Stadia
HELSINKI POLYTECHNIC

FACULTY OF TECHNOLOGY

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FINAL PROJECT

FEASIBILITY OF REPLACING MULTIPLE ADSL CONNECTIONS WITH MULTI-DWELLING ACCESS

Author: Jussi Torkko
Supervisor: Seppo Lehtimäki
Instructor: Kirsi Kekki

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Seppo Lehtimäki
Senior Lecturer

STADIA
HELSINKI POLYTECHNIC

PREFACE

This final project was made for the Broadband/Implementation department of TeliaSonera Finland. At the start this project was hard to imagine as written on the paper. The subject itself is so case sensitive that it seemed impossible to find a overall solution that would give even a guide to network optimization work at TeliaSonera. After several conversations with colleges at TeliaSonera the right view for the solution started to shape up.

I would like to thank all my colleagues who have shared their thoughts with me and especially Ms. Kirsi Kekki who instructed me on this project. My sincere thanks go to Mr. Seppo Lehtimäki who supervised this project and Mrs. Marjatta Huhta who helped me with the language.

Special thanks go to my family that had to make concessions to help me find more time to finish this project. Thank you, I doubt that I would have made it without your help.

I learned a lot presenting TeliaSoneras Network and functions of it, whereas many interesting details and device manufacturers and models had to stay confidential.

Helsinki 11 April 2007

Jussi Torkko

INSINÖÖRITYÖN TIIVISTELMÄ

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Työn valvoja: Lehtori Seppo Lehtimäki Työn ohjaaja: Aluepäällikkö Kirsi Kekki	

Tämä lopputyö on tehty TeliaSonera Finlandin Broadband yksikön verkkosuunnittelu osastolle. Kysymys johon tämä projekti on antanut yhden ratkaisuehdotuksen on seuraava. Milloin TeliaSoneran tulisi korvata useampi samaan ositteeseen vuokrajohtimilla toteutettua ADSL liittymää kiinteistöliittymällä, joka puolestaan perustuu Ethernet/kuitu tekniikkaan keräilyverkossa.

Projekti alkaa lähiverkon tekniikkaa kuvailemalla ja esittelee TeliaSoneran keräilyverkossa käyttämiä teknologioita. Seuraavana vaiheena rajataan ja määritellään ongelma joka on ilmennyt osassa TeliaSoneran ADSL toteutuksissa. Tämä ongelma on vuokrajohtimien käyttö, joka saattaa maksaa yhtäpaljon TeliaSoneralle vuosien mittaan kuin verkon laajentamiseen investointi, jos vuokrajohtimia on useampia samaan kohteeseen.

Tämän projektin ehdotus ratkaisuksi on kiinteistöliittymän käyttö, sekä määrittely millaisessa tilanteessa se on järkevää. Kun tyydyttävä ratkaisu on löydetty on katsottava kuinka tämän yleinen soveltaminen vaikuttaa verkon rakenteeseen. Tämä vaikutuksen tarkastelu johtaa toiseen ongelmaan, lisääntyvien optisten kuitukaapelien ruuhkautuminen keräilyverkon liitäntäpisteellä. Viimeiseksi tämä projekti ehdottaa myös EPON-tekniikan käyttämistä kiinteistöliittymien runkoyhteyksien liittämiseksi verkkoon.

Avainsanat: ADSL, Ethernet, Access network, Multi-Dwelling, EPON, MPLS

STADIA HELSINKI POLYTECHNIC

ABSTRACT

Name: Jussi Torkko	
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Instructor: Seppo Lehtimäki, Senior Lecturer Supervisor: Kirsi Kekki, Area Manager	

This final project was made for the Broadband/Implementation department of TeliaSonera Finland. The question to be examined is if the operator should replace multiple ADSL connections implemented over a leased line with Multi-Dwelling access based on an Ethernet/Optical Fibre access network.

The project starts with describing the technology related to these access network solutions and presents the technology that is used in TeliaSonera Finland's access network. It continues from the technology to describe the problem with some of the ADSL implementations of TeliaSonera. The problem is the implementations done over a leased line that can cost TeliaSonera over years as much as a possible investment to extend network when there is several lines leased to the same building.

The project proposes a Multi-Dwelling access as a solution to this problem and defines the circumstances when to use it. After a satisfactory solution has found the project takes a view how implementation of the solution might alter the network and a new problem is found. When used commonly to replace need of ADSL implementation Multi-Dwelling access would significantly increase optical cable congestion near operators POP. As a final deed this project also proposes a technical change to existing way to implement multi-dwelling access with EPON technology.

Keywords: ADSL, Ethernet, Access network, Multi-Dwelling, EPON, MPLS

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ABBREVIATIONS

AAL	ATM Adaptation Layer
ADSL	Asynchronous Digital Subscriber Line
ATM	Asynchronous Transfer Mode
CoS	Class of Service
CP	Customer Premises
CPE	Customer Premises Equipment
CPU	Central Processing Unit
CSMA/CD	Carrier Sense Multiple Access / Collision Detection
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
EFM	Ethernet over the First Mile
EPON	Ethernet Passive Optical Network
FSC	Frame Check Sum
GW	Gateway
IEEE	Institute of Electrical and Electronics Engineering
IP	Intrnet Protocol
ISP	Internet Service Provider
LAN	Local Area Network
MAC	Media Access Control
ME	Metro Ethernet
MPLS	Multiprotocol Label Switching
MPMC	MultiPoint MAC
NIC	Network Interface Card
NNI	Network-Network Interface
OLT	Optical Line Terminal
ONU	Optical Network User
OSI	Open System Interconnection
PC	Personal Computer
PE	Providers Edge
POP	Point of Presence
POTS	Plain Old Telephony System
TCP	Transmission Control Protocol
TDM	Time Division Multiplexing
UNI	User-Network Interface
WAN	Wide Area Network
VC	Virtual Circuit
VCI	Virtual Circuit Identifier
VLAN	Virtual Local Area Network
VoIP	Voice over IP
VPI	Virtual Path Identifier
VPLS	Virtual Privalte LAN Service

1 INTRODUCTION

The subject of this project came from another project at TeliaSonera Finland, where they moved the location of one of their Point of Presences (POP) in Helsinki. At the end of the year 2006 TeliaSonera Finland started planning to move the location of one of its POP in Helsinki city area. When a location of a POP is moved, all the network connections have to be rebuilt. During this rebuilding it is reasonable to optimize also the network for the current and future use.

Building the network is an investment for the operator. It has to meet the current needs and provide some future value. The current need is clear but the future value is always a bargain. The latest technology is very expensive and the true futures needs are impossible to predict. The media used in communication networks is mainly optical fibre but copper cables are still used in access networks with for example the ADSL technology.

As a part of this rebuilding of operator's POP connections to network and optimizing the used technology, one of the many questions was, whether the current ADSL connections at the POP area should be rebuilt with copper wiring or to be replaced with optical fibre and a Multi-Dwelling access. The question became the research question for this project.

Rebuilding the ADSL connections with copper would be an easy and cheap solution, but it would likely serve only this purpose. Most of the copper line connections would be probably rented from other operator, this way expensive building of the physical network is avoided. A part of the ADSL connections provided by TeliaSonera in the Helsinki area are implemented by renting a copper line connection from one their rival. Some years ago there have not been any other ways to solve this problem, but today when need for bigger bandwidth is constantly increasing the TeliaSonera is starting to have another option for this problem. TeliaSoneras optical fibre network has very good coverage of Helsinki in. The optical network is mainly used for business connections that have relatively bigger demands for bandwidth and capacity. To solve problem of rented copper pairs TeliaSonera could build an optical connection to buildings where ADSL subscribers are located and replacing ADSL with Multi-Dwelling access. This would be very expensive but would also have more value. Multi-Dwelling access would provide ready connectivity for whole building and would make faster connections possible for all inhabitants. This solution is in use already and functional, but it is not in common use as a method to optimize network. The research question that this project seeks to solve is “When it is reasonable to replace multiple ADSL connections in a one building with a Multi-Dwelling access built on an optical network”. This question will be solved by comparing the two products, the ADSL and the Multi-Dwelling access, by their benefits and implementing costs. Method used to solve the question is paper research, based on written public and TeliaSoneras internal material.

As a result of this project a proposal for the TeliaSonera Network Implementation department will be provided. It will define in which cases it is more reasonable to invest in a Multi-Dwelling access solution. The proposal will be delimited to the Helsinki and to the capital area of Finland.

2 PROTOCOLS AND TECHNOLOGY CONNECTING US OVER THE NETWORK

This project is focused on two very common network access technologies and comparing them to each other. To be able to understand their differences one must first have an overall knowledge of how networks work. This section will briefly cover technologies related to this project. The purpose here is to give the reader a background of this project.

2.1 The OSI Reference Model

A connection to a network may sound like a simple procedure but it is a complex sum of several processes. Because of this complexity it is common to divide the whole process into layers to explain it more precisely. There are two layer models used to describe network processes, The Open System Interconnection (OSI) model and the Transmission Control Protocol / Internet Protocol (TCP/IP) model.

