed network is quite high. People are living very sparsely; there are few customers per site and loop lengths are long. Cash flows of the scenarios in this area are calculated. It is examined if any cost savings are made in dismantling a copper access network in this area. Cash flow analysis is made for ten year time period with values defined before in the sections 5.3 and 5.4. Calculations are made for the area where copper access network maximum technical speed is below 8 Mbps and population density below 1.5 households/km^2 (which is the maximum radio capacity for 3G, links located in masts).

Results of the cost and revenue estimations of the two rural area scenarios are seen in the Figure 18. If evolution of costs and revenues continue as before, maintaining both mobile broadband and copper access networks would make minus sign profits in 2015. The result from the scenario of dismantling DSL network and maintaining only wireless 3G network shows that revenues are decreased but costs are decreased more than revenues. Cost savings are made if there is a whole DSLAM site emptied from fixed copper access customers. It is assumed that directed OA&M costs of copper access stay the same (assumed 55 % share of total OPEX). For an operator it would be profitable to dismantle DSL network in the 3G capable areas.

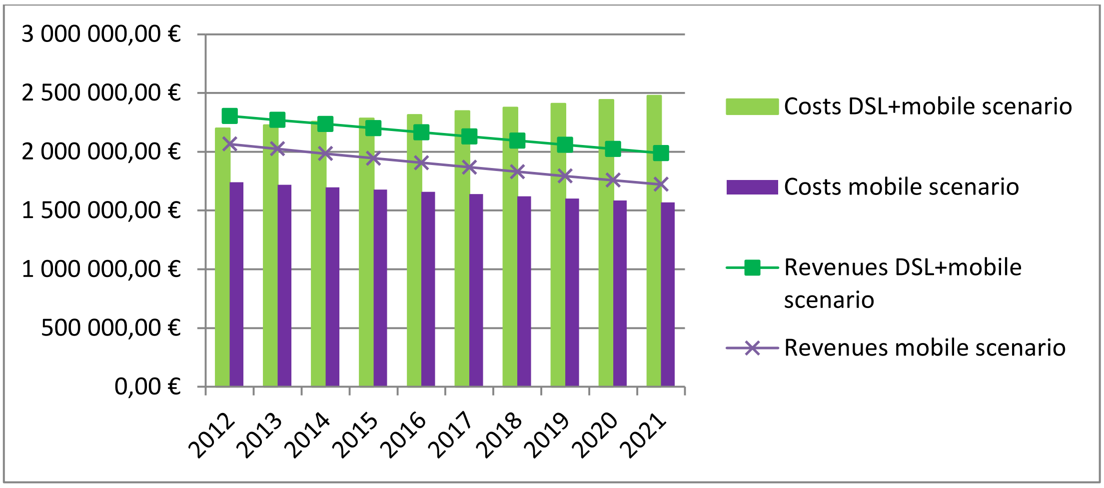

Figure 18 Rough cost and revenue curves for the rural area scenario

Areas where current maximum copper access line data rate is under 8 Mbps, 3G would be more attractive option for an average broadband user who value data rate and good price. If a customer would be forced to change from 24 Mbps DSL subscription to 3G, there is a great possibility for a disappointment even if price would be cheaper. However, DSL 24 Mbps subscription line is not always able to offer the maximum data rate as maximum data rate is defined according to computational loop length. Data rate could be less depending on type of a copper cable and an actual loop length.

5.5.2 Results sub-urban

From a customer's perspective fiber access would be better option over copper access due to its lower error rate and relatively higher data rates. However, a customer is not always willing to pay more for a fiber access or a greater data rate. If an operator makes fiber installations and changes their existing customers to fiber access, many are assumed to keep their old subscription type and few are assumed to pay a bit more for increased data rate. For a competitive operator fiber access installations could bring more customers and expensive leased lines could be canceled.

From operator's point of view a copper access maintenance costs and fiber access installation investment profitability are examined. With previously defined cost and revenue evolutions, copper access network profitability is decreasing and turning negative until years 2015 - 2016 at CLEC area and on 2017 in ILEC area. This is a pessimistic forecast as it is assumed that a number of copper access subscriptions and tariffs are linearly decreasing at a rate it decreased last year. Cash flow analysis for an average network area is shown in the Figure 19 below. Note that these evolutions do not take into account possible renewing of a copper access network which could slow down a cost of failures.

