Automatic Network Planning for Access Networks in FTTH with and without Redundancy

——— Master Thesis ———

Network Planning and Management 2007

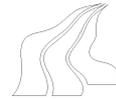*07gr1080*

Gustav Helgi Haraldsson

Omer Beshir

Faculty of Engineering and Science

Aalborg University

Computer Engineering - Network Management and Planning

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GROUP MEMBERS:
Gustav Helgi Haraldsson
Omer Beshir

SUPERVISORS:
Tahir M. Riaz and Ole Brun Madsen

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Abstract

This report presents a automatic network planning method for FTTH access networks with and without redundancy. First some background into the fiber technology and topology used is shown. Second a comprehensive look into the case study area is done. The project is dealt into two phases. Both phases deal with creating the automation process. Phase one analyzes methods for reducing fibers in the access network in a small scale tests. Results are given based on the fiber cost of each scenario to determine viable scenarios for large scale testing. Phase two takes the results from phase one and compiles scenarios which show potential in offering redundancy without much extra cost. An analyze is done to view what method is the best for creating automatic districts, tests are then performed to view the full effect of the automatic districts. Finally a cost estimation is presented, including digging, fiber and housing. Both phases have their conclusion but the project is finished of with an overall conclusion and further work. The appendixes support the report with detailed information.

Preface

This projects concerns the creation of an automatic planning method in FTTH access network with and without redundancy.

The report is prepared at the *Faculty of Engineering and Science* at *Aalborg University Network Planning and Management*, in the period from the 4th of September 2006 to the 7th of June 2007. The overall theme for the semester is *Network Planning*. The project group have hereby selected the project proposal *Of automatic planning access network with and without redundancy,*

Instructions for reading

Some practical guidelines about how to read this report.

- Citations will be referred to with square brackets e.g. test-citation[3]. The number in the square brackets can be looked up in the back of this report under 'Bibliography'.

- Footnotes will be used to deepen sentences e.g. This needs a additional comment[1].

- Abbreviations will be fully written the first time they are used e.g. Please Shorten This (PST).

- All source materials will be available on the enclosed disk found on the rear page of the report.

Report Structure

The report is structured like stated below. It is divided into four parts which follow a step by step approach.

Part I: Background: The first part contains the introduction to network planning and then the area of the case study. It will then list and describe the scenarios used in this project. At the end of the part it will furthermore define the project goal.

Part II: Phase 1: This part will introduce phase 1, which main goal is to reduce fiber in small scale tests. Also introduction s given to the automation process. Next results are given to scenarios created and compared. Finally a conclusion is given to the results, and criteria's set for phase two.

Part III: Phase 2: This part will introduce phase 2, which will finish of larger parts of the automatic process. Scenarios are created based on criteria's given in phase 1. Results are given and compared. Finally a conclusion is given to this phase.

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[1]The footnotes will try to deepen the sentence

Part IV: Recapitulation: The forth part will make a conclusion to the automatic planning process creation and the results of both phases.

Part V: Appendix: The last part contains the appendix with supporting/elaborating information to different parts of the report.

The enclosed CD contains the program code, a copy of the report in portable document format (PDF) and all calculation sheets. All satellite photos in this report are the property of the respected owner as indicated on the photos, and acquired using Google Earth.

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Gustav Haraldsson

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Omer Beshir

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Nomenclature

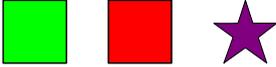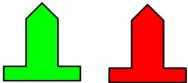Table 1 shows symbols used frequently throughout this report in mapinfo.

Symbol	Description
☐	Network Termination Point (NT)
🟩 🟥 ★	Distribution Node (DN)
⬆ ⬆	Splicing Points
——	Segments
●	Segment Points (SP)
—— ——	Main Duct line
——	NT to SP line

Figure 1: Nomenclature of frequently used symbols in mapinfo.

Table 2 shows symbols used frequently throughout this report in Google Earth.

Symbol	Description
	Network Termination Point (NT)
	Distribution Node (DN)
	Splicing Point (DN)
	Segments
	Districts
	Digging

Figure 2: Nomenclature of frequently used symbols in Google Earth.

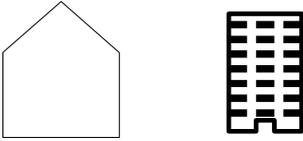Table 3 shows symbols used frequently throughout this report in Visio.

Symbol	Description
	Network Termination point (NT)
	Distribution Node (DN)
	Splicing Point

Figure 3: Nomenclature of frequently used symbols in Google Earth.

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Part I

Background

Introduction

1.1 Background

Data communication over the Internet has been exponentially growing since the 90's. The now in place plain old telephone system (POTS) network has been great in meeting the demands of increasing bandwidth (with integrated service Digital network (ISDN), asymetrical digital subscriber line (ADSL), Symmetric digital subscriber line (SDSL),etc..) demands over it's copper network. However the POTS network is already being pushed to it's limit in trying to offer more bandwidth with new technology over the coppers. The downside is that in order to use this new technology over the old POTS network the user has to be closer and closer to the connecting equipment.

Today more and more services are being introduced through this copper based network, not only the Internet, therefore making it an all purpose network. These services (VoIP, VoD, Internet and more) are demanding a lot of bandwidth so it is apparent that though the current network media holds, it is becoming exhausted and a new type of media in which to use this all purpose network, is required.

Optical fiber is one possible successor in planning a new installation, upgrading or expansion of and to an all purpose network. The optical fiber offers new possibilities compared to the older medium of copper based communication systems. One of these possibilities is Fiber To The Home (FTTH), where the complete network infrastructure is fiber, from the supplier all the way to the NT (end user). By doing so the NT has a greater amount of capacity available.

1.2 Motivation

As a side effect all NT's are now more than ever becoming reliant on the reliability of an all purpose network since telephony, Internet access, television and other services are now being transferred to this all purpose network. However today's network planning has mainly focused on the upper levels of the network, when creating redundancies rather than planning the access networks with non redundant topologies. But as NT's in the access network are relying on the network, some research is needed to offer redundancy to the access network without introducing too much extra cost.

A previous study [9] viewed how the ear topology can be used to offer access network redundancy by reducing the cost of planning by reusing trenches, however excessive amount of fiber was used bringing the cost up. The network is only planned manually in the study and with the home run method of offering fiber. Viewing how to reduce fiber along with automating the network planning process is of interest.

1.3 Defining the project

The project will be broken into two phases, phase one and phase two.

1.3.1 Phase 1

The goal of phase one is to investigate automatic network planning of the access network with and without redundancy. The automated planning without redundancy (tree topology) will be done in order to learn the process and to use as a comparison to the automation of the access network with redundancy (The ear topology). Phase one will set to automate network planning in a small scaled controlled area and the previous study used as a basis. By doing so the automation can be compared to the manual creation of the network. This also involves that some parts of phase one will still be manual in order to achieve consistency between studies.

Additional network planning properties are added in phase one to view other possibilities for reducing fiber. Since previous study was only done by planning the fiber with the home-run method it is of interest to view how the ear topology is planned with Passive Optical Network (PON). Other means of offering redundancies in the access network will be created (eartree topology). After comparing the automated process with redundancy and without redundancy, conslusion of the cost analysis for both plans will be presented.

1.3.2 Phase 2

Phase two of the projects sets out to finish the automation by dealing with larger programming parts left behind during phase one as well as problems that occurredin the process. The main purpose of phase two will be to focus on reviewing the most plausible options which are found from phase one. This is to create a cheap redundant alternative usable in today's network infrastructure scheme. Further investigation involves adapting the automation process to a large scale test. Phase two will mainly focus on solutions which could easily be adapted to today's network and economic standards in the IT world.

As phase one is mainly viewing methods for reducing fibers for redundant access network, all other cost factors are left out. However in phase two, other cost factors will be added, those being digging, housing and equipment. In order to get a good sense of what equipment will be needed the traffic will also be investigated.

Another possible access network topology will be presented as a possibility for further study into the redundancy of the access network. And finally a program which enables simplicity and more configurable in viewing results when using Danish GIS data is presented.

Network Planning

2

2.1 Introduction

The history of communication technologies, has been done in such manner that one communication network is built for each application. For example, telephone and TV run on different networks. Additionally the communication network was planned in an ad-hoc manner. But we are moving towards one general purpose network which is designed to communicate over IP, example VoIP, VoD and Internet.

Other than these applications which exist today there are new applications that are expected in the future like Machine-to-Machine communications [12]. It is obvious that these applications need a different and stronger Quality of Service (QoS).

The IP based communication networks allow different applications to run on a common platform. This results in the convergence of communication technology. This converged communication technology needs to be planned in a systematic manner so that the network can satisfy the QoS requirements for the existing applications and the ones expected in the future.

From the network planning view there are many aspects that a plan should consider. The general approach for the network planning can be seen in figure 2.1. A well designed plan should consider technology/equipment, environment/geograph, traffic, structures and cost. Considering this, a careful network planning should be done that satisfies a future-proof communication network.
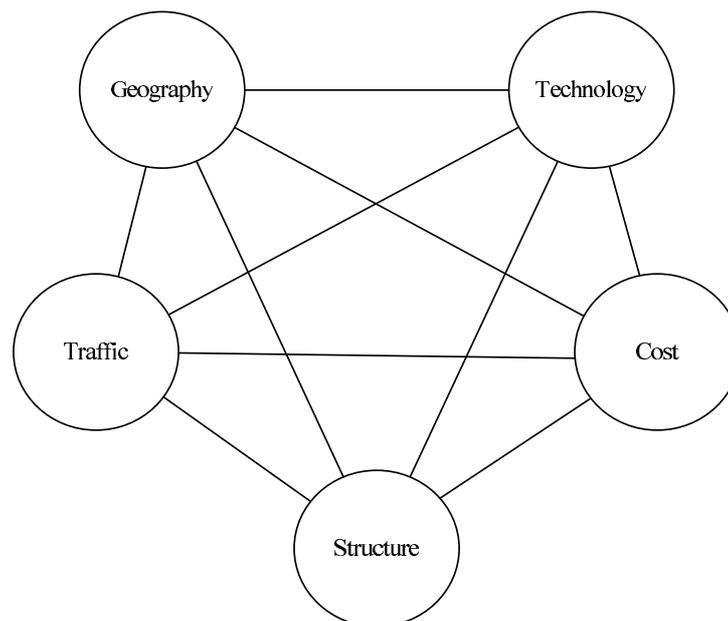
Figure 2.1: Network Planning factors [23].

Environment/geograph: Developing an IT infrastructure for a country or a region knowledge is needed about the physical and human dimensions of that area. By applying a geographical concept in designing a network it gives information to indentify the population, sorting out densely populated area from a less populated area, the landscape of the area and etc.

This type of analysis helps the network planner in deciding what capacity (For example, bandwidth) is needed in that area.

Technology: The telecom networks have become larger and more complex. From POTS system running on copper wires to inventions of new technologies (ISDN,ADSL,SDSL and etc.) on that medium and now to an optical medium (optical fiber communication) as well as wireless communication (satellite and radio link communication) are existing. The planning should consider the existing technologies as well as future technologies.

Traffic: an IT infrastructure design needs careful planning of the amount of traffic that the network is generating internally as well as incoming traffic from outside. In designing an optical fiber infrastructure, analyzing the traffic is important for knowing more information on node dimensioning, node capacity etc.

Structures: Understanding the structure of a network is an important concept in planning an IT infrastructure. Which includes a good understanding of scalability, redundancy, reliability as well as ensuring structural quality of service (SQoS). A recent study [12] shows that the lack of global structural qualities are causing a number of problems in today's network planning. The study gives a solution by designing a network, it is highly dependent on the physical topologies.

Cost: The IT infrastructure should be planned to achieve future long term goals. To achieve these long term goals the plan should give different types of cost estimation prior of implementation. For example, according to [24], there are different types of costs when designing a fiber optic network. The fundamental IT infrastructure with fibers, ducts, etc. has a long lifespan (30 to 40 years) and relatively fixed high cost implementation. On the other hand the fast evolution of prices for electronic devices plays an essential role for the investments as the life time of switching equipment is only 3-5 years.

2.2 Terms and definitions

Some terms and definitions are used throughout the report to explain different aspects of the network. These terms can have different meanings between projects all depending on the geographical scope of the network. The Swedish ICT commission [28] has standardized some terms used in planning a fiber network. In order to clarify these terms they will be explained here as they will be used throughout the project.

2.2.1 Network Architecture

Figure 2.2 shows how the network architecture is set up of 3 network layers and are as followes:
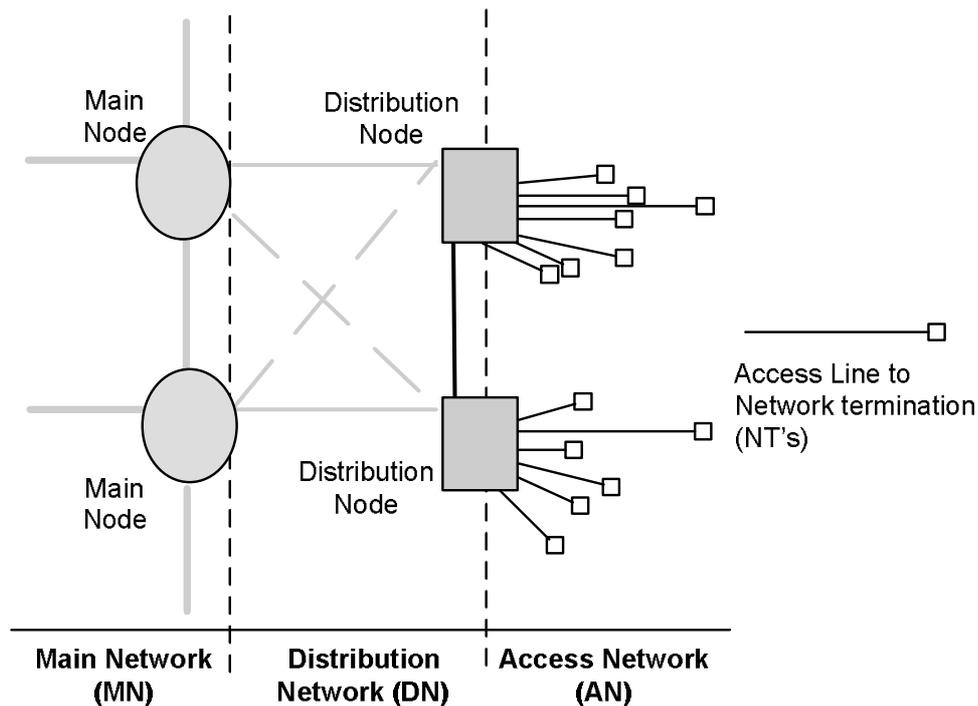
Figure 2.2: Network architecture hierarchy.

- **Main network:** The main network sometimes called the backbone network is what connects the distribution network to the outside world. In this project the main network is the regional backbone, which is the highest level in a municipality network hierarchy. This layer connects the municipality to the external network with links going out of the municipality.

- **Distribution network:** The distribution network consists of distribution nodes and lines which connects the access network. In this project the distribution network is the municipal network. Where nodes are mostly placed in dense areas in the municipal in order to connect the access network.

- **Access network:** The access network is a network of Network Termination points (NT's) connected to the distribution node. NT's nodes are households, business and government places. This project will not distinguish between household, business or government. Each NT can withhold more than one NT, e.g. an apartment building. The project will only view each NT as one connection.

The main focus of this project lies on the access network and offering redundancy. To be able to create an access network some knowledge of the upper network layers are needed to be able to construct an access network, this involves research into the distribution network. The main network is out of scope in this project and will therefore not be considered.

2.2.2 Level of service

In [28] the Swedish ICT commission has constructed different layers to represent an IT-infrastructure. This section will outline these levels and go on to explaining which levels will be represented

in this project. The infrastructure can be seen in figure 2.3.
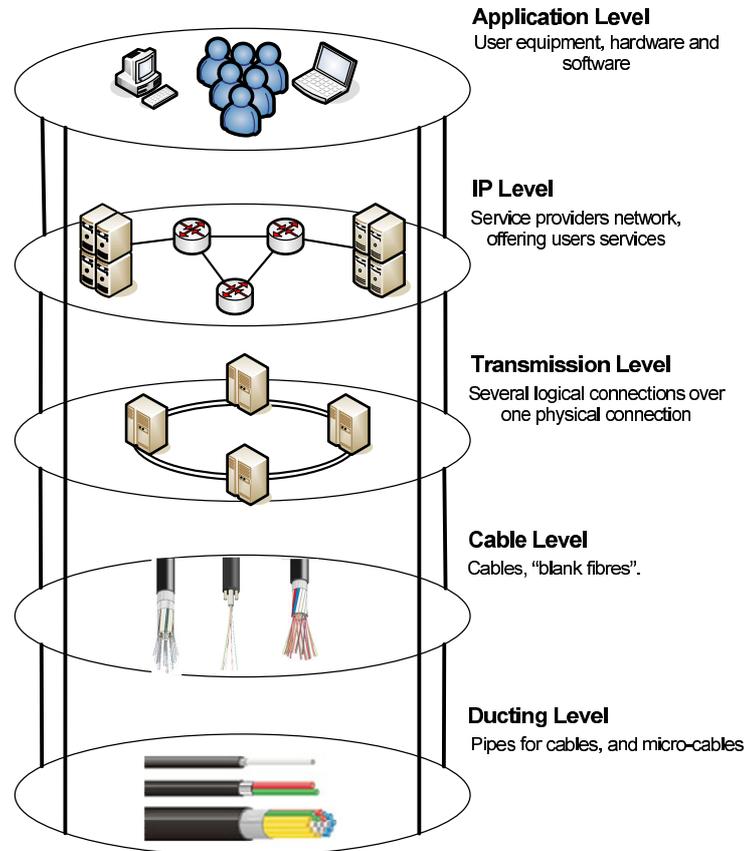
Figure 2.3: Network architecture levels.

Ducting level

This level holds the ducts and pipes for cables. The expected lifetime of this level is 30-40 years. This is the level that needs most planning, because one of the most expensive parts of creating a fiber network is the digging. The lifetime of the material is long, so the planning should be made with the long lifetime in mind. When planning, it is important to utilize the digging effectively in order to circumvent later excavation and digging. This also involves placing enough pipes so further extension is possible without having to excavate again. According to [17] there is one level below ducting level called trace level whitch corresponds to planning and allocating the space to dig. But that layer will be combined with the ducting level.

Cable Level

This level holds the cables and air blown fibres. The expected lifetime is around the same as for the pipes. In the future the need for more bandwidth might be possible thus the planning of fibers should incorporate easily replaceable fibres, so that old fibers can be replaced with newer fiber. This way by replacing the cables it can hold to the physical lifetime of the pipes.

Transmission level

The transmission level is where number of logical connections are connected to one physical connection, this means a number of services used on each cable. This is where the switching equipment is placed. The lifespan of the equipment used depends largely on the technologies existing each time. Implementation and changes in this level are fairly cheaper than in the lower level as there is no infrastructure on this level, so changes or implementation only means changing or implementing equipment.

IP level

This is where different service providers connect to the IT-infrastructure. The service providers are those offering the service to the customers through the fibers.

Application level

This level holds the NT's, these are the users that buy the service provided by the level above. This can be TV, Internet, IP telephony and more. The main issue in this level is whether the levels below have the capacity to offer the services being offered.

The goal of this project is to create an automatic planning process of access networks with and without redundancy. The main idea is to automate the planning process with two or more different topologies and look at them cost wise. This means that the project focuses only on the duct, cable layers and somewhat on the transmission layer. The layers above will not be discussed or reviewed. This is due to the fact that this project is only focused on laying a network in different methods but not the functionality of it.

2.3 Fiber optic

This section only explains the fiber technologies which will be considered in this project, further background and explanation of fiber technologies can be seen in Appendix A on page 122.

2.3.1 FTTH access network infrastructure

The definition of an access network can be thought as set of equipments and infrastructure in order to create a connection between the network termination points (NT's) and central offices (CO's). There are two infrastructures available in today's FTTH networks. First is the home-run method, where a dedicated fiber is planned from the CO's to each NT's. This means that huge amount of fibers is needed as a pair of fiber would be planned to each end user and each CO would have vast amount of fiber. Figure 2.4 on the next page shows the home run method.

The second method is the Passive Optical Network (more on PON can be seen in appendix A.4.4). PON can be used in access networks in order to reduce the amount of fiber needed from COs. A single fiber is split to several subscriber lines or NT's depending on splitting ratio and
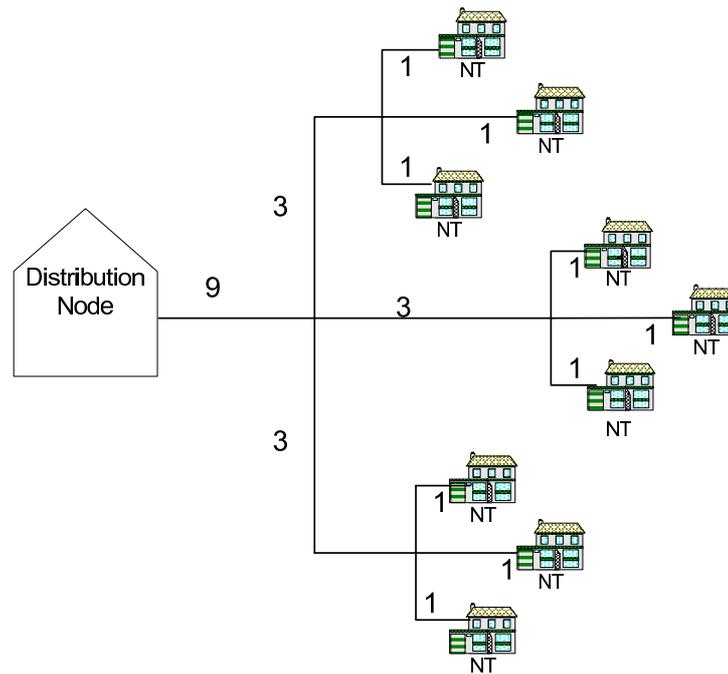
Figure 2.4: Home run architecture.

with the help of passive optical splitters. Since the splitters are passive there is no need for power supply or maintenance. PON is usually done in levels and figure 2.5 shows PON with 2 levels. It is obvious from comparing home run and PON that the home-run method requires
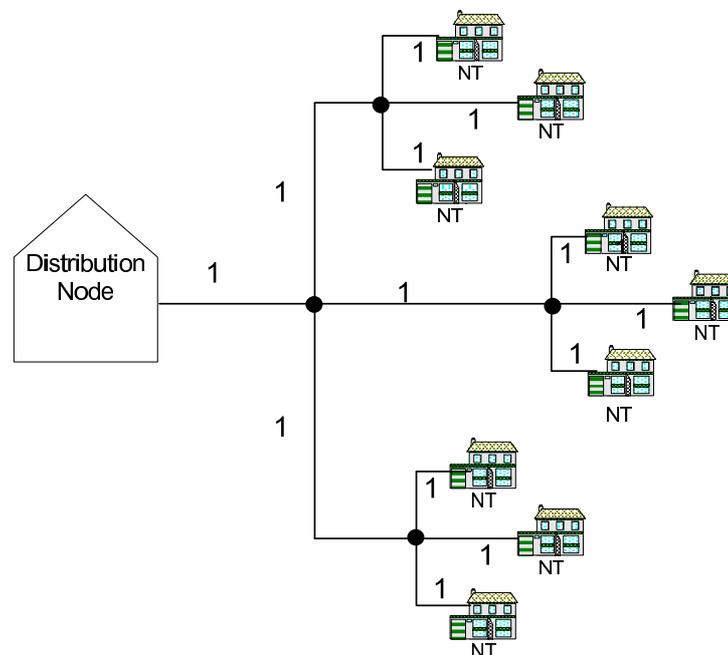
Figure 2.5: Pon Archtecture.

more fiber and more termination which are both cost factors. PON would require man-holes or street boxes in order to store the optical splitter. Though home-run method would also require manholes or street boxes in order to accommodate for the maximum blowing distance of single fiber of one km, there would be greater amount of manholes needed for the PON. More expen-

sive equipment would also be necessary for PON as it would require a more complex equipment both for NT's and in CO's in order for PON to function properly.

Another factor is that in case of a digging accident, 2 fibers serving 96 NT's would be cut and only need to re-splice 2 fibers for PON. With home-run the same cut would sever 96 fibers serving 96 NT's, so it would take longer time to fix with home-run than PON.

Lastly the bandwidth is a factor because with several NT's sharing a fiber it's obvious that it would offer less bandwidth than the home-run method. More research has been done into DWDM so that each user could have it's own wavelength by virtually creating fibers to each user and acquiring acceptable bandwidth to NT with PON. A PON with WDM (More on WDM can be seen in A.4.2 on page 128) could offer enough bandwidth to sustain the future requirements of bandwidth [24].

Though the analysis of the difference between PON and home-run clearly indicates the superiority of PON is still of interest to view both home-run and PON in this project. Practically planning the networks with both home-run and PON can give the results on just how much the difference can be. Also as cost of fibers are rapidly decreasing the difference can be lower than what initially was thought.

2.3.2 FTTH access network topology

The most basic idea behind network topologies is to explain a network and is determined by the configuration between the nodes in a network. It can be said that network topologies are a part of graph theory. Network topologies are only a means to view a network without other variables. While some network topologies show simple means in connecting a network, other network topologies are more focused on offering redundancy and availability in a network. There are several amount of network topologies available, however it will not be detailed here. For further information regarding network topologies and graph theory see appendix B on page 131.

The focus here will be on available access network topologies. Today most networks are planned in such a manner that the access network is created in a cheap manner and without redundancy. This means that a tree structure topology, as seen in figure 2.6 branches out to each NT in the shortest and cheapest way possible. It is clear that this type of network topology offers no redundancy so in case of a line break near the root of the tree, it would cause several NT's to be affected. Not much research has been done into offering redundancy to the access network level as it would be too expensive. A new topology designed for the access network might be able to offer redundancy by cutting cost with it's design. Figure 2.7 shows the ear topology and with it's design it cut costs by reducing the extra digging needed. Here two fibers are planned to each NT's from two different distribution nodes creating a closed loop to each NT's and therefore redundancy. In case of a failure the NT's can switch to the active line keeping the connection available as can be seen in figure 2.8 on page 22. The digging is then done by placing the fibers in the same trench but coming from opposite directions reducing the cost of digging. There is a golden rule to be used with the ear topology which is: **Trenches can**
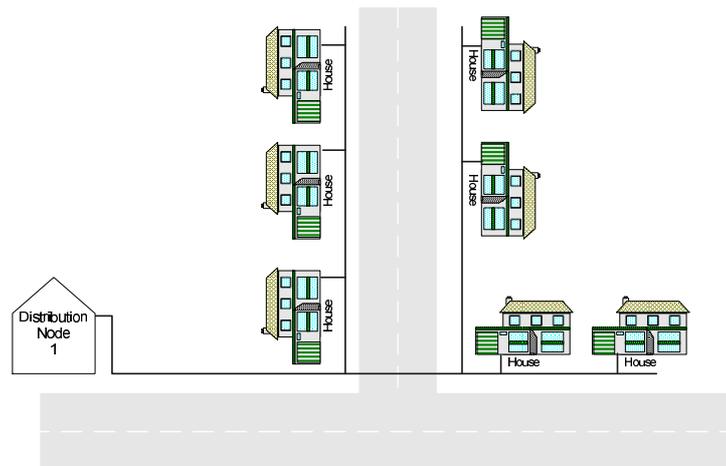
Figure 2.6: The tree topology.
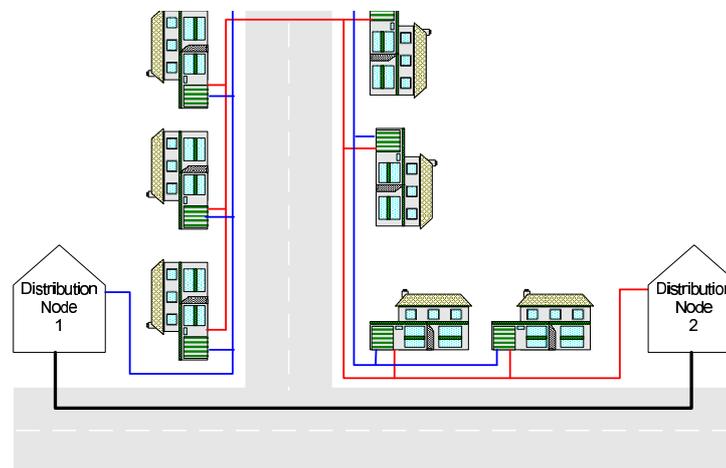
Figure 2.7: The ear topology.

never be shared in the same direction to or in the same districts, if this was to be broken it would avoid the redundancy.

This has clearly been backed up by another research on practical planning of the ear topology [9]. That study also revealed that vast amount of fiber is needed causing the cost to almost double. In that study the network was manually planned and only with home-run. It is of interest to automatically plan the network here in order to try reducing the fiber amount needed both with home-run and PON (more on PON can be seen in A.4.3 on page 128).

This project also introduces a new technique, which is the combinations of two previously mentioned topologies, the tree topology and the ear topology. The new topology referred hereafter The Eartree topology utilizes both ideas, that is from the DN to splicing points[1] and the ear topology. The eartree topology can be seen in figure 7.3 on page 48 and 7.4 on page 48. That means that each splicing point would have two separate fibers from two separate DNs causing

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[1]Splicing Points is a a point from which the fibers from the DN or MN is distributed, this is also sometimes called POP.
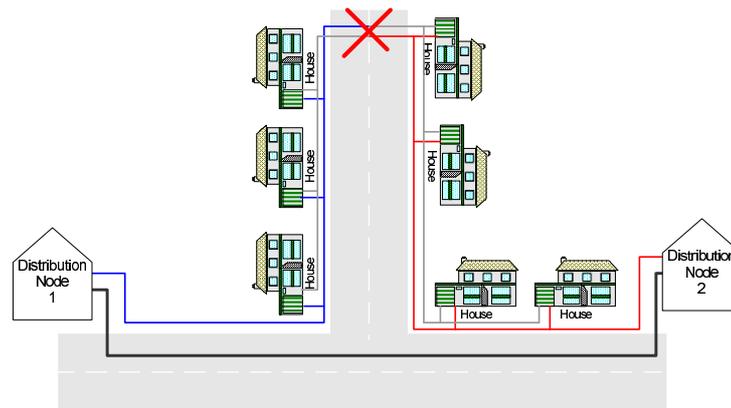
Figure 2.8: The ear topology with single point of failure.

the splicing point to be redundant. From the splicing points to the NT's the tree topology is used, that is only one fiber per NT. So the main amount of extra fiber shown in previous study of the ear topology is addressed. It is obviously not as redundant as the ear topology but that loss of redundancy is minimized as the most important part of the way is redundant but only a small amount of NT's could be affected in case of a line cut. Worst case scenario in a line cut of the eartree topology would be that 96 NTs would loose connections, that worst case zone is fairly small.

It should be noted that the golden rule mentioned before for the ear topology can not be broken in the case from DN to splicing points. However it is not as strict as for the ear topology because from the splicing points to the NT's is only tree structure so the trenches can be reused.

2.3.3 FTTH access network factors

Like explained in chapter 2.1 on page 14, there are five factors which need to be considered while planning a network. Though this project has main interest in the cost factor. The environment and geographic factor which are explained in chapter [4] play also an important role. Information regarding the location of the planning and number of NT's and such surely affects the cost. The traffic factor will not be daitailed here.