The OSI reference model was released in 1984 to give network technology manufacturers a set of rules for greater compatibility and interoperability. Today the OSI model is the most referenced networking model, especially in educational use. It is a seven layer model that is used to divide network communication into layers and to describe how information is exchanged. Picture 1 illustrates the OSI reference model.

Picture 1: The OSI reference model

The main idea is that a lower layer provides its services to the upper ones. The first layer is the physical connection between two points. It relates to binary transmissions, media, connectors and data rates. The data link layer is access to media and direct link control. This provides reliable transfer across the media and connectivity between two systems. The network layer provides addressing and best path determination by reliable transfer across media and path selection between two host systems. End- to end connections are made in the transport layer. The transport layer is concerned with transportation issues between host systems, such as reliability of the connection. The 4th layer also establishes, maintains and terminates virtual circuits and is responsible of fault detection and recovery information flow. The Session layer takes care of interhost communication. It establishes, maintains and terminates sessions between applications. The presentation layer ensures that the data is readable by receiving system, data structure and format of the data. It also negotiates data transfer for application layer. The application layer provides network services to applications and processes. [1]

The OSI model is only a one view to model functionality of the communication network entity. Other common reference model that simplifies upper layer functions that are handled by software is TCP/IP model.

2.2 The TCP/IP Reference Model

The Transmission Control Protocol/Internet Protocol (TCP/IP) model is the historical and technical standard for the internet. Although the TCP/IP model has similar layers with the OSI model, they do not correspond to each other. The model structures the connections as follows.

Picture 2: The TCP/IP reference model

The TCP/IP models application layer handles representation, encoding and dialog control. This corresponds to the OSI models application, presentation and session layers. The Transport layer takes care of quality of service issues, reliability, flow control and error correction. One of the functions of the transport layer is also to pack application layer data to segments. The data segments are divided into smaller packets at the internet layer to be transferred over the network. When multiple routes to destination exist, the best path selection happens on this layer. The network access layer concerns to all logical and physical elements needed to make a physical link. It corresponds to the OSI models first two layers, physical and data link. [2]

The most important differences between these two models are that the OSI model is protocol-independent and the TCP/IP defines the protocols to use. Both are used in the industry but the OSI is more often used in teaching because of its protocol free and more detailed structure.

The name for TCP/IP reference model comes evidently from the TCP/IP protocols but the reference model and the independent TCP/IP protocols are their own entities. In the following this project will cover these two protocols in more detail.

2.3 TCP/IP

TCP/IP consists of two independent protocols, TCP and IP. Both protocols have their own functions, but together these provide connections between hosts over the network. These protocols are defined in TCP/IP reference model to be used in communication over internet, but are also independent standardised protocols.

The Transmission Control Protocol (TCP) creates bidirectional logical transfer path between two hosts and ensures successful exchange of data. TCP uses three way handshake to establish connection between hosts. Host A sends synchronisation information that host B needs to reply with an acknowledgement and send its own synchronisation that host A need to acknowledge. This prepares both hosts for data transfer and makes sure that they are aware of it. IP networks do not provide reliable transferring of data. There can be delays in packet transfers or the packet transferring order can differ from receiving. In the worst case packets can be lost. TCP provides sliding windowing and flow control to adapt to these problems. TCP numbers the data pieces to send and keeps account of them. Receiving host sends acknowledge for every received data and information how much more it could receive or if there is need to slow down the transfer rate. Both hosts keep table of data pieces where they mark received data, data that is currently being transferred and data that is waiting for transfer. A "window" marks the numbers of data that is being transferred. When data transfer acknowledge is received the window slides forward the table. The window size depend receivers and networks capabilities. If data is not acknowledged in time it is re sent. The other host can also ask for re sending of data if data is corrupted. TCP provides also piggybacking-method that enables sending acknowledgements and other flow control information inside data segments.

The Internet Protocol (IP) is an unreliable connectionless network service. The goal of the IP is to make a virtual network that connects several private and public networks together. IP provides ways to identify active network elements and determine paths over the network. The identifying of active elements is done by IP-addressing. IP-address is a 32 digit binary number that is usually presented in dotted-decimal notation. When device connects to the network it must be assigned an IP address before it can start communicating with others. IP-Routing and switching from device to device is done according to IP-address. IP packs upper layer data into IP packets, which contains a data part and a header. The header contains the destination and source information. [3]

TCP/IP protocols work up at the layer 4 of the OSI model and need lower layer services to establish the physical connectivity to the network. Ethernet is the most popular technology used to create the network connectivity. It operates from lower part of layer 3 down to the layer 1 of the OSI model.

2.4 Ethernet

The Ethernet is the most common Local Area Network (LAN) technology that is used, mainly because it is defined in the TCP/IP reference model as one of the access technologies in physical layer to be used. Today Ethernet is also gaining respect as a carrier network technology. Ethernet as an access technology to operator network is in this project's focus and therefore it is covered in more depth than some other technology.

The first Ethernet standard was released in the 1980 by a consortium of Digital Equipment Company, Intel and Xerox (DIX). It introduced multiple user access to a single connecting media. Later in the 1985 the Institute of

Electrical and Electronics Engineering (IEEE) released their standard 802.3 that was based on the Ethernet standard. IEEE 802.3 standard was developed to make Ethernet compatible with International Standardisations Organization and OSI model. To achieve its goals 802.3 had to change few details of the original Ethernet standard.

To uniquely identify computers and interfaces in the network Ethernet uses Media Access Control (MAC) addresses. MAC address is 48 bits long and contain manufacturer and interface serial number. MAC address of a computer is burned on Network Interface Cards (NIC) read only memory and can not be changed. At the data link layer the MAC headers and trailers are attached to upper layer data. These MAC headers and trailers contain control information for the destination system. The NIC determines according to the MAC address of a packet whether it should pass received information to upper layers of OSI model. The decision process does not take resources from the computer itself, CPU is only needed when the received data is addressed to its system. Every computer in Ethernet LAN must examine MAC header when received.

At the data link layer Ethernet uses identical framing structure regardless for speed of the interface. In the physical layer where the frames and data are modulated for transmission there are a lot of differences between different interface speeds. Picture 3 shows the Ethernet frame structure.

Preamble	Destination	Source	Length	Data ⋮ Pad	FCS
8	6	6	2	46 to 1500	4

Picture 3: The Ethernet frame structure

In the Ethernet frame the preamble is for time synchronisation that is needed in 10 Mbps implementations which are not synchronous. Faster implementations than 10 Mbps are synchronous and do not need this. The destination address can be unicast (to one), multicast (to many) or broadcast (to all). The Source field contains source MAC address. The length field tells how many bytes of data is followed after this field. The data field in Ethernet frame must be between 46 and 1500 bytes, if less, padding is used to fill 46 bytes. Frame Check Sequence (FSC) is used to identify damaged or bad frames. If the FSC does not match the frame is discarded. [4]

For actual communication technique Ethernet uses Carrier Sense Multiple Access / Collision Detection (CSMA/CD). The NIC listens to connective media and if no transmission is sensed it is free to start transmitting if needed. Because only one media connects multiple users collisions of two transmissions on the line is quite likely. In collision the signals are mixed and result in higher amplitudes than signalling what makes it possible for NICs to sense it. When a NIC senses a collision it will have to start so called back-off algorithm. During the back-off NIC will have to stop transmitting and wait for random period of time decided by the algorithm. [5]

There are four standardised interface operating speeds for Ethernet, 10 Mbps, 100 Mbps, 1Gbps and 10Gbps. Ethernet uses shielded and unshielded twisted pair copper cables or optical fibres as its connecting media, depending on interfaces in use. One of Ethernet's many benefits is that all interfaces are compatible with each other. This makes it very easy to extend the old network without upgrading the whole network. Ethernet is also a part of the TCP/IP standard and therefore it is widely spread in many forms all over the world.

Most of our computers at home use Ethernet technology to access the internet. But this does not mean that Ethernet technology is used to connect to Internet Service Providers (ISP) network. In case of a block of flats, there are usually no Ethernet cabling between the flat and the technical premises of the building, where ISP can terminate its network. In new buildings today the Ethernet cables are implemented with other cables but in older buildings there have been no need in sight for this when they were built. For the buildings that have no Ethernet cabling there is a simple solution, we can use existing phone cabling to provide the needed connection between consumer's apartment and ISP network. But because of the physical difference of the network cabling used by Ethernet and the phone cabling an additional technology is needed to carry the transmission over the phone line. One of the most common technologies that do this is the ADSL.