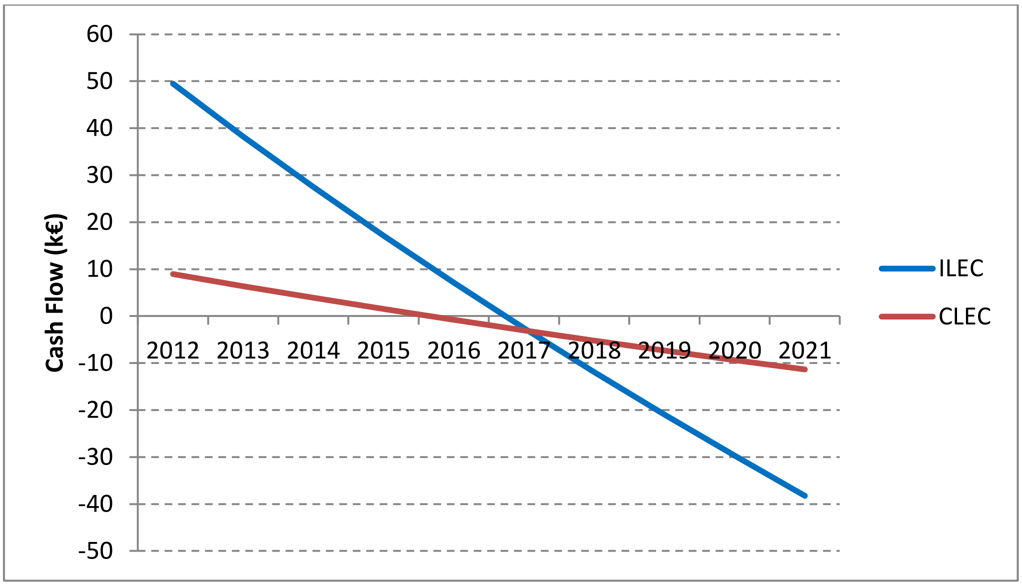

Figure 19 DSL cash flow analysis for CLEC and ILEC operators in sub-urban area

Profitability of fiber installation investment for an average network area is shown in the Figure 20. Cost of an investment plays a crucial role in the investment profitability. As mentioned before, installation meters are setting the cost per household. With an initial value of 10 meters per household NPV would be negative and IRR is below the discount rate used in the calculations. The same profitability analysis is accurate for both ILEC and CLEC. Payback period would be 6 to 7 years. Sensitivity analysis in the section 5.6 shows when a fiber installation is profitable. In the sensitivity analysis also a probability of investment profitability is examined as some values used in this calculation are not definite and can vary a lot between different types of network areas.

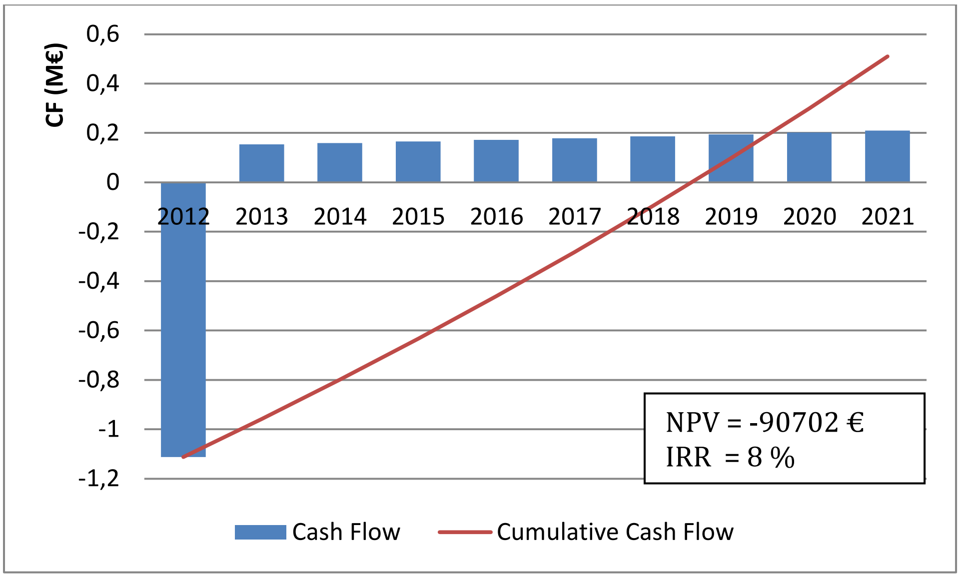

Figure 20 Yearly cash flow and cumulative cash flow of operator fiber access investment per network area

In addition to previously made cash flow analysis, a decision of new access technology installations is affected by competitive technologies as well. Operators want to make sure the penetration rate is big enough compared to investment. If an incumbent operator offers 100 Mbps subscriptions, it is harder to enter to the market with a same type of a product. Similar situation is faced when a competitor has already installed fiber access lines and incumbent operator must decide whether to roll out fiber in the area or not.