So the three remaining factors are the structural factor, the cost factor and the technology factor which is tied with the structural factor. They are explained as follows:

Technology and structural factor

As it has been explained throughout this section the technology used will be fiber. There are however a lot of possibilities when choosing the technology to use with fiber, this consequently ties itself with the structure in the manner of choosing ducts, digging and so on.

There are a lot of things which need to be determined in order to assure that the right type of fiber technology is used under different circumstance, which affects the cost factor. These

are:

- Fiber type

- Fiber laying type

- Fiber laying method

- Ducts to use

- Splicing method

- Splicing points

- Digging

Appendix E on page 155 explains in detail the possibilities available for each item listed above. An analysis of each item is made and drawn a conclusion to which method suits best and the guidelines are created. Analysis and guideline were created for a previous project [8], which this project's research is based upon. From this analysis an updated list of guidelines can be used for creating a fiber network.

Guidelines

These guidelines are updated from the guidelines created in a previous study [8]. A research is also done for the guideline, further explained in Appendix E on page 155 .

Fiber Laying

- Type: Duct cable or direct burial cable (DN-to-SP)

- Method: Blowing

Ducts, fiber and digging

- Enough ducts need to be placed for possible expansion

- Fiber: Loose tube system

- *Ducts DN-to-SP: Direct burial cable*

- *Ducts SP-to-NT: Duct cable - Large PVC with smaller tubes*

- *Splicing points: Placed in NT districts to connect NT's to main duct.*

- *Maximum splicing point number: 96 or 192 fibers*

- *Maximum splicing point distance: 1000-1200 meters*

- Must incorporate all possible connection

- Splicing method: Fusion splicing

- Splicing point: Street box or wells depending on district size.

Cost factor

From the guidelines and all the factors the estimated cost for all the variables can be explained, again this is based on the previous projects [8] [24]. As previously explained the automating planning process will first focus on creating the scenarios based on reducing fibers and introduce a new scenario which offers redundancy but with less fiber cost affect as in ear topology. This means digging cost, housing and equipment (which is tied to the traffic factor) will not be added until phase two. This should not affect the main estimation in phase one as the main problem in the previous study was the amount of fiber needed. The previous study clearly showed that the ear topology works by reducing extra digging cost. Phase two will try to incorporate as much of the relevant cost factors to it's data in order to view the whole cost affect on each scenario. But again the cost data will be based on the two sources previously mentioned.

2.4 Geographic information system (GIS)

A map can be used to represent real things that are in the real world, for example, roads, rivers or buildings can be represented in a map. This map information can be stored in a digital form in a system like GIS. The GIS software helps to display digital map data and allows users to query and analyze that data. Storing a map in GIS can make maps easier to store, reproduce and update the information.

As GIS data can store roads, rivers, bridges and other structures it is ideal for network planners to use. Network planning with GIS data makes it easier to locate possible places through population density for Central offices or nodes. As well as placements of pipes and lines for the communication infrastructure. For further information regarding GIS see Appendix C on page 137.

2.5 Automated network planning

As stated before in previous study the network was planned in a manual way. Manual planning has a lot of drawbacks, i.e. it takes more time, more cost, and mistakes are easily made. If an access network is planned automatically it can reduce the degree of problems and drawbacks, that can be observed in a manual process of planning an access network. A recent research [25] shows a method on how to automatically plan a network, where GIS data and a set of algorithms was used to make the planning process more automatic.

Network objects are modeled as nodes and links. The network model contains logical information such as connectivity relationships among nodes and links, directions of links or segments, and costs of nodes and links. With logical network information, it is possible to analyze a network. For example for a road network, it is possible to find information like the shortest distance between two nodes, and to find out the closest node for a specific network termination point.

2.5.1 The digital road map

When planning an IT infrastructure a digital road map can be used for approximating the trace level in the level of the IT infrastructure[17].

For example, one type of digital road map describes the middle of the road as a set of interconnected line segments and associated set of attributes like:

- Road number

- Municipality id

- Address guideline information

Figure 2.9 shows the use of GIS vector maps is a useful tool for extracting the most interesting properties of a network, such as node degree, crossing points, segments lengths and distance between segment points or any other related. To do the automatic planning method a set of sce-
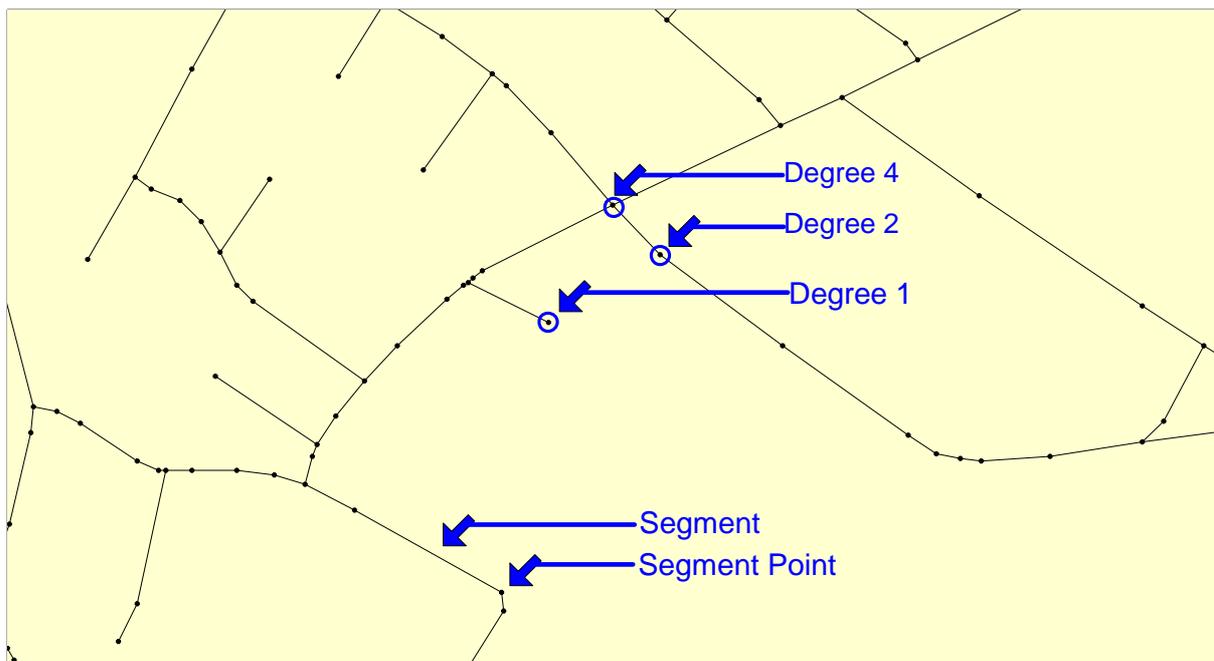
Figure 2.9: GIS Vector Maps [17].

narios are created for automating the planning process. The planning is done for each scenario separately.

Case Study 3

3.1 North Jutland county

The county of North Jutland is located in Northern Denmark with an area of more than 6,000 square kilometers. The County of North Jutland is the largest province in Denmark. There are just under half a million inhabitants distributed over the region's 27 municipalities with approx. 17,000 employees which makes North Jutland one of the largest places of work [4]. Figure 3.1 Northern Jutland is the top most IT sector developer in Denmark. Due to this the Danish

Figure 3.1: North Jutland County.

government is investing a lot of funds for this region. For this investment a special IT project was constructed called the digital North Denmark

3.1.1 The digital North Denmark

The digital North Denmark is a regional IT project, which is to run over a period of 3 years with a funding of DKK 170 mill. granted by the Ministry of science, technology and innovation [5].

The objective is to explore the potentials of the network society for all citizens of North Denmark. This is done via 89 various IT projects within different themes. One of the themes is IT infrastructure. The IT infrastructure theme has four projects. i.e the NT net, the access net, the transport net and facilities for access, storage and distribution of information [26].

One of the major projects is Nordjysk netforum. The main objectives of Nordjysk netforum is a long-term strategy and development plan for the North Denmark regional IT infrastructure. The intention is at the same time to let Nordjysk netforum act as centre of competence in the field of IT infrastructure [17].

In order to meet the demands of the next technology applications that needs high bandwidth, the present structure of the networks should be restructured, so that FTTH has to be established within the next 10 years, in order to meet the demand for next generation services.

According to the digital North Denmark, special emphasis has to be invested in planning methods in order to implement a new fiber based infrastructure covering all citizens in an economical realistic scale and to ensure that the future needs for QoS is supported.

3.2 Municipality of Hals

Hals is a municipality in North Jutland county on the east coast of the Jutland peninsula in Northern Denmark. Figure 3.2 shows the locatioān of municipality of Hals according to Northern Jutland. Neighboring municipalities are Brønderslev, Aalborg to the west and south, and
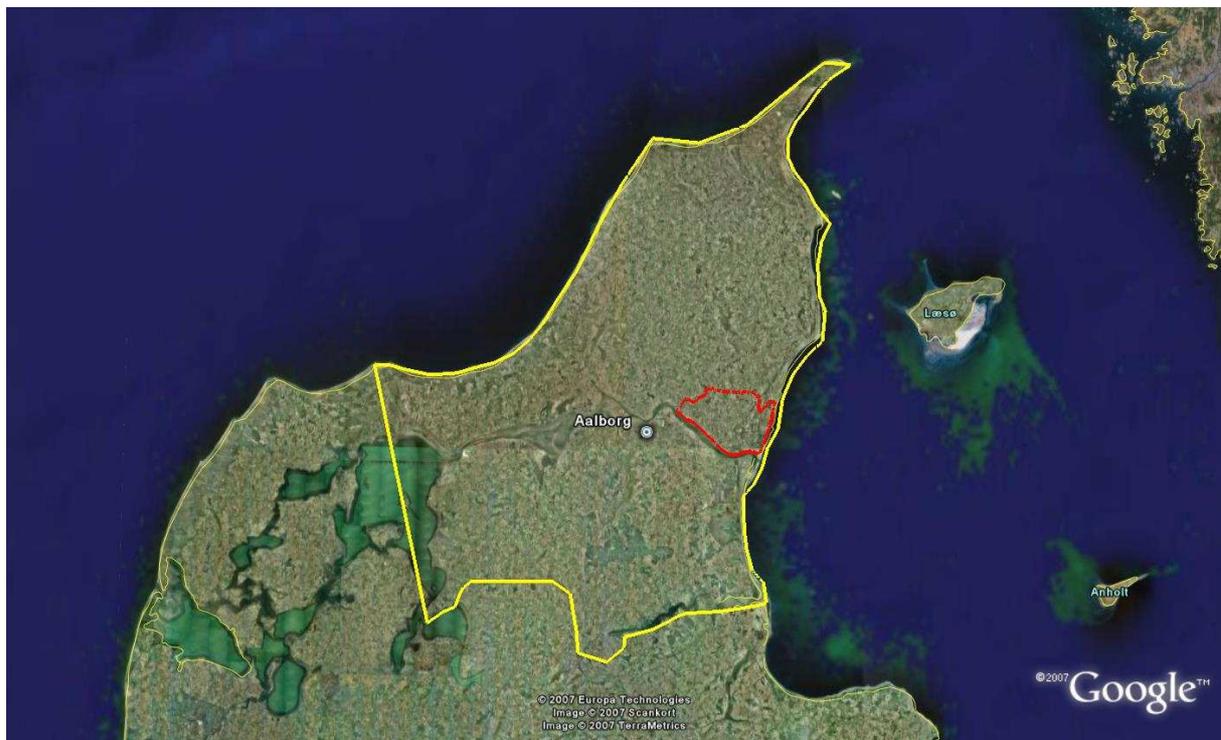
Figure 3.2: Municipality of Hals.

Sejlflod to the south. The municipality covers an area of 191 square km, and has a total population of 11,257 [10].

The Municipality has 3500 households, and around 3400 summer houses. The municipality

has 6 towns namely Hals, Vester Hassing, Gandrup, Ulsted, Hou, and Stae. Table 3.1 shows the population in the 6 towns.

Town	Population
Hals	2378
Vester Hassing	2255
Gandrup	1485
Ulsted	1057
Hou	709
Stae	414

Table 3.1: Inhabitants by March 2005 [10].

Hals is the biggest town, but the site of it's municipal council is the town of Gandrup. The geographic locations of the towns in the municipality is shown in figure 3.3. The municipality
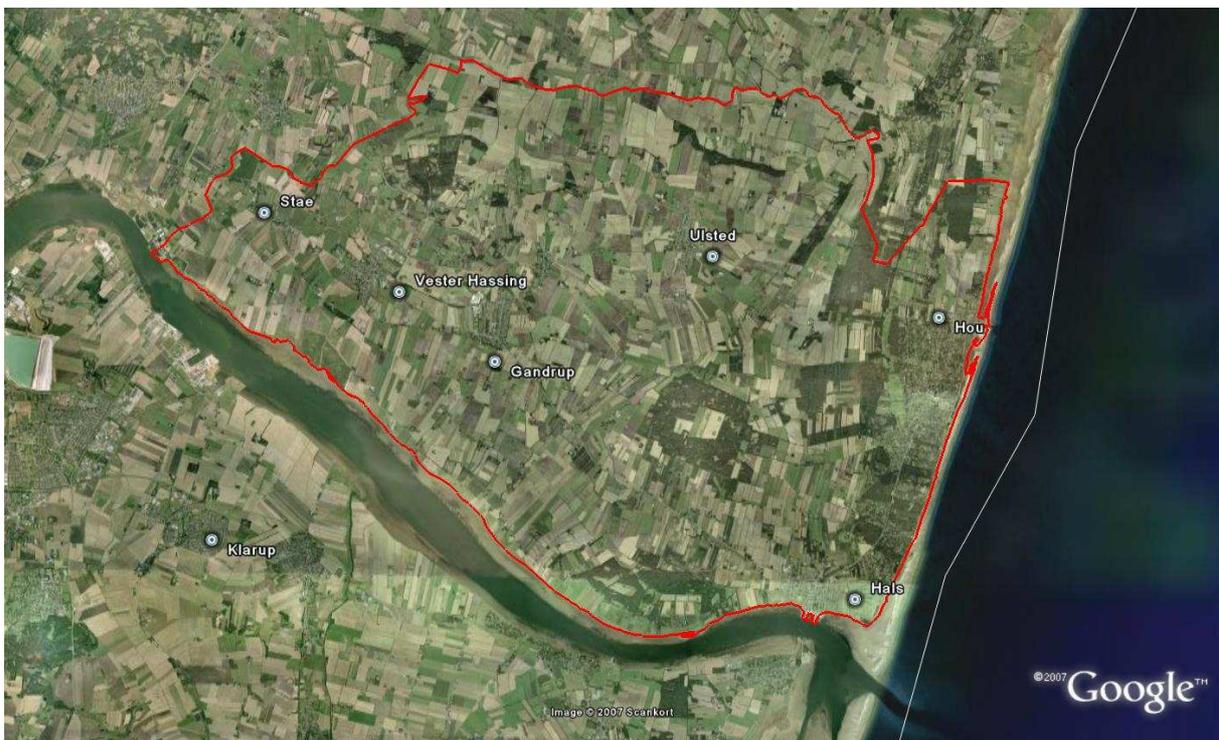
Figure 3.3: Geographical locations of the towns.

has around 49 public institutions and 604 workplaces that include both businesses and agriculture, for which 346 have more than one employee. Seven of these businesses are considered most important. The private households, public institutions and business are mainly situated in villages while the agriculture is more spread out.

Like other places in Denmark the municipality has the same number of percentage of people between 0-5 years as the rest of Denmark. But the growth in this group is lower in Hals than the rest of Denmark as well as the county of Northern Jutland. But on the other hand, the group of inhabitants between 6 and 16 years is larger than in the rest of Denmark, provided that the

growth is a bit slower than the average. The average age is 67 years and there is less of people in this group than in the rest of Denmark [10].

Figure 3.4 shows the population projections for Denmark, the county of Northern Jutland and the municipality of Hals. The graph shows the next 24 years of population projection for Denmark, Northern Jutland and for the municipality of Hals. As shown in the graph the population of the municipality is increasing for the next 24 years so that it needs a careful attention for planning the IT infrastructure.
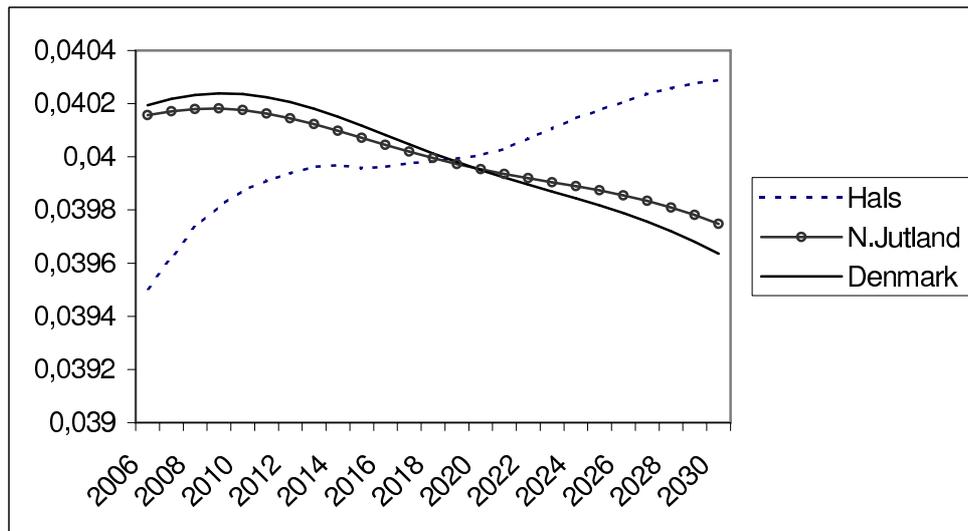
Figure 3.4: Population projection for the next 24 years [1].

3.2.1 IT infrastructure in the municipality of Hals

As the municipality of Hals is a part of the Northern Jutland that supported several IT projects, the IT infrastructure in the municipality must be restructured. To do that in the following section the existing geographical environment (including population and location of roads) is presented to give a systematic plan for the FTTH technology.

Knowing the densely populated area in the municipality gives information for deciding where to place the distribution nodes in the area. Also knowing the road network gives the same information for running the fiber optic on that path. Identifying the heavily populated areas in the municipality is done by griding the GIS data based on Network Termination (NT) points. The distribution of the NT's in the manucipility of Hals is shown in figure 3.5 on the next page. There are different sectors in the municipality, like the public sector, the private house holds, the business and the agriculture sector. The project will not distinguish between them.

3.3 Distribution network

In order to plan an access network some knowledge of upper networks is needed. This mostly entails the need for information regarding the distribution network, including the location of
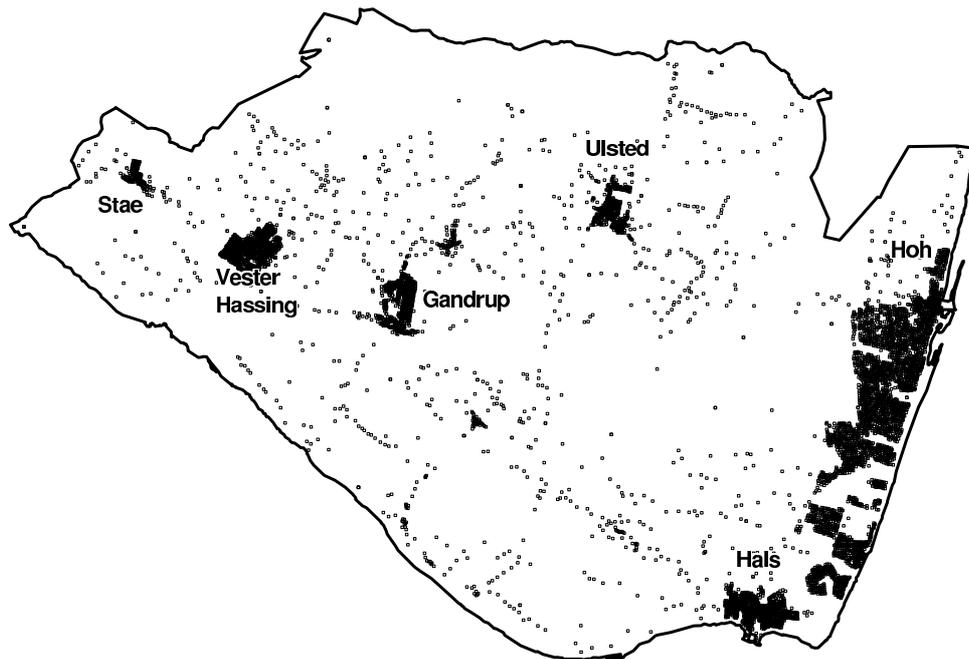
Figure 3.5: NT distributions in Hals.

the distribution nodes. Normally as access networks have been planned with a tree topology there is only need for one distribution node (DN) which is generally placed in the most densely populated area. Building and supporting a house can be quite expensive, but the solution could be to use existing houses like Tele Denmark (TDC) central offices.

TDC central offices

TDC is the largest telephone company in Denmark. The central offices that are placed by TDC are placed in a densely populated areas in the municipalities. Therefore when looking at locations for distribution nodes in the municipality it has advantages to opt to use the central offices that are build by TDC. The first advantage is, since placing a distribution node needs a building as well as a switching equipment placing the distribution nodes already in the TDC central offices is a benefit. The second advantage is TDC is obliged by the Danish national Tele and IT agency to rent a CO to external service providers, the price for renting the different CO's are in some way of regulated. Figure 3.6 shows the TDC central offices in the municipality of Hals.

As this project focuses also on redundant access network topology two independent DN's can be required. There are four ways to solve thit problem. First one location can virtually create two location within it's housing. Second two TDC CO's could be used to service that need. Thirdly, two buildings could be built in separate locations depending on the need of the topology. Finally a combination of a new building and a TDC CO can be used.

DN: One location

As has been stated in chapter 2.3.2 on page 20 the ear topology needs two distribution nodes to function. In order to compensate for the scenario with only one TDC CO available within a
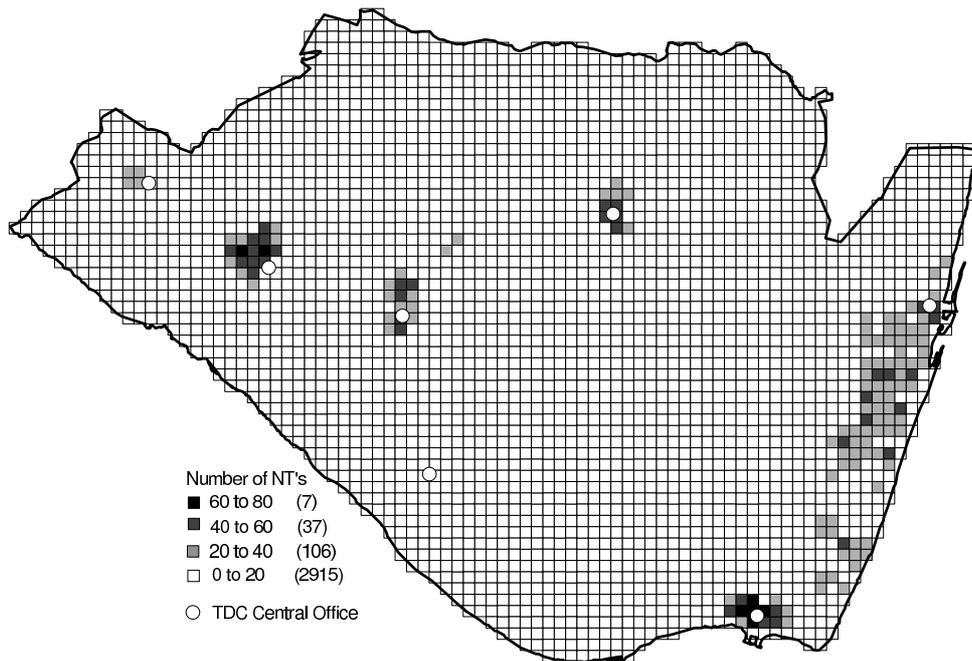
Figure 3.6: NT weight distribution with a grid size of 250m. Also showing TDC Central Offices.

reasonable distance, two separate distribution nodes are created within the same housing. This means that two "virtual" distribution nodes are placed in the same housing, this can be seen in figure 3.7. With this work around some off the redundancy is lost as any problems caused in or near the housing would mean total failure of the network, e.g. fire, line cuts in or near the house. It is the most cost efficient. This can also be viewed as a possibility if there is a decision made to build own housing but only use one location.

A previous project [8] already viewed how much it would affect the whole planning cost by
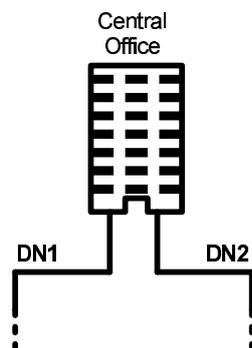
Figure 3.7: 1 CO - 2 DN.

using one housing instead of two. The cost only increased around 5-8% in the whole network planning by adding one house.

DN: Two new locations

The use of one location is not the only scenario which can be viewed. Two location DN's should also be considered, since the ear topology was planned with double ring distribution node in mind therefore having two locations available.

It should though be kept in mind that in all cases for ear and eartree topology two independent path are needed between the two DNs whether in one or two locations. This is due to the fact that ear and eartree topology act as a ring.

DN: Two TDC locations

The third option is to use two TDC CO offices, this option could become problematic for the scenarios as the length between two TDC CO's can be quite long causing excessive amount of fiber being needed and the placement of the TDC CO's are not done with the need for access network redundancy. If the security risk of one location is considered ti be high it could be interresting to view this option against creating two new housings.

DN: Combined locations

The final option would be the combination of using one TDC CO and then carefully place a new housing for each access network. This also could be a viable solution, but again the building and maintainance of the new building is a big cost factor.

The method for planning the network is quite different between the previous study and this one, this is automatically planned versus the previously manually planned. It is still of interest to view how much different it would be to have the DN in one or two locations in order to show that this would be applicable in older network topologies. Though previous study showed that there is not much cost increase between having one or two locations it is of course quite obvious that it is heavily dependent on the location of the two nodes.

Further information regarding geographical location and the solutions used can be seen in section 6.2 on page 39 for phase 1 and in section 10.4 on page 70 for phase 2.

Problem Delimitation

4

The subjects

The "Network planning" chapter gives an introduction to network planning and the typical problems associated with it. The key subjects of network planning aspects, level of service, fiber, access network infrastructure, access network topology and access network factors were chosen and described in more detail among other more common items. In the "Case study" chapter the North Jutland county is explained and then narrowed down to the desired area of Hals. Furthermore the distribution network and the different possibilities available to accommodate the redundant access network topology needed is explained.

The delimitation

The project is devided into two phases, phase one starts by creating the automation according to previous study. While phase two will focus on reviewing the most plausible options gotten from phase one. This is to create a cheap redundant alternative usable in today's infrastructure scheme. The following is a list of the subjects described in the two phases, however all subjects will not be treated thoroughly:

- Network planning aspects
  Phase one: The only planning aspects which will be considered in phase one is the cost factor, and then mainly fiber cost. Environment/geography, technology, structures and traffic will not be considered as we want to review only the cost factors in order to determine the feasibility.
  Phase two: In phase two all the avilable cost factors will be reviewed and the traffic factor will be introduced.

- Network architecture
  Phase one and two: The access network is the main network which will be reasearched. Some knowledge of the upper layers is needed, this being the location of the distribution node. The main network is not considered at all.

- Level of service
  Phase one: The projects interest falls only on the duct and cable layers. The reason being that this project is only interested in laying the fiber cost but not the functionality of it.
  Phase two: As for phase one the project interest fall mainly to the duct and cable level. But some part of the transmission layer will be considered though mainly what equipment is needed within the distribution node.

- Fiber Networks
  Phase one and two: The type of fiber network investigated will only be FTTH. The interest only lies in creating an all fiber network.

- Access network infrastructure

  Phase one: Both home-run and PON infrastructure will be reviewed in this project.
  Phase two: Depending on the result from phase one the more viable solution will be chosen, if both show prospect, each in it's own way both will be chosen.

- Access network topology

  Phase one: Both tree topology and the ear topology will be reviewed. The project will include investigation into additional access network topology, called ear-tree topology.
  Phase two: Depending on the result from phase one the viable solution to offer in today's network infrastructure will be chosen.

- Access network factors

  Phase one and two: The network will be created with the set of guidelines explained.

- Automated network planning

  Phase one: Previous project has researched if offering redundancy is feasible costly wise. That planning was done manually, so it is of interest to duplicate that process in an automatic fashion to view if it is possible to decrease the fiber needed.
  Phase two: Based on results from phase one, phase two will finish the automatic process as there will be parts left out of phase one. As well as making the process more dynamic to be used with any kind of scenario.

- Location

  Phase one: Will only look into one town in the municipality of Hals. As previous study has used Vester Hassing, this town was chosen as the small scale test grounds.
  Phase two: Will take the results from phase one and plan it on a more large scale test, where the municipality of Hals in whole has been chosen. From this, with few modifications, other locations can be used.

- Distribution node housing

  Phase one: Already available TDC central offices will be used instead of creating new housing. In case of two distribution nodes needed, it will be virtually created within the same housing. The other case where using two distribution nodes located in two different locations, the project will create two housings. This is done to be able to compare to previous result.
  Phase two: Will only use one location as this would be the most viable solution to offer in today's IT infrastructure. But it's also dependent on the results from phase one.

Through the previous delimitation the problem domain of the project has been narrowed making it possible to formulate the goal of this project in the next chapter.

Problem Description

Project goal

The project is divided into two phases with separate yet similar goals where the results from phase one will assist in creating phase two.

Phase one

The goal of this phase will be to evaluate the feasibility of offering redundancy to the access network with automated network planning with respect to cost and in comparison to previous study. To achieve this goal, three scenarios will be created in the phase. The first scenario will be to create a basis for the evaluation of the project. This is done by planning the access network in the most common manner with tree topology in the town of Vester Hassing. The cost of this planning will then be calculated and gathered. The second scenario will be to plan an access network in the town of Vester Hassing with the ear topology. The third scenario will be planning the access network with ear tree topology. As opposed to the commonly used tree topology the ear topology offers redundancy to the access network and has been shown to cut the cost by reusing trenches. Previous study showed excessive amount of fiber usage which will be mainly addressed within this phase. The cost of planning the second scenario and the third scenario can then be gathered in order to compare to the first scenario. Different access network infrastructure will be tested in order to come to a conclusion in which manner it would be feasibly, costly wise to offer redundancy in the access network regarding to fiber.

Phase two

The goal of this phase will be to take the results from phase two, and plan the network on a larger scale. Some aspects of automation process will be left out in phase one, but will be dealt with here. The main focus on phase one is to try several methods to decrease fiber in the access network. As previous study shows that excessive amount of fiber is used in the redundant access network topology. The tests which shows good promise of offering redundancy in the access network will be chosen.

Phase one focuses on creating these tests, in a controlled small scale testing, therefore phase two will plan the network on a larger scale, to view the full effect. The small scale testing in phase one is done based on a previous study, some larger aspects of the automation process will be done manually and dealt with in this phase. This includes the district and splicing point placement, which accompanies with the large scale testing, it will be the main focus. At least two scenarios will be done, one basic which will again be the tree topology and a second redundant topology. If decreasing fiber is successful in phase one, both ear and eartree topology will be investigated. Finally a calculation of the scenarios will be done where more cost factors are included.

A second goal of this phase will be to investigate the traffic in the network, based on different

distribution network topologies. This part does not affect the network planning aspect, but is rather done as a learning experience.