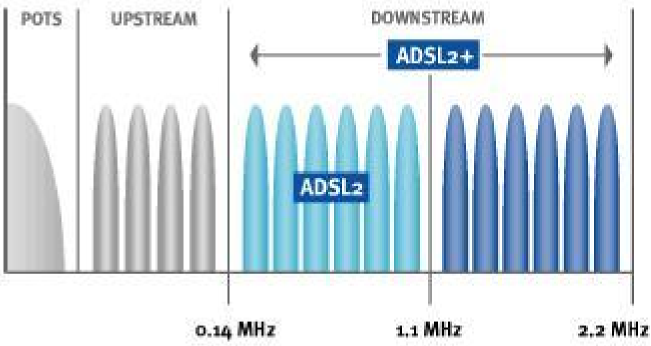
2.5 ADSL

Asynchronous Digital Subscriber Line (ADSL) is one of the many technologies that use existing twisted copper pair phone cables to provide connectivity to ISP network. End user connects PC to an ADSL modem using

Ethernet Technology and ADSL modem modulates signal suitable for transmission over the phone cable. At the ISP end of the cable transmission is demodulated and transported through access network, to the operator's core network, for further routing to its destination.

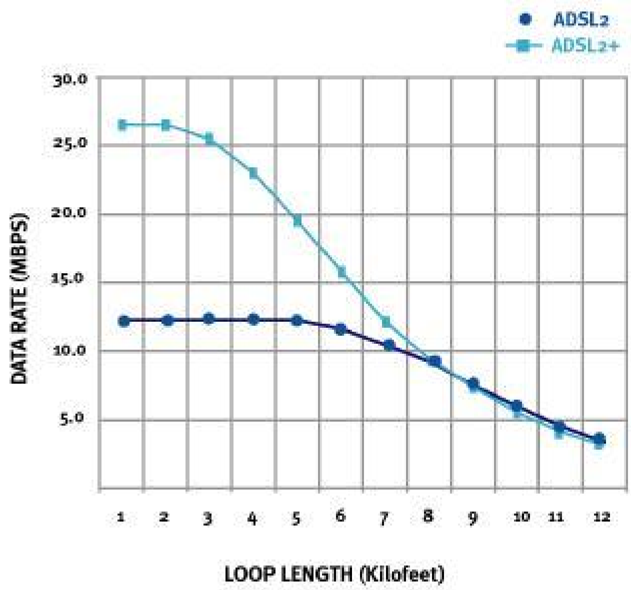
Although ADSL is advertised as a service by network operators, it really is an advanced signalling technology operating in the 1st layer of OSI model. It carries upper layer protocols such as ATM or Ethernet frames. ADSL is a broadband technology, this means that it does not conserve all bandwidth in the media like baseband transmission, instead it uses particular frequency levels for upstream and downstream transmissions starting from 35 kHz. This feature makes ADSL compatible with Plain Old Telephony System (POTS) that uses frequencies up to 4 kHz. This makes it also easy to extract normal voice call and data transmitted at the same time just by using high- and low-pass filters. [6]

Picture 4 presents the frequency usage of ADSL.



Picture 4: ADSL operating frequencies

In the picture 4, POTS refers to the normal telephony service that uses frequencies up to 4 kHz. The upstream is the bandwidth reserved for the data flow from the user to the network and the downstream is the bandwidth reserved for the data flow from the network to the user. The picture also shows us the difference in the downstream size between ADSL2 and ADSL2+. The transferring bit rates of ADSL are 256 kbps, 512 kbps, 1Mbps, 2Mbps, 8Mbps, 12 Mbps and 24 Mbps depending of the technology and quality of the copper line. The attenuation of the signal in copper cable is quite high and therefore the distance between ISP and end user is a negative factor to provided speeds. The picture 5 illustrates how the maximum available bitrate is dependent of the distance between the user and the ISP.

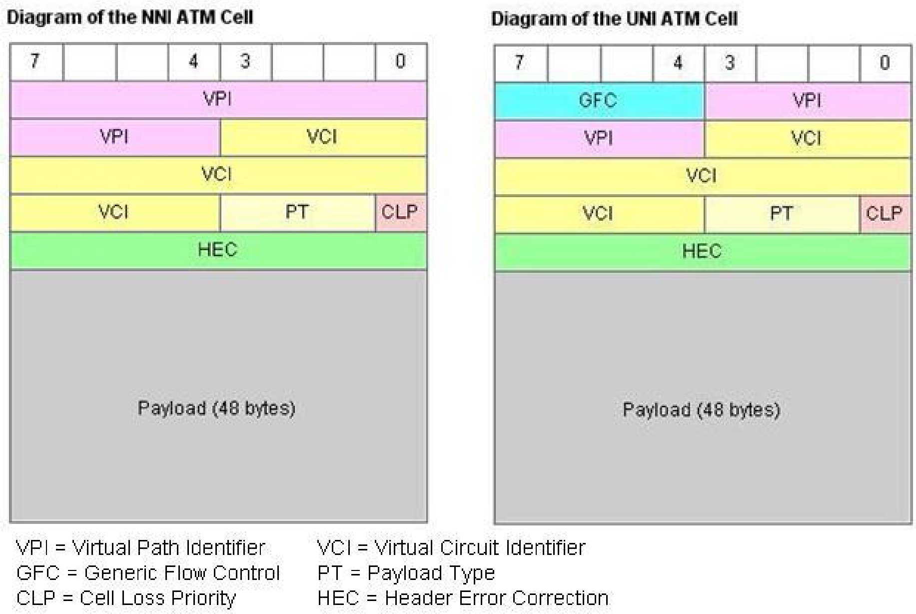


Picture 5: Effect of copper line distance to possible bitrates in ADSL

As shown by the picture 5, the bitrate that ADSL can provide is dependent to the distance of the copper line. Therefore the ADSL transfer connection is terminated at the shortest possible distance to avoid attenuation. The Terminating of ADSL lines is done in Digital Subscriber Line Access Multiplexer (DSLAM). DSLAM is equipment that adopts several DSL connections and aggregates them into one higher bitrate connection to the ISP network. Most of the DSLAM technology in the market uses Asynchronous Transfer Mode (ATM) connections as an aggregate connection to the network, but in the last few years there have also been Ethernet compatible technology available in the market. Since the ATM has been the one of the most common technology to connect the DSLAMs to the network, it is logical that the ATM technology is introduced here also.

2.6 ATM

Asynchronous Transfer Mode (ATM) is a cell relay, circuit switching network and data link layer protocol. ATM encodes upper layer data into small fixed 53 byte cells that contain 48 bytes of data and 5 bytes of header information. ATM technology uses synchronous optical networks layer 1 links to provide data link layer services. This differs from packet-switched networks such as Ethernet, in which variable size packets are used and transmission bitrates can vary. Before any data is transferred in ATM network a logical connection must be established between two endpoints, ATM is a connection-oriented technology. In ATM virtual circuits are used to identify path between source and destination. Virtual circuits are comprised of a virtual circuit Identifier (VCI) and a virtual path identifier (VPI) that are both located in an ATM cell header. ATM has two different cell types, user-network interface (UNI) and network-network interface (NNI). The structure of these two cell types are shown in the picture 6.



Picture 6: ATM cell structures

Virtual circuits can be dynamically defined by a routing protocol or they can be static, predefined by network administration. This VC type information does not travel inside cell header, it is defined in the interface before VC is established. ATM supports different types of services via ATM Adaptation Layers (AAL). Standardized AALs are numbered from AAL1 to AAL5. The AAL1 is used for constant bitrate services and circuit emulation. AAL2 trough AAL4 are used for variable bitrate services. AAL5 has no guarantee for bitrate and is usually used just for data transferring. [7]

ATM has been widely used as a network backbone technology. Also many network operators have used it in their Wide Area Network (WAN) cores and many implementations have made where ADSL access connections are gathered to the ATM network. Even that it has achieved success in these areas it has not become a common LAN technology that it originally was intended to. This is ATMs VC addressing and IP addressing of the internet are not compatible together, to route VC in IP network or vice versa there needs to be a dedicated server node to map an IP to a VC and other way around.

ATM technology is also fairly expensive and complex even if used in pure ATM network. Today ATM is loosing its advantages as core network technology over to rising Metro Ethernet technology that provides IP and ATM compatible routing protocol MPLS and transfer speeds up to 10 Gbps. Metro Ethernet is described more detailed in the next section.

Now we are at the end of this chapter and we have an overall picture of how our connection from home to the internet is formed. When an application we use on our computer needs an internet connection it demands service from the TCP/IP protocol. The TCP/IP protocol forwards the request for connection to the Ethernet technology and manages the established connection. The Ethernet may take the connection all the way to the ISP's network or it may be cut of by telephone lines. In case of the telephone lines, we can use the ADSL technology to provide the connection over the telephone lines. The ADSL connection is terminated with many similar connections to the ISP's DSLAM equipment that multiplexes the ADSL connections into one higher bitrate ATM connection in to the ISP's network.