5.5.3 Results urban

Customers are expected to change their broadband subscriptions to a faster connection as demand for bigger data rates increase. The project of Finnish Ministry of Transport and Communications where in range of two kilometers 100 Mbps connection is offered for everyone in Finland by 2015 (by Ministry of Transport and Communications) could give an impact on demand of higher bit rates. Even if the project would not succeed in time, it endorses higher data rates. It could be assumed that 24 Mbps copper access loses for 100 Mbps fiber access after 2015. Overall churn in copper access subscriptions in Finland was 4 % last year. In fibered areas the churn rate may be greater as customers have a possibility for an alternative broadband technology. To be able to change from copper access, alternative must be available.

Customers value different features of broadband more than others. Value of data rate for a customer must be recognized to be able to define a maximum possible price that a customer is ready to pay. Of course prices depend on competition and regulation, but price difference in relation to data rate difference is also important in pricing. Current prices per data rate unit for different types of access speeds are shown in the (Figure 21). It can be seen that a price per unit decrease when there is more data rate available. Changing from 10 to 24 Mbps subscriptions, there is 1.4 times more data rate available and price is halved per unit. Similarly from 24 to 100 Mbps subscriptions, data rate is four times greater and price is one third per unit. These prices can be assumed to be set by an operator according to how much customer value data rate in comparison to price. Similar kind of marketing is made in sales when offering two products for the price of one.

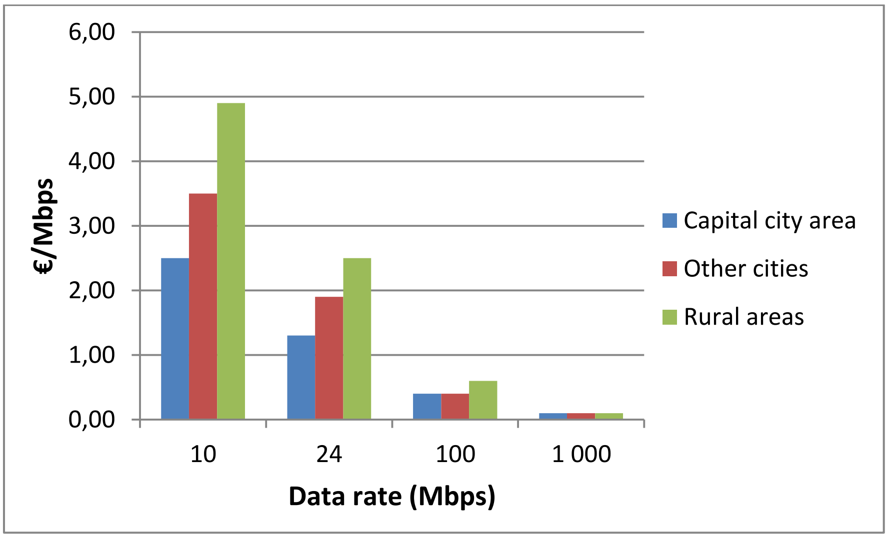

Figure 21 Illustration of prices per unit (Mbps) at different types of subscriptions and geographical areas

Now this comparison is used in the capital city area on competition between two technologies (and also competition between two operators as well). Let's assume there are fiber access maximum data rate of 100 Mbps and DSL access maximum data rate of 24 Mbps with prices that are presented in the Table 5 (in section 5.3) and Figure 21. In addition to quality features, there are three main variables that a customer compare when choosing a subscription type:

1. 24 Mbps – 100 Mbps
2. 30 €/month – 40 €/month
3. 1.3 €/Mbps – 0.4 €/Mbps.

From an operator's perspective copper access network is profitable if number of customers per station and tariffs are balanced. Following figure (Figure 22) illustrates variable costs and revenues per user per year with cost and price evolutions defined before. Cost per customer crosses revenues per customer between 2016 and 2017. In the densely populated urban areas price is most probably lower than list prices as competition is harder. This figure illustrates only costs and revenues evolutions but gives a clue of how long copper access lines can be maintained as cash cows in parallel with fiber access.