Part II

Phase 1

Phase 6 1

This chapter will analyze the theory and parts used in this phase, before revealing the scenarios. The chapter will start of by showing the area where the planning is made, from that the districts and splicing point method is explained. All of this will be explained and shown with the help of GIS data (see appendix C on page 137) and mapinfo (see appendix C.5 on page 140).

6.1   Location

From chapter 3 on page 26 the town of Vester Hassing in the municipality of Hals has been chosen as the testing ground for planning the access network. The reason why this area has been chosen is mainly due to two factors, first in order to be consistent between this study and a previous study on the same subject. By holding the consistency between the two studies a comparison can be made. The second part is that the area is in fact ideal for study of this kind, it is an ideal size layout but also has difficulties so often portrait in the road network.

Because municipality of Hals is a combination of both dense residential areas and more rural farming areas boundaries were created to only the more dense area of Vester Hassing. So with these boundaries the area gives us an excess of 830 NT's spanned over 1 square kilometer area. Figure 6.1 shows how Vester Hassing is represented in mapinfo with the help of GIS data. Figure 6.2 shows Vester Hassing from a satellite photo.
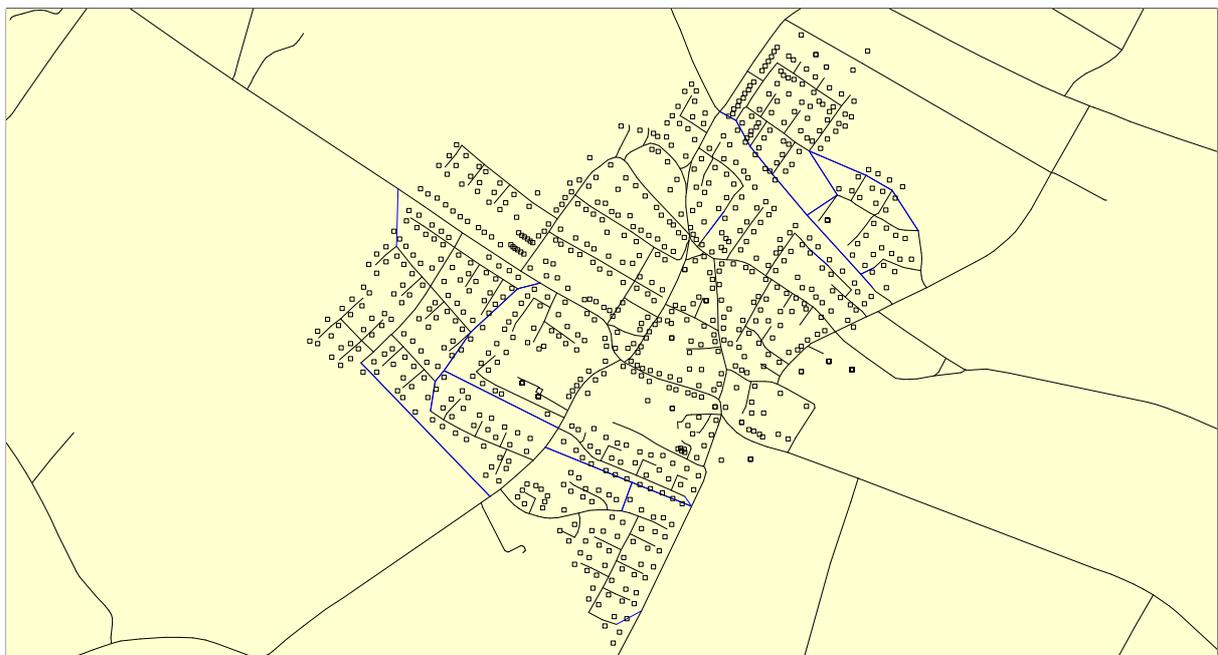
Figure 6.1: Vester Hassing as presented in mapinfo.

Figure 6.2: Vester Hassing from a satellite.

6.2 Distribution nodes

As explained in a previous chapter some knowledge of the upper network layer is needed even if the planning involves only the access network. Mainly it is the location of the distribution node or nodes so it is possible to determine the starting point for the network. Now like in the previous study [9] two possible scenarios where chosen. First with one location available and the second with two location available.

The ear topology and eartree topology for that matter are planned in such manner that two DN's are needed like explained in chapter 7 on page 45. It is of interest also to view it from one location in order to see how possible it is to integrate into today's network where in most cases only one DN is available within a decent range. Where as studies in double ring, N2R topologies utilize more housings (as they have more nodes) than previous for example pyramid or mesh topologies. When creating such networks two locations can be used without adding much distance.

Figure 6.3 shows the location of the one housing which is a TDC central office. Figure 6.4 shows the location of two housing making up the two distribution nodes. The location of the two housings is based upon a previous research of double ring distribution network in Hals, with some modification of moving the housing closer to the town of Vester Hassing.

It should be mentioned that it would be possible to use two TDC central offices where one is located in Vester Hassing and the second in a nearby town. In order to be more consistent in
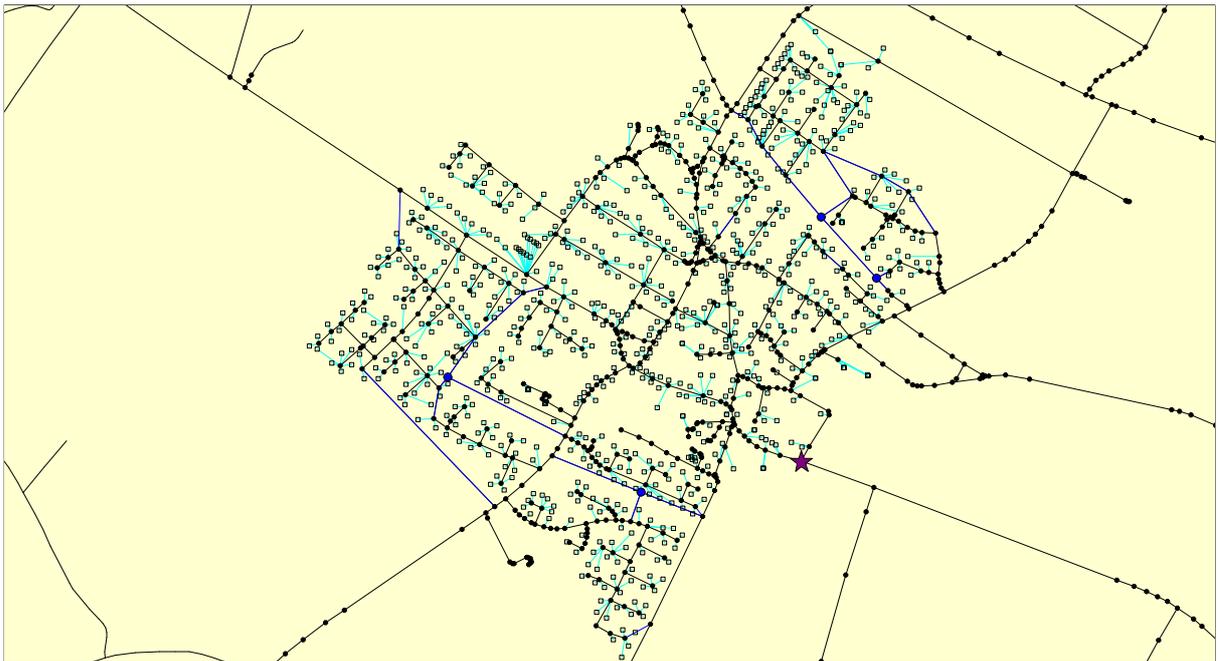
Figure 6.3: Vester Hassing and the location of the one DN.
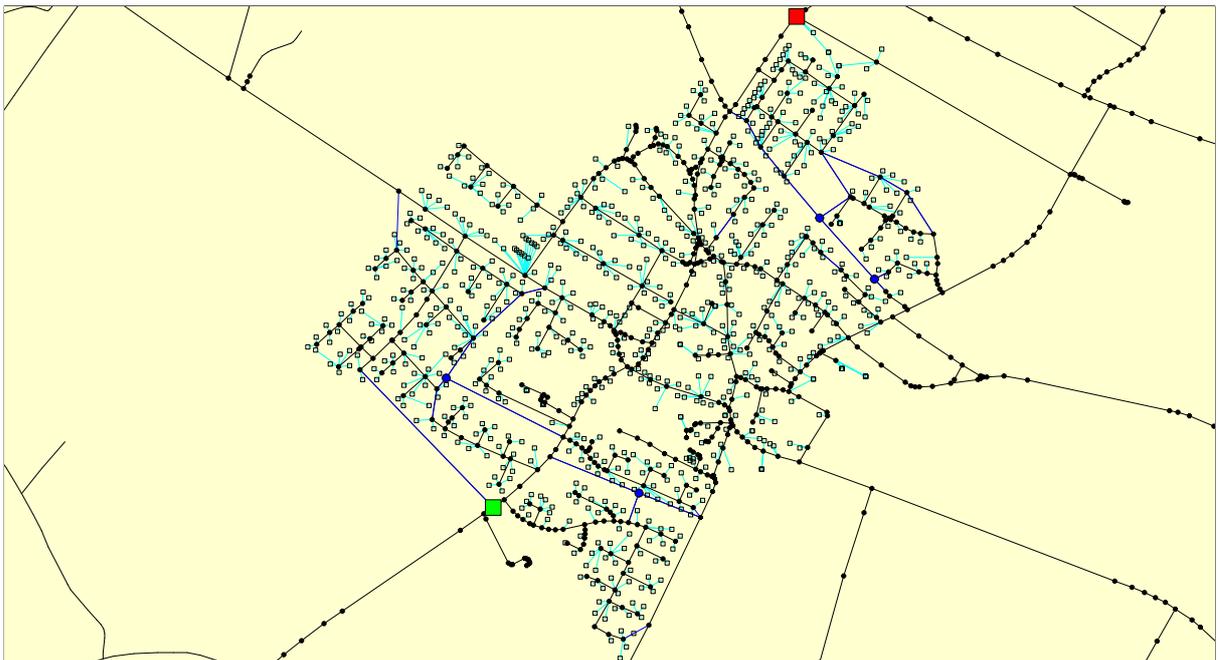
Figure 6.4: Vester Hassing and the location of both DN's.

these testings and the previously created one is used, as well as having them in similar place-
ments (distance) as the one location in this first step.

Further it is important as the ear topology and eartree topology act as a ring that each DN needs
to have at least two independent path to each other.

6.3 Districts

In order to simplify the network planning process and reduce fibers needed, districts within the planning area were created. These districts were created by first distinguishing each road to determine how many NT's are within each road. The guidelines (see appendix E on page 155) created some restrictions on the behavior of creating each district, these are as followed:

- District cannot exceed the limitation of the splicing point of 96 fiber per splicing box.

- District can not exceed the blowing distance of 1 km from one end to the other to avoid the need for extra manholes/splicing boxes.
  It should be mentioned that these rules were created for the ear topology as the splicing points are placed on each opposite end of the district. The tree and eartree topology could have districts within 2 km as the splicing point would be centered making maximum distance only 1 km. The districts are kept unchanged between scenarios to be consistent.

Were created as can be seen in figure 6.5.
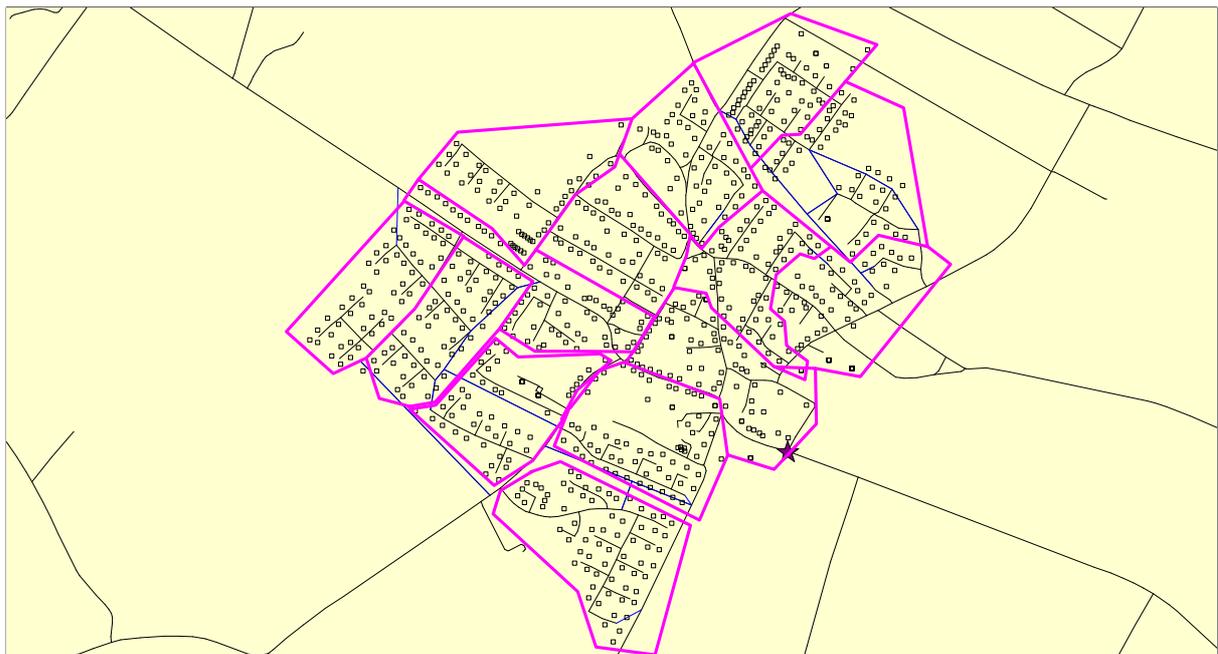
Figure 6.5: Vester Hassing districts.

6.3.1 Remaining problem

This method of planning the districts was done in the previous study [8]. Therefore this is manual planning of districts. To start with it is of interest to use the previously created districts to keep consistency with the previous study in order to do a comparison. This means that the automatic network planning cannot be integrated to other scenarios unless manually creating every district. It is therefore decided to program an automatic way to create districts in phase two of this project, which would be in coalition with the automatic placement of splicing points.

6.4 Splicing points

Asplicing point is a point to connect the districts to the distribution node. By doing so we are able to run a single cable with number of fibers to each district in stead of having large number of cables traveling through the same trench. Also it is cheaper to i.e. having a 96 cable instead of 96 single cables.

There are 2 main ways to create a splicing point, these are:

- Street boxes.

- Manholes, shafts and wells.

As mentioned in appendix E on page 155, street boxes are chosen as the mode of splicing point. The placement of splicing points differ from tree and eartree topology to ear topology. For tree and eartree topology the splicing point is mainly placed in the center of the district offering shortest distances to each NT. This is not possible with the ear topology as the golden rule of ear topology does not allow fibers from each DN to travel in the same direction, so splicing points are generally placed on each opposite end of the district, ensuring that the ear topology rule is withheld. Figure 6.6 shows the location of the splicing points for tree and eartree topology. Figure 6.7 shows the location of the splicing points for ear topology with one location while Figure 6.8 shows the location of the splicing points for ear topology with two locations. The
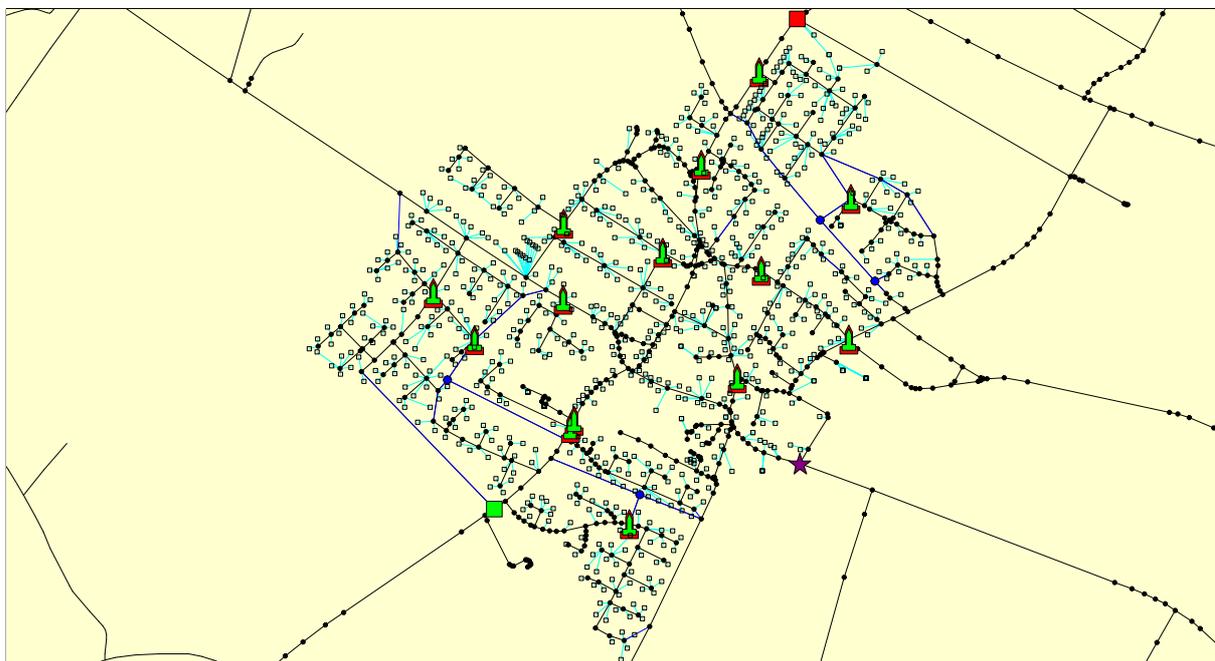
Figure 6.6: Vester Hassing tree and eartree topology SP locations.

reason there is a difference between scenario 2 with one and two DN's is mainly to withhold the rules of the ear topology, in district 8, 9, 11 and 13 the location of the splicing points within these districts had to be switched. This is due to the fact that the two scenarios are in different locations, for those districts the placements of the splicing points had to be switched in order to have each splicing point closest to the corresponding DN in order to ensure that the rule of the ear topology is withheld.
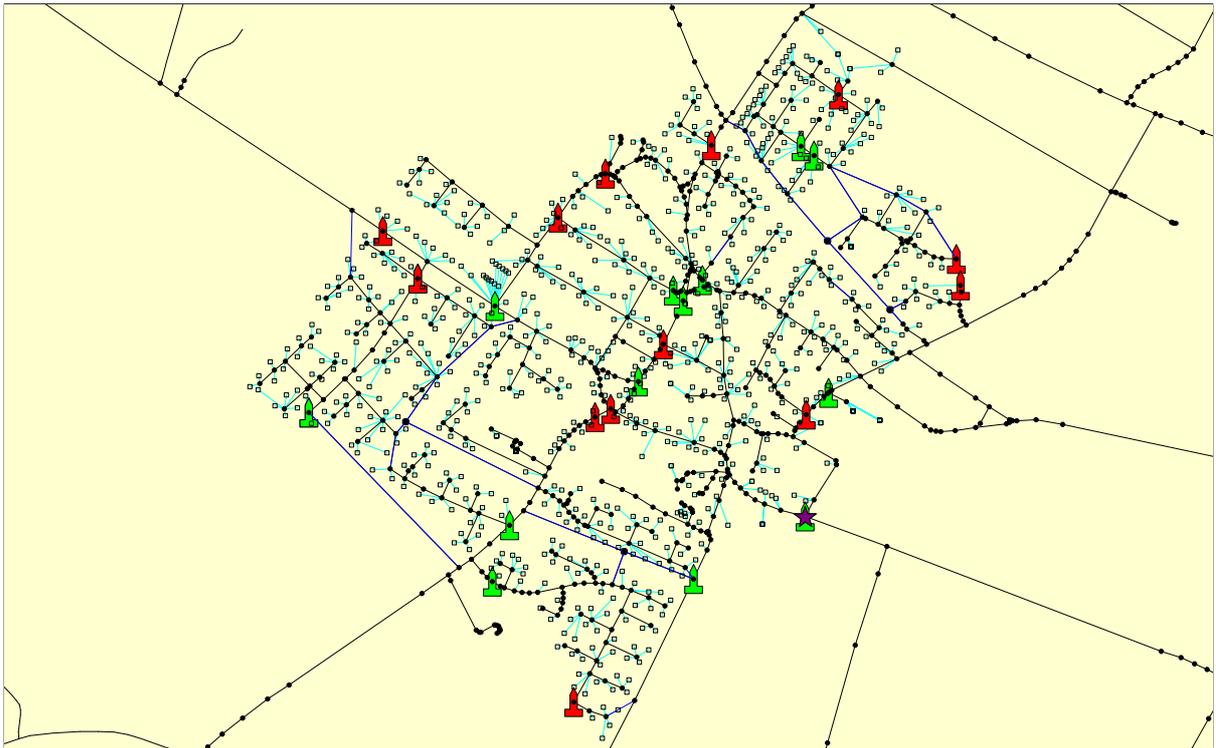
Figure 6.7: Vester Hassing ear topology 1DN - SP locations.
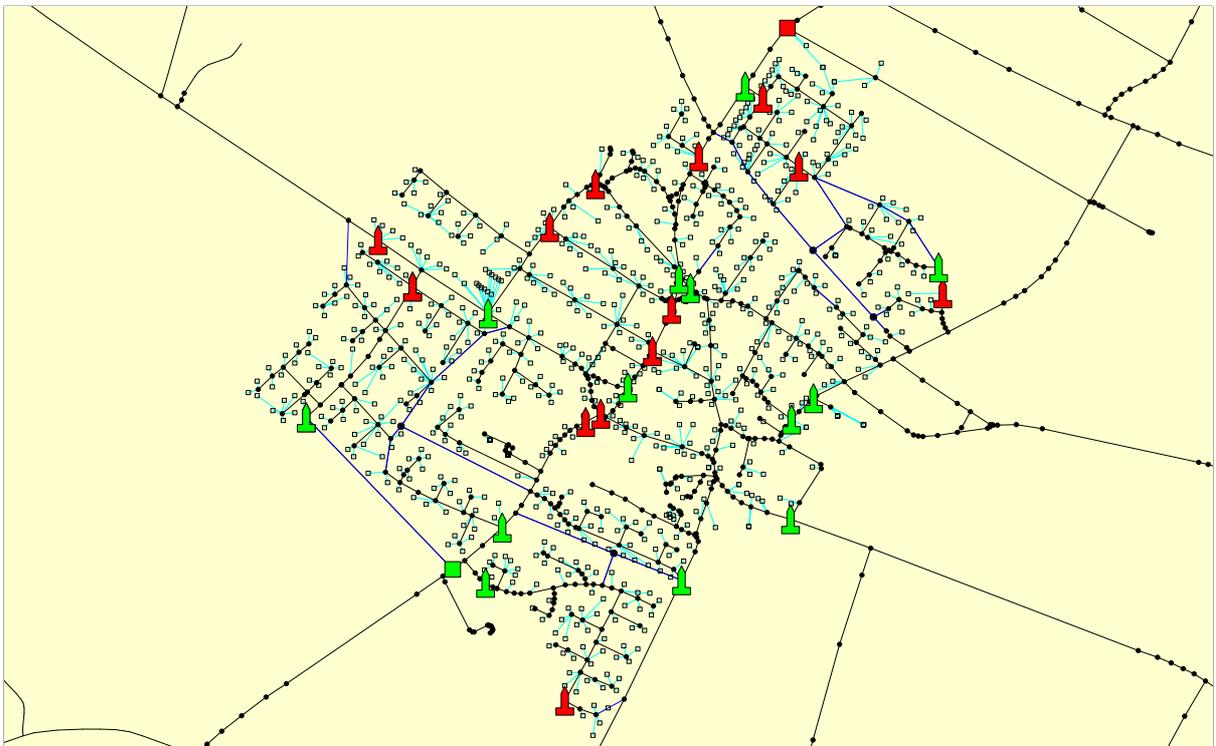
Figure 6.8: Vester Hassing ear topology 2DN - SP locations.

This is quite different from the previous study as the solution there was to withheld the structure and from one DN location travel to the same location as with the two DN's and carry on

in the same way as with two locations. This project deemed that to be unnecessary as will be explained in the next chapter.

6.4.1 Remaining problem

Like with the district remaining problem since the districts where manually planned so was the placement of the splicing points. However this problem is connected to the district problem and since the splicing points are created in the districts therefore this is the same problem and will be addressed when the automation of the districts is created in the next phase.

6.5 Cost

From previous projects[9] [24] and again for this project it is clear that acquiring legitimate and accurate prices is fairly hard as no one is willing to offer estimated prices regarding any part of the fiber technology. This is mainly due to the fact that there is a lof of fears competitiveness in the fiber market. Therefore the estimation prizes from the previous study will be used. There are two prices which are not available in this phase but estimated prices will be used for street boxes, the price of wells will also be used. But as the eartree is just a concept it is impossible to estimate a price for a eartree splitter so that will be left out at this stage. That will give the possibility to compare the results from an automotive process to the manually created one. The estimated prices are listed in table 6.1 and are in DKR.

Variable	Cost [m]/[u]
96 Fiber pairs	54
Fiber pair	4
Blowing of fibers	7
Wells	5000
Termination	300
Splicing	250
Street box	N/A (5000)
PON splitters	200
Eartree splitters	N/A

Table 6.1: The cost factor for phase one.

Phase 1 Scenarios

7

In order to simplify both the reading of this report and the project itself a set of scenario is created. Basically there are three types of scenarios that are considered in this project these are tree topology, ear topology and eartree topology. These scenarios will be explained in this chapter and can be seen in table 7.1.

7.1 The scenarios

There are three scenarios each with four sub-scenarios which are as follows: As it is mentioned

Scenario 1	
Scenario 1.HR.1	Tree topology with home-run and 2DN in the same location
Scenario 1.HR.2	Tree topology with home-run and 2DN in different location
Scenario 1.PON.1	Tree topology with PON and 2DN in the same location
Scenario 1.PON.2	Tree topology with PON and 2DN in different location
Scenario 2	
Scenario 2.HR.1	Ear topology with home-run and 2DN in the same location
Scenario 2.HR.2	Ear topology with home-run and 2DN in different location
Scenario 2.PON.1	Ear topology with PON and 2DN in the same location
Scenario 2.PON.2	Ear topology with PON and 2DN in different location
Scenario 3	
Scenario 3.HR.1	Eartree topology with home-run and 2DN in the same location
Scenario 3.HR.2	Eartree topology with home-run and 2DN in different location
Scenario 3.PON.1	Eartree topology with PON and 2DN in the same location
Scenario 3.PON.2	Eartree topology with PON and 2DN in different location

Table 7.1: The three scenarios.

in chapter 2.3.2 on page 20 the access network of today is usually planned with the traditional tree topology, the reason why the tree topology is used is the fact that it is the cheapest and most simple one to plan. This topology is a combination of a bus topology and star topology. Star shaped districts connect to the main bus line making it a tree liked shape. The tree topology does not offer any redundancy and in a case of a single point failure a number of NTs can loose connection. For example, if single point failure occurs in main bus line the whole network can go down. therefore the ear topology and eartree topology have been presented which could offer a redundancy in an access network in a feasible manner.

7.1.1 Scenario 1.HR.1:

The home-run architecture is a network that can be realized with a pair of fiber that runs from the CO to each NT, due to this reason the home-run architecture is also called point-to-point

architecture [3]. This architecture uses a larger amount of fiber, and all demand separate termination at each end. Figure 2.4 on page 19 shows the home-run architecture.
The main drawback of this type of architecture is the amount of fiber cost [13].

7.1.2 Scenario 1.HR.2:

Same as scenario 1.HR.1 but now the network is connected with two different distribution nodes in two different locations.

7.1.3 Scenario 1.PON.1:

A PON is a point to multi-point network over a passive fiber plant comprising fibers, splitters and an active equipment at the end [3]. The PON architecture is used to reduce the amount of fibers terminated in the CO's. Figure 7.2 on the following page shows the PON architecture. That is a single fiber leaving the CO may support several NT's, depending on the splitting ratio. This architecture gives an important reduction in costs but also an increase of complexity. In this case, there is one fiber to be shared between all users, the amount of fiber is reduced.

In this scenario the network is planned in tree like manor from the single location to each of the NT's.

7.1.4 Scenario 1.PON.2:

Same as scenario 1.PON.1 but now the network is connected to two different distribution nodes in two different locations.

7.1.5 Scenario 2.HR.1:

This scenarios is similar to scenario 1.HR.1, instead of one fiber from the distribution node (DN) to each home now single fiber is offered from two different DN's which are placed in the same location. Figure 7.1 shows the ear topology with home-run with two distribution nodes.
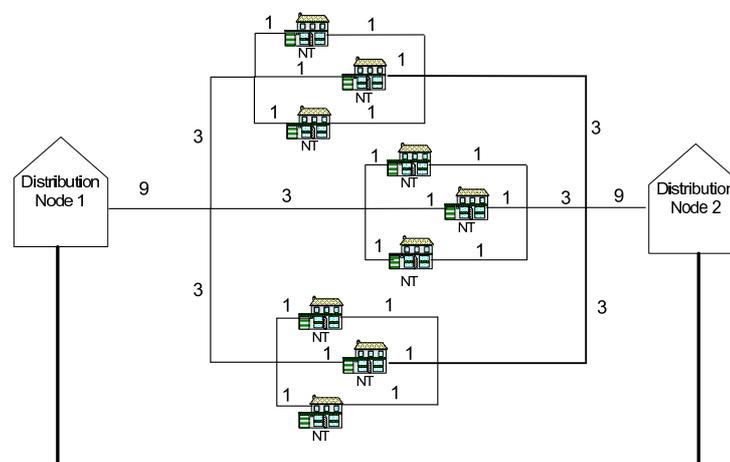
Figure 7.1: Ear topology with home-run.

7.1.6   Scenario 2.HR.2:

Same as scenario 2.HR.1 but now the network is connected to two different distribution nodes in two different locations.

7.1.7   Scenario 2.PON.1:

This is a scenario where the ear topology uses PON but the two distribution nodes are placed in the same location. In this scenario instead of one fiber running from each distribution nodes to NTs, in this technique a single fiber is offered from two DN that are placed in the same location as shown in figure 7.2.

Figure 7.2: Ear topology with PON.

7.1.8   Scenario 2.PON.2:

Same as scenario 2.PON.1 but now the network is connected to two different distribution nodes in two different locations.

7.1.9   Scenario 3.HR.1:

The eartree topology is a topology which is a combination of the tree and the ear topology. This topology uses the ear topology from the DN to the splicing point (see Appendix E on page 155) and tree topology from the splicing point to the NTs.

This topology like the tree topology will try to choose the shortest distance to each splicing point with the ear topology. But as we do not use the ear topology from the splicing points to the NT's we are not bound as tight by the ear topology rule of sharing trenches in the same direction. However as this scenario has only one DN location and one splicing point per district, it is obvious it will try to follow the same path from both DN's to the splicing point. This can be avoided by ensuring that the 2 fibers traveling to each splicing point use different sides of the road. By doing so we minimize the fiber (by not using alternative route) and the digging. Figure 7.3 on the next page shows how this is done.
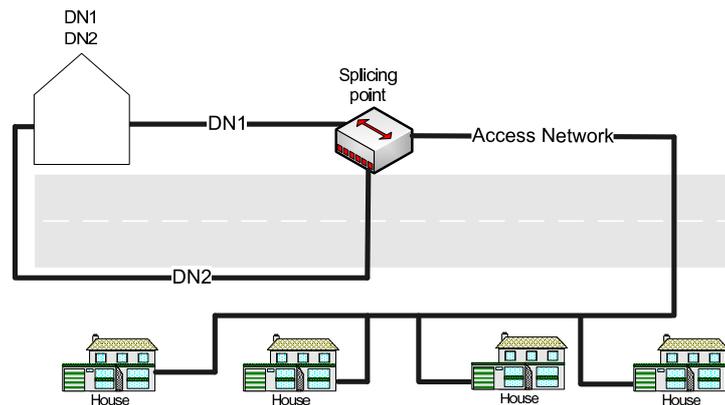
Figure 7.3: Eartree topology with 2DN in the same location.