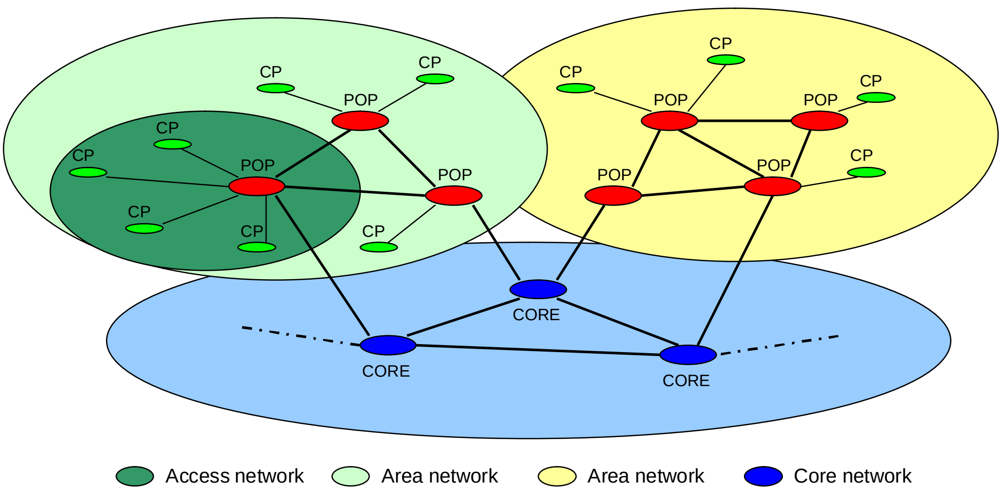
This is the case that relates to this project, but it is just one of the several possible solutions that can provide the same connectivity to the internet. The introduced technologies in this section were covered only in needed depth of detail to perceive the connection between user and ISP. This basic understanding of the connection is needed to understand the problem and the proposed solutions of this project.

3 ARCHITECHTURE AND THE NETWORKELEMENTS

This project addresses the implementation of an ADSL connection to the TeliaSonera network. Before talking of the problem it is essential to understand the basic structure of the existing network and its technology. This section introduces the Metro Ethernet network, the ADSL access as well as the Multi-Dwelling access product and their implementations.

3.1 Segments in the Network

The communication network can be segmented into parts that all have their own characteristics. Here we have divided the network in three segments called Access, Regional and Core Network. The following presentation of network segmenting is used in TeliaSonera.



Picture 7: A simple model of Access, Regional and Core Network relations

The Access part of the network has a simple task it provides access for customers into operators network. A network operator has several access points referred as Point of Presences (POP) all over operators area of service. A certain geographic area around POP is its service area. All the customer network connections are made from Customers Premises (CP) to their service area POP. POPs can be located for example by postal codes or by city districts. The access network includes several overlapping networks operating on different technology. The designing of access network is challenging because the network is built on customer demands and not necessarily by cost effectiveness. The architecture in access network is more or less ‘spoke and hub’-type, where the hub is POP and the connections to CPs are spoke type. For extra redundancy some of the customer connections are doubled and physically put on different paths.

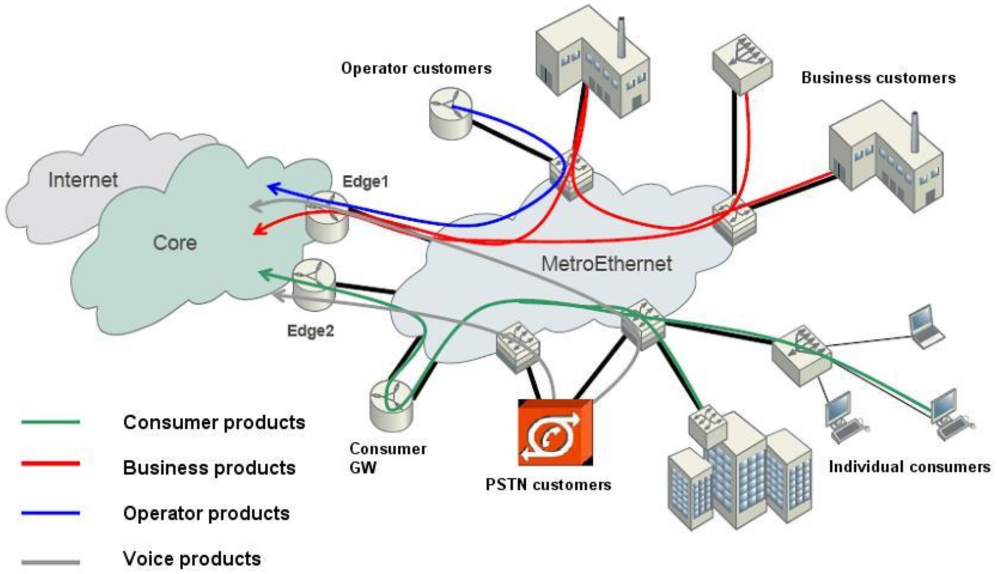
The Regional Network is formed by interconnections of POPs. The architecture implemented in area network is ‘partial mesh’ –type. Every POP is in connection at least with two other POPs, to make able to provide redundant connections to most demanding customers and to systems in own use that require it. Regional network is never used to provide access to a single customer. Geographically an regional network can be for example a city area. Every regional network has at least two POPs that provide connection the core network. These locations that act as a gateway from network to other are often called an edge.

The Core network provides a transport and an access between regions, other operator’s networks and to the internet. The architecture here is also a ‘partial mesh’ –type. All locations have to be secured and all systems have back ups for in case of a network failure.

A one segment of the network can contain several network of overlapping technologies that serve their purpose. This derives from operators need to provide different services for their customers. The Metro Ethernet network is one network that is included to the access network.

3.2 Metro Ethernet Network of TeliaSonera

The Metro Ethernet (ME) network is a regional access network providing connectivity to the core network for consumer and business customers. The ME network is an Ethernet based network platform that provides foundation to internal and external operator network services. The ME network is based Multiprotocol Label Switching (MPLS) routers and their optical fibre interconnections. ME is not a nationwide network, it consists of several separated areas that are connected through the IP core network. The versatility of the ME network as a service platform is illustrated in the picture 8.

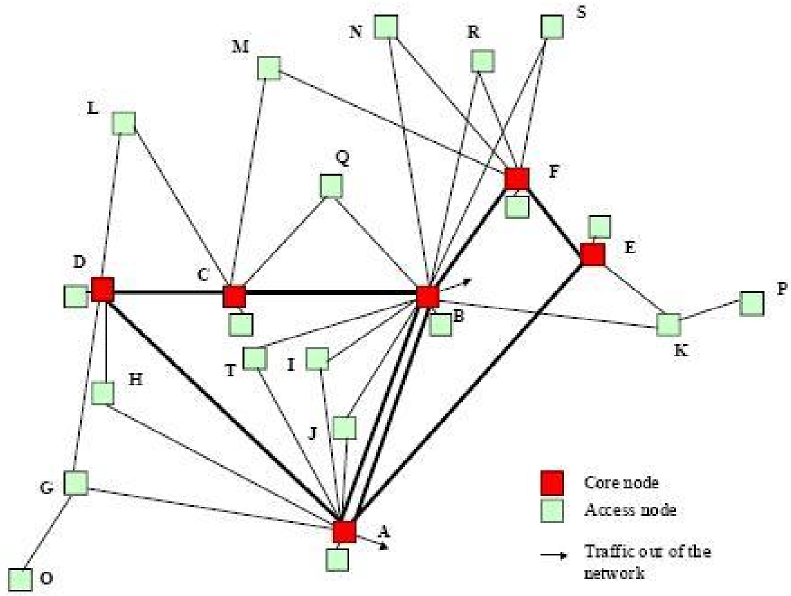


Picture 8: Example picture of the ME network's function

As we can see in the picture 8, ME network is a product itself and a platform for other services. It provides transit connections to the operators, direct connections for the business customers, backbone connections for Multi-Dwelling access and DSL connections that connect individual consumers. Even phone services can be connected to the ME network. The ME network can provide internal connections or it can forward the service on to its destination to other networks.

MPLS is a data-carrying mechanism which emulates properties of a circuit-switched network in to a packet-switched network. It was designed to provide unifying datagram service for both circuit- and packet-switched systems. MPLS can be used to carry different kinds of traffic, including IP packets as well as native ATM and Ethernet frames. MPLS encapsulates incoming data with a MPLS header that contains one or more labels, this is called a label stack. MPLS labelled packets are switched after label lookup instead of examining the IP route table. Label lookup and switching is faster than usual routing information table lookup because it can be done in switching fabric and there is no need for processing time of CPU.

The customer's physical interface to connect can be optical 1 Gbit/s or electrical 10/100/1000Mbit/s Ethernet interface. True bitrate of the connection can be altered by administration according to supplied service. The following picture takes us to the structure of the TeliaSonera's ME network.