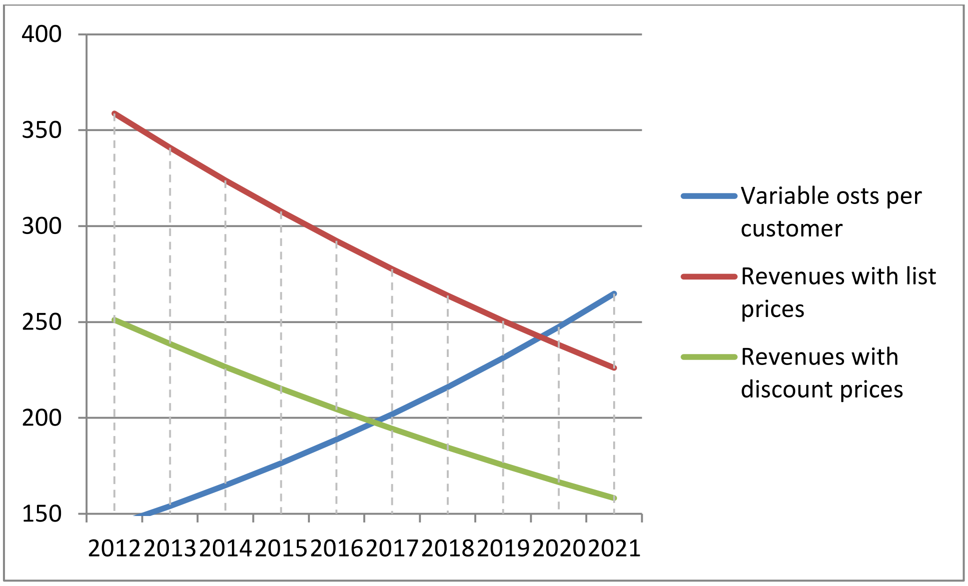

Figure 22 Costs and revenues per customer per year

An important perspective of the competition between fiber access and copper access is a number of customers. If there are no investments required in copper access network, it still brings revenues as long as there are enough customers. Also copper network operator is able to keep prices low. Copper access is able to compete with fiber access data rates in short distances (below 300 meters).

5.6 Sensitivity and risk analyses

To be able to take into account possible uncertainties in profitability calculations in this study and also define the most critical parameters, sensitivity analysis is performed. Sensitivity analysis is made only for rural and sub-urban areas because only at these areas profitability calculations were made. Urban area profitability was inspected only verbally and affecting factors were recognized.

5.6.1 Rural

Rural area results are rather approximates and the main results are definitions of types of areas where mobile broadband would be capable to offer broadband, sensitivity analysis was already made for the radio capacity calculations as multiple monthly data transmission values and ISD values were examined. Illustration of the wireless broadband capable area sensitivity to monthly data and technology is shown in the Figure 23. Bigger household density means a greater geographical area. Use of 4G would double the radio capacity compared to 3G meaning that there would be more wireless broadband capable network areas. Also the actual received capacity would be increased.