7.1.10 Scenario 3.HR.2:

Same as scenario 3.HR.1, but now the network is connected to two different distribution nodes in two different locations. The sharing trenches is not as great a factor as can be seen in figure 7.4.
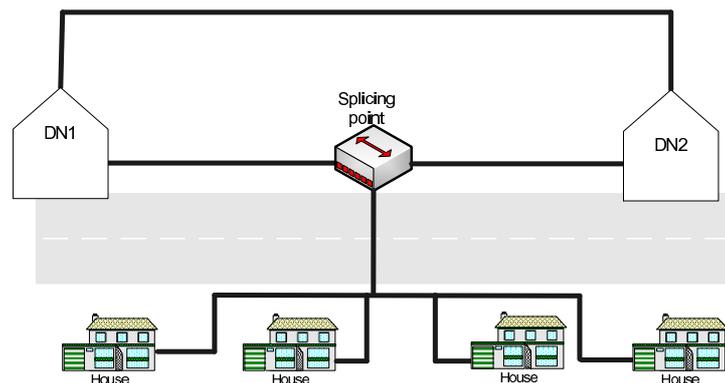
Figure 7.4: Eartree topology with 2DN in different locations.

7.1.11 Scenario 3.PON.1:

This is a scenario where the ear tree topology uses PON but the two distribution nodes are placed in the same location. In this technique a single fiber is planned from two DN's that are placed in the same location to each district.
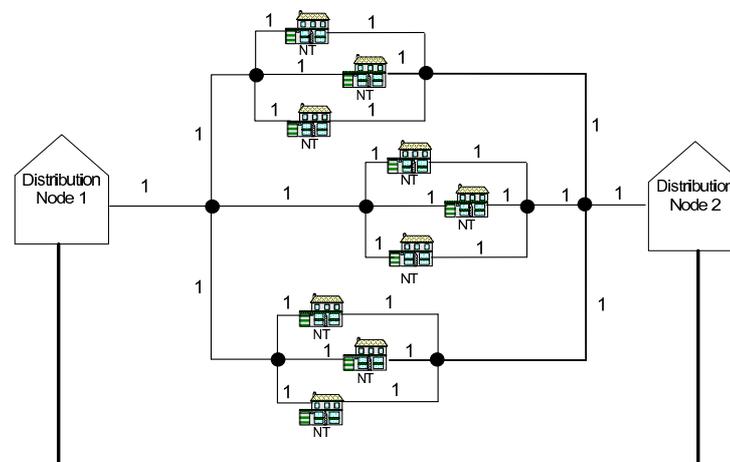
7.1.12 Scenario 3.PON.2:

Same as scenario 3.PON.1 but now the network is connected to two different distribution nodes in two different locations.

Phase 1 Planning

This chapter will start by explaining how the scenarios were in general planned using existing GIS data for the municipality of Hals. Next it will explain how each scenario was planned. At last the algorithms used to create each scenario will be shown and explained.

8.1 General planning method

The scenarios where planned using PHP (see appendix D on page 142) programming language to interface to the GIS (See Appendix C on page 137) data which is stored in a MYSQL database (see appendix D on page 142). In general sense the scenarios were created by extracting needed data from the original database containing GIS data for municipality of Hals. After that the data was manipulated using algorithms to create the network scenarios and stored in a new database. The method in which this program was written was to be able to use this in any scenario with most GIS data but with as little reprogramming as possible. There are still some missing parts to make it fully integrate-able in any scenario, as will be explained later.

As explained throughout this report, the main focus of this first phase of the project is to create scenarios and automate the planning of a network and focus on the reducing the amount of fibers. The digging was kept open for this phase or else planned for creation in the next phase if needed. The reason for it is not to be included is the fact that after initial review it was decided to be quite complicated to achieve this, so the focus was laid on the fiber.

This chapter will not go into details about the contents of the databases or the tables created, those information can be seen in appendix D.3 on page 150. The chapter will also not go into full details of every small algorithm used or the PHP scripts used for creating them, it will rather be explained in appendix D.2 on page 143. The PHP scripts themselves can be viewed on the enclosed CD. Rather the chapter will explain the larger algorithms used in all scenarios and then explain the scenerios and the planning result.

8.1.1 Remaining problem

The focus of phase 1 was to create the automatic network planning method with and without redundancy, but focus on creating scenarios to reduce the excessive fiber needed by the ear topology seen in the previous study. To get the whole picture of cost and to further confirm the genius part of the ear topology to reduce digging shown in the previous study it is of interest to add support to take the digging into calculation. This was not included in this phase as this was found to be quite complicated. As the road segments would need to be duplicated and then marked with either 1 or 0 depending on which side. Then for an algorithm to choose between the different sides, also 4-way intersection and other road anomalies would cause some problems in routing. Thus this part was left open for the next phase, depending on the results from this phase.

This two sided road problem isn't that much of a problem for the tree or eartree topology per say but more for the ear topology. Since all the splicing points created are in the opposite side of a district this eliminates the problem and we ensure that the ear topology comes from opposite side for every house.

Previous study that was planned by using GIS data did not include digging on both sides of the road as far as this project can explains. This is mainly due to the fact that it has in most cases been done as an estimation planning, which does not go into full detail but rather an overview of the planning and cost. Also this has not been a problem for those cases as though it would not give fully correct digging results because access network needs to dug down on both sides of the road in order to access houses. But as this was mainly dealing with one access network this can be overlooked and an estimation of the digging cost can be given. To do this, it would almost give the same result for each access network scenario and would be useless to compare the digging between the scenarios. But as previously stated this part is left open, as previous study already confirmed the theory that not much extra digging is needed and is only a small contributor to excessive cost increase.

8.2 Road segments and segment points

The main data used from the GIS data is the location of NT's (network terminations points) and location of roads. Because the GIS data is represented in x,y coordinates the roads are divided into segments with values x1,y1 and x2,y2 and the distance calculated from that with the help of Cartesian Coordinate Distance formula: $Distance = \sqrt{(x2 - x1)^2 + (y2 - y1)^2}$. This means that we now have two points and a line between it. The roads are rarely just straight lines, the roads have lots of segments making up the road network.

In order to use this road network for planning a network infrastructure it needs some points to distinguish location. The creation of segment points can be done by the use of x1 and y1 and x2 and y2 of the road segments. By doing segment points (or nodes) to use for planning a network infrastructure. We had already calculated the distance of each segment point, now we have calculated the distance between each segment point. There after the NT's can be assigned to it's closest segment point giving a connection between the DN (an NT with an assigned segment point). Appendix C on page 137 explains this in more general sense.

8.2.1 Remaining problem

Because the segment point which is created from the original segment GIS data, there is some inaccuracy in assigning of NT's especially where segments are quite large, but the houses are scattered along the segment. Figure 8.1 on the next page shows this problem as a fiber is planned to the segment point. Then it needs to backtrack a certain distance, causing extra fibers being planned. There is a solution for fixing this, a rule of max segment length is created and then the Cartesian coordinate midpoint formula: $Midpoint = ((x1 + x2)/2), (y1 + y2)/2)$ can be used to shorten the segments until the rule is uphold. Then segment points can be recreated and NT's
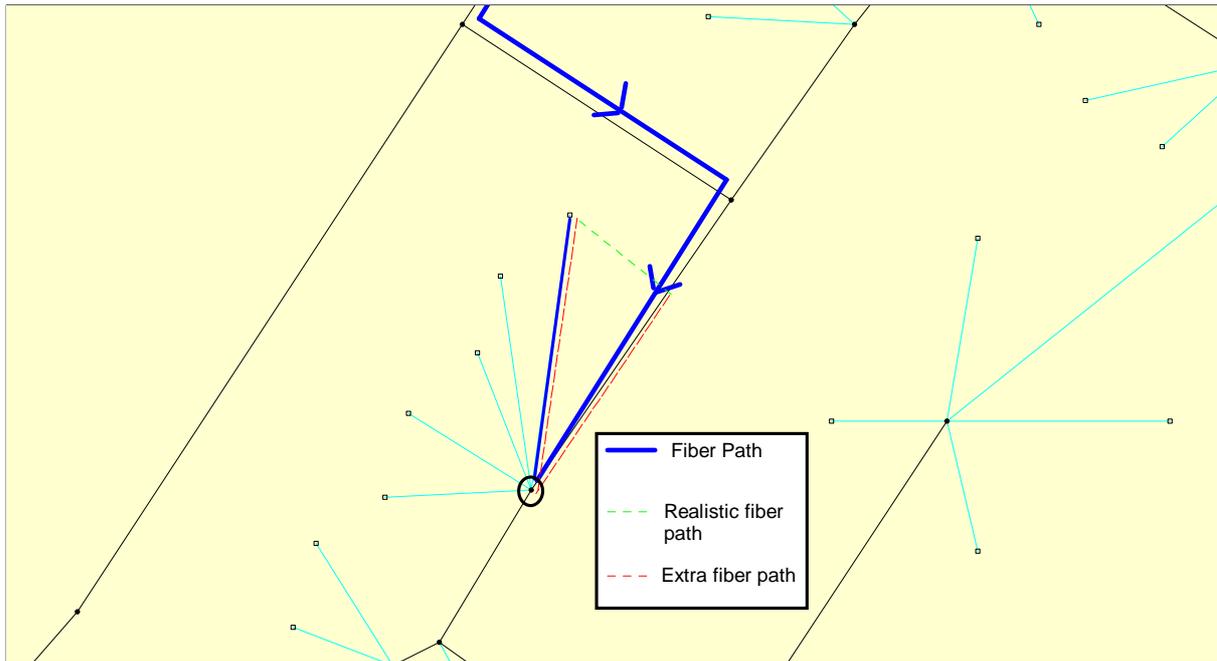
Figure 8.1: Segment inaccuracy problem with current GIS data.

assigned to a new closest segment point.

The reason this hasn't been done is purely because doing so would cause even greater inaccuracy with the ear topology. As fiber traveling inside a dead end road and with NT's on the both sides of the road the ear topology would connect both NT's in the shortest distance possible as the two side road problem hasn't been fixed. Now since most dead end roads have only two segment point at the start and end the inaccuracy is the same for both. It should though be stated that this isn't a crucial part in an estimation planning since the GIS data is not that accurate. That is to say the correct distance could not be acquired as houses are different and the entry point can differ, therefore creating on it's own a false detailed planning.
Solving this is an interesting task though still can have false NT locations in the GIS data. So this problem should be considered for phase two.

8.3 Spanning tree algorithm (shortest path)

The shortest path algorithm plays an important part in creating a network. With the help of segment points and NT's assigned to segment points finding the shortest distance between NTs and DN is quite simple. This is done with these simple steps:

- The starting point is chosen (DN's segment point).

- Check which segments are connected to each segment point.

- Those segments are then checked for the second segment point

- The second segment point of each segment is then update with which it's ancestor is and the distance (Ancestor distance + Segment distance). Also the level of the segment point

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from the starting point is updated.

- Finally this is done until each segment point has been updated.

Figure 8.2 shows how the spanning tree is done in GIS. Now normally the NT would be updated
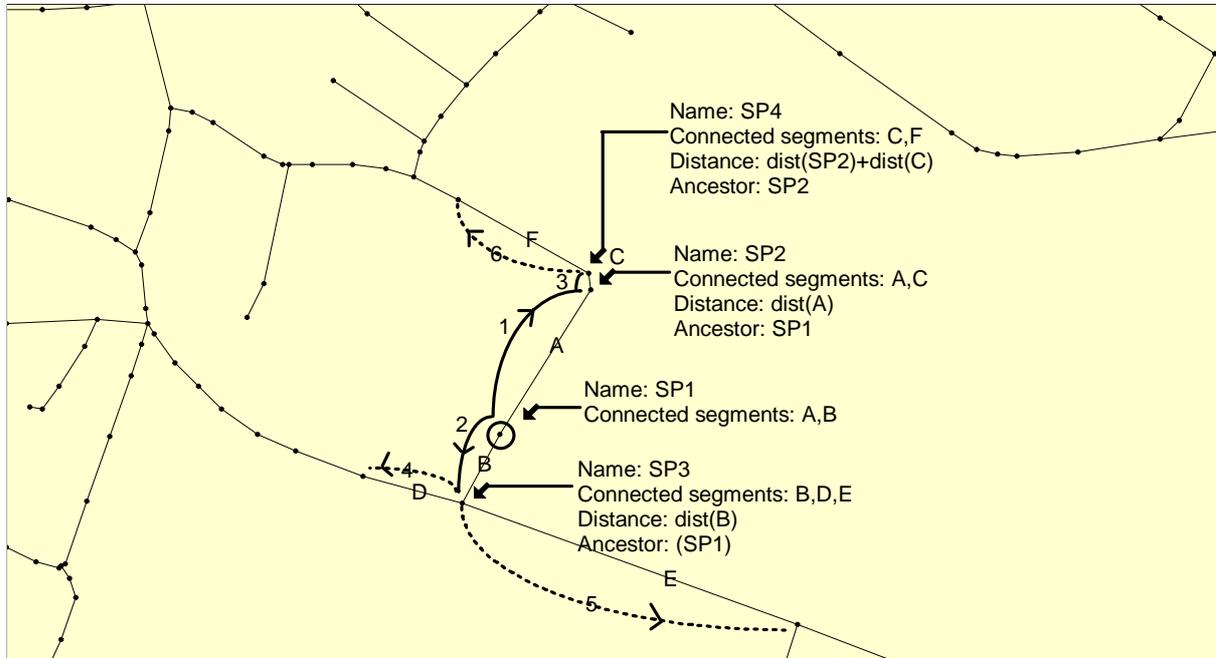
Figure 8.2: Spanning tree with GIS data.

with it's distance to the connected DN, however since this project uses splicing points, only the splicing points are updated with the distances to the DN. The same tree algorithm is then created for every splicing point to each segment point again. As each segment point is assigned to a splicing point, the NT can now be update with the distance to the splicing point rather than directly to the DN. The last part of updating the NT is the distance from the segment point to the NT which is again calculated with the Coordinate Distance formula:
$Distance = \sqrt{(x2 - x1)^2 + (y2 - y1)^2}$.

8.4 Path Algorithm

The path algorithm is mainly used for visualization in mapinfo. After having created the shortest path algorithm and updating it with the ancestor creating a path is quite simple. By following these steps an paths between either any node to DN or any node to splicing points:

- Starting point is chosen (Splicing points segment point).

- Segment points ancestor is checked and the path table is updated with the two points.

- The algorithm checks that which segment has both segment points and updates the path table with the segment.

- This is done until level reaches 1 again. (As mentioned earlier each segment point has a level, that is to say how many segment points is between itself and the destination).

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Now it is created the path between two points. This is only done between the splicing point and DN to visualize the path.

8.5 Home-run or PON

It was decided to test all the scenarios with PON in order to try to decrease the amount of fiber needed, this has no affect on the planning or changes between the planning of home-run and PON because this only affects the amount of fibers used in each scenario thus the results will only be detailed as there is no extra algorithm difference between scenarios with home-run or PON. Therefore the following section will be marked 1.*.1 rather than 1.HR.1 and 1.PON.1.

8.6 Scenario 1.*.1

This scenario is pretty straight forward as explained in the scenario explanations. Here the main duct is created from the DN in one location to each district. From the splicing point the network is planned in a tree structure manner where the shortest distance is chosen from the splicing point to each NT. The splicing point is placed in a good position to have the shortest distances to every NT.

8.6.1 Planning result

Figure 8.3 shows the results of planning the ear topology from one location. Appendix F on
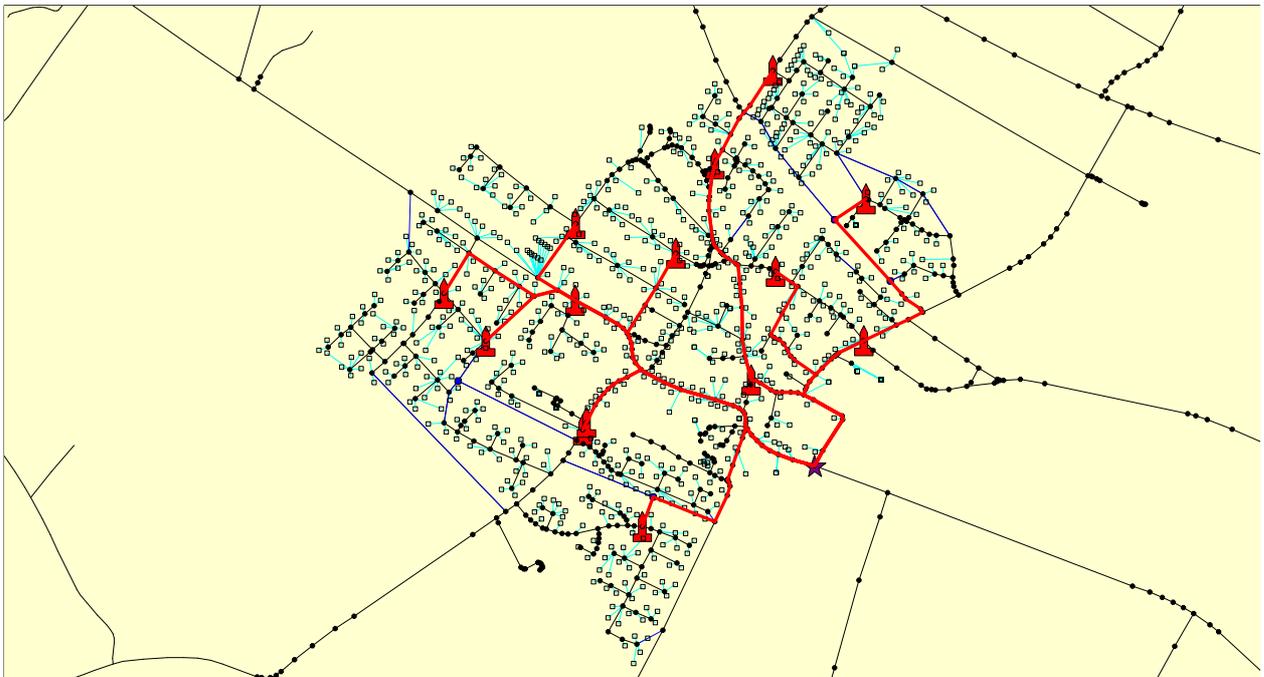
Figure 8.3: Scenario 1 - Whole - One DN location.

page 161 shows each district in more details and the result for each district. The results in total length of fiber needed and cost for this scenario can be seen in chapter 9 9 on page 59.

8.7 Scenario 1.*.2

Like in scenario 1.*.1 it is pretty straight forward and is planned much in the same manner as scenario 1.*.1. The difference is that now the DN's are in two locations meaning the splicing point chooses a DN closest to it. From there the main duct is planned from it's chosen DN to the splicing point, and then the tree topology is planned.

8.7.1 Planning result

Figure 8.4 shows the results of planning the tree topology from two location. Appendix F on

Figure 8.4: Scenario 1 - Whole - Two DN location.

page 161 shows each district in more detail and the result for each district. The results in total length of fiber needed and cost for this scenario can be seen in chapter 9 9 on page 59.

8.8 Scenario 2.*.1

This scenario covers the ear topology coming from one location. The previous study tried to follow the ear topology rule in case of only one location available by planning the network from opposite sides of the town and traveling with both the main duct line and the NT to splicing point lines from opposite end of the town/district, this ensured that the rule was not broken. It was thus derived to plan all the main duct lines to the opposite side of the town (to the same location as the the scenario with DN's in two location). By doing so the rule was uphold and it only needed some extra main duct line fiber. After further research it was realized that, this is not necessary but it can be planned with a shortest distance algorithm and still making sure it still follows the three rules based on the ear topology rules, these rules are:

- Main duct must never enter a district in such a manor that it violates the same direction rule within the district.

- Main ducts from separate DN's may travel in the same direction in the same trench if and only if they are not for the same district.

- Main duct from separate DNs traveling in the same direction may follow the same road network. It needs to be in separate trenches on each side of the road if it is going to the same district.

The ear topology can use the shortest path algorithm for one location as long as it adheres to these rules. The main duct line is planned from each virtual DN inside the same location to each of the matching splicing points in the district. Now as always the planning tries to place the splicing points in each end of the district, the network can be planned from each end in a spanning tree manner, and since the splicing points are in each end to ensure that the rule is uphold.

8.8.1 Planning result

Figure 8.5 shows the results of planning the ear topology from one location. Appendix F on

Figure 8.5: Scenario 2 - Whole - One DN location
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page 161 shows each district in more detail and the result for each district. The results in total length of fiber needed and cost for this scenario can be seen in chapter 9 on page 59.

As mentioned as we come from one destination the three rules mentioned earlier can be broken. In scenario 5, the splicing points main ducts broke the rule so a rerouting of these splicing points had to be done to these broken districts as can be seen in appendix F on page 161 and then compared to detailed district.

8.9 Scenario 2.*.2

This is much like Scenario 2.*.1, however because it was coming from two DN's locations they should be placed in each end of the network planning area to ensure the ear topology rule. It is not encountered as many problems as from one location, however the rules stand. The main duct line is then planned from each district to it's designated splicing point. As again the splicing points are on the opposite side, it is possible to use spanning tree to plan from the splicing points.

8.9.1 Planning result

Figure 8.6 shows the results of planning the ear topology from two location. Appendix F on

Figure 8.6: Scenario 2 - Whole - Two DN location

page 161 shows each district in more detail and the result for each district. The results in total length of fiber needed and cost for this scenario can be seen in chapter 9 on page 59.

8.10 Scenario 3.*.1

This scenario was created as a compromise in order to reduce the fibers needed but at the cost of full redundancy. The downside is minimized by the network design where redundancy is all the way in the access network till splicing points making the worst case scenario that 96 users get disconnected. This also minimizes the cost factor as the main fiber cost factor is from the splicing points to the NT's. From both DN's a main duct line is planned to each splicing point is done in a spanning tree method choosing the shortest distance from the DN in one location to each splicing point. Now in order to ensure redundancy the main duct line would need to be placed on either side of the road, this should not affect the digging cost, as digging in dense areas means that there are already trenches on both sides to service houses on both sides of the road. The rural areas might become more costly, but the same would be in the case of the ear topology.

Now as we have now made the district redundant and we only use one splicing point, the splicing point can be placed in a more optimal position for the ear topology shortening the distances to each NT. So from the splicing point the network is planned with the tree structure.

8.10.1 Planning result

Figure 8.7 shows the results of planning the ear topology from one location. Appendix F on
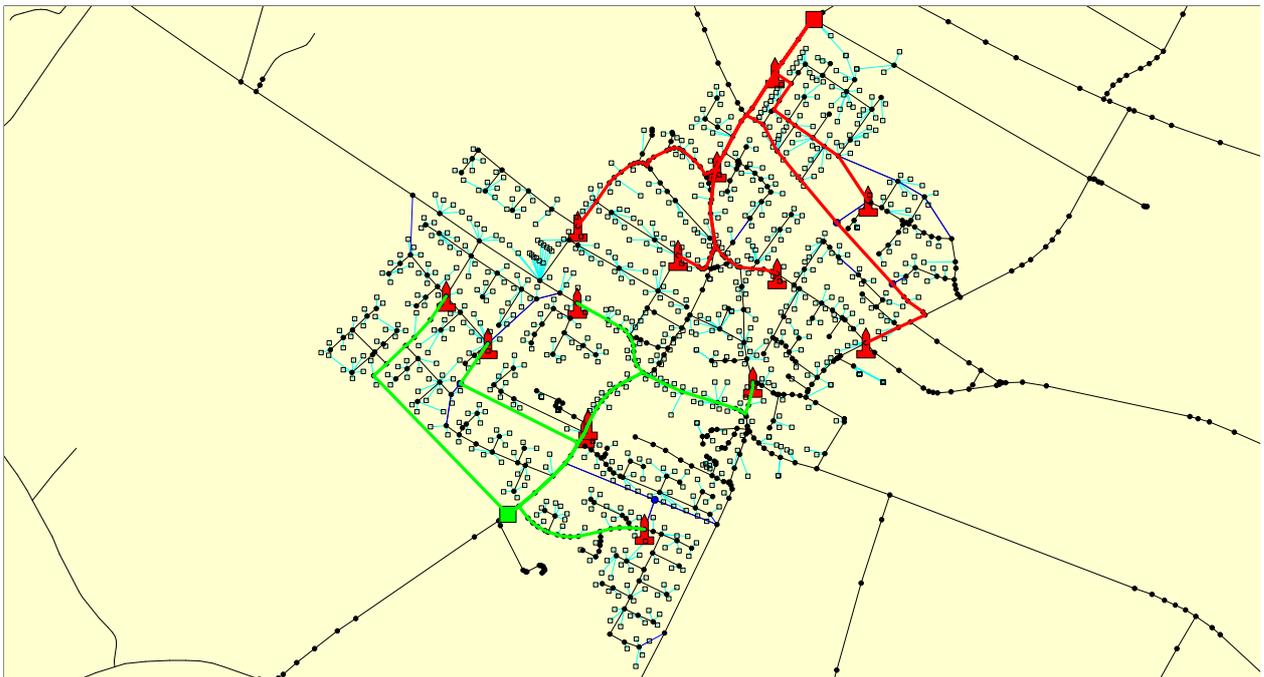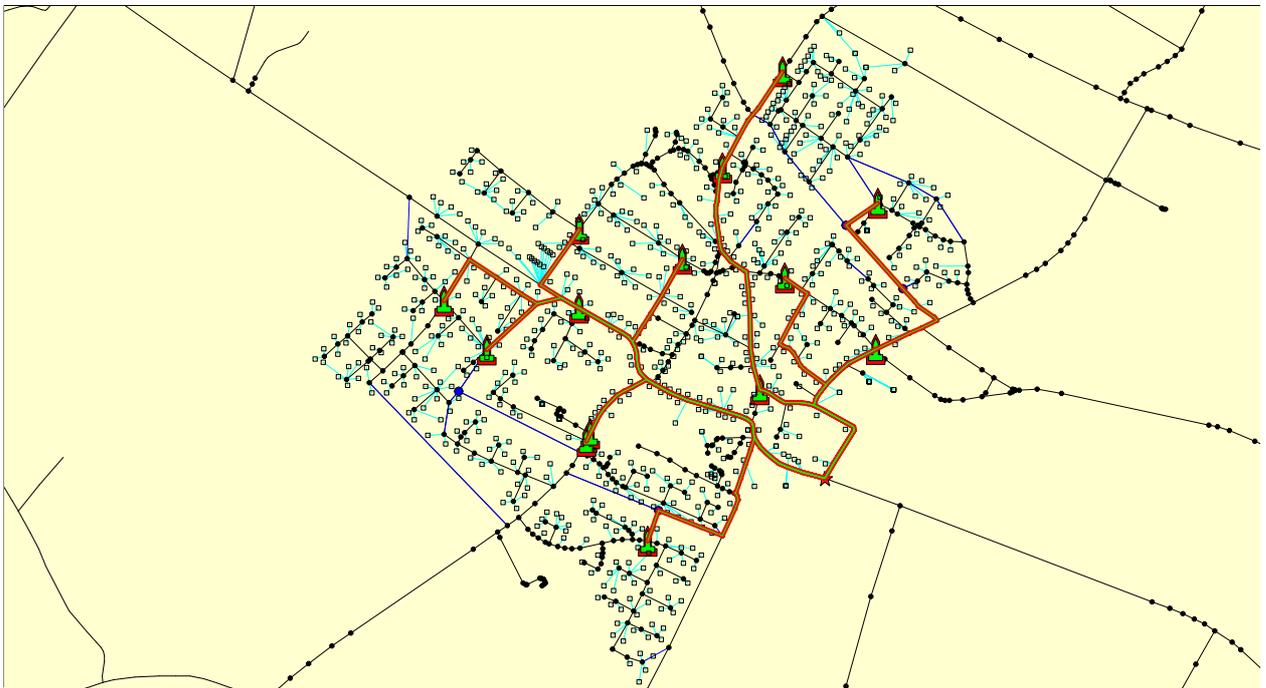

Figure 8.7: Scenario 3 - Whole - One DN location.

page 161 shows each district in more detail and the result for each district. The results in total length of fiber needed and cost for this scenario can be seen in chapter 9 on page 59.

8.11 Scenario 3.*.2

This is much like scenario 3.*.1 but now the DN's are in separate locations. Which means that the main duct line is created with the shortest distance from each DN to the splicing points. And because they are in different location in most cases. It do not share same path to the splicing point. In those cases though again it is needed to ensure that each DN main duct lines use each different sides of the road.

8.11.1 Planning result

Figure 8.8 shows the results of planning the ear topology from one location. Appendix F on
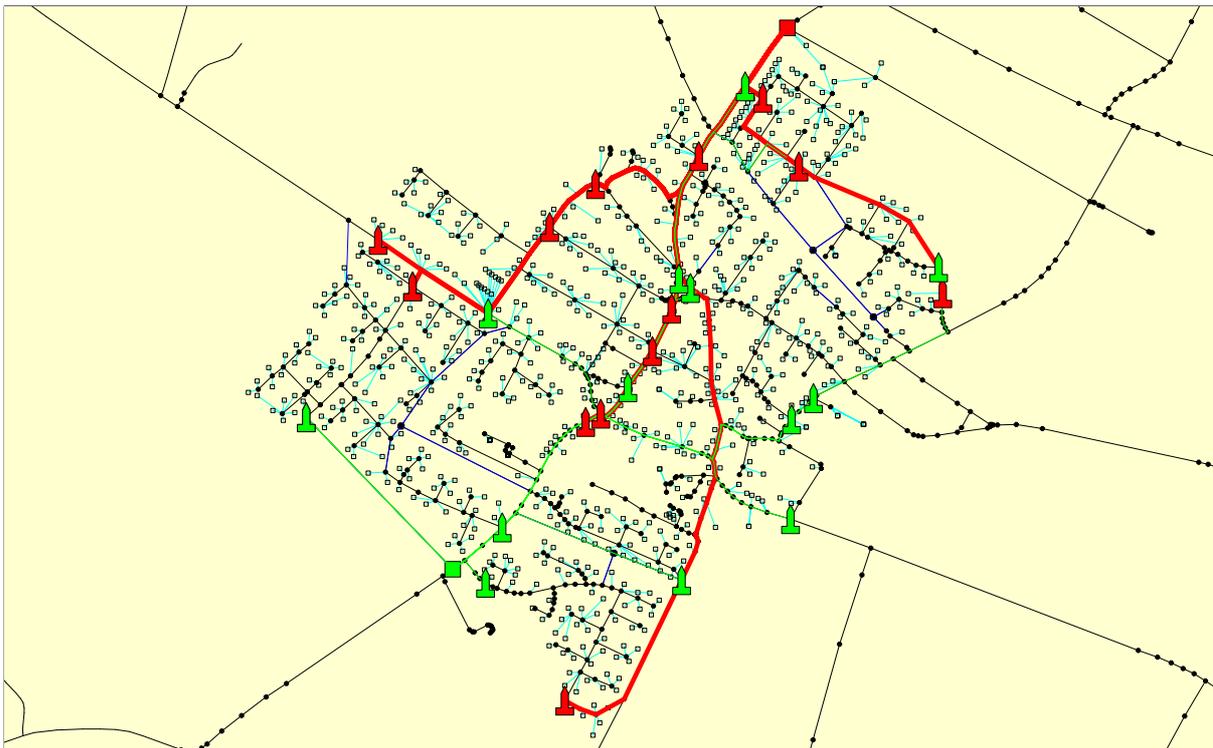

Figure 8.8: Scenario 3 - Whole - Two DN location.

page 161 shows each district in more detail and the result for each district. The results in total length of fiber needed and cost for this scenario can be seen in chapter 9 on the following page.