Picture 9: An example of a possible ME network structure in a larger city

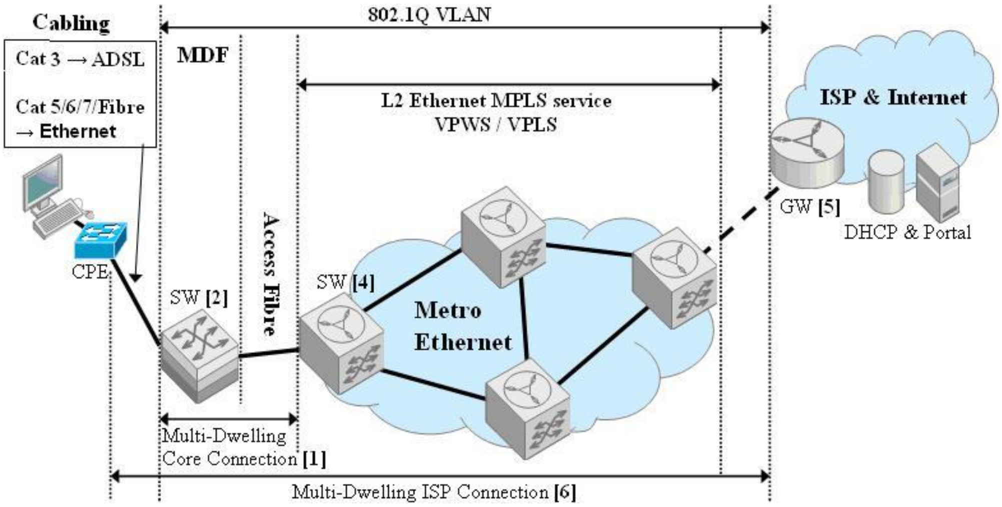
The structure of on local ME network depends on the areas need for service. There are access node and core node devices that can be both used to provide access to the network, but only core nodes are connected to core network. Each access node is connected at least to two different core-nodes and these connections must have different physical paths. If two different connections to core nodes are not possible this access node can not be used to provide certain business services that require extra redundancy. [8]

The Ethernet is very simple and efficient technology and together with the MPLS it can be used to merge ATM and IP networks together. TeliaSonera uses its ME network as a product as well as a platform for other services. One of these services is the Multi-Dwelling access that is discussed next.

3.3 Implementation of TeliaSoneras Multi-Dwelling Access to the Metro Ethernet network

A Multi-Dwelling access is a product that is sold to a company representing a residence building or buildings. There is option to connect all dwellings to the network or just some of them. If the whole building is connected to the service, the fees of the service are somewhat lower.

The idea of the Multi-Dwelling access is to build an optical fibre connection between a residential building and the TeliaSoneras ME network instead of taking many individual resident connections out of the building and terminating them to the nearest telephone central. There are two ways to implement this product depending on buildings existing cabling. In most of the buildings in Helsinki there is no dedicated network cabling, in these cases the existing traditional phone cabling will be used and the access type is ADSL. If there is existing network cabling to the dwellings and it is at least Category 5 (Cat5) classified, an Ethernet access is used. The picture 10 illustrates the Multi-Dwelling access from user to interface.



Picture 10: Multi-Dwelling access to the ME network

On the left hand side in picture 10 the Customer Premises Equipment (CPE) describes the PC of the user. The user is connected to the Main Distribution Frame switch with the ADSL or the Ethernet technology. The MDF switch connects to the ME network that simply passes the service over to the IP network.

The multi-dwelling access equipment includes an optical fibre panel where the fibre cable to the network is terminated and an Ethernet switch. If the phone lines are used as a connective media to the dwellings, a number of small DSLAM equipments and copper pair connection lines are also implemented.

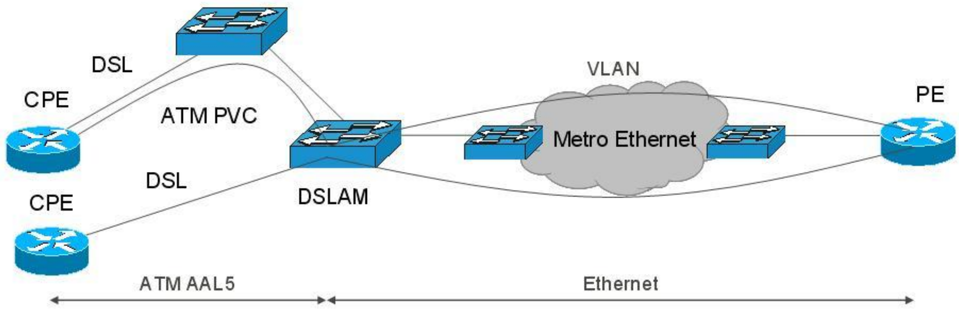
In the customers premises the optical fibre is terminated to the main distribution frame, where all telecommunication lines usually terminate. One fibre pair of the cable is used to provide the trunk connection of the switch. The optical trunk connection operates in symmetrical 1Gbit/s bitrate. The switch provides up to 100Mbit/s electrical connections from its ports to the users, of course the bitrate is altered depending of users subscription. In Ethernet access an individual resident connects a PC directly to network wall plug which is connected from other end to the switch. In ADSL access case the individual resident connects a PC to an ADSL modem that is connected to a phone plug. The other end of phone line is split in the cross-connection line and connected to DSLAM that filters the data part of the transmission and forwards it to the switch. Other end of the split phone line is connected outgoing phone line that connects to telephone exchange.

If ADSL is used as an access type, it restricts the transfer rates of data to standardized maximum of 24Mbit/s downstream and 2Mbit/s upstream, but this maximum bitrate is available for every user because of the short distance inside the building. Ethernet access type provides up to100Mbit/s downstream and 10Mbit/s upstream connection, which is significantly more than ADSL could offer. [9]

From user point of view the services provided by the ADSL and the Multi-Dwelling accesses are the same, regarding the possible bitrate. This makes Multi-Dwelling access a possible replacement for the ADSL service if the investment is feasible. To be able to compare the ADSL and the Multi-Dwelling access it is necessary to know more of the ADSL. Next will be introduced the DSL access and the implementation of the ADSL connection.

3.4 DSL Access to the TeliasSoneras Network

An Ethernet service is configured through the ME network between the edge/providers edge (PE) router and the DSLAM. The Ethernet service can be point to point Virtual Leased Line (VLL) or a multipoint Virtual Private LAN Service (VPLS). Customer Premises Equipment (CPE) routers have a DSL connection to nearest DSLAM. An ATM Private Virtual Circuit (PVC) is configured between CPE and the DSLAM, which connects to the ME network. This DSLAM is also known as the root DSLAM. The root DSLM performs translation between the AAL5 frames, which are used on the ATM/DSL connections and the Ethernet frames, which are used in the ME network. TeliaSonera has a large installed base of ATM DSLAMs. These will not have Ethernet interfaces and they are connected with an ATM trunk to a root DSLAM. The picture shows the principle structure of DSL access.

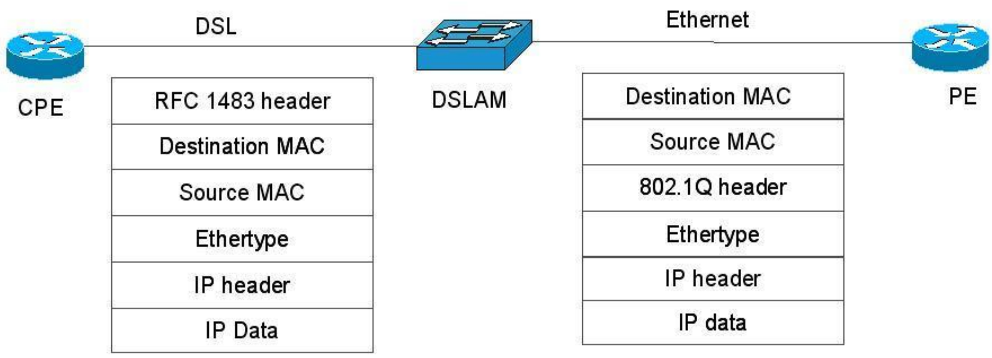


Picture 11: DSL access connections

In the picture 11 we can see that CPEs can be connected to an ATM based DSLAM that is linked to an Ethernet based DSLAM that uses the ME network to connect to the Provider Edge (PE) that is a gateway router to the core network. CPEs can be also connected directly to the DSLAM based on the Ethernet.

Encapsulation on the ATM/DSL connection is RFC 2684 bridged mode. The frame is an AAL5 frame, which has Ethernet source and destination MAC addresses. This supports the quality of service. [10]

In case of an ADSL service sold to consumer the CPE is just an ADLS modem and the service does not support quality of service feature included with business products. The picture 12 illustrates the protocol translation done in a DSLAM.



Picture 12: Bridged Ethernet encapsulation

In picture 12 the CPE sends a message using RFC 2684 (RFC 1483) encapsulation over ATM. The RFC 2684 simply wraps the message with MAC and IP information in to an ATM frame and puts a header on it that contains the encapsulation and information required by ATM. When DSLAM receives and opens the encapsulation, a ready Ethernet frame drops out. The

DSLAM just adds the VLAN (802.1Q) information defined in the service and sends the frame forward.

3.5 Implementation of TeliaSoneras ADSL Access Product

The ADSL is a broadband service marketed for consumer users to gain access to the internet and other web services such as e-mail.