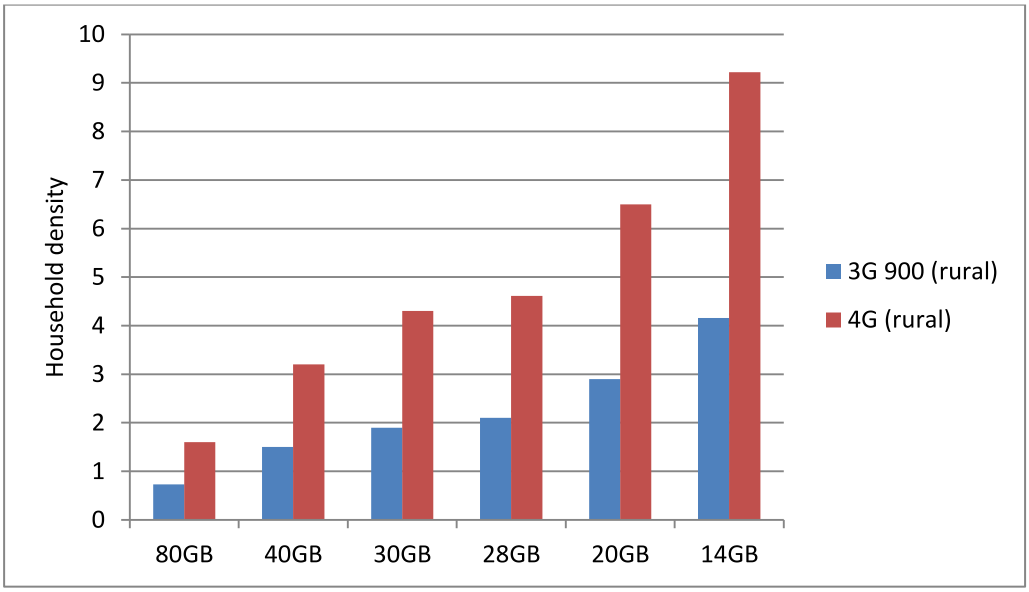

Figure 23 Radio capacity sensitivity to data traffic and used technology

5.6.2 Sub-urban

Results for fiber access investment profitability were negative which indicates that copper access would have a living space in sub-urban area. However, the fiber installation meters were estimated according to supposed value per household. Sensitivity analysis defines a limit value for a fiber installation meters per household and will set a critical factor. After defining these values, it is possible to define an area where fiber access installation is profitable and therefore copper access living space is narrowed. After sensitivity analysis, risk analysis is performed. Risk analysis returns a risk probability of an investment.

According to the background information gathered in the previous sections, the most uncertain values are installation meters per household, number of customers and ARPU. Installation meters are hard to predefine as it varies hugely between areas and depend on a location of already existing fiber and sites. This variable can be used as a coefficient in defining the cost of a fiber installation investment. Number of customers is dependent on marketing, competition and brand popularity which both are hard to predict forehand. ARPU value changes along competition and markets which are also quite unpredictable and dependent on multiple different factors. Note that ARPU is stable at the non-rival areas (i.e. rurally populated areas).

Sensitivity analysis is made by shifting the uncertain variables from the most probable value (most probable values were used in the profitability calculations in section 5.5.2). All the variables were shifted with a deviation of 50 %. Affection on NPV was examined. The result can be seen in the Figure 24.

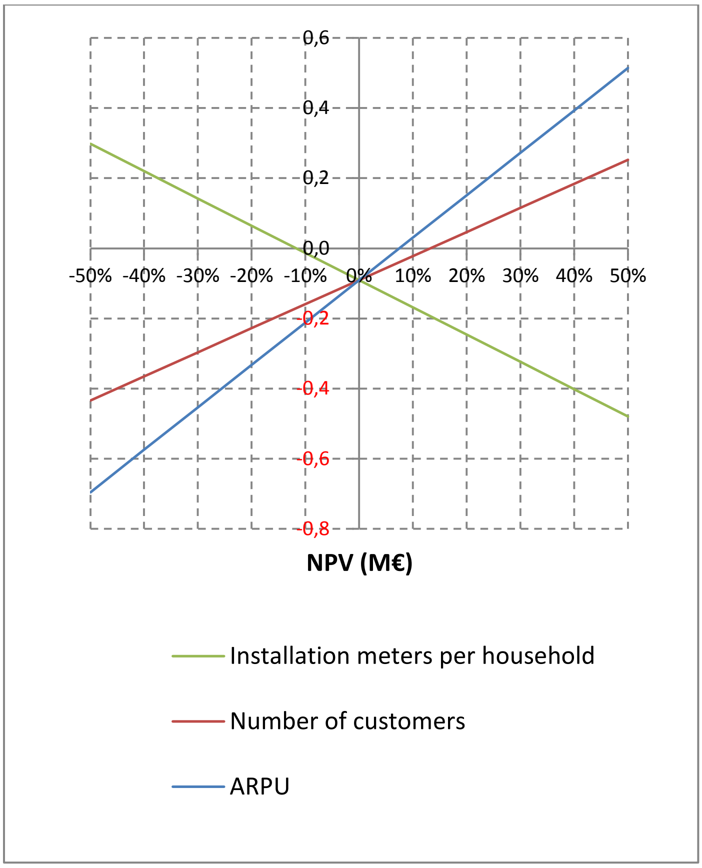

Figure 24 NPV sensitivity to installation meters, number of customers and ARPU

NPV sensitivity to fiber access installation meters per household is quite similar to its sensitivity to number of customers. ARPU seems to have the biggest impact on profitability of fiber deployments. ARPU would be thereby considered as a risk factor. The most important variable that would help in defining copper network life-cycle is the required meters of installation per household. If installation meters are below eight meters (deviation -20 %) and other variables stay the same, an investment seems to be profitable. NPV is above zero ~65 000 € and IRR greater than used discount rate: 12 % > 10 %. Payback period is 5 to 6 years.

Next, risk analysis for fiber investment profitability is performed with Monte Carlo simulation. In the risk analysis, same uncertain factors are used and varied randomly along suitable probability functions and inside defined deviation levels. Risk analysis is performed to see affection of different uncertain input value combinations i.e. the risk level of an investment that takes into account future uncertainties. Mean values and deviations that are used in the Monte Carlo simulation are presented in Table 11.