Phase 1 Results
9

In this section comparison of the result data will be done, as it is quite large it has been moved to appendix F on page 161 to ease the readability of this section. First the new data is compared to the old data. The new results will then be compared to view whether it is possible to reduce the fiber usage from the manual planning as well as comparing the scenarios to each other to reach a conclusion, if it is indeed feasible to offer redundancy in the access network. The detailed explanations about the scenarios can be seen in chapter 7 on page 45.

9.1 Comparison

This section will now take the data presented in the previous section and present in a visual form and then compared to derivere a conclusion of the results. First the old data will be compared to the new to establish if the two different methods of planning give similar results.

9.1.1 Old study and new study

Figure 9.1 shows the amount of fiber used in the old study while 9.2 shows the result from the new study. Now comparing scenario 1A to scenario 1.HR.2 we can see that there is not much difference. Actually the difference is 37 meters for the NT to splicing points distance and 30 meters for main duct. Same goes for scenario 2A to scenario 1.HR.1.

The difference is a bit larger for scenario 1B and scenario 2.HR.2 or 54.232 meters for the NT to splicing points distance and 45 meters for the main duct. The reason for the severe decrease in fiber needed for the NT to splicing points can be several. It could be because the ear topology had no rules so while planning it by hand may results a lot of mistakes to happen, mainly that at some splicing points where poorly placed which caused an increase in fiber usage. Also the automatic process of the ear topology is quite different and there are still some unsolved problems with the use of GIS data which does not yield the same results when done manually. The same goes for scenario 2B to scenario 2.HR.1, with one difference. Because it is a revised rule of ear topology it was actually possible to severely minimize the length needed in the main duct.

In conclusion it can be said that as the difference isn't that much as would be expected, and one of the reasons for automating the process, was to view if it was possible to decrease the fiber needed. It was able to decrease the main issue of NT's to splicing points length mainly by reordering the splicing points, this decrease is still not efficient enough. The decrease in the 1DN main duct line shows some success of the automation, cause this wasn't realized until the automation had been done.

9.1.2 PON Vs. HR

Figure 9.2 shows the comparison between the scenarios with fiber length while 9.3 shows the total cost of the fibers and connections. It should be noted that in figure 9.2 the difference in
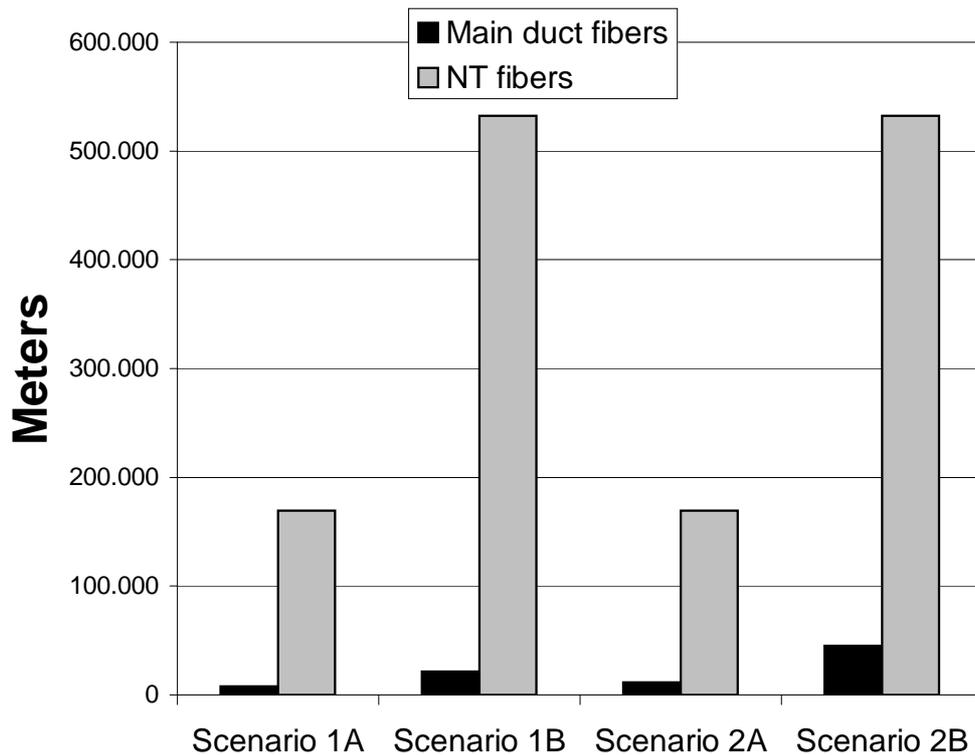
Figure 9.1: Length of fiber used in the old study.

main duct line between PON and HR is not compatible as PON uses $3 * length$ with a single fiber while HR uses length with a 96 cable fiber. Which have different cost factors.

The results of PON is quite dissatisfying, as the hope for decreasing fiber is somewhat based on the use of PON. The way the network is planned with HR is actually done in a PON manner meaning that instead of using a single fiber from the DN's to the NT's. The cost is cut cost by grouping NT's together and dragging a larger cables to a closer point and from there distribute with single fibers. This cut cost as it is cheaper to use a 1 grouped cable than many single cables. The only way PON can be used is from the DN's to the SP's. As it is needed more equipment the cost saved from PON will increase again. This makes all the PON scenarios actually neglectful as the cost difference is not that large and it would only cause more complexity. However it is a possibility.

As a conclusion it would not yield any more information to investigate further in phase two just by the way this network is planned.

9.1.3 Ear topology comparison

The main factor of this phase was to view if the ear topology could be improved by reducing the fiber needed with different technologies and automating the process. The result confirms the previous study that with this type of network planning the ear topology is unfeasible. The results show that in comparison to the ear topology the amount of fiber is still almost triple making the cost difference about two and a half times more than in the tree topology. This means that the ear topology is still quite unpractical. Even though as explained the automation process
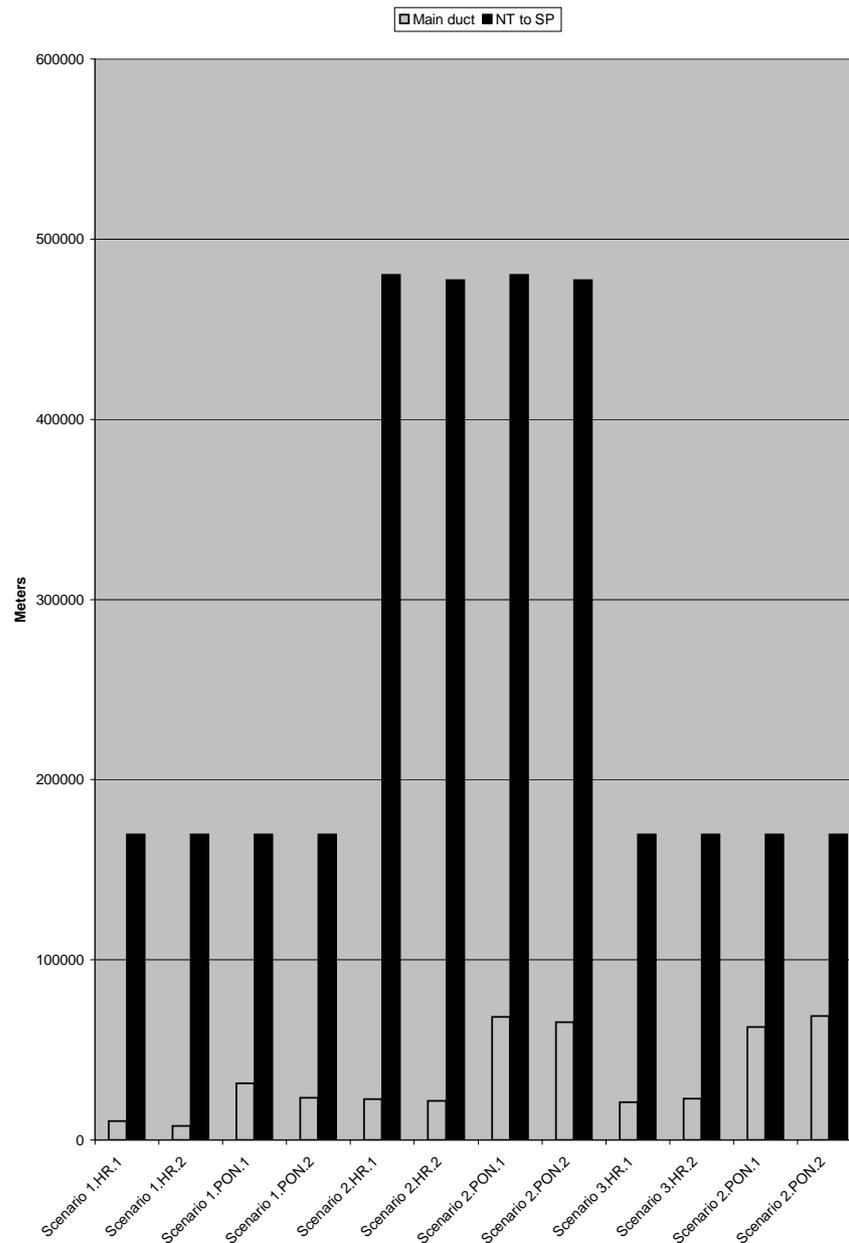
Figure 9.2: Length of fiber used in the new study.

is still in development there is not much chance that this can be fixed.

The reason for this is the design of the ear topology, and even though a different network planning method where to be used the excessive amount of fiber is still a problem. Figure 9.4 shows why the ear topology has a problem with excessive amount of fibers being needed. While a tree topology can place a splicing point (or DN or any kind of distribution point) in an optimal position to acquire the least amount of fiber. In order to offer the redundancy and offer savings on extra digging means that the placement of the splicing points are to faulty in this problem. Because it is needed to situate them on each side of the district the distance will grow more rapidly as we need to access NT's from each side all over the district.

This is actually noticed in the creation of the topology but as it was a theory, it is based on

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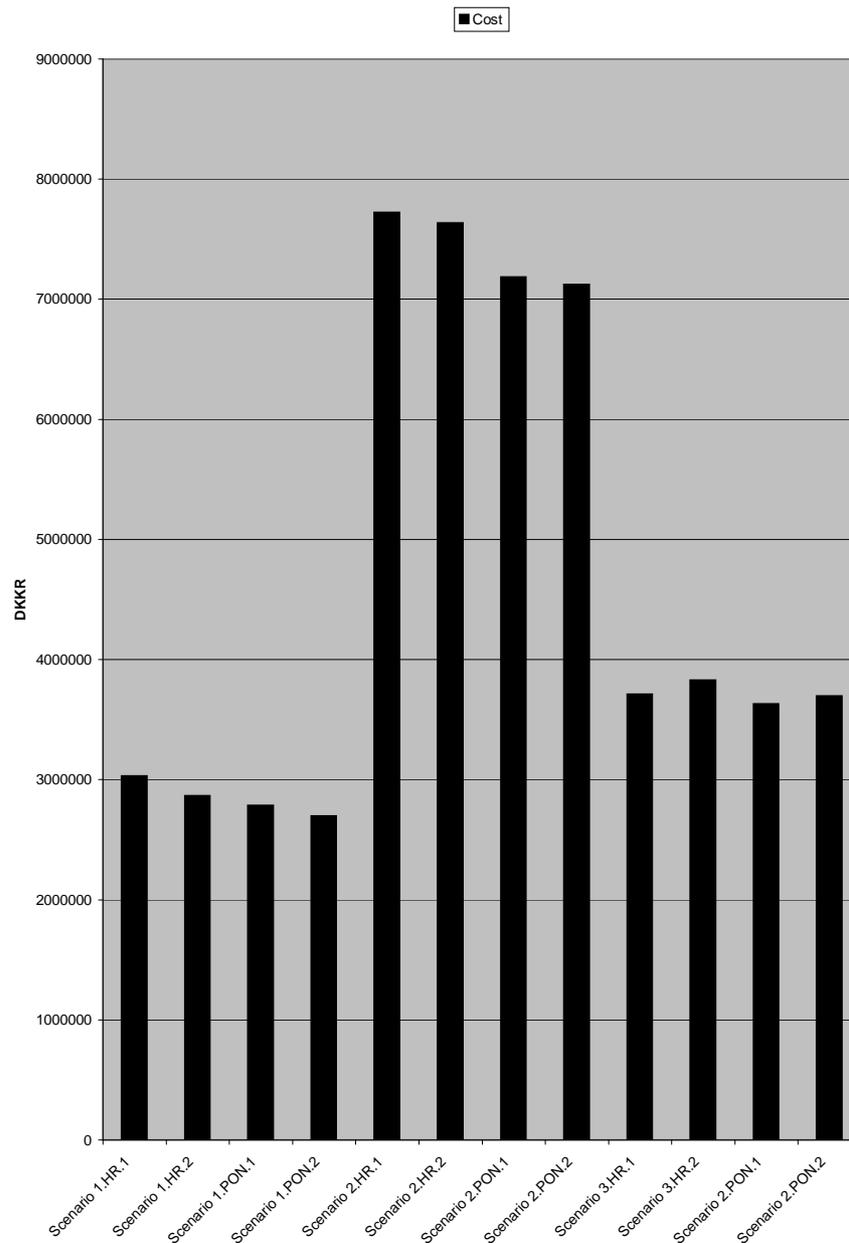
Figure 9.3: Total cost of fiber usage and connections.

the fact that fiber prices are going down making it not a deciding factor. There are more factors involved like blowing of the fiber, and for a single fiber the blowing is actually more expensive, making the fiber a more deciding cost factor than realized before.

All of this actually collaborated with the results acquired, making the ear topology not a feasible manor in offering redundancy unless there is actually a urge need for it. The ear topology is still an interesting topology, if some method will be found to decrease the fiber for the ear topology it could be interesting. Another solution is to look at it when the fiber prices have gone even further down, but then again the tree topology cost would also decrease.

In conclusion it is not of interest to research this further in phase two as it has been shown both in this project and previous ones, that though a resourceful topology with possibilities it

still needs extra amount of fiber.
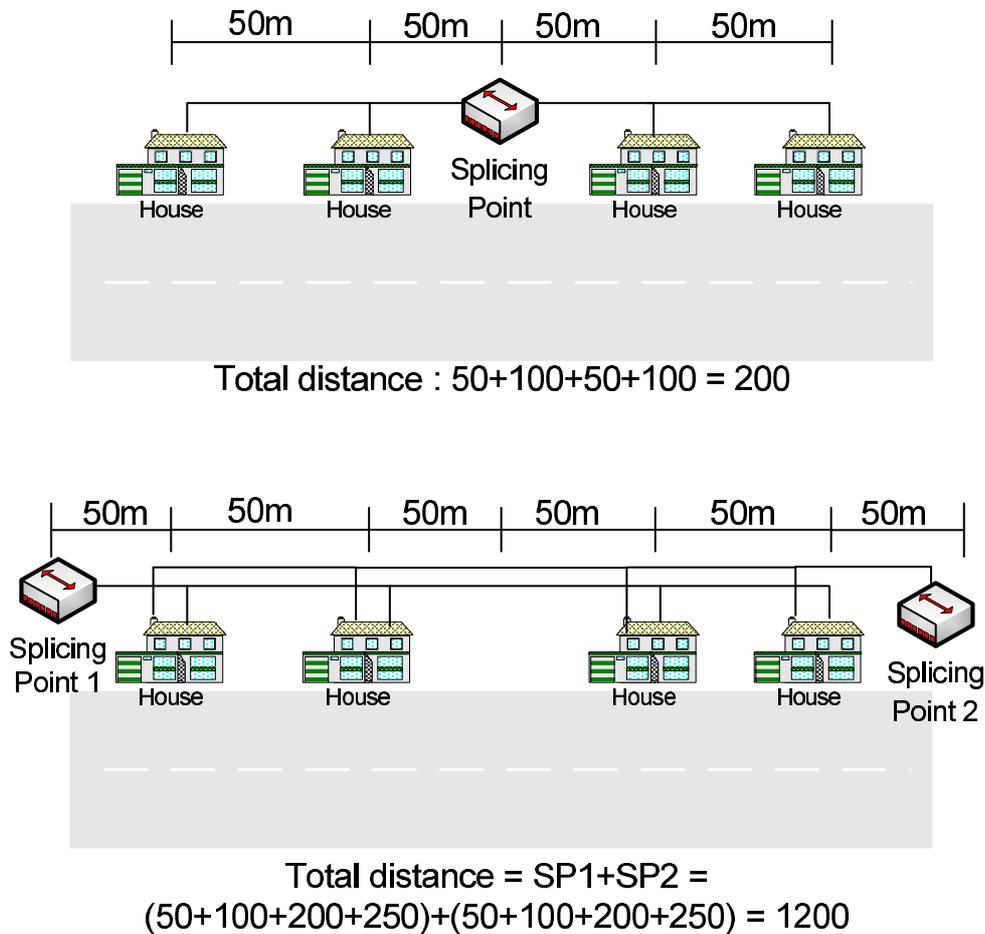
Figure 9.4: Explanation of the excessive amount of fiber use by the ear topology.

9.1.4 Eartree Topology Comparison

Another factor in this study was to come up with a new topology which could offer redundancy to the access network but not use excessive amount of fiber like the ear topology. The result was the eartree topology which is a sort of a combination of the ear topology and the tree topology. Where each splicing point would be redundant but from the splicing point the tree topology would be used. Obviously this is not as redundant as the ear topology, but it limits the amount of caused user in case of a dig up accident. For this topology the absolute worst case scenario (taken that the DN in one location doesn't burn down) is that it would loose one district, when either a splicing point would be made unavailable or a cut near the splicing point. The further the cut is from the splicing point, in most cases, the less number of NT's become affected. Now the only extra fiber needed is doubling the main duct lines making the NT to splicing points fiber needed unaffected in comparison to the tree topology. Now since this is done that limit the extra amount of fiber by not doubling the NT to SP.

The results of the scenarios collaborate this idea as we see a double increase in the main duct line but the NT to splicing points lines are the same as for the tree topology. Now comparing

the cost it ca be seen that the cost only increases around 25% between the eartree topology and tree topology throughout the scenarios. Now with that much added redundancy to the access network and not that much increase in cost the eartree topology is definitely a feasible solution to offer redundancy at least as close to NT's as possible.

So in conclusion the results shown is quite good and is found a viable and interesting solution to offer redundancy or at least minimize the affect of digging accidents to a few NT's. From this conclusion it is of interest to further research the eartree topology in comparison to the tree topology to truly view if redundant topology can be planned without costing more than a normal tree topology in a large scale environment.

9.2 Conclusion

The goal of this phase of the project was to automate part of the process of planning an access network with and without redundancy. With that said the focus was on lowering the needed fiber by the access network with redundancy. This was two folded, first does the automatic process help lower the fiber needed in comparison to a previous experiment. Second, is it possible to enhance the ear topology or/and propose a new topology which offers redundancy but does not use excessive amount of fibers.

9.2.1 The automation programming

It was decided to use PHP programming language to program the network infrastructure with the help of GIS data, placed in a MySQL database. The programming was done in such manor that it should be applicable with any scenario or location. But as the focus was also on using a previous study as a background for this one, there were the network planning mainly done manually, one main factor is still not automatic. This is the automation of the districts and the placements of splicing points, in this phase a small area which was used in the previous study was used again so the districts and placement of the splicing points were kept the same. It should though be mentioned that the next phase should focus on automating that process and making it adaptable to any scenario.

Other problems which were noticed during programming, mainly concerning the digging. Now in previous cases digging was just estimated and no assessment taken on which side of the road the digging occurred. But as the ear topology requires this factor to ensure that it's rules are uphold, the two sided digging is needed. Because the main factor in this phase of the project was to automate the planning process and focus on the fiber, the digging was left aside. After some research this problem can be quite tricky, but if the ear topology is to be used and a full estimation of the network planning is to be done this needs to be fixed. As the next phase will include digging as part of the cost but ear topology will not be included the road problem will not be investigated further. It should be noted that in case of others wanted to automate the ear topology and include digging this two sided road problem should considered.

Another problem was with the location of the SP's towards the NT's which it connects to. The problem was that with larger segments the distance in the automation planning was greatly increased or decreased making the distance calculations too unreliable. But as explained since there are more inaccuracy, this isn't as crucial as initially stated, it would be of interest to create a solution to fix this problem in the next phase.

9.2.2 The scenarios

The results from the scenarios show a bit of a disappointing results when PON is used. As the planning method used, tried to minimize the cost with home-run in mind, by grouping NT's together and using cheaper and larger cables in stead of many single cables, the PON had no real affect there.

With the automation process some modification to the ear topology rules was created, decreasing the needed fiber. But as set forth, due to the nature of the topology the needed fiber is still almost tripled. And as the cost of fiber is one of the larger contribution in a fiber network design the cost of the ear topology is quite unfeasible as a method for offering redundancy to the access network. This means it would be hard to sell any one the idea of more then doubling prices just to secure each and every home. So at the moment the ear topology is in no manner a good solution.

This called for research into other viable solutions to offer at least some redundancy to the NT's without adding too much extra cost, the solution was the combination of the ear topology and tree topology, named eartree topology. The ear topology main problem was with the location of the splicing points towards the NT's therefore making the NT to splicing point the problem area. It was decided to use the tree topology from the splicing points to the NTs but making the splicing points themselves redundant. This concept proved to work and the increase in fiber needed was minimal but redundancy is provided most of the way.

Finally it was shown that all the scenarios can be done from either one DN location or two DN's locations without much cost increase. Ensuring that whether a double ring which offers two DN's locations or mesh, which in most cases offers only one, therefore is it possible to plan both the ear and eartree topology without much extra cost.

9.3 Phase two criterias

Phase two of this project involves finishing the automation program and planning it on a larger scale. One of the greater tasks of finishing the automation process will be the automation of the districts as well as road segment point problem. Further addition like traffic analysis will be added as well as some research into other possible topologies.

All parts which are done in phase one will not be included in the planning process for phase two but rather the selection of those which show the best result on successfully planning a redundant access network and those will be detailed as well. This way the main criteria behind phase two

will be to plan and test solutions which could offer a redundant alternative to the tree topology without much extra cost.

Automation of districts: Now the most important part of phase two will be to finish the automation of districts, mainly because without that a larger scale testing would mean manually placing every splicing point. This includes an investigation into methods of creating a district, as well as investigation into criteria such as number of NT's per district. After the creation of district a splicing point will be placed on the SP which is the closest to all the NT's within that district, creating an almost ideal placement within a district automatically.

Fixing the NT to SP inaccuracy: This problem should be addressed to ensure more accurate estimation price of the fiber.

Large scale planning: After the automation is done a large scale network planning should be done to view the true cost of offering redundancy to the home. This involves also planning the distribution network. It should incorporate a real network planning that is viewing of how the plan is today, example viewing TDC fiber backbone and the tree infrastructure of copper last miles could be incorporated as a basis for this large scale planning.

Traffic analysis: After all of this it is of interest to learn and view traffic analysis over these networks created on a large scale.

Skipped criterias:

- *PON:* As PON shows little or no affect on the current network planning scheme

- *Ear topology:* As has been mentioned several times, the ear topology has a downside due to its design and in coalition with the current network planning scheme.

- *Two DN's locations:* It has been shown in previous study and confirmed by phase one, one or two locations have little affect on the amount of fibers. This means that either method can be used to plan. But as we are trying to offer a cheap alternative to the tree topology it is rather use only one location to keep the cost down.

Part III

Phase 2

Phase 2 Analysis

This chapter will analyze the theory and parts used in this phase. The chapter will start of with an introduction of this phase leading from phase one, explaining the area. All of this will be explained and shown with the help of GIS data (see Appendix C on page 137), mapinfo (see appendix C.5 on page 140) and Google earth. It should also be mentioned that as this phase includes scripts to use Google earth as a planning tool most of the visual data presented will be in that format rather than using mapinfo as a visual aid.

10.1   Introduction

Phase two's goal will be to finish the automation access network process and then from that plan the network with and without redundancy. Phase two will base it's criteria heavily on the research done in phase one. This means that rather than test multiple new theories it will plan the network in such manner which shows the best result from phase one, therefore testing the best possible redundant solution against a normally planned non redundant access network. As the focus are on the access network there are possibilities for implementing these ideas to a green field or an already operational network.

The criterias used in this phase have been presented in the previous chapters. Following is a list of criterias, which will be reviewed and researched in this phase:

- Large scale testing

- Segment adjusting

- Automatic district creation

- Two network scenarios

  - Tree topology and eartree topology

  - Home-run only

  - Distribution nodes in one location

- Traffic analysis

- Other access network topologies

- New visual mapping tool

10.2   Location

In the previous study [8] and in phase one, the location of the study has been limited to one town in the municipality of Hals, namely Vester Hassing. This town was specically chosen due to layout and interesting road network. This is only one town and therefore a small scale test area. That is necessary in order for the testing to be reliable. If testings of the scenarios were directly done in a large scale environment the smaller problems would be harder to detect, as well as small problems could become relatively larger and more complex to solve. Not only was the small scale testing done to iron out problems in the automation process but also to hold consistency to the previous study.

Part of phase one is to do a large scale testing, so after everything had been tested in the smaller scale the location of the networks were gradually made bigger until the whole chosen location could be planned and most problems had been covered. The location chosen for the large scale testing was the whole municipality of Hals. The reason for choosing the municipality of Hals is based on the fact that lot of testing has been done in the area as well as it offers both testing of densely and rural populated areas, while not being to large.

This means that a new factor entered the planning process which is namely the fact that now rural areas have to be planned. This is mainly due to the fact that the small scale testing was bound to work only in a dense town area, so this on it's own can create it own set of difficulties which needs to be addressed.
More detailed information and figures can be seen in chapter 3 on page 26.

10.3   Green field and operational networks

Because many of the older telephone companies or in general those who run the copper line infrastructure today, are trying to utilize the copper infrastructure as much as possible, they are switching it out with fiber from the top down. This entails that in order to increase bandwidth they are step wise approaching and moving the fiber closer to the home starting with the backbone and now moving closer down the network infrastructure. One of those companies doing so is TDC here in Denmark, and already they have replaced most of the backbone with fiber and are moving into the distribution areas. According to information gained at a network course in Aalborg University, they have even started testing with fiber to the curb (FTTC). This means that during or from that step TDC could implement the eartree topology. There are three possibilities for introducing the eartree topology, first one is to introduce it while they are creating the FTTC. Second one is to introduce it after they have finished the FTTC and even FTTH. The third, which would be the cheapest, is to add the eartree topology after FTTC and during FTTH step. The first and second option would have equal amount of cost factor as trenches would need to be dug down from their distribution nodes (DN's) to the street boxes. The third option would be cheapest as with that trenches dug for the FTTH process could be reused for the second line to the street boxes, making the cost mainly extra fibers cables to the street boxes.

It should be mentioned that this is only an idea presented due to the design of the topology

that this is a possibility. It largely depends on the network in question and the current development of moving towards fiber. As a second option even companies with already made fiber networks could implement it, however it would introduce the extra digging and fiber cost. But it should be limited based on the fact that it is only laying bulks of fibers between two places.

Now if taken into account the TDC method of stepwise approaching, it's customers with fiber it could be said that this phase adheres to investigating the price difference of distributing the fiber with and without redundancy. This is mainly due to the fact that the planning method used is not involved directly in the upper layers.

10.4 Distribution nodes

Though the focus is on the access network some knowledge of the upper infrastructure is needed in order to connect the access network to the distribution network. For this phase the locations of the TDC central offices (TDC CO's) are mainly needed, these will then act as the distribution nodes in the scenarios. For the redundant scenario, two virtual DNs will be created within the same TDC CO. The location of the TDC COs are based on the density of NTs and as can be seen in chapter 3.3 on page 30, there are seven TDC CO's located in the municipality of Hals.

In a previous study [24] it was concluded that the best solution for their study would be to plan it using only five of those TDC CO's. As it is a goal in this phase to accommodate both the possibility for green field planning as well as implementation to already an operational network all seven TDC CO's will be used. The use of all the seven TDC CO's also offers more testing ground as districts that are created are based around the DN. It should be mentioned that a prerequisite for this to work is that either the green field network or the already made network has distribution nodes with redundancies, or offering redundancy in the access network will become unnecessary.

The seven TDC CO's used in this phase are as follows:

- DN: Uls

- DN: Stae

- DN: Hoh

- DN: Hals

- DN: Gaas

- DN: Gad

- DN: Vha

Figure 10.1 shows the location of the TDC CO's from a satellite photo and the road network.
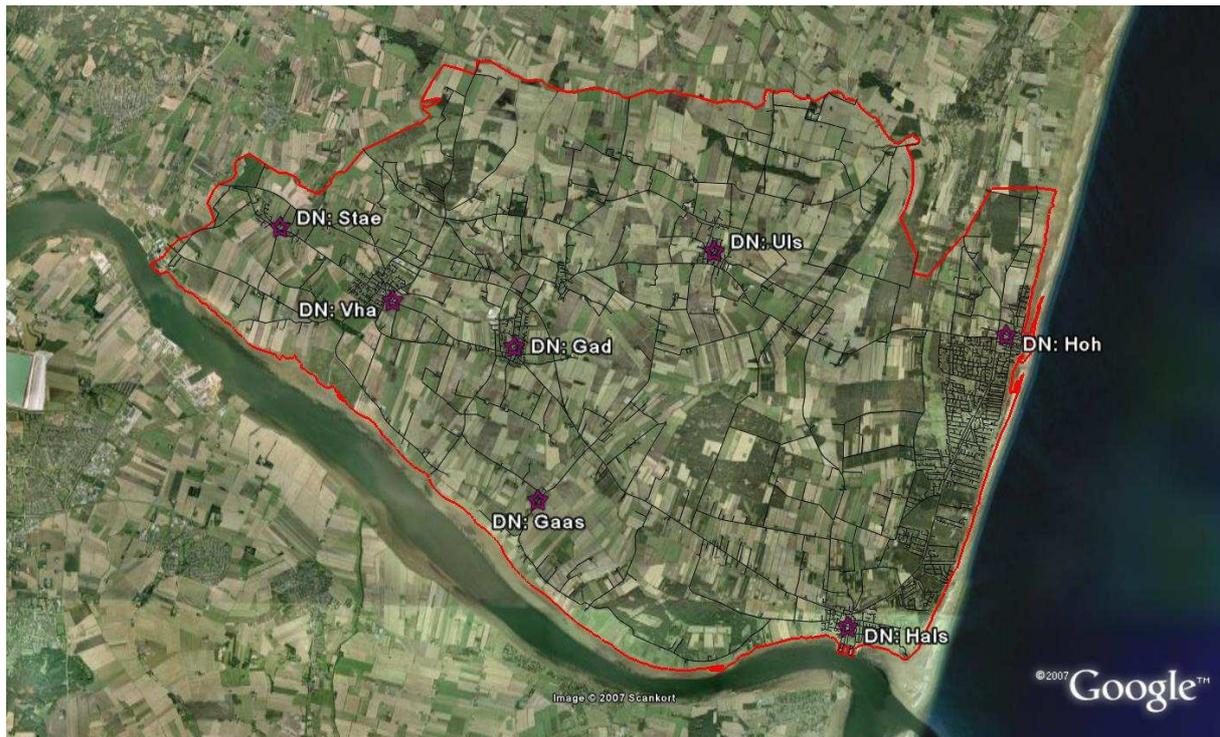
Figure 10.1: Location of TDC CO's in Hals and the road network.