The implementation of an ADSL connection is very simple. To connect the user to the ISP network is done using the phone line. The phone line is connected to the nearest telephone exchange, where the line is split and connection is made to the nearest DSLAM which is usually in same premises. If operator does not have connection to own network it can be built or leased from other operator.

DSLAM separates the data transmission from phone service and forwards it to the data network. The user is expected to install an ADSL modem between the computer in use and the phone line. The connection between ADSL modem and DSLAM is bridged ATM/ADSL connection using RFC 2684 encapsulation.

4 FEASIBILITY OF OPTIMIZING MULTIPLE ADSL CONNECTIONS TO ONE MULTI-DWELLING ACCESS

Internet connections are more common in households every day. The demand for bigger bandwidth is therefore growing and while people are investing to faster connections the more bandwidth eating services are provided, such as video downloads, IP-TV etc. The ADSL service is one of the most popular ways to implement an internet connection to households. The competition in the market has pushed the prices lower in Finland than in many other European countries. In Finland there are regions where a certain operator is obligated to provide phone services and therefore they have connections to every building. In Helsinki TeliaSonera is not the one obligated to provide the phone services. This gives an advantage to a rival in the ADSL market, when other operators need to build a connection or rent connection from their competitor. When lines are leased from other operator to provide service to a customer, some of the profit collected from a customer is shared with a competitor. In worst case there might not be profit left. Is the Multi-Dwelling access a product that can compete with an ADSL implementation and in which circumstances? This section is dedicated to find answers to these questions and to propose an improvement if Multi-Dwelling access becomes more common implementation.

4.1 ADSL implementation with leased lines

As mentioned before, one of TeliaSoneras rival has an obligation to provide fixed phone service to all real estates in the Helsinki area. This means that this rival has to invest heavily to build phone network that covers a 100% of Helsinki. Business in fixed telephone services is not that profitable these days when people are mostly using mobile phones for voice services. Instead of using existing phone lines for telephony they are increasingly used to provide broadband access to ISP network. TeliaSonera does not have a competitive copper network to challenge all other rivals in ADSL market. Therefore implementing ADSL connection over a leased line is TeliaSoneras most common way to provide ADSL service to customer. TeliaSonera has installed DSLAM units to this competitor’s telephone exchanges to reduce the distance to customers. When ADSL connection is subscribed from TeliaSonera and there is no connection to own network, a copper pair is leased from the rival. After the leasing is agreed by the rival a mechanic is sent to the telephone exchange to mount a splitter to phone line and to connect other split end to TeliaSoneras DSLAM unit.

The internal statistics of TeliaSonera tells us that a significant part of the implemented ADSL connections are done by using a leased line. These numbers are just the ADSL connections implemented to a TeliaSoneras DSLAM located in some rivals premises, but there are hundreds or thousands of ADSL connections more in Helsinki over a leased line. Cases that are done over a leased line but are forwarded from rivals premises with interconnecting cable to TeliaSoneras premises are not shown in these statistics.

4.2 Benefits of Multi-Dwelling Access Implementations

TeliaSonera has the Multi-Dwelling access to offer as a competitive product to ADSL. The Multi-Dwelling access is implemented by building own network to provide subscribed service. This expands TeliaSoneras own network and no money is lost for renting connections from other operators. Once Multi-Dwelling access is implemented it provides connectivity to a whole block of flats and not just one user. The transferring capacity of an optical fibre makes it possible to extend its use to provide other services also. These services in future could be Voice Over IP (VoIP), IP-TV, Cable TV or maintenance services for the real estate.

The TeliaSonera website provides the following prices for Multi-Dwelling Accesses and for ADSL connections in Helsinki.

ADSL

Bitrate (Down/Up)	Monthly fee
256 kbit/s / 256 kbit/s	20,50 €
512 kbit/s / 512 kbit/s	22,90 €
1 Mbit/s / 512 kbit/s	23,90 €
8 Mbit/s / 1 Mbit/s	43,90 €
24 Mbit/s / 1 Mbit/s	49,00 €

Multi-Dwelling Access (ADSL)

Bitrate (Down/Up)	Monthly fee
1 Mbit/s / 1 Mbit/s	24,90 €
10 Mbit/s / 2 Mbit/s	39,00 €
24 Mbit/s / 2 Mbit/s	49,00 €

Multi-Dwelling Access (Ethernet)

Bitrate (Down/Up)	Monthly fee
10 Mbit/s / 10 Mbit/s	39,00 €
100 Mbit/s / 10 Mbit/s	49,00 €

Multi-Dwelling Access (ADSL), prices included to residence service fees

Bitrate (Down/Up)	Monthly fee
10 Mbit/s / 2 Mbit/s	24,90 €
24 Mbit/s / 2 Mbit/s	29,90 €

Multi-Dwelling Access (Ethernet), prices included to residence service fees

Bitrate (Down/Up)	Monthly fee
10 Mbit/s / 10 Mbit/s	24,90 €
100 Mbit/s / 10 Mbit/s	29,90 €

Picture 14: Price comparison of ADSL and Multi-Dwelling Access (www.sonera.fi , visited April 10th 2007)

By comparing prices of provided bitrates in ADSL and Multi-Dwelling Access, picture 14, we can see that there is no significant difference until Multi-Dwelling access is charged in the residence service fees. In cases where a building has Ethernet cabling consumers can get over four times faster transfer rates with Multi-Dwelling Access.

There is just one drawback in implementing the Multi-Dwelling Access instead of every subscribed ADSL connection. The implementation where network needs constructing it is very expensive. One of the TeliaSoneras advantages in Helsinki area is dense optical fibre network that should be used when ever it is possible. If TeliaSonera would be able to build dense enough optical fibre network to connect residence buildings it would increase TeliaSoneras competitiveness against the rivals copper networks. Without a doubt this is what TeliaSonera is aiming for and there have been started processes to reach this goal.

When Ethernet is used from end to end access it lowers the protocol hierarchy in the network and less necessary protocol translations are needed that create latency in transferring. Decreasing the number of protocols the devices can be also more simple what often makes them less expensive.

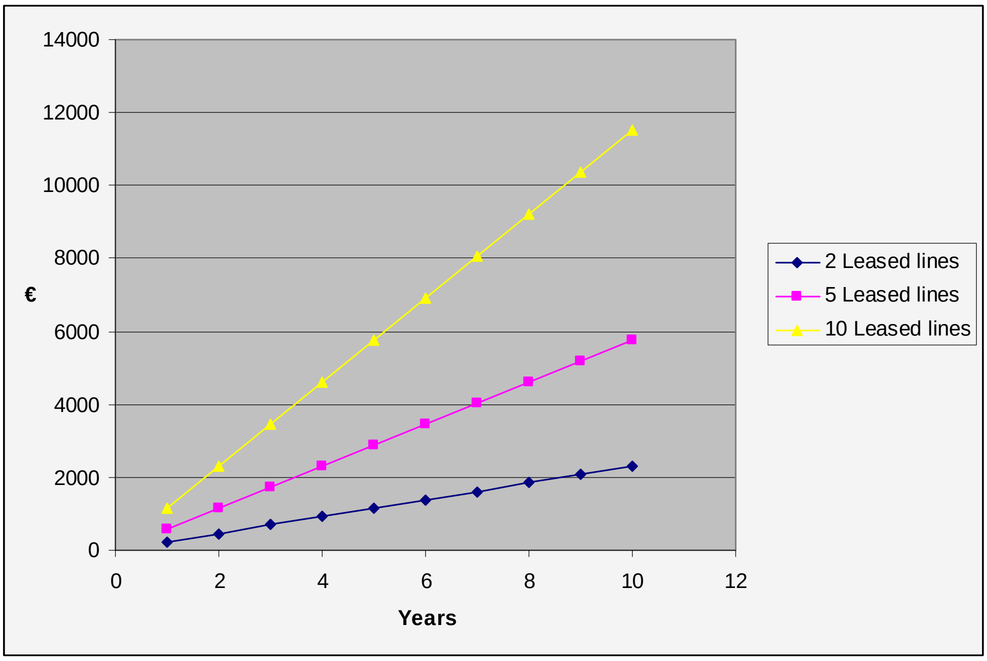
4.3 Feasibility of Multi-Dwelling Access as an ADSL Optimization Method

The optimization process is almost constant in such a big operator network as TeliaSoneras. The optimization process tries to find weak implementations from the network and rebuild or modify them to work in more efficient way. The ADSL is rather a simple and effective way to provide connection to individual user and by time it has become as effective technology over copper line connection there can be. To get to the problem we have to look past the technology and focus on media used in significant part of the ADSL implementations in Helsinki area.

A leased line from TeliaSoneras rival has been used as a connective media to the subscriber quite often. This is a good idea when there is no connectivity to the own network and building fixed connection is extremely expensive. It is good to remember that these implementation decisions are made by individual subscriptions that have no guarantee of continuity. By time and more automated subscribing systems the possibility of investing to own network is more seldom evaluated option.