Table 11 Parameter values used in the Monte Carlo simulation

Parameter	Mean	Deviation
Installation meters per household	10	50 %
Number of customers (of total HH)	400	40 %
ARPU	30.31	33 %

For each variable a normal distribution function is used. For variables: Installation meters and ARPU, the most suitable distribution function would be triangular distribution as an approximate minimum and maximum values are known and the mean values are assumed to be quite stable. As mentioned before, triangular distribution is hard to realize in Excel® with freeware add-ons. Therefore, for all of these variables normal distribution is used with the deviations according to Table 11. There were random 3000 samples taken within the given limits and the results are shown in the Figure 25.

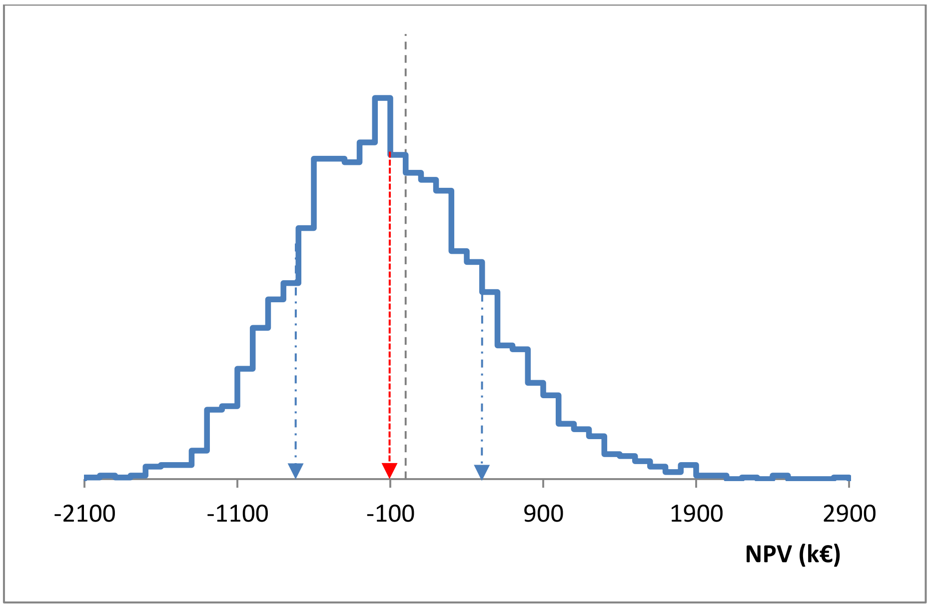

Figure 25 Monte Carlo simulation 1

Summary Statistics	
Average value	-92.3 k€
Standard deviation	629.2 k€
Percentage positive	39 %
Best case scenario	2.8 M€
Worst case scenario	-2.0 M€

The height of an indicator represents a relational probability of NPV value that is defined by the x-axis. Dashed line in the middle of the graph represents NPV value of zero. Average NPV from all of 3000 simulations is negative -92.3 k€. Mean value is slightly below the most probable value that was calculated in section 5.5.2 (-90.7 k€). Standard deviation limits are shown as dash dot arrows in the chart (Figure 25). Dashed arrow in the middle indicates the mean NPV value. As seen in this figure, a possibility that a fiber access installation in this type of a network area would be profitable seems to be about 39 %. This means that the risk probability is 61 %.

Let's see how risk probability change if we lock meters per installation to be exactly 8 meters per household (which is the value that brought positive NPV in the sensitivity analysis performed before). Other variables stay the same with also the deviations defined before in Table 11. Locking the installation meters means that there are no installations made in houses that would require more than eight meters of fiber installation. NPV with average values and installation meter value of eight was 64.7 k€ and IRR was 12 %. Results for Monte Carlo simulation are shown in Figure 26.