10.5 Districts

The main part of this phase is to automate the district creation process. As automating the process of the district creation it is necessary to investigate what is needed before creating it. Mainly because the manual creation had a manner in which it chose it's district which of course is not applicable here. Furthermore the placement of splicing points would need to be rethought. As well as reviewing whether the guidelines created for manual process would uphold here.

10.5.1 District creation methods

Two main ways were researched in order to create an automated district. This either blindly created the districts based on set of rules or started from one point and worked from there. Both ways were investigated and number of solutions were suggested and reviewed.

Blind selection

First suggestion was to randomly choose points in the road network. In order to do so a set of rules were created in order to evenly distribute the points. From that a post process could be done to normalize the district by joining smaller districts together. The main downside to this is that it affects dense and rural areas the same making this quite unsuitable. This is because in dense areas districts only need to be small but in rural areas district need to be at it's maximum. Finding a suitable distance between the random points could prove hard, and leave a set of problems. Also mainly the idea of randomly placing points could create a chaotic network where the interest of creating a cost efficient network could be problematic.

Grid districts

Another suggestion was based on blindly creating the districts in a grid format using a set of rules to define the grids. Those rules were numbers of NT's, inside each grid and second the size of the grid from end to end. Figure 10.2 shows the result of the tests. As can be seen in the figure there are a lot of problems involved within this process mainly is the fact that as the road network is not involved in the grid making process therefore districts can have several number of roads which not necessarily are easily connected. First it was thought that the solution to that problem was to dig through yards to access roads on the other side, however it would prove to be very complex to have each district covering several roads and maybe even only segment in another road. This grid mechanism was borrowed from Tahir M. Riaz's, Aalborg University, study on grid making for WiMax towers but adapted to be used in this manner.

Figure 10.2: Grid selection.

Blind grid districts combination

From these two ideas came the third which was to combine these ideas which could solve the problem from both suggestions. This involves first creating a grid district and from that choose a point near the middle of each grid on a road segment and from there create each district. This would solve the problem that each point would only create districts with the available segments closes to it, therefore eliminating the problem of covering several roads in different places. Second it would create a more even distribution in both rural and dense areas. This solution, like the blind selection was thought to be to chaotic and the results from that would be to much based on luck rather than practicality.

Spanning tree districts

The last solution was to use the TDC CO's as a starting point for each area from there the closest number of NT's based on the rule would be chosen and a district created. This would then be done until every road segment had been traveled. After that a point in the segments just outside the district would be chosen as the next starting point. Now this solution sounds more practical as we would choose a fixed point and then with the help of spanning tree choose the next amount of closest NT's until everything is finished.

But as the others it did not come without it's problems. First choosing the points outside the district would need to be found in order to create the next district. Second because the limitation on number of NT's which could be chosen, their might be the problem of cutting dead end streets to short creating lots of small districts. Empty district could be formed as each district would have a limitation, and traveling to rural areas could mean empty district.

This method was chosen based mainly on the fact that in it's process it was most practical as it chose districts from one point and created each district in the shortest distance possible. Those problems mentioned would have to be fixed in order to make it useable.

10.5.2 Splicing points

The placement of splicing points plays an important part in the network process as the placement can mean the difference of several km of fiber per district. Since the process is automatic we have the advantage of viewing where inside each would be the optimal placement, i.e. which segment point is the closest to all NT's.

Like explained in the previous phase the splicing point is the point in which the districts are connected to the splicing point. By doing so it can run multi fiber cables to each district rather than a lot of single fiber cables which costs more. Thus it shorten the distance of needed single fiber cables. Like in phase one the chosen splicing point would be a street box mainly for it's easy access, it is also possible to use trenches if those are more available.

Now as rural areas will for the first time be tested it includes a number of small districts which will form as a limitation on how long a district can be due to blowing distance. In those cases we will not be requiring 96 fiber cables but can rather decrease that number to a more suitable one depending on the size of the district, therefore saving on costs. And in the smallest one street boxes are unnecessary and it would be more practical to use wells or manholes.

10.5.3 Guidelines

Now as can be seen in E on page 155 a set of guidelines weere created to plan the network by, these are as follows:

- Districts cannot exceed the limitation of splicing point of 96 fibers, but should be lower in order to allow for expansion.

- Districts cannot exceed the blowing distance of 1 km. This means that from the splicing point to the NT, furthest away cannot be greater than 1 km.

Now in phase one a hard limit of 70 NT's was set in order to allow for expansion. This hard limitation will in some degree hold, this means that the district should not exceed a number which does not allow for some expansion. But in order to accommodate for the larger problems occurring during the automatic process (namely cutting district in a dead end road) this hard limitation should be somewhat flexible. This should not be a problem as research will be done in the automatic process to find how many NT's should be inside each district. This meaning that the fewer the NT's the less amount of single fiber cables used. Which should lead to cheaper network.

10.6 Traffic

For this phase a simple analysis of the traffic, which will be generated, will also be included. The different aspects of analyzing traffics will be explained and then the distribution nodes used in this project will be tested with different redundant topologies. This part is mainly introduced in this phase as a learning process but does not have a great affect on the whole picture of planning these networks.

10.7 Cost

Prices for most of the aspects in FTTH access networks will be detailed here. These aspects include fibers, digging and housing. As has been mentioned before acquiring prices for these aspects is quite a complicated task as the market is unwilling to give out prices due to fears competitiveness on the market. Two researches have though acquired some prices which will be used here [25] [8]. Much effort has gone into acquiring a set of updated prices but the research got the same problems as mentioned in [8], where prices where not given to other then companies involved in the business and then in full confidentiality.

It should though be mentioned that some of these prices are 4 years old, and therefore these prices should be a bit on the higher end than what the market offers today. The prices are an estimation, and since this project is based on estimation rather than full details, the prices can be used. In such case later on when updated prices are acquired it is a simple matter of recalculating the results in order to get updated prices.

The cost factor will only be looked at as one a time payment and updates, upgrades or yearly costs will not be looked into, as the project focuses on the starting cost of these networks rather than running cost.

10.7.1 Fiber

The type of fibers used in this phase are several, the main duct line will use 96, 48 and 24 fiber cable. The number of fibers in the main duct depends mainly on the size of the district the fiber is traveling to. Also the blowing of fiber cost is included, and as can be seen the blowing of fibers cost is quite high as mentioned in previous phase. The splicing points will also be mentioned as well as the splicing itself and termination of the fiber in one end.

The cost can be seen in table 10.1.

Variable	Cost [m]/[u]
192 Fiber pairs	108 DKK
144 Fiber pairs	81 DKK
120 Fiber pairs	69 DKK
96 Fiber pairs	54 DKK
48 Fiber pairs	27 DKK
24 Fiber pairs	15 DKK
Fiber pair	4 DKK
Blowing of fibers	7 DKK
Wells	5000 DKK
Termination	300 DKK
Splicing	250 DKK
Street box	N/A (5000) DKK

Table 10.1: The fiber cost factor for phase two.

10.7.2 Digging

Previous phase did not include digging, as the main focus was to decrease the fiber rather than the focus would be mainly on the fiber cost. As this phase strives at reviewing the complete cost of the network planning it will now include the digging. According to [24] there are different prices for different type of soil. This study will not distinguish between this but rather have one general price estimation for digging. Also the prices of pipes and handling of pipes will be viewed. The price of the digging will include large enough trench such that all necessary piping can be placed eliminating the need for later excavation. The cost for the digging can be seen in table 10.2.

Variable	Cost [m]
Digging	150 DKK
Pipes	10 DKK
Handling of pipes	8 DKK

Table 10.2: The digging cost factor for phase two.

10.7.3 Housing

As explained in F on page 161 the project uses already available TDC CO's as a location for distribution nodes. By doing so costs can be saved as there is no need for building houses to host the distribution nodes, as well as running costs are kept down. The reason for this being a possibility is the fact that TDC is required by law to rent out spaces in their CO's to other competing businesses. This is not free and there are costs involved. There are two types of costs, the startup cost as well as yearly running costs. But as explained this project focuses only on the startup cost. The price for the rental of a TDC CO's is 1000 DKK per m^2 per year, so assuming that each DN would use $10m^2$ it can be seen that renting of the house will cost 12.000 DKK per year per TDC CO. All costs can be seen in table 10.7.3. The sum is shown at the bottom of the table showing total cost for each housing.

Variable	Cost [u]
Housing	12.000 DKK
Rack space	11.282 DKK
48 VDC Plug	3189 DKK
230 VAC Plug	3189 DKK
48 VAC Service Plug	3189 DKK
Sum	32.849 DKK

Table 10.3: The housing cost factor for phase two.

Traffic analysis

11

11.1   Introduction

In this chapter the traffic analysis for the municipality network will be presented. The chapter starts by reviewing the physical main nodes model then, by using this physical reference model. The traffic matrix will be discussed in detail and finally the link and node dimensioning will be presented. For mored detailed traffic estimation and analysis please check the enclosed CD in a folder "traffic".

11.2   The physical main nodes reference model

The physical redundancy is a parameter on the connectivity level, this helps in knowing how many independent links connected to the nodes are available. The overall goal is to support the network with high degree of redundancy and connectivity. A brief discussion for deciding how many links are needed to connect two nodes as presented [12], the research explains it by considering redundancy, QoS and SQoS.

The availability of a network is one of the most important aspects considering the structure planning of the network. This impact is directly related to the redundancy offered by switching and application services placed upon the IT infrastructure.

There are seven main nodes, which are used in the municipality. For researching the network analysis for the principality two scenarios are created which have different types of physical backbone structure. The first structure is shown in figure 11.1. The physical backbone in this scenario, each main node has a minimum degree three for all the municipality main nodes. The main node at Gandrup has a degree six that connects the municipal to other higher level networks in the country of Northern Jutland. The second scenario, which is shown in figure 11.2 is a type of ring structure. Here each main node has a degree two for all the municipality main nodes.

11.3   Traffic matrix

A traffic matrix is a matrix between nodes in a network that is used to estimate the amount of data transmitted between every pair of network nodes. This matrix can be used for capacity planning like when the network changes, for optimization of a network as well as for analysis of a network under failure conditions.

In order to get an insight into the traffic that will flow in the main nodes, estimated traffic matrices were built with the use of a network planning tool called planet and a spread sheet application, excel. Estimated traffic matrices use predefined information, for instance, service bandwidth demand and routing information. The traffic that flows on the network varies in the
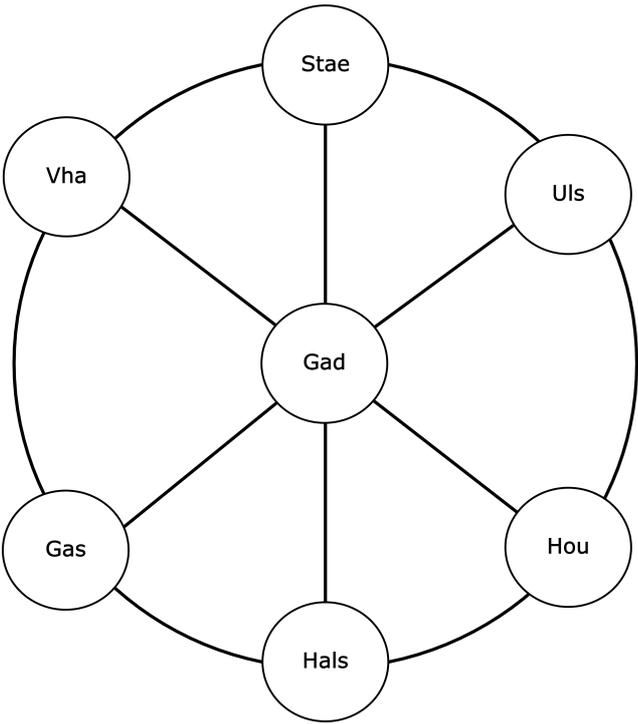
Figure 11.1: Physical backbone model for scenario 1

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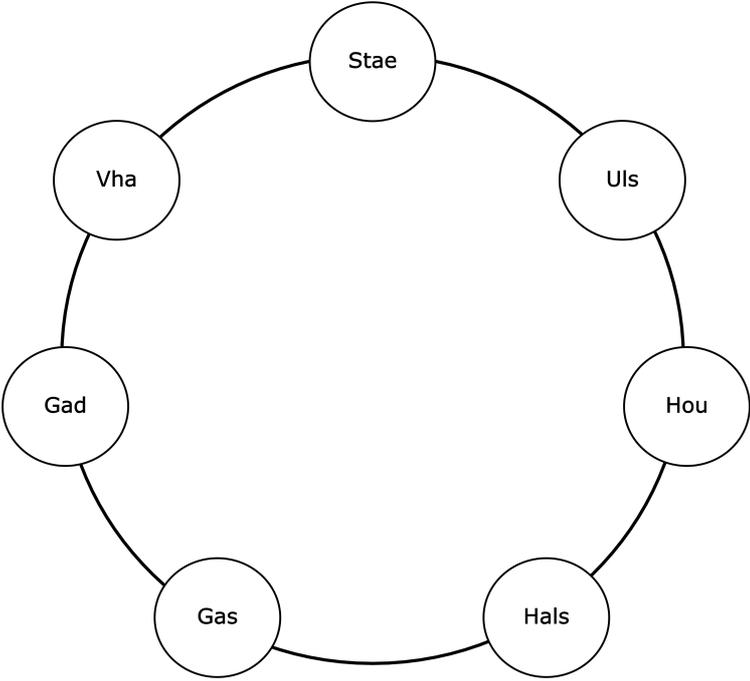
Figure 11.2: Physical backbone model for scenario 2

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way it is deployed.

For all the matrices it is assumed that traffic travels the shortest path possible. For calculating the traffic matrix for the municipality the following steps are done.

- assign number of NT's for each node

- calculate the sum of all NT's in the network

- calculate the percentage of NT's for each node

- do so for all the nodes

- create all-to-all traffic

The following table 11.1 shows the number of NT's for each main node in the municipality.

DN name	Abbreviations	Number of NTs
V.Hassing	vha	988
Gandrup	gad	761
Hals	hals	2356
Hoh	hou	2717
Ulsted	uls	673
Stae	stae	192
Gaser	gas	217

Table 11.1: DN name with number of NT's

.

11.3.1 Traffic matrix for scenario 1

By using table 11.1, for the Hals municipality, the internal all to all traffic matrix is shown in table 11.2.

Node	vha	gad	hals	hou	uls	stae	gas	Total NT's	Percent
vha	124	95	295	340	84	24	27	989	12.50
gad	95	73	227	262	65	19	21	762	9.63
hals	295	227	702	810	201	57	65	2357	29.78
hou	340	262	810	934	232	66	75	2719	34.35
uls	84	65	201	232	57	17	19	675	8.53
stae	24	19	57	66	17	5	6	194	2.45
gas	27	21	65	75	19	6	6	219	2.77

Table 11.2: All-to-all traffic matrix for scenario 1.

The traffic matrix in the table 11.2 gives the total numbe of NT's each municipality main nodes, For example, the sum of the first row in the above table gives the total number of NT's in Vester Hassing.

The all-to-all NT percentage, NT traffic matrix is also shown 11.3.

Node	vha	gad	hals	hou	uls	stae	gas	Total
vha	1.57	1.20	3.75	4.30	1.06	0.30	0.34	12.50
gad	1.20	0.92	2.87	3.31	0.82	0.24	0.27	9.63
hals	3.73	2.87	8.87	10.23	2.54	0.72	0.82	29.78
hou	4.30	3.31	10.23	11.80	2.93	0.83	0.98	34.35
uls	1.06	0.82	2.54	2.93	0.72	0.21	0.24	8.53
stae	0.30	0.24	0.72	0.83	0.21	0.06	0.08	2.45
gas	0.34	0.27	0.82	0.95	0.24	0.08	0.08	2.77

Table 11.3: All-to-all traffic percentage, traffic matrix for scenario 1

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An all-to-all traffic matrix placed on a topological structure can be used to determine the size of the links and nodes. For example, to see wheather traffic is evenly distributed over the network. The NT matrices represent the volume of NT's on the links, assuming that all NT's are communicating. The probability of that happening is very small and therefore a binomial distribution is used to estimate the number of active NT's in the network. For reducing the number of NT's by using binomial distribution a significant level of $\alpha = 0.001$ and $p(activeuser) = 0.4$. Details about binomial distribution can be found in [24].

In order to use binomial distribution to scale the NT's all-to-all matrices for dimensioning the network, the probability of a single user online has to be estimated. An analysis has been done on the number of active users in short and long term. In a short term case in the municipality of Hals the active users are set to be 20%, in the middle of the term the number of active users increase to 30%, and in the long term view the number of active users will be 40% [24].

Table 11.4 shows internal all to all traffic matrix by using binomial distribution.

Node	vha	gad	hals	hou	uls	stae	gas	Total NTs	Percent
vha	43	32	107	124	28	7	8	349	12.25
gad	32	24	81	94	22	5	6	264	9.63
hals	107	81	266	309	21	17	20	871	30.56
hou	124	94	309	358	82	20	23	1010	35.44
uls	28	22	71	82	19	5	6	233	8.18
stae	7	5	17	20	5	1	2	57	2.00
gas	8	6	20	23	6	2	1	66	2.32

Table 11.4: All-to-all traffic Matrix with binomial distribution

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The all to all NT percentage, NT traffic matrix by using binomial distribution also given below in table 11.5. .

The planet network planning tool gives the matrix a graphical view of the nodes with the links between the nodes. From figure 11.3 on the next page, which shows the graphical view of

Node	vha	gad	hals	hou	uls	stae	gas	Total
vha	1.51	1.12	3.75	4.35	0.98	0.25	0.28	12.25
gad	1.12	0.84	2.84	3.30	0.77	0.18	0.21	9.26
hals	3.75	2.84	9.33	10.84	2.49	0.60	0.70	30.56
hou	4.35	3.30	10.84	12.56	2.88	0.70	0.81	35.44
uls	0.98	0.77	2.49	2.88	0.67	0.18	0.21	8.18
stae	0.25	0.18	0.60	0.70	0.18	0.04	0.07	2.00
gas	0.28	0.21	0.70	0.81	0.21	0.07	0.04	2.32

Table 11.5: All-to-all traffic percentage traffic Matrix for binomial distribution

the nodes, the distance matrix can be easily observed (for example the distance between hou to Vha are 2 hops and the distance between hals to hou is one hop). The accumulated traffic matrix and the distance matrix for the nodes for scenario 1 is shown in table 11.6 and 11.7 respectively.
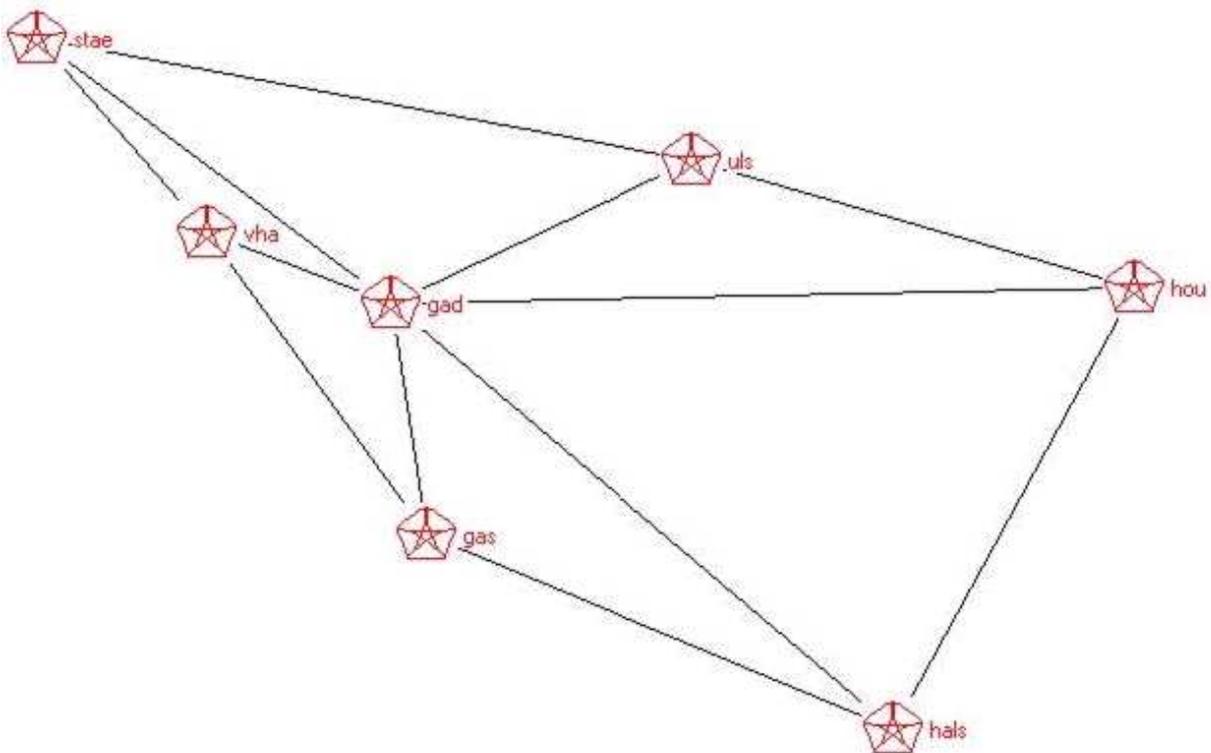
Figure 11.3: Graphical view of the main nodes for scenario 1.

11.3.2 Traffic matrix for scenario 2

By using table 11.1, for the Hals municipality, the internal all-to-all traffic matrix as well as the all-to-all traffic matrix with binomial distribution results in the same matrix shown in table 11.2 and 11.5 respectively except for a different graphical view of this scenario which is shown in figure 11.4.

Node	vha	gad	hals	hou	uls	stae	gas	Total
vha								
gad	1626							
hals		1558						
hou		1483	1620					
uls		736		463				
stae	58	283			33			
gas	65	228	129					

Table 11.6: Accumulated traffic matrix for the nodes for scenario 1.

Node	vha	gad	hals	hou	uls	stae	gas
vha							
gad	1						
hals	2	1					
hou	2	1	1				
uls	2	1	2	1			
stae	1	1	2	2	1		
gas	1	1	1	1	2	2	

Table 11.7: Distance matrix for the nodes for scenario 1.
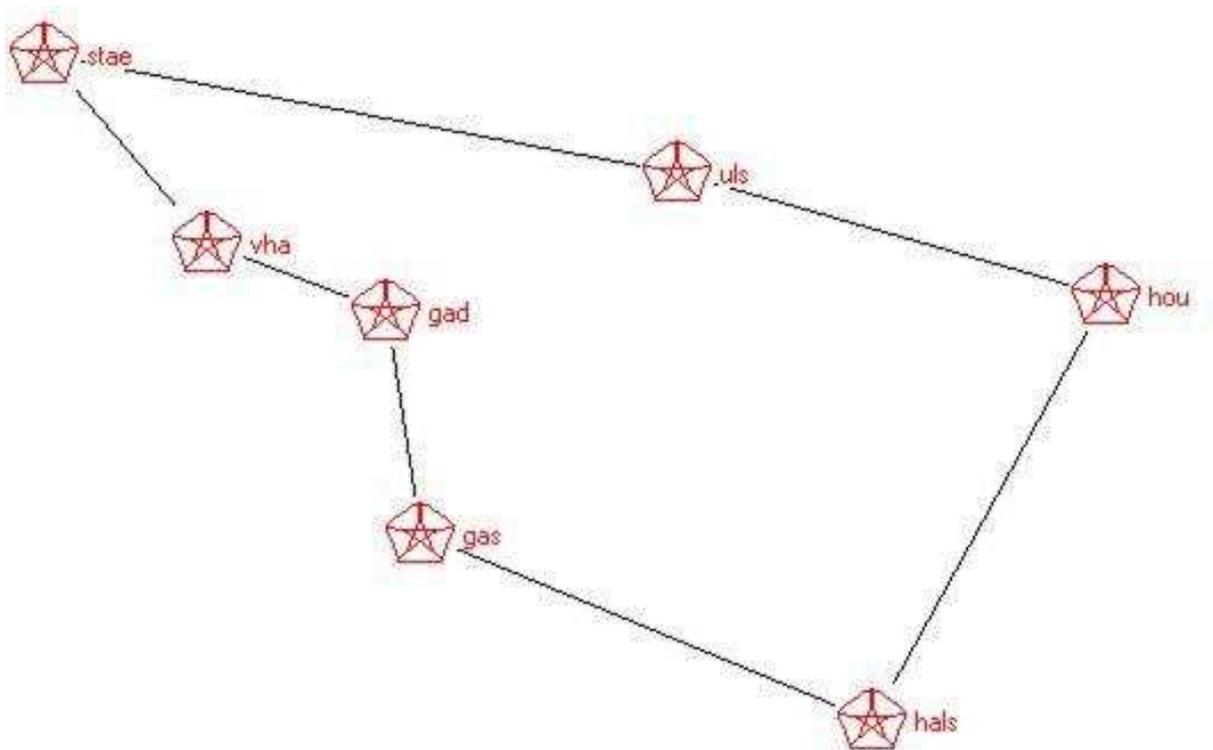
Figure 11.4: Graphical view of the main nodes for scenario 2

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From figure 11.4, which shows the graphical view of the nodes, the distance matrix can be

easily observed. The distance matrix given in table 11.8, shows the shortest distance between any pair of nodes. Since scenario 2 has a different physical structure for the node, the accu-

Node	vha	gad	hals	hou	uls	stae	gas
vha							
gad	1						
hals	3	2					
hou	3	3	1				
uls	2	3	2	1			
stae	1	2	3	2	1		
gas	2	1	1	2	3	3	

Table 11.8: Distance matrix for the nodes for Scenario 2.

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mulated traffic in the links also varies. The accumulated traffic for the links is shown in table 11.9.

Node	vha	gad	hals	hou	uls	stae	gas	Total
vha								
gad	361							
hals								
hou			1048					
uls				648				
stae	385				441			
gas		604	670					

Table 11.9: Accumulated traffic matrix in case of scenario 2

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11.4 Network dimensioning

In this section the accumulated traffic into the links and nodes will be calculated for the two scenarios which are discussed in section 11.2 on page 77. Link and node dimensioning is calculated based on distribution of main nodes and internal traffic.

11.4.1 Link dimensioning for scenario 1

The link dimensioning is calculated based on the network structure given at figure 11.1 and in the accumulated traffic matrix table 11.6. The traffic matrix does not take care of link restoration in case of link breakage. Planet is used to find the worst link break based on the traffic matrix. Figure 11.5 shows the logical connection of the main nodes. The worst link breakage in the network is the link between gad to vha. In case of one link breakage at the same time and when the network is routing the traffic for full restoration, figure 11.5 should be changed to
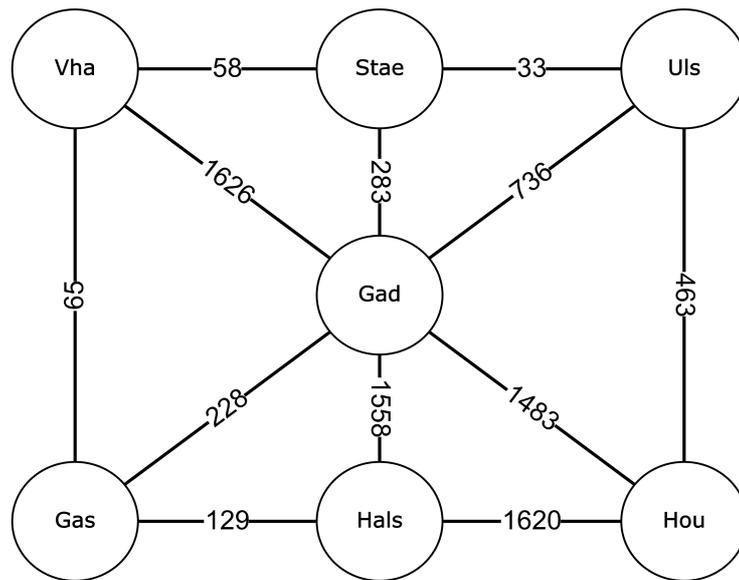
Figure 11.5: Estimated traffic.

other logical connections for restoration purpose. (More on restoration can be seen in [2] and [8]). The traffic intended for the broken link is therefore distributed along other independent paths. The extra traffic is added to the accumulated traffic to find the appropriate link size. This procedure is then repeated for the second worst link break and so on, adding only the extra traffic to links that they have not been added to before, until all the links have their worst case traffic load in case of any link break.

For full restoration in case of one link breakage a careful analysis of 11.5 results to a logical connection that supports full restoration, which is shown in figure 11.6.
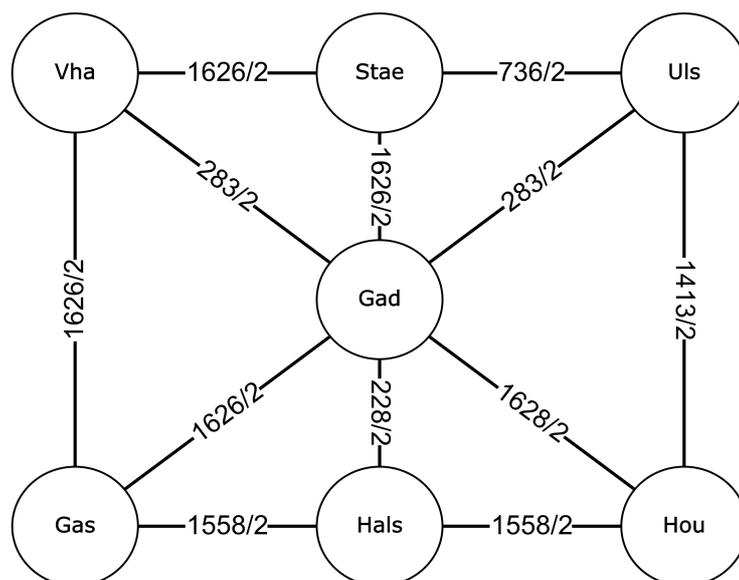
Figure 11.6: Estimated physical traffic in case of one link breakage for scenario 1.

For one link breakage the redundant traffic matrix for full restoration for the municipality is shown in table 11.10. Note that the link breakage does not include a node failure as well as more than one link breakage.

Node	vha	gad	hals	hou	uls	stae	gas	Total
vha								
gad	1768							
hals		1672						
hou		2297	2399					
uls		878		1170				
stae	871	1096			401			
gas	888	1041	908					

Table 11.10: One link breakage full restoration traffic matrix for scenario 1.

The units in estimating an Internet connection is in Mbps, the Internet connection can have the data traffic for all the usual Internet services, i.e. browsing, email and FTP. The new services like home surveillance and security systems. In this project it is assumed that the offered bandwidth is 100 Mbps. It is assumed that an average user uses 10% of his connection [24]. Applying these assumptions on all the NT's matrices it can be scaled down to 10 Mbps.

If table 11.10 is scaled with a bandwidth demand of 100 Mbps, the estimated link size can be easily generated. This is shown in table 11.11.