The heart of the problem is that leased lines are not free of charge, they cost money. By the current price-sheet for operators the service obligated rival of TeliaSonera charges 9,60 €/month for one leased copper pair in Helsinki area. In addition there is a connection fee of 140€. This sounds like a decent price at start, it is only 115,20 € per year. When investing in network construction we would have been talking about thousands of euros or even of tens of thousands of Euros.

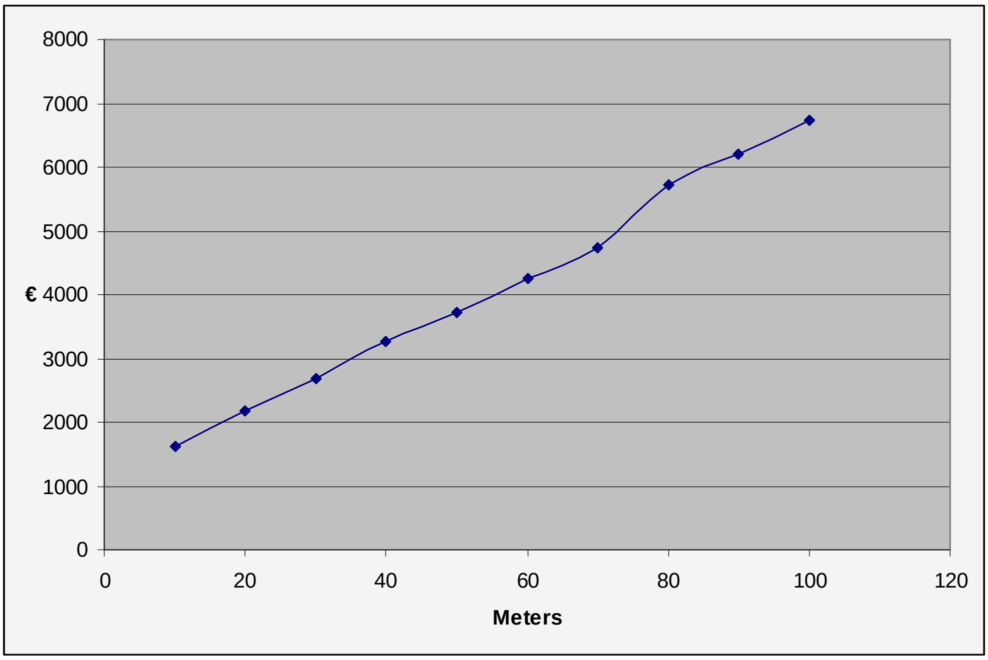
When doing this in an individual case or few there is no problem, but if done often it becomes a problem. TeliaSonera has several active ADSL implementations over leased lines in Helsinki, and these are only the sure cases, there probably is even more. There is not much that can be done to avoid using the leased lines, but it would be wise to review the need for all of the done implementations regularly. The picture 15 shows how much would two or more leased lines to the same building cost, if they are kept for longer period of time.



Picture 15: Costs of several leased lines

One solution could be to look for occasions where there are multiple ADSL implementations done on a leased line to the same building. In these cases TeliaSonera could evaluate extending its optical fibre network to the building and replacing these ADSL connections with a Multi-Dwelling access product. In addition of optimizing own costs TeliaSonera would be able to provide service to all residents in the building.

It is indeed expensive to build an operator network, but by looking chart in picture 15, in cases that there is several leased lines it could be feasible. A general cost model for network building is hard to develop. The prices vary significantly depending on the materials, environment and the contractor. The picture 16 illustrates how length of a new optical fibre connection effects to the implementation price.



Picture 16: Rough estimate of building costs of a fibre access connection in Helsinki area

Picture 16 calculates costs for a single-mode fibre cable, implemented in a plastic pipe under the ground. A common type of residential area in Helsinki has been selected as environment, light (class 5) asphalt, which could be a pavement or a small road. Street paving influences in both digging and covering costs. The costs are restricted only to the new extension of the network, in real cases the connection might be build deeper into the existing network, the connecting happens in a nearest available fibre junction point that has the capacity. The prices used to estimate investment are TeliaSoneras currently used negotiated contractor prices calculated with custom designed calculation tool. More detailed information about prices is internal information.

The two graphs in pictures 15 and 16 could be used together as a simple tool for estimating cases where TeliaSonera should invest to own network extending and when to let things just as they are. For an example, when there are 5 leased ADSL implementations to a single block of flats, it could be reasonable to invest the money to own network if the distance to construct extension is less than 20m. The investment would be worth in four years and it also would bring the other benefits of the product as well.

The ADSL technology provides sufficient bitrates and services for the needs of the users and does not need to be replaced itself. The ADSL implementations on leased lines are another case. These implementations on leased lines should be replaced if the investment to extend the network of TeliaSonera is feasible.

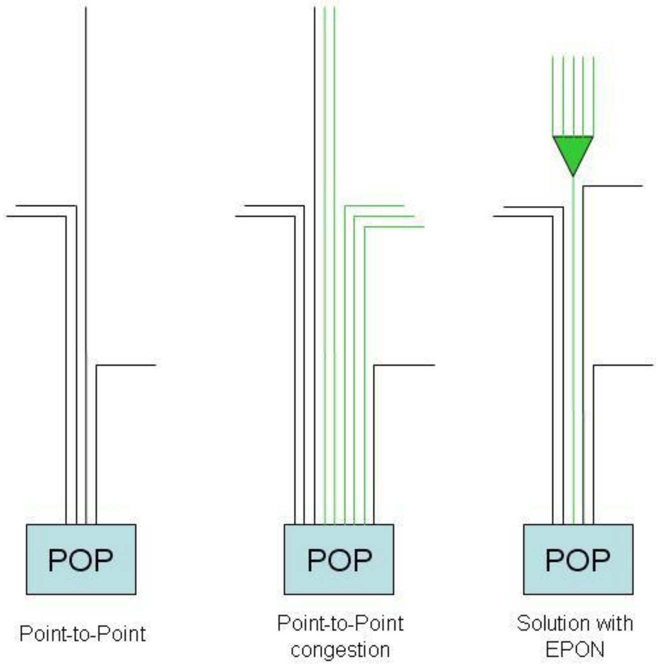
The way this project would propose optimization of the multiple ADSL implementations on leased lines in Helsinki to be done is following. The whole area should be divided into smaller ones and taking one at a time under the scope. Each of the smaller areas should be evaluated by their market value to TeliaSonera, how much they want to increase their presence and their market share in the area. Then should be all potential optimization cases filtered from all the cases of the current area and try to make the cost estimation for network building as accurate as possible by these selected cases. When getting to the comparison of the current costs and investment costs the areas market value estimation should be taken into account.

4.4 Improvement Proposal for Connecting Multi-Dwelling Access to the Metro Ethernet Network

If the Multi-Dwelling product becomes a more common product or an optimization solution, TeliaSonera will have another smaller problem to take into account.

Each Multi-Dwelling implementation demands minimum of two fibres from each cable to be connected to the ME router and the routers are located in some of the POPs in the area network. This will lead into an increasing amount of optical access cables into the POP and also between POPs if router is not in the first POP. There are locations in Helsinki where this already is a problem, the existing cable pipelines are congested and new cables are hard to fit in. The expanding the pipelines are equally expensive or more expensive than implementing the pipelines in one go. In all the cases the expanding would not just be possible because of other elements under the surface. There are phone lines, electricity lines, water pipes, TV cables and cables belonging to another operator in surprisingly many cases.

There is a technology that could solve this problem the cable congestion problem by reducing the number of the required cables, Ethernet Passive Optical Network (EPON). The picture 17 illustrates the congestion problem and the solution with the EPON.



Picture 17: EPON solution to fibre congestion

As the picture 17 illustrates the EPON is used to establish point to multipoint connections using passive dividing of the signal from one fibre to many. Details how EPON works is presented in the following.

EPON is defined in the IEEE 802.3ah standard. It is one of the most promising Passive Optical Network (PON) technologies. Ethernet over the First Mile (EFM) is a general name for access technologies defined in the IEEE 802.3ah standard. One common feature to all of them is that they are based to the Ethernet technology and they are intended to be used as access network solutions. The three technologies defined in IEEE standard 802.3ah are in the table of picture 18.