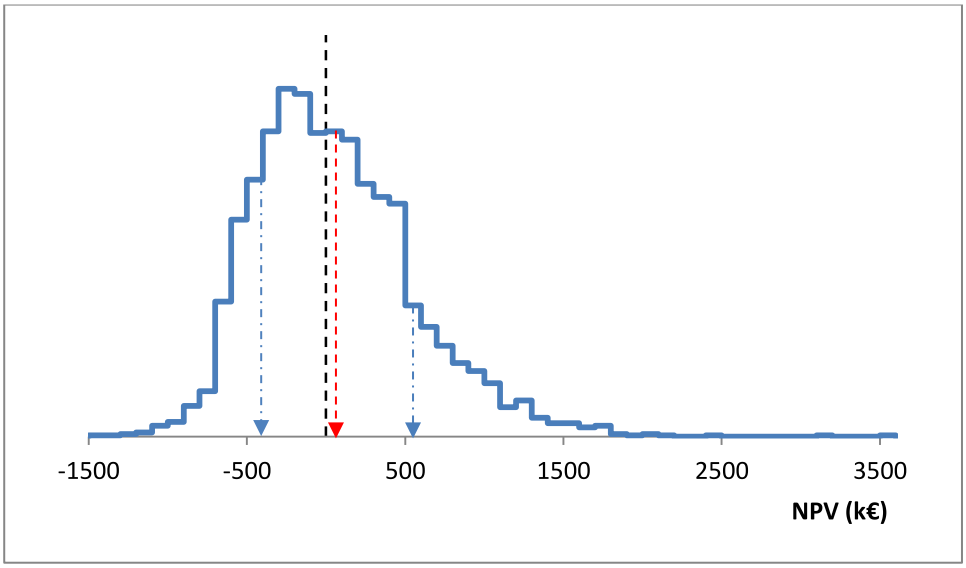

Figure 26 Monte Carlo simulation 2

Summary Statistics	
Average value	56.7 k€
Standard deviation	508.6 k€
Percentage positive	49 %
Best case scenario	3.5 M€
Worst case scenario	-1.4 M€

Monte Carlo simulation shows that the average NPV value is quite much less than calculated with the most probable values (56.7 k€ vs. 64.7 k€) but it is still positive. Risk probability is 51 %. Standard deviation got smaller than in the previous simulation where three variables were deviated. It can be seen that basic cash flow analysis gives a little bit too optimal results, when the Monte Carlo simulation average value is affected by uncertainty factors and is more reliable. Future costs and revenues are hard to predict.

6 Conclusions

6.1 Results and discussion

The purpose of this thesis was to examine life-cycle of copper access network from economic perspective but inside the frames of copper access technological capabilities compared to competing technologies. The main research questions were that "How can life-cycle of copper broadband access network in Finland be defined with techno-economic modeling?" and "What is the life-cycle according to the model?" Background information was gathered to be able to understand the factors that influence to copper network existence. Technological and economic factors in broadband business were examined as well as techno-economic modeling as a method was defined.

Literature review and interviews concentrated on gathering information about different broadband access technologies in use in Finland and their capabilities. In addition to copper access network technologies, other fixed broadband technologies introduced were optical fiber and coaxial cable broadband. Introduced wireless broadband networks were Universal Mobile Telecommunication System (UMTS), Long Term Evolution (LTE), @450 network and satellite broadband. Differences between fixed and wireless broadband technologies were clearly brought out. Chapter of broadband business encompassed the nature of telecommunications trading. Also, broadband business in Finland including business areas and the main players in the field of broadband business were presented.

Based on the background information there were five different types of broadband access network domains recognized. In three of them there were copper access network remaining. It was possible to define a competition scenario for each area. Competition scenarios differ between areas depending on a number of potential customers, currently offered broadband access capabilities, competition and regulations. At each area an operator's current broadband technology is copper access. At each area following scenarios were weighted:

1. Continue with copper access
2. Change copper to wireless broadband access
3. Install fiber access to replace copper
4. Rent competitor's fiber access to replace copper

Three examined areas were named as rural, sub-urban and urban. Radio capacities with different link station characteristics and different expected monthly data transmission values were calculated for UMTS (3G) and LTE (4G) (capacities shown in the Table 3). Radio capacity appointed rural areas by their average population density. Existence of fiber access network defined urban area, and sub-urban area was the area in between rural and urban. Evolution of number of customers, customer tariffs and maintenance costs were predicted according to previous year's information.

In the rural area copper access network could be replaced with wireless broadband if maximum data rate of the replaced copper access network is below wireless broadband actual data rate. Dismantling a copper access network brings cost savings if a DSLAM site is completely emptied from customers. Existing 3G network could replace 8 Mbps copper access network in areas which household density is below 1.5 hh/km^2. Future 4G network could replace 24 Mbps copper access network in areas which household density is below 3.2 hh/km^2.

In the sub-urban area fiber access installations could lower the use of copper access network and finally completely replace it. Fiber access installations in an average sub-urban area are profitable if installation meters per household stay below 8 m (40% penetration rate is assumed). Fiber access installations are more profitable in an apartment building than in a detached house. Investment risk was examined with Monte Carlo simulation which result a risk probability of 61 % varying all three uncertain factors and 51 % with fixed installation meters and varying remaining two uncertain factors.