Source	Destination	Bandwidth
gad	vha	176.8Gbps
hals	gad	167.2Gbps
hou	gad	229.7Gbps
hou	hals	239.9Gbps
uls	gad	87.8Gbps
uls	hou	117Gbps
stae	vha	87.1Gbps
stae	gad	106.9Gbps
stae	uls	40.1Gbps
gas	vha	88.8Gbps
gas	hals	100.8Gbps

Table 11.11: Estimated link sizes for scenario 1.

11.4.2 Link dimensioning for scenario 2

The link dimensioning for this scenario is calculated based on the network structure given at figure 11.2 and the accumulated traffic matrix table 11.9. Figure 11.7 on the following page shows the logical connection of the main nodes.
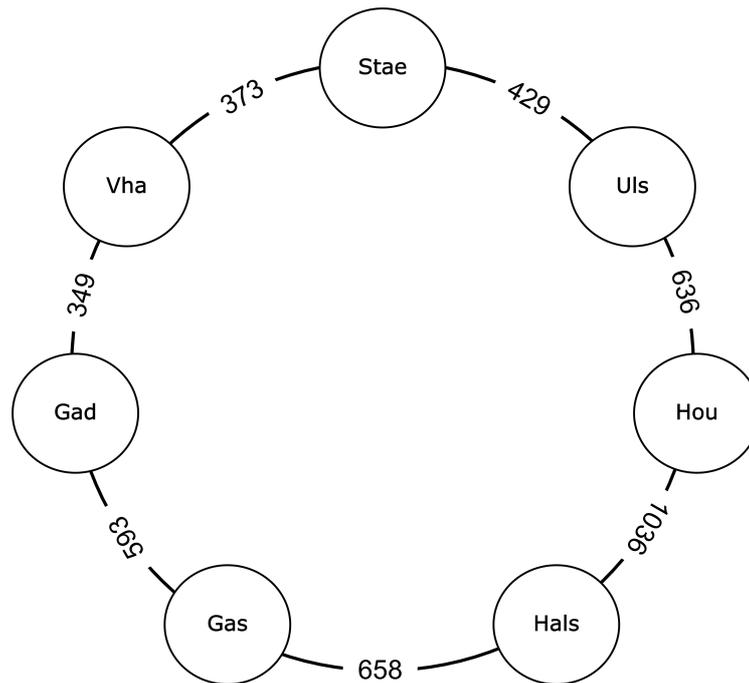
Figure 11.7: Estimated traffic for scenario 2.

For one link breakage the redundant traffic matrix for full restoration for scenario 2 is shown in table 11.12. Note that the link breakage does not include a node failure as well as more than one link breakage.

Node	vha	gad	hals	hou	uls	stae	gas	Total
vha								
gad		953						
hals								
hou			1687					
uls				1684				
stae	814					814		
gas		1262	1212					

Table 11.12: One link breakage full restoration traffic matrix for scenario 2

If table 11.12 is scaled with a bandwidth demand of 100 Mbps, the estimated link size can be easily generated. This is shown in table 11.13.

11.5 Node dimensioning

To make sure that the nodes are able to handle the traffic that is carried by the links, it is necessary to know how the nodes operate, to carry the traffic offered by the links. To do this it is necessary to know how the node sizes are estimated.

Source	Destination	Bandwidth
gad	vha	95.3Gbps
hou	hals	168.7Gbps
uls	hou	168.4Gbps
stae	vha	814Gbps
gas	gad	126.2Gbps
gas	hals	121.2Gpbs

Table 11.13: Estimated link sizes for scenario 2.

Normally a node has to be dimensioned through it's local traffic, transit traffic and external traffic as shown in figure 11.8. Since the network is planned in an hierarchical model, the re-
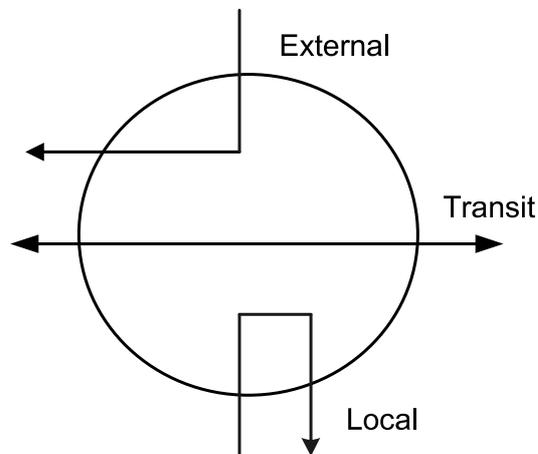
Figure 11.8: Node dimensioning [24].

sults to that at the local traffic is set to zero. The local traffic is zero because no traffic from the access network must be processed by the municipal main nodes before it is sent back to the same access network.

11.5.1 Node dimensioning for scenario 1

For this scenario the nodes are dimzeroensioned with the bases of the accumulated traffic matrix given on table 11.6. The transit traffic matrix on a node is found by adding all the links connected. The amount of traffic a node is accumulating is calculated by equation:

$T(_a) = (T(_t)) - (2 * T(_x)) + T(local)$ [24].

Where $T(_x)$ is the transit traffic from other nodes in the municipality. The municipal main node in Gandrup carries the traffic in and out of the municipality, and is the most heavily loaded. On the other hand stae is the least heavily loaded.

With the help of the planet network planning tool the estimated node traffic is shown in table 11.14. This table is used in order to scale by the bandwidth demand for the municipality that was stated in section 11.4.1 on page 83. The local traffic should not be understood as the local traffic belonging to the particular access network, and will not be included in the estimation of the required capacity of the municipal main nodes. The required node capacity of the

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Node	Accumulated	Local	Transit
vha	3726	248	3500
gad	7436	146	11828
hals	8018	1404	6614
hou	9000	1868	7132
uls	2578	114	2464
stae	760	10	750
gas	856	12	844

Table 11.14: Various types of node traffic for scenario 1.

municipality main nodes is found by the following equation:

$RequiredNodeCapacity = T(accumulated)) + T(transit)$

As discussed, the expected bandwidth demand for the municipality is set to 100 Mbps, and table 11.14 is scaled by this bandwidth demand to estimate the required node capacity. Table 11.15 shows the estimated node sizes for the municipality. From table 11.15, can be seen that

Node	Accumulated	Transit	Capacity
vha	372.6	350	722.6
gad	743.6	1182.8	1926.4
hals	801.8	661.4	1463.2
hou	900	731.2	1613.2
uls	257.8	264.4	504.2
stae	76	75	151
gas	85.6	84.4	170

Table 11.15: Expected bandwidth demand for the nodes in Gbps for scenario 1.

the node stae needs the least capacity and the node gad needs highest capacity.

11.5.2 Node dimensioning for scenario 2.

For this scenario the nodes are dimensioned with the bases of the accumulated traffic matrix given in table 11.9.

With the help of the planet network planning tool the estimated node traffic is shown in table 11.16. This table is used in order to scale it by the bandwidth demand for the municipality that was stated in section 11.4.1 on page 83. As discussed, the expected bandwidth demand for the municipality is set 100 Mbps, table 11.16 is scaled by this bandwidth demand to estimate the required node capacity. Table 11.17 shows the estimated node sizes for the municipality in case of scenario 2. From table 11.17. Like scenario 1 the node stae needs the least capacity but node hou needs highest capacity.

Node	Accumulated	Local	Transit
vha	704	88	734
gad	533	50	953
hals	1746	534	1706
hou	2024	718	1684
uls	469	40	1077
stae	120	4	814
gas	138	4	1262

Table 11.16: Various types of node traffic for Scenario 2.

Node	Accumulated	Transit	Capacity
vha	70.4	73.4	143.8
gad	53.3	95.3	148.6
hals	174.6	170.6	345.2
hou	202.4	168.4	370.8
uls	46.9	107.7	154.6
stae	12	81.4	93.4
gas	13.8	126.2	140

Table 11.17: Expected bandwidth demand for the nodes in Gbps for scenario 2.

Phase 2 Planning

12

This chapter starts by explaining how the networks were in general planned using existing GIS data for municipality of Hals. Then a new tool for viewing GIS data and the method for using it will be explained. Next, each major part of the network planning and respective algorithm, is explained in this phase. Remaining problems with each aspect of the network planning will be explained in the respective sections.

12.1 Planning method

The method for planning in this phase is much the same as in the previous phase. Here the networks where planned using PHP (see appendix D on page 142) programming language to interface to the GIS (see appendix C on page 137) data which is stored in a MYSQL database (see appendix D on page 142). The main difference lies in the creation of a tool to use Google maps to visualize the created networks. Previously a GIS mapping tool called mapinfo (see appendix C.5 on page 140) was used. The tool has some limitation which affected this phase of the project. Therefore a tool was created transforming the GIS data to be able to view results in Google earth. The reason why method was chosen is that the results are highly configurable and can be viewed in endless possible ways making it easier to review the results, and debug problems.

Now like in phase one the original road network was used as a basis to create the network, cause with the help of the road network in GIS format it have connections between all NT's which are connected to the road network. Having this we are able to manipulate the GIS data in such a manor, that with the creation of algorithms any kind of topological network structure can be created and stored in databases. After everything has been planned in a satisfying manor the cost factor can be introduced to the results giving the estimated price of the network.

It should be mentioned that like in phase one this chapter will not go into details about the contents of the databases or the tables created, those information can be seen in appendix D.3 on page 150. The chapter will also not go into full details of every small algorithm used and the PHP scripts used for creating them, it will be explained further in appendix D.2 on page 143. The PHP scripts can be viewed on the enclosed CD. Rather the chapter will explain the larger algorithms used in all scenarios and then explain the scenarios and the planning result.

12.1.1 Digging problem

As explained in phase one, it was realized that in order to correctly estimate the price of digging for the ear topology it would be necessary to calculate digging on both sides of the road. But as the goal of that phase was to view procedures in which the length of fiber needed would be reduced, this was not researched further. Furthermore in this phase as ear topology will not be

reviewed it was deemed that the road side problem would be kept optional. It was realized that including digging on both sides of the road is quite large and complex task and as this is an estimation it was thought necessary to focus on other parts rather than this one.

When actually planning the fiber directly to each NT it can become of interest to accommodate digging on both sides of the road as houses need to be accessed on both sides. Now in estimation planning it can be said that this is an estimation and using only digging in one place is sufficient, those numbers could be quite faulty as they don't give close picture on the digging cost. This meaning that in some roads only half the way needs to be dug on one side and the other half on both sides. While other roads only require one side or two sides. This would give us a totally new estimate.

This being said makes it harder to skip it in this phase, but it is necessary as this problem could be a project on it's own. Therefore solving it here is not a possibility but it is strongly recommended for further development of automating network planning.

In most cases the effects of digging between tree topology and eartree topology is not that different. While the eartree topology needs to dig it's main duct on both sides of the road while tree topology only needs one side. This does not affected so much in dense areas as we already need to dig most of the area on both sides in order to access NT's on both sides. This can be seen in figure 12.1.
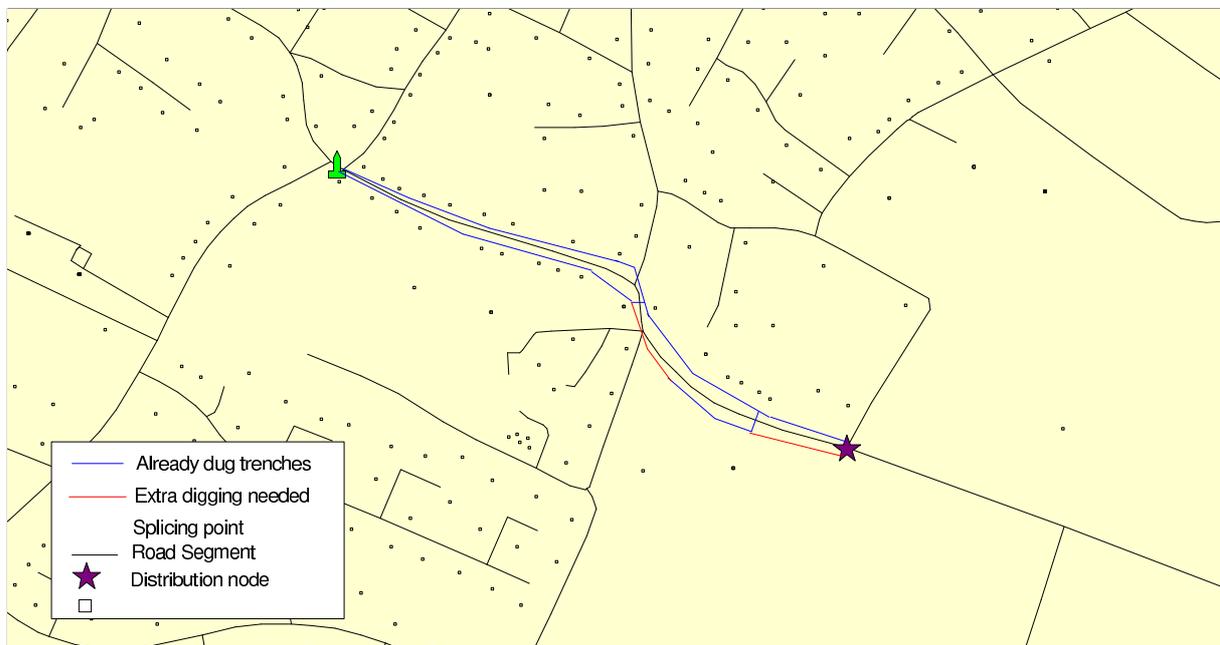
Figure 12.1: Dense digging problem.

In some cases it can affect the rural areas as large segments of road do not have NT's, therefore digging for tree topology is only needed on one side. In comparison to the eartree topology, where we would have to dig on both sides causing the digging to increase for the eartree topology. This can be seen in figure 12.2. This is only meant for the main duct line so all of the rural areas would not be needed to be dug on both sides. So this problem should be

kept in mind, that eartree topology in more rural areas affects the digging.
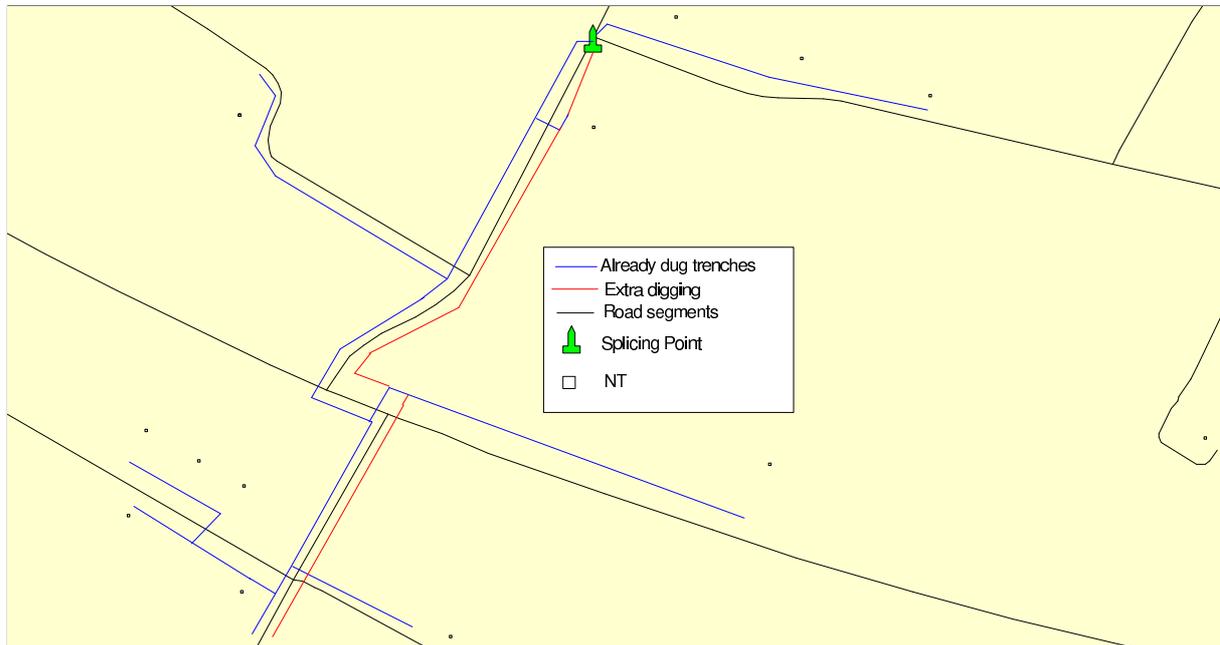
Figure 12.2: Rural digging problem.

12.2 Google earth

As explained previously in this report, regarding this phase, a tool was created which enables us to use the Danish GIS data in coalition with Google earth. This possibility offers a tool to network planners which makes it easy to illustrate it's data in multiple manner. Now like other planning tools Google's earth browsers are all based on layers where each layer could hold point, lines or polygons.

12.2.1 KML and KMZ file format

The layers of Google earth is based on the creation on what is called KML files. The KML file format is used to display geographic data in an earth browser like, Google earth, Google maps and Google maps mobile. KML is based on the XML standard, this means that it is easy to integrate a program which takes the results from the GIS database during or after network planning and generates a KML file usable with any part of Google's earth browsers. And like XML, KML offers variety of configurations, making visualization good and it can simplify debugging during network planning. KML files can be opened using any of Google's earth programs. The KMZ file format is the collection of KML files, this means that all layers (roads, NT's, network, etc.) can be stored in one file which would be the KMZ archive. KMZ files can be opened using any of Google's earth programs. Due to KML being a relative to XML it is possible to add every part of information from the database for set point, line or polygon which in return can assist network planners to identify locations of problems.

It should be mentioned that viewing the KML and KMZ files in Google maps is a quite new process and as of now is quite limited with the amount of data it can show.

12.2.2 Other GIS tools

Other programs which are used for visualizing GIS data are good and namely MapInfo. This project is not stating that the tool created here should be used to substitute mapinfo, because GIS tool like mapinfo are very powerful for example in large corporations where the GIS data is stored in large databases and then accessed through DB connections in mapinfo. This option is of course, as of now, not possible in Google earth. This is presented as a supplementary, tool especially in such cases as presented in phase two. As an example is the automatic district creation, now as the districts will be in the numbers of hundreds it is of interest for the whole view to distinguish between the districts. By doing so it can be better visualized how the distribution of districts occurs with the algorithm created. Doing this operation in mapinfo is quite daunting as separating the districts would mean to take them in one by one and color code them separately. As the numbers of districts could be hundreds this would be quite time consuming. With this process this can be done in the KML making process where the segments marked with the same number of districts could be colored in the same color automatically. Providing us with a simple manner to view the results as the programming of the algorithm occurs.

12.2.3 Transformation

Today Google earth has the possibility of importing GIS data and can be used to present GIS data and thus this really should not be a problem or even worth mentioning. But this requires that the coordinations for the points or lines should be in a universal coordination system format like longitude and latitude. This causes the main part of the problem, as most of the available GIS data in Denmark uses the Danish system 34 coordination system, which Google does not recognize. Thus a mathematical formula for transformation was sought after but proved to be a hard task.

After some research it was found out that the newest version of mapinfo offered the possibility to transform from system 34 long/lat, and even a tool was available to transform the mapinfo tables to KML. Which recognized that MapInfo was already taking steps to use Google Earth as a supplementary tool. All of this would beat the point of making this automatic, so after some research it was found out that they used a transformation library acquired from the Danish environment minister, which turned out to be free of use. This library is however windows, therefore a software would have to be created servicing the needs of those who would use this library.

12.2.4 The process

As this project was unable to come up with the mathematical formula for the transformation in time for the automating process to be created which could call the converting script instead of having it directly in PHP. This means that a process was developed in order to create the KML

files to be used in order to evaluate this phase.

The process was as follows:

- The system 34 X/Y coordinates as called from the database.

- The X/Y where run through the converter program (using a php system call).

- The program returned long/lat which where then placed with the id of the item converted to the database again.

- Then finally a script acquires the needed data from the database and generates a KML file based on the configuration wanted.

Now the possibilities with this are almost endless and can be a great tool to assist network planners who are working with GIS data and doing research. Where data is dynamically changed and a quick visual is needed of the ever changing complex solution.

12.2.5 Remaining problem

The first remaining problem is the fact that Google earth only has satellite photo layer as basis, this means that results can not be viewed in pure map format like can be seen in Google maps. As Google maps limits the use of KML and KMZ files in it's system it can not be used for larger projects to view it's result. Google earth however has a full set of road network as a layer so it can be used but the basis is always there.

Second problem is the fact that instead of being able to implement the mathematical transformation formula directly in PHP it has to rely on outside software to do the transformation. The project contacted the makers of the library to either give information regarding the mathematical formula or get access to the source files which do the transformation. Close to the end of the project they complied and sent a copy of the source files making this possible. But as there was little time left, it was not possible to researched this any further. Rather will the source files be included on the enclosed cd, in case there is interest for further development of this process.

12.3 Segment shortening

As explained in phase one (see section 8.2.1 on page 50) the GIS data have some inaccuracy attached when connecting NT's to the road network. As the NT's connect to the segment points (the point where two segments connect) it can be come problematic in cases where segments are quite long making the distance to the NT's longer or shorter than it should be. Figure 8.1 on page 51 shows this problem. So it was of interest to come up with a solution to fix this problem. At first it was thought to be quite a serious problem but as more research went into the problem it was figured that this really is only estimation planning and is actually in total evens out as some have short and some have long distance. And as both tree topology and ear topology use the same basis the problem occurs with both. Non the less it still will give some inaccuracy in

the planning.

As stated in phase this problem was thought to be quite easy to solve as there were ways to shorten the segments with a simple cartesian coordination midpoint rule. In order to be accurate the segments where kept low. And the matter of then largening it again was to simply ensure that segment points with NT's to them would not be erased.

12.3.1 Algorithm

The theory stated before on how to shorten the segments would now have to be programmed. The algorithm was broken into two parts segments shortening and then segment lengthening. The first algorithm created for this was the shortening and can be seen by these steps as follows:

- First segment in the database was chosen and checked for length.

- If length is more than the maximum length criteria set, it would shorten it by cutting it in half with the midpoint rules.

- This is done until the segment is less than the maximum length criteria set.

- Then the new segments are placed in the database and the old one discarded.

- This is done until every segment meets the criteria.

- Create new segment points based on the segment table.

- Connect NT's to new closer segment points.

This part proved to be a bit harder to tackle than initially thought but after several tries it worked. The second part was to lengthan it, now again this was thought to be quite simple but would prove to be harder than initially thought. This part though is mainly to make the network planning process simpler, as more segments mean more segment points therefore more difficult for the network creation algorithms to create the network. The steps created for this algorithm are as follows:

- Check if segments connecting have segment points, not of degree 2.

- Check if segments connecting have segment points with NT attached.

- If neither, the X1/Y1 of segment 1 and X2/Y2 of segment 2 would create a new segment.

- The next segment point to the new segment was checked if it withheld any of the criteria mentioned above.

- And to ensure that it would not remove bends in the road, thus creating shortcuts (loosing the accuracy again). Check if the initial placement of the segment point to the new placement had a greater value than x meters.

- If not combine the segments.

- This is done until everything is finished.

This algorithm proved to be more difficult than first thought. After several tries on a small scale some baring result was accomplished. Some difference in road structure was observed, but could be negligible. As the transformation to large scale occurred this difference became quite large and was thought to be worse than the inaccuracy now occurring. Any attempt to resolve this was unsuccessful, and other problems followed as other solutions where tested. Many attempts were done to rewrite this algorithm but none of them worked. Thus as much time had been invested in solving this problem, it had to be abandoned so other parts of this phase could be solved.

12.3.2 Remaining problem

The remaining problem of the segment shortening is the second part of fixing the segment inaccuracy. As every attempt to fix that problem had been unsuccessful it will be placed as an remaining problem. The main factor of this part was solved and could in theory be used on it's own to fix the inaccuracy problem. Using it on it's own would not be practical as it would be quite hard on other algorithms which use the segments and segment points. Therefore the inaccuracy is kept in this project. And as stated since this is based on estimation and both tree and eartree topology are affected in exactly the same way it will not affect the results in comparing the two solutions.

12.4 Districts

The automation of the districts is the main focus of this phase like has been explained throughout. First part of this was to investigate how this automating process was to be done as was explained on 10.5 on page 71 where several solutions where proposed. These were blind selection, grid selection, blind grid selection and finally the spanning tree selection. As mentioned the method chosen was the spanning tree selection. This method involves using the spanning tree algorithm to find the closest amount NT's within a set distance. This process relies heavily on criteria's, mainly how many NT's should be situated inside a district and how long a district can be.

Now in the manual planning these criteria's were set using guidelines which instructed the planning on how large a district can be based on maximum blowing distance as well as limit the NT's inside a district based on limitation of the splicing point. Not only did the limitation of the splicing point affect the number of NT's but also the practicality of always having enough space for later expansion. This way expensive excavation and such could be avoided. Now in the automatic process this will still be used however some flexibility is done in order to accommodate problems occurring when automating the process.

The automatic district creation is split in two, first is the creation of the districts based on the criteria. Second is the post process which tries to iron out problems occurring during the automatic district creation. This part also has criteria's. Which are as follows:

- **District creation:** Maximum number of NT's.

- **District creation:** Maximum length of district.

- **Post process:** Maximum number of added NT's.

- **Post process:** Maximum length of added district.

In order to utilize the automation as much as possible, some research into the best possible criteria limitation is needed. It should be mentioned that the district creation criteria's are only soft criterias, as when post process is added, both length and NT's are increased.

12.4.1 Determining district creation criteria's

Maximum length of district

It is known based on the physical limitation of blowing fiber that from splicing points to the NT's length cannot be greater than around 1 km. But as mentioned in the guidelines in appendix E on page 155 this means that an ideal situation, a district from end to end, cannot be greater than 2 km. But as the automatic process is based on starting from one point and in a spanning tree manner collect NTs, this cannot always be true. Also this number cannot be to high as the post process might add extra length to the district.
Some small tests where done creating a network with the limit of 2000 meters for district and with the increment of 100 meters down it was found that 1200 meters was most suitable. This is again attached to the post process distance, so this is only a soft criteria.

Maximum number of NT's

It becomes quite parent that by reducing the amount of NTs per district the amount of single fiber cables needed are reduced. This is possible as NT's are grouped close together to form a district, but instead we have more district and therefore more main ducts and main duct lines. Now as the digging is not affected to much because we re-use trenches all the way, it is interesting to find at which number of NT's per district is the cheapest to plan the network based on this case study. This means that in order to find the number of NT's which show the best result needs to be researched based on the amount of fibers used.

This is possible by planning each distribution node with a different number of NT's and compare the combined cost of single cable fiber, main duct fiber and number of SP's. From that a conclusion can be drawn to which maximum number of NT's per district is suitable in each distribution nodes case. By doing this it was tried further to bring the cost down with the help of the automation process. It should be mentioned that the cost results shown here are in no way the final results but rather a method for determining the best NT's per district ratio.

As the post process is included, the amount of NT's set per district can vary. Not only is it the post process but also the layout of the road network. This means that one distribution node can break the rule of maximum NT's per district when 70 NT's are chosen as a soft criteria. While other distribution nodes will not break the limit until 90 NT's are chosen.

The absolute maximum limit of NT's per splicing point has throughout this study and previous study always been held at 96 NT's, due to the limitation of the splicing box capacity. Also a factor is that larger districts will mean more NT's are affected in case of a line break near the splicing point in the eartree topology. It would be of interest to research what affects on the cost larger district have on the cost of fiber, as larger districts means fewer districts, less main duct line but more NT to splicing point line.

This means that two scenarios are created, which are as follows:

- Scenario small districts: Maximum NT per district is 96.

- Scenario large districts: Maximum NT per district is 192.

The first scenario will review what is the best soft criteria number of NTs per district, with a hard limitation of 96 NT's per district. The second scenario will than add larger districts to see if larger districts could be used to decrease cost. The second scenario hard limitation is a double small district or 192 NT's.

12.4.2   Determining post process criteria's

The post process has two tasks, ensure that no empty districts are calculated in the equation and ensure that a small districts does not form inside a dead end road. The criteria for this is base on two things; number of NT's per district and length of district. Number of NT's has been chosen to ten, and the combined length of the district to 500 m. By doing so it is ensured that districts which could hold 80 NTs within 400 meters are not combined to others, as well as we ensure in the rural area that do not combine two large (size) districts together breaking the blowing of fiber rule.

12.4.3   Algorithm

The algorithm for the automatic district creation was broken into two parts as mentioned earlier. First the districts are created based on criteria and than a post process ensured to iron out problems occurred during the automation process. Though in theory the spanning tree district creation sounds quite simple the programming aspect is another thing. By following these steps it can be seen how the district creation algorithm works:

- A segment point is added to a junction table which will be the starting point.

- Based on the criteria's mentioned earlier a spanning tree will run until it has found it's amount of NT's or the length limit is exceeded.

- All the segments, segment points and NT's are marked with a district number.

- It than searches for the next junction points by checking which segment points have ancestor segment point marked with districts.

- Those segment points are placed in the junction table.

- Process is run again on the next junction point in the list.

- The junction list is updated in every run to ensure that new junction points are added and old or already used segment points are removed.

- Done until everything is finished.

Second part of the automatic district creation is the post process to ensure that no empty district will be included or a very small district will be added to it's parent district. The steps taken in the post process are as follows:

- Each segment is checked based on the criteria that it has less than 10 NT's and is less the 500 m total.

- If so each segment in the district is checked if it has a connecting segments in another district.

- The number of that district is checked.

- Segments, segments points and NT's from the small district is than marked with the connecting district.

- All districts in the segment table are checked if they exist in the NT table.

- If not those segments and segment points are removed.

12.4.4 Splicing point placement

After the district creation is done it is possible to find the best placements for the splicing point. In order to insure a good placement we need to find at which segment point in the district has the least amount distance to all other segments points. This is done with a simple algorithm where we create a spanning tree from each segment point to all other segment point and calculate the distance. The segments points with the least distance to all other segments points in the district will be the placement of the splicing point.

12.4.5 Remaining problem

A lot of work was done into researching and creating the automatic district process. So per say there are no remaining problems, rather will this section investigate further optimizations possibilities.

Rural areas district creation could be optimized better mainly the grouping of NTs. What this means that the spanning tree will create a district until the criteria's are met, and from that point create a new district. So rather than looking at NT's distribution it will blindly create for example two districts for close NT's because of the spanning tree method, this can be seen in figure 12.3.
A similar problem occurs in more dense areas, when the automation process enters a large neighborhood with a road leading to many dead end roads. This can cause the fact that 3-4

Figure 12.3: Rural district problem.

districts are created in that neighborhood because the criteria's are early met inside the district cutting of several dead end roads. This can be seen in figure 12.4. And because the post process

Figure 12.4: Dense district problem.

criteria has a limitation those are not affected. By some method of NT's grouping and normal-

ization we could rather create two medium sized districts in stead of one large and three small. This can be seen in figure 12.5.

Figure 12.5: Normalization problem.

Again the same problem can affect the splicing point placements. This means that it only chooses the best segment point for the placement based on length. It should also include the NT placement as a factor, as the main volume of NT's could be located in one end of the district. This can be seen in figure 12.6.

12.5 Scenarios

The scenarios in phase 2 are not as extensive as in phase 1 and are therefore not in a special chapter. But to ease the readability, scenarios are created.

There are two parts of the scenarios, first there are two district scenarios and from that there are two final scenarios. Depending on the results of the district scenario, two sub scenario might be added to the final scenarios. This will only be done if larger district show possibilities in reducing cost. The two district scenarios are, as mentioned earlier, the tests of small districts and than including the larger districts. The final scenarios are than the complete calculation of everything for the tree topology and the eartree topology. Included in that will be the sub scenarios of small and large districts for both topologies if the result from district scenario show potential.