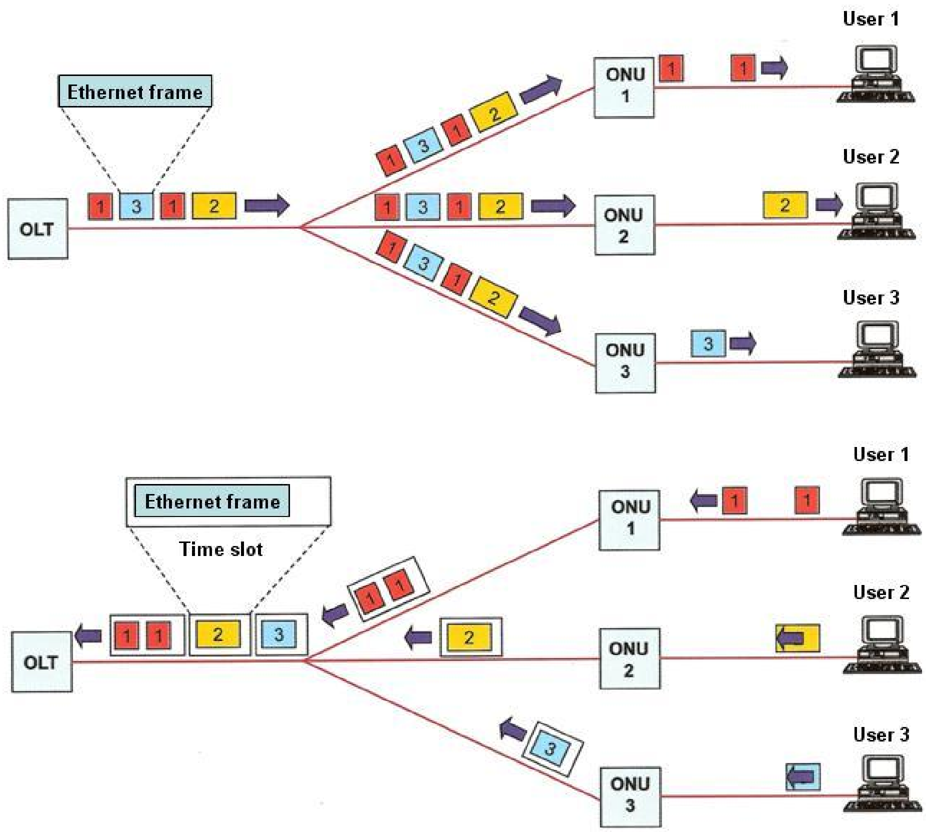
EFM Copper (EFMC) • Uses existing telephone network providing 10 Mbit/s transfer speed up to 750 m. • Using existing telephone network providing 2 Mbit/s transfer speed up to 2700 m.
EFM Fibre (EFMF) • Using single mode fibre providing transfer speeds of 100 Mbit/s and 1000 Mbit/s up to 10 km.
EFM PON (EFMP) • Using single mode fibre in a passive optical network providing 1000 Mbit/s transfer speed up to 20 km.

Picture 18: Table of technologies included in IEEE 802.3ah standard

The table in picture 18 summarizes the main characteristics of the different technologies embedded to the IEEE 802.3ah standard.

The one this project sees most useful is the EFMP that is the real EPON solution using the passive dividing of the optical fibre. The EPON solution is based to a one single mode fibre transfer technique. The transfer rate is 1Gbit/s to both directions. There are different wavelengths reserved for the two directions, downstream uses 1490nm when upstream uses 1310nm wavelength. This makes it possible to transmit and receive at the same time. EPON network has two required elements; the Optical Line Terminal (OLT) closer to the POP and the Optical Network Unit (ONU) that is the device at the customer premises. The typical number of ONUs to one OLT in a EPON network is 16 but can be up to 32 if the attenuation stays within the limits of the devices.

How the transmission processes work to both directions in the EPON system is described in the following picture number 19.



Picture 19: Transmissions in EPON network

Transmission in an EPON network happens in the following form. All transmission from the OLT is received in all ONUs. An ONU will recognise the frames addressed to its users and discard the others.

The frames used in an EPON network are standard Gigabit Ethernet frames, except for the first 8 octets of the frame that are specific to EPON. When transmission happens from ONU to OLT it situation is a bit different. Every ONU can only transmit during a timeslot that is specified for it. This is often referred as Time Division Multiplexing (TDM). This traffic rearrangement is needed in all PON networks to avoid collisions in the media. [11]

For traffic control there is used an additional layer 2 protocol in EPON called Multipoint MAC (MPMC). MPMC uses three different 64 octets' long messages for traffic control. GATE message is sent by OLT and it defines information of when and for how long an ONU can transmit. GATE messages are send as a response to a REPORT message that is sent by ONU and contains information of buffer usage of the ONU. The last type of message is REGISTER and it is used to identify new active ONUs in the network. MPMC can also measure the distance or more precisely the transfer times to ONUs, this relates to the time slot calculation process.

The EPON has important features that make it compatible to be used as a part of the access network. Such important features are support for IP services like VoIP, IPTV and IP video subscribing services. Because EPON belongs to the 802.3 family of standards, it supports also the Class of Service (CoS) defined in standard IEEE 802.1D and the Virtual Local Area Networks (VLAN) defined in standard IEEE 802.1Q. Support for VLAN is very important feature, otherwise security of point to multipoint transmissions would questioned. [11]

EPON could also be used to connect multiple Multi-Dwelling access sites together with a passive fibre splitter and only one fibre would be needed to be taken to the POP. This implementation would also save connection ports in the router itself. The type of traffic would be same in multi-dwelling access solutions at the same area. The necessary network information of DNS and DHCP servers and portals would also be the same.

TeliaSonera is using CoS and VLANs to control and manage traffic in the Metro Ethernet network and EPON would also satisfy these demands. The only obstacle that stops TeliaSonera from taking EPON immediately in use is the transfer rates. The Multi-Dwelling products are specified to be using symmetrical 1Gbit/s connection in both directions. It will be a rare situation when one Multi-Dwelling access would really require the 1 Gbit/s transfer rate but it would be wrong to mismatch the promised and provided rates. An example of this, if TeliaSonera would divide 1 Gbit/s with for example 5 implementations, that would leave only 250 Mbit/s for each implementation. IEEE has already pointed a workgroup (at Spring 2006) that is working to extend EPON standard to support also 10 Gbit/s Ethernet. Hopefully there is enough time for IEEE to develop support for higher bitrates before this proposal is fully considered by TeliaSonera.

5 DISCUSSION AND CONCLUSIONS

The research question of this project derived from TeliaSonera's need to rebuild network connections to a POP when its location was changed. Before starting to rebuild all the connections, TeliaSonera wanted to evaluate whether some connections could be implemented in more reasonable way, in other words optimized. The research question given to this project was, "When it is feasible to replace ADSL connections with a Multi-Dwelling access?" and this question was bound to concern Helsinki area only.

The ADSL technology uses the copper phone cabling to establish connections to the operator network. Since TeliaSonera does not have Helsinki fully covered by its copper network, some of the ADSL implementations are done by leasing line from a rival operator. The Multi-Dwelling access is based on the Ethernet technology and uses optical fibre as a connecting media to the network. TeliaSonera has a good but not full coverage of Helsinki with its optical fibre network. If the Multi-Dwelling access implementation would be used to replace ADSL connections, it would provide the same service to the user with a possible lower fee and a higher bitrate. In addition the Multi-Dwelling access brings potential connectivity to all the residents in the buildings represented by the same company. The fibre implementation also provides possibilities for future cervices such as IPTV, VoIP and house management services.

The Multi-Dwelling access would be a good replacement for any ADSL implementation, but not a feasible one in most cases. The Multi-Dwelling access implementation is so expensive that it is not reasonable to use to replace ADSL connection done over TeliaSonera's network. The ADSL implementations done on leased lines are cases that should be evaluated if there are more than two leased lines to a single building. When there are more than two leased lines to the same building the annual lease costs rise to high values after several years. In these cases the use of the Multi-Dwelling access should be used as a replacement to ADSL when the distance to construct the fibre network is less than 20 meters.

The Multi-Dwelling access is a product that sells quite well. If it is taken into use as an optimization implementation for the ADSL connections there will be effects to the fibre network structure. Because of the point to point structure of Multi-Dwelling access, each implementation takes a fibre pair between the CP and the local areas POP or even beyond this if the closest ME network switch is not located there. This will lead to increasing cable congestion at the surrounding area of a POP. There can be other reasons for this and it is not a totally new phenomenon.

This congestion problem of cables could be relieved by using the EPON technology in Multi-Dwelling access implementation. By the use of EPON, it could be possible to take one fibre from POP closer to a residence area and split the fibre using a passive device into a several fibres. These split fibres would be used as the network connection of the Multi-Dwelling access switches. The most important features that EPON technology supports are the CoS, VLAN, VoIP and IPTV. These features make it compatible with the Multi-Dwelling access and other potential use of it. The obstacle that stops TeliaSonera from taking EPON into use directly is the lack of its support for higher bitrates. The highest bitrate supported by the EPON is 1 Gbit/s which is the specified bitrate for one Multi-Dwelling accesses network connection. The IEEE that has standardised the EPON technology is already looking to extend the support of the EPON up to 10 Gbit/s.

The solution found to the defined problem was after all pleasing. It does not seem like much but the simplicity of it makes it easy to use and tune it by current needs for more accurate estimates.

The proposal to rethink the trunk connection of Multi-Dwelling access and using of EPON was a positive surprise to myself. When thinking afterwards, the solution ended into a merging problem and it was reasonable to solve this too.

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