In the urban area copper access network life-cycle is dependent on a number of customers using it. There were two copper-fiber competition situations recognized. If an incumbent operator owns both transmission mediums, copper access lines are mainly used for operator customer business operations. If a competitive operator owns fiber access, an incumbent operator maintains copper lines as cash cows. Copper network (VDSL2) is able to compete with fiber access at short loop lengths and lower prices.

As a result, this study examined a copper broadband access network life-cycle and created a techno-economic model for it. Living space of copper access network is at the area where household density is greater to wireless broadband radio capacity and where installation meters per household is greater than 8 m. This living space is narrowed from both directions. From rurally populated areas as wireless broadband technologies develop e.g. 4G is deployed at larger surface area. From densely populated areas as core fibers move closer to customers and as fixed line installation techniques develop e.g. micro trenching. Micro trenching would decrease digging costs and allow fiber installations for longer distances. Exact profitability calculations should be made for each network area separately to gain more precise results. This study gives a basic idea of how copper access network life-cycle would move closer to the end of its life and how new technologies could replace copper lines.

6.2 Assessment of the results

Profitability calculations were made with averages according to characteristics of a network area. Currently most probable average values were used in the calculations. Thus, in real life every network area must be separately examined with the model created in this study. Every network area differs at least from their infrastructure and household densities.

Common evolutions used in ten years study period would most probably be non-linear, affected by external factors such as marketing and state regulation. However to simplify the model and to avoid giving too optimistic result, linear evolutions were used. Deviations used in the Monte Carlo simulation were hard to define and it was the most important phase in construction of the simulation. Deviations for number of customers and ARPU's were realistic and based on real information. Also, chosen distribution functions were not able to be used and therefore normal distribution was used for all of the uncertain values instead of triangular distribution function. This effects on the risk factor negatively.

6.3 Future research

In this study, profitability of replacing copper access lines with wireless broadband were made assuming that no investments were required in wireless broadband network. However, 4G network is not yet deployed for rural areas. It will require investments in the future. Investment profitability could be calculated for 4G 800 MHz installations. Cost of installation would be directed to mobility service business and broadband business. Investment cost would then be compared to cost savings gained from dismantling a copper access network.

WLAN brings wireless indoors which also other Wireless Wide Area Networks (WWAN) can offer if reception is good enough. Security in wireless mobile networks, such as 4G and 3G, is better than security in WLAN. WLAN transmission happens in is so called free frequency band (2.4 GHz). Traffic at those frequencies is easily disrupted by other WLANs and signals. Mobility is possibly an important feature for a user in the future, as it is already begun to be when WLANs have gotten more popular. There are multiple wireless devices connected to Internet nowadays. Capability comparison between WLAN and wireless mobile broadband network should be examined. Advantages of 3G and 4G compared to WLAN would be that user can travel outside from home and still be connected to the same network, there would be no need to pay for two different types of connections to be always connected (indoors and outdoors) and it is more energy efficient to have only one active device receiving a signal than having a wireless modulator and a receiver. Future research should be made of 3G/4G and WLAN competitiveness as it clearly effects on the popularity in the future.

Problems have been met with new energy saving insulation regulations of new construction houses. Selective glass windows prevents radio signal to pass through it. Thick walls and energy efficient insulation of new houses are attenuating WWAN (e.g. 3G and 4G) indoors. Then only option for wireless broadband connection indoors seems to be WLAN. Selective glass blocks also wireless speech signal which is transferred through 2G or 3G. A possibility of WLAN solving this problem should be examined. Possible solutions could include repeaters or fixed line solutions.

Energy efficiency and environmental issues are a hot topic nowadays. There are regulations set by European Union about telecommunications energy consumption per subscription. Newer equipment is built to consume less energy. Energy consumption regulation affection on the used broadband access technologies and on network renewals should be studied.

Possible households that rest inside the boundaries of “maximum of eight meters of installation per household” should be recognized. These households are recognized in the micro planning of broadband access network. Each area should be examined separately and identify their potentially to be profitable areas to invest in fiber access. In addition to the profitability calculations, also existing competitive network should be considered as a parameter when deciding whether to deploy new technology or not. Competitive network effects on the deployment rate of a new network.

Profitability of possible co-operation could be examined as an option in denser network areas. Co-operation already exists with the electricity distributors and somewhat with competitive operators as well. Fiber installation together with a competitor decreases costs but makes competition much harder. Furthermore, customer involvement in fiber access lines installation costs should be inspected and calculated. Currently customers do not pay for rollouts. Price limit that a customer is ready to pay and price limit that would tempt operators to build, should be examined.

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