Figure 12.6: Splicing point placements.

Phase 2 Results

13

This chapter will outline the results for both district scenarios and the complete final scenarios. First the chapter will go into showing the results found for the district scenario. From that the complete scenario can be formulated and calculated. Finally a comparison of the results can be done in order to determine what the results really show.

13.1 District scenarios

The results of the district scenarios are based on testings done in each distribution node (DN). Here the soft criteria of maximum NT's in a district where tested from 30 to 150 with the increment of 10. From that the border of small and large district could also be established for each DN. As this test is quite extensive meaning that the result data is quite large, the entire result can not be shown here. The extensive results can be found on the enclosed CD in "CalculationNT.xls". From that file a compilation of the results for each DN was done, but once again to ease the readability the results are not shown here but can be found in appendix G on page 167. The final conclusion of that appendix will however be shown here.

13.1.1 Scenario small districts

From appendix G on page 167 it can be concluded that which amount of NT suits best for each DN. This is done by evaluating the cost factor shown for each district test. The one which show the least amount of cost is preferable the best amount of NT's for set DN. This can differ between the tree topology and eartree topology. In order to distinguish between a small and large district, the graphs in the appendix have red vertical stapled line, indicating the transformation of set DN to a large district. The result for tree topology are as follows:

- DN: Uls - 70 NT's

- DN: Stae - 30 NT's

- DN: Hoh - 30 NT's

- DN: Hals - 30 NT's

- DN: Gaas - 30 NT's

- DN: Gad - 30 NT's

- DN: Vha - 30 NT's

The result for eartree topology are as follows:

- DN: Uls - 70 NT's

- DN: Stae - 30 NT's

- DN: Hoh - 70 NT's

- DN: Hals - 40 NT's

- DN: Gaas - 40 NT's

- DN: Gad - 30 NT's

- DN: Vha - 30 NT's

From this it can be seen that there is not much difference. In those cases where there is difference between tree and eartree topology NT criteria, the cost shows almost negligible difference. Following this it is of interest to see the cost increase in percentage to determine how much extra fiber cost is between the tree and eartree topology under best circumstances. Table 13.1 shows the cost for each result and the percentage increase.

DN	Tree Cost	Eartree Cost	Percentage
Uls	$4, 4$ Mill. dkr.	6 Mill. dkr.	37%
Stae	1 Mill. dkr.	$1, 3$ Mill. dkr.	29%
Hoh	13 Mill. dkr.	$19, 2$ Mill. dkr.	47%
Hals	10 Mill. dkr.	$14, 6$ Mill. dkr.	47%
Gaas	$2, 2$ Mill. dkr.	$3, 1$ Mill. dkr.	42%
Gad	$3, 2$ Mill. dkr.	$4, 3$ Mill. dkr.	34%
Vha	$4, 2$ Mill. dkr.	$5, 9$ Mill. dkr.	40%
SUM	38 Mill. dkr.	$54, 4$ Mill. dkr.	43%

Table 13.1: Cost increase between topology.

13.1.2 Scenario large districts

In this scenario it is included a large district. This means that instead of absouloute maximum of 96 NT's per district, now there are 192 NT's per district limit. In appendix G on page 167 it can be concluded that which amount of NT's suits best for each DN including the large districts. This is done in the same manner as the small district but the scope of district sizes are increased. Again this can differ between the tree topology and eartree topology. The result for tree topology are as follows:

- DN: Uls - 70 NT's

- DN: Stae - 30 NT's

- DN: Hoh - 30 NT's

- DN: Hals - 70 NT's

- DN: Gaas - 30 NT's

- DN: Gad - 30 NT's

- DN: Vha - 30 NT's

The result for eartree topology are as follows:

- DN: Uls - 70 NT's

- DN: Stae - 30 NT's

- DN: Hoh - 70 NT's

- DN: Hals - 70 NT's

- DN: Gaas - 40 NT's

- DN: Gad - 30 NT's

- DN: Vha - 30 NT's

Following this it is of interest to see the cost increase in percentage to determine how much extra fiber cost is between the tree and eartree topology under best circumstances. Table 13.2 shows the cost for each result and the percentage increase. As expected in almost all cases the

DN	Tree Cost	Eartree Cost	Percentage
Uls	$4, 4$ Mill. dkr.	6 Mill. dkr.	36%
Stae	1 Mill. dkr.	$1, 3$ Mill. dkr.	29%
Hoh	13 Mill. dkr.	$19, 2$ Mill. dkr.	47%
Hals	$9, 8$ Mill. dkr.	$13, 7$ Mill. dkr.	39%
Gaas	$2, 2$ Mill. dkr.	$3, 1$ Mill. dkr.	42%
Gad	$3, 2$ Mill. dkr.	$4, 3$ Mill. dkr.	34%
Vha	$4, 2$ Mill. dkr.	6 Mill. dkr.	40%
SUM	$37, 8$ Mill. dkr.	$53, 6$ Mill. dkr.	41%

Table 13.2: Cost increase between topology.

smaller district showed less cost factor. As the amount of SP-NT fiber is decreased, therefore decreasing the largest factor. The only difference by including the larger district is the eartree topology for Hals, which benefits from the large district. All other cases show that larger districts only increase the cost as we use more SP-NT single fiber cables.

From these results it is not deemed necessary to include large district scenarios into the complete scenarios. As it was used strive to hold as much redundancy as possible, it will not include the full calculation of the larger district but only use the small district.

13.2 Complete scenarios

As explained in the previous chapter there are two scenarios. The two scenarios are the tree topology and the eartree topology. And as smaller districts show much better outcome than large ones, those will only be included. Unlike in phase 1 and in the district scenario, the total cost will be calculated here. The total cost includes the fiber, digging and housing. Equipment will not be looked into as the eartree topology is a theory and no equipment is available to handle that topology.

Each scenario will brake down the cost in a table and a figure shows results of districts and splicing points for all 7 DN's. A figure of the needed digging is also shown. All the costs factors can be seen in section 10.7 on page 74. Appendix G on page 167 shows the results for each individual DN, which this compilation is built on.

13.2.1 Scenario 1: Tree topology

This scenario is the tree topology. Table 13.3 shows the brake down cost for the scenario while figure 13.1 shows the district layout of the scenario. Figure 13.2 shows the digging needed in this scenario. All costs are in DKR.

Factor	Cost [u]/[m]	Amount	Cost
MD:96 fiber	54	55.355 m	3 Mill. dkr.
MD:48 fiber	27	260.249 m	7 Mill. dkr.
MD:24 fiber	15	422.647 m	6, 3 Mill. dkr.
MD:1 fiber	4	52.800 m	0, 2 Mill. dkr.
Main duct fiber		791.051 m	16, 5 Mill. dkr.
SP-NT fiber	4	1.804.948 m	7, 2 Mill. dkr.
Blowing of fiber	7	1.804.948 m	12, 6 Mill. dkr.
Wells	5000	348 u	1, 7 Mill. dkr.
Termination	300	15.112 u	4, 5 Mill. dkr.
Splicing	250	7556 u	1, 9 Mill. dkr.
Digging	150	425.221 m	63, 8 Mill. dkr.
Pipes	10	425.221 m	4, 2 Mill. dkr.
Handling of pipes	8	425.221 m	3, 4 Mill. dkr.
Housing	30.849	7 u	0, 2 Mill. dkr.
SUM			**116 Mill. dkr.**

Table 13.3: Cost brake down of scenario 1

Figure 13.1: District layout for scenario 1.

Figure 13.2: Digging for scenario 1.

13.2.2 Scenario 2: Eartree topology

This scenario is the eartree topology. Table 13.4 shows the brake down cost for the scenario while figure 13.3 shows the district layout of the scenario. Figure 13.4 shows the digging

needed in this scenario. All costs are in DKK.

Factor	Cost [u]/[m]	Amount	Cost
MD:96 fiber	54	201.808 m	$10,9$ Mill. dkr.
MD:48 fiber	27	310.192 m	$8,4$ Mill. dkr.
MD:24 fiber	15	737.964 m	11 Mill. dkr.
MD:1 fiber	4	120.264 m	$0,5$ Mill. dkr.
Main duct fiber		1.370.228 m	$30,8$ Mill. dkr.
SP-NT fiber	4	2.030.786 m	$8,1$ Mill. dkr.
Blowing of fiber	7	2.030.786 m	$14,2$ Mill. dkr.
Wells	5000	297 u	$1,5$ Mill. dkr.
Termination	300	22.668 u	$6,8$ Mill. dkr.
Splicing	250	7556 u	$1,9$ Mill. dkr.
Digging	150	427.138 m	64 Mill. dkr.
Pipes	10	427.138 m	$4,3$ Mill. dkr.
Handling of pipes	8	427.138 m	$3,4$ Mill. dkr.
Housing	30.849	14 u	$0,4$ Mill. dkr.
SUM			**135,4 Mill. dkr.**

Table 13.4: Cost brake down of scenario 2

13.3 Comparison

This section will analyze the data given in the previous chapter as well as involved appendixes. First the small vs. large district will be compared and then scenario 1 will be compared to scenario 2. For each case a conclusion is drawn.

13.3.1 Small Vs. Large districts

As can be seen in appendix G on page 167 and in figures 13.5 and 13.6 that in almost all cases the total prize goes up as the maximum NT soft criteria is increased (red stapled line indicates the small/large district point). Meaning that by reducing district sizes the single fiber lines are reduced causing the cost to go down. The only distribution node (DN) to benefit from a large district is Hals in the eartree topology. Now bare in mind that this benefit is on the line of small and large districts.

This results shows that it is possible to keep the districts in low numbers, which in turn increases the redundancy as in a worst case scenario of a break near or at the splicing point only a few amount of NT's are affected.

Tests furthermore show that there is not much difference in choosing the maximum NT's for a district between the tree and eartree topology. Using the same district's between tree topology and eartree topology is a possibility, as the cost difference would not be that great. In hindsight it can be argued that weighing the extra digging that would be needed by the eartree topology district creation exceeds the decreased fiber benefits. This meaning that some review between
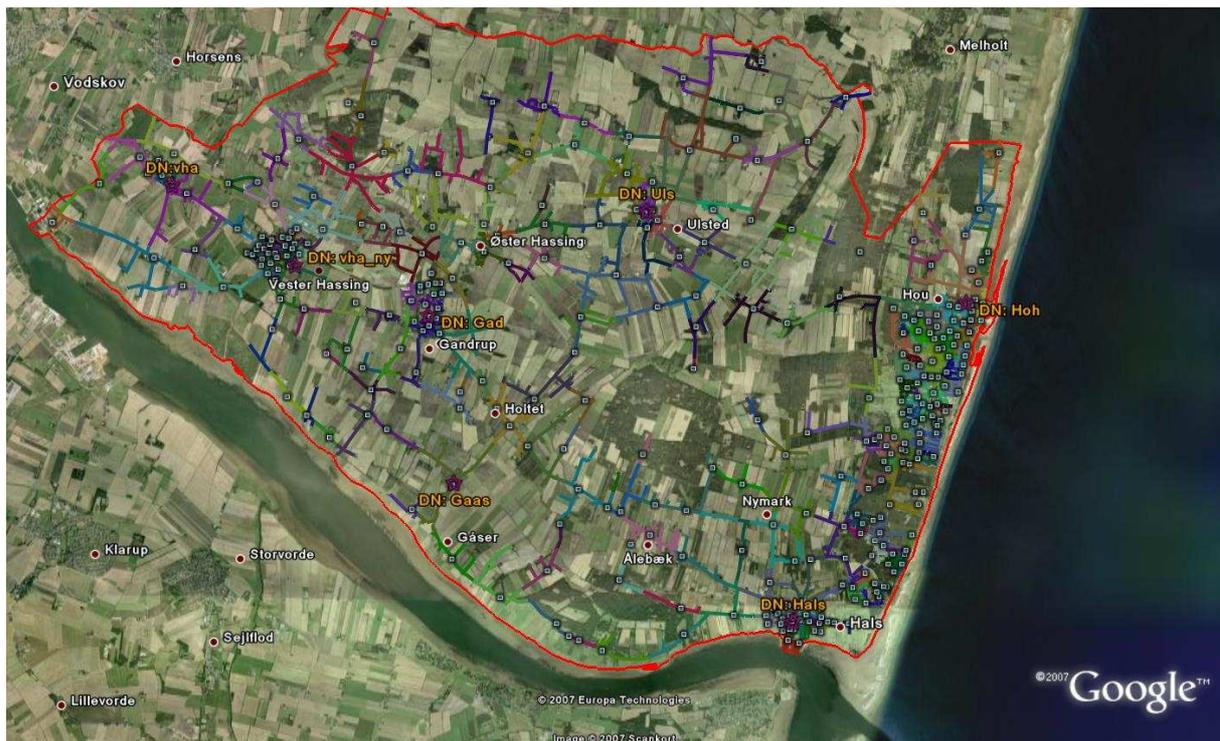
Figure 13.3: District layout for scenario 2.

the digging needed by each scenario according to the districts chosen should also be weighed in.

13.3.2 Eartree topology

The main factor of this phase was to view a redundant topology against the basic one. In phase two it was obvious that according to the tests it was done, and the network planning method, the ear topology could not be used. A newly introduced eartree topology was used in phase two as it showed some promise during the small scale testing.

The results show increased fiber usage compared to phase one. Now this is mainly due to the fact that we now introduce the eartree topology to rural areas. By doing so we increase longer distance for main duct line, also we have more districts with fewer NT's to service. It was tried to limit that increase by only offering smaller main duct cable instead of 96 fiber main duct cable to each district. This means that for districts with 10 NT's one 24 fiber cable is placed to that district rather than a whole 96 fiber cable. Thus decreasing the cost of the main duct lines. In order to accommodate large expansion of a small district, more fiber cables can be placed in the duct at a later time without having to excavate.

Now with the small district in mind we see that between scenarios the cost increase of the fiber is 43%. Now this is quite large compared to the 25% increase shown in phase 1. But that is mainly due to the facts mentioned above.

When all the cost factors are added we see that for the tree topology it would cost 116 Mill. dkr.,while the eartree topology would cost $135, 4$ Mill. dkr.. This means that planning the access network redundancy would cost 17% more than with the normal tree topology. Now
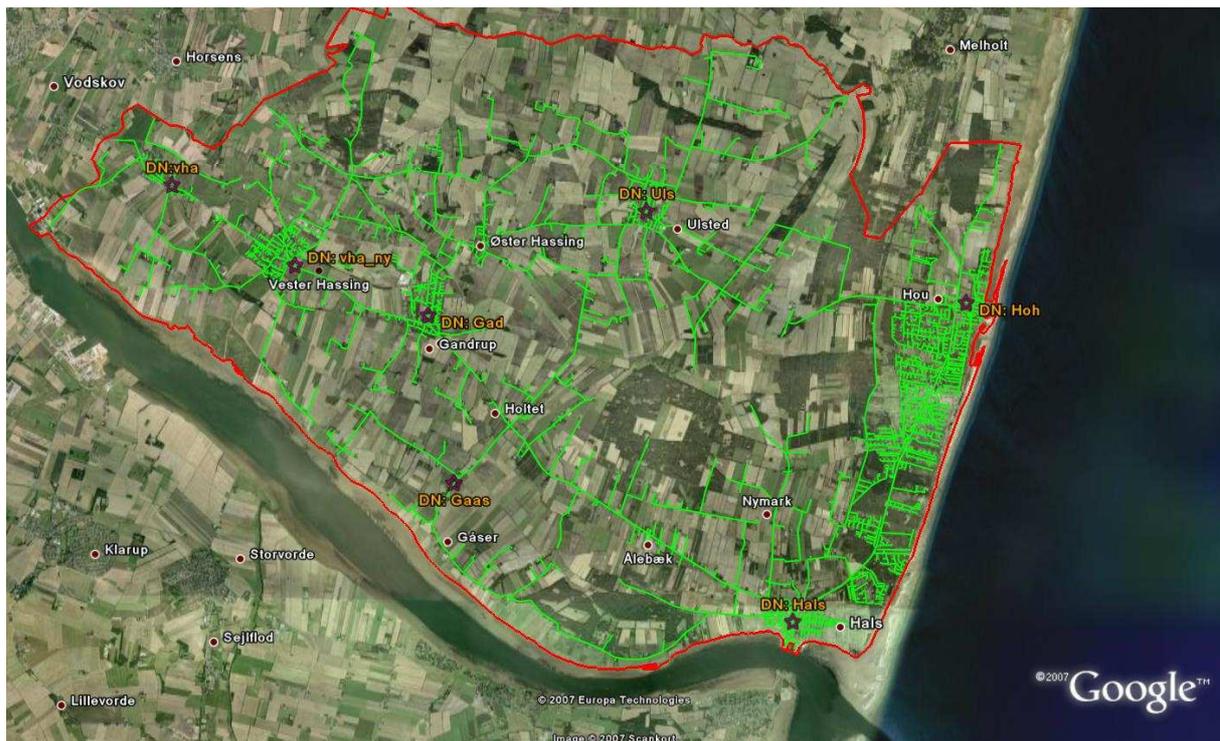
Figure 13.4: Digging for scenario 2.

comparing that to the previous study, where the increase between the tree topology and eartree topology show almost 100% cost increase, this comes as a good result.

There is still some problems which do affect the cost result, and could not be treated in this project period. First the equipment needed for these scenarios has not been added, as there is no available equipment for the eartree topology as it is only a theory. But special routers and passive splicing point equipment will be needed. Second is the digging problem, now before starting phase 2 it was not thought as much of a problem due to the fact that only calculating the digging on one side should affect the tree and the eartree in the same manner. But on closer review it was seen that more digging would be needed in the rural areas as the main duct lines for the eartree topology need separate paths. But this is not a large factor in the dense areas.
Now in most of the DN cases the rural areas cover a lot more ground but in most cases only hold 8% to 15% of the NT's. So in order to save cost but offer redundancy to main part of the population this could be done in a step wise approach. This meaning that in step one only the closest districts inside the dense area would be created with the eartree topology, while the rural areas would be planned with tree topology all the way but offered an wireless as redundancy. Second step would then be to add physical redundancy to the districts in the rural areas by making the splicing points redundant.
By doing this we would largely decrease the main duct fiber for the start run, as well as minimal extra digging would be required to achieve redundancy in the denser areas. This would mean that even with the extra digging it could be achieved to hold the cost increase 15% to 25% for the first step. And by doing so we would offer at least 80% of the population full physical redundancy in the first step. The rural area's could have wireless redundancy for this step.
This all is an idea and has not been tested, therefore it would be of interest to view this step wise
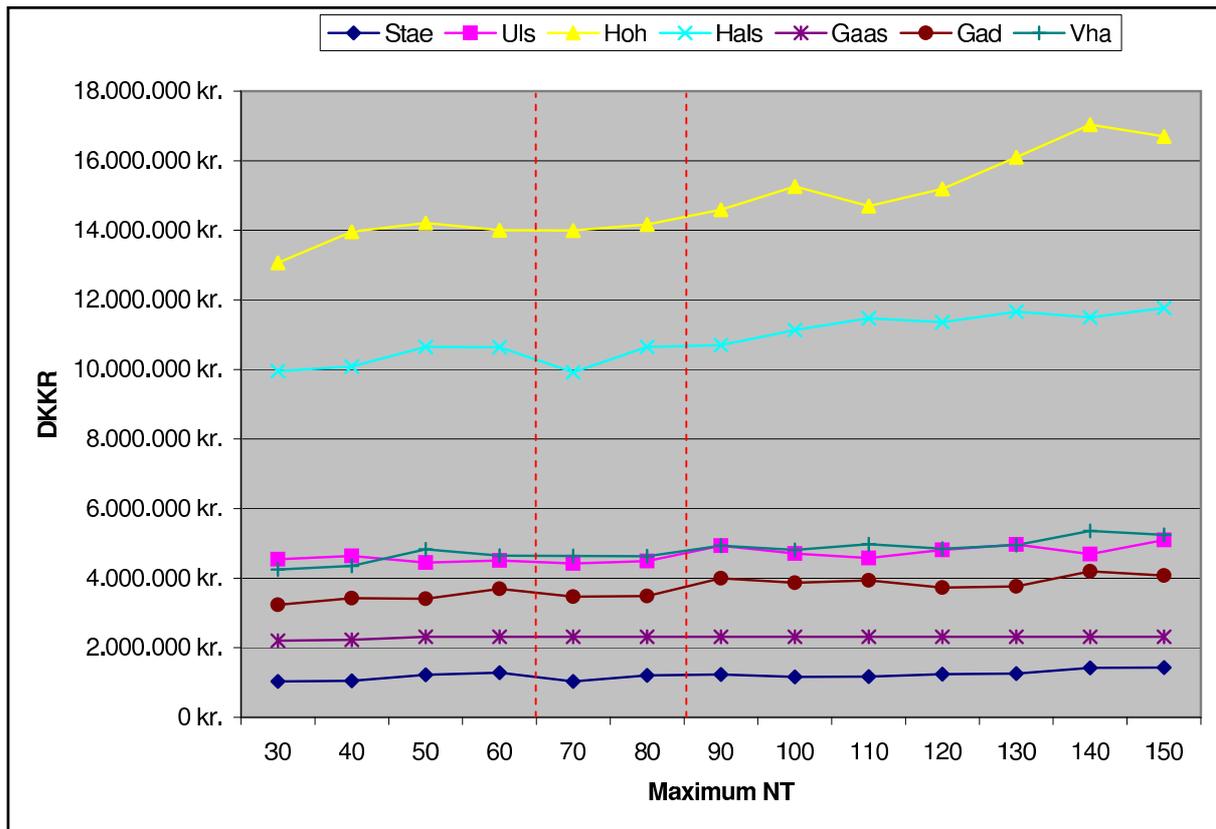
Figure 13.5: Graph illustrating cost depending on maximum nt soft criteria for tree topology.

approach in order to offer redundancy to most NT's with as much little extra cost as needed.

13.4 Conclusion

The goal of this project was to finalize the automation process and plan the scenarios in a more large scale setting. The focus of this phase was to create scenarios based on phase one which would show possibility of offering redundancy in the access network without much extra cost. The calculation of traffic was also done on the side, where two distribution network scenarios were performed.

13.4.1 The automation

The automation process was carried on from phase one using PHP programming language to manipulate GIS data in a MySQL database. The programming was also done in such manner that minor changes are needed to be made in order to be applicable with other GIS data. Phase 1 left one of the larger parts out, namely the automatic district creation which made it the main focus in this phase. Several tests were done in order to find a good viable method of creating district. The method chosen was using the spanning tree algorithm in order to assist in the creation. The result of the district creation and further the splicing point placement was good. There still are some optimization problems which should be addressed, in order to perfect the
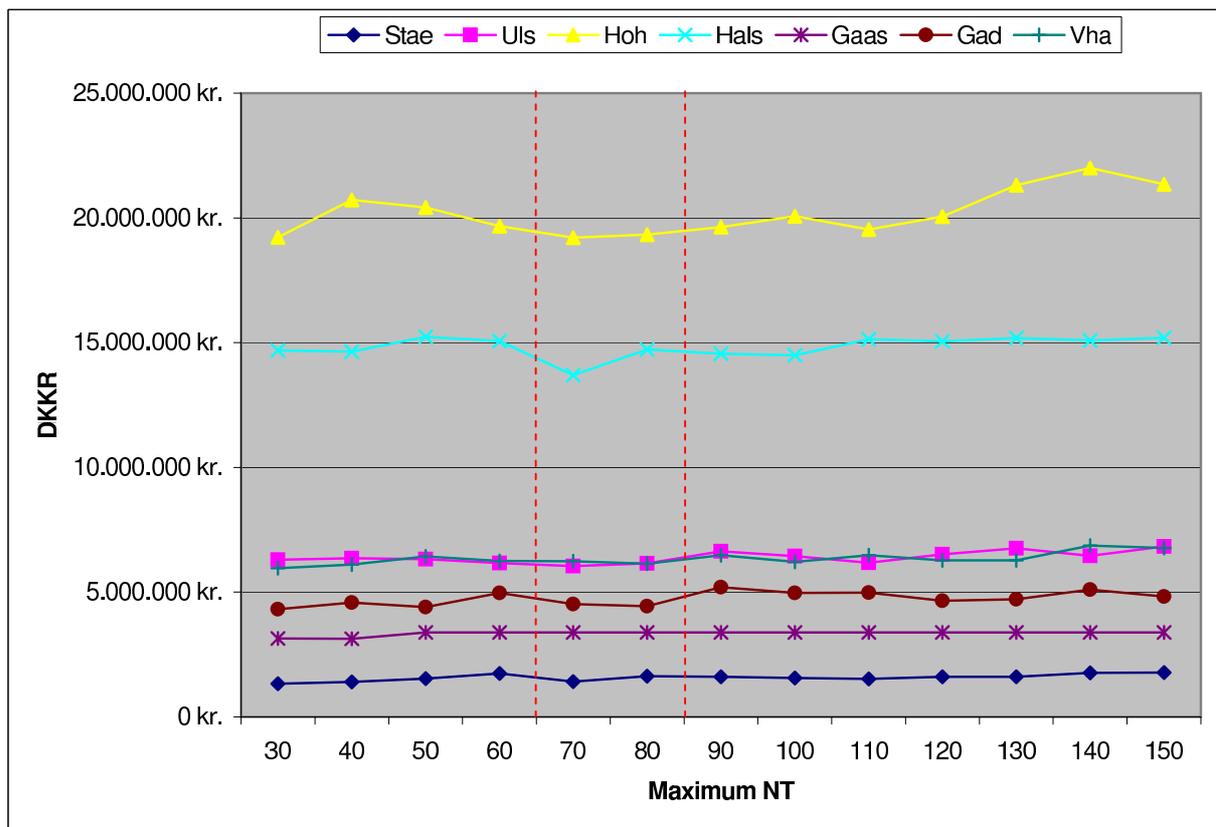
Figure 13.6: Graph illustrating cost depending on maximum nt soft criteria for eartree topology.

district creation.

Second was the segment inaccuracy, the process of increasing the segment points in order to get the NT's closer to the segments was successful. When it came to decrease the number of segment points several problems occurred which could not be fixed. The need for decreasing the number of segment points again is based on other algorithms using them as marking points when creating a network. This means the more segments points, the harder it will be for the algorithms.

A new method for viewing the results was created, which offered the possibility to view the Danish GIS in Google maps. This method made it much easier to debug problems occurring in automation process as results could be viewed directly after the automation had been done. The method offers endless possibilities for network planners working in this manor. As the desired look of the outcome can be programmed more efficiently than available in some of today's GIS viewing tools.

13.4.2 The scenarios

Scenarios were created in order to simplify the reading of the results. The scenarios were broken into two parts. First set of scenarios was the small districts versus the large districts. The results clearly indicated that by using smaller districts the cost would decrease. The main reason being

that the smaller the district the less amount of single fiber would have to be used. Aside from one result, all of the results show that using smaller districts decreases the cost. This is not only good result cost wise, as smaller district means more redundancy. Meaning that in a worst case scenario of an accident near or at the splicing point now causes fewer NT's to be affected.

The second set of scenarios were the main part of this phase, where scenario 1 was the tree topology and scenario 2 was the eartree topology. Though increased fiber costs are shown from phase 1 to phase 2, it was possible to limit the real cost by choosing smaller fiber cables to smaller districts. Further as the digging is the main part the cost increase is lower than expected as the difference between the scenarios is only 17%. There is still a problem with the digging as shown, when including rural areas the digging will increase dramatically as these are the longest distances.

A possibility to overcome that problem from the start is to do the redundancy in a step wise manner. This meaning that physical redundancy will only be offered in the more dense areas, which should cause the main duct line cost to decrease as well as extra digging should be kept minimal. This way redundancy is offered to the main part of the population from the start but the small % left out could be offered wireless backup, until physical redundancy is viable.

In general the eartree topology can offer high redundancy with only the fifth of the added cost. As we are moving into an era where everything is being done over a multipurpose network, offering redundancy in this manner can be feasible.

13.4.3 Traffic

The traffic analysis is done by considering two scenarios. The first scenario which is semi meshed structure and the second one is ring like structure. The average link capacity in scenario 1 is estimated around 129 Gbps, and 329 Gbps for scenario 2.
On the other hand the average capacity for the nodes in the municipality is estimated 936 Gbps for scenario 1, and 200 Gbps for scenario 2.

Part IV

Recapitulation

Chapter 14   Conclusion

This report presents a working network planning method in automating FTTH access networks with and without redundancy. The report is broken into two phases, where the first phase starts the automation programming and reviews different possibilities of reducing fiber in the access network. This phase did so in small scale testing. The second phase finishes the automation programming and does so with large scale testing in mind. As well as including some traffic calculation with hypothetical scenarios.

The motivation for doing so is that today's network are moving towards becoming a multi purpose networks. This meaning that more service for the home are now being offered through this network. In order to ensure reliability of these services some physical redundancy is needed. To date no real investigation have been done into offering redundancy in the access network, meaning that it should be considered a necessity to review this.

The network planning method used throughout is where districts are created within the area being planned. By doing so we simplify the network planning process and especially the laying of the fiber. After districts are created splicing points are placed within a district, this is the point where multi fiber cables from a distribution node is connected to a district. Depending on the topology the fiber is then distributed in the manner explained for each of the three topologies. The topologies investigated are the basic tree topology, ear topology and eartree topology.

The project starts of by taking a previously planned access network and automate it, as it was manually planned to start with. Due to this some large automation where not done, mainly the district creation. This is due to the fact that the phase strived at duplicating the methods used in the previous study to get a good basis for comparison. During this process several alterations to the planning method were introduced in order to reduce the fiber needed. Also PON was tested to see if it would affect the fibers needed.

The results showed that PON little or no affect on the cost as the district method already mimicked the PON affect. Furthermore it showed little or no difference in the fiber usage when using two DN locations or one. This could be investigated further where the location of two DN could be checked to use less fiber.

Three scenarios where created with the three topologies in question. The PON and DN location was included in those scenarios as sub scenarios, but as explained, had little effect. This project was unsuccessful in reducing the fiber enough for the ear topology to become a cost efficient solution. Though reducing the fiber somewhat by the automation process and the updated planning method, it still showed similar cost increase of the fiber as in the previous study. The eartree topology showed some good results and in comparison to the tree topology the cost difference of the fiber showed to be only around 25%.

Phase two focused on taking the most promising scenarios in phase one and plan them on a larger scale with seven DN instead of one. In order to do so the automation process was finished and problems encountered during phase one was solved.

The main factor in phase one was to create the automatic district creation and splicing point placement. This was solved with the help of the spanning tree algorithm, where districts where chosen based on grouping the closest NT's together from a starting point. Then a point within each district which had the shortest distance to all NT's was chosen.

When creating a district some criteria's had to be created to set the limits of each district. One of those criteria's which has the most affect is the maximum NT per district. From that scenarios where created where tests where done to see which number of maximum NT would cause the network to use the least amount of fiber. The tests done where from 30-150 NT's, and the results show that in almost every distribution node that smaller districts cost less then larger ones. Which is contributed by the decreasing amount of single fibers used. This in turn is also good for redundancy as fewer NT's per district means more redundancy.

Finally an estimation cost of each scenario was done, this was Scenario 1 - Tree topology and Scenario 2 - Eartree topology. For scenario 1 the final cost was close to 116 million DKK, while scenario 2 had the final cost of $135, 4$ million DKK. This showed an increase of 17% between the scenarios. Which shows that it could be a viable solution.

Consideration should be taken into account that these are very rough estimates, using prices from old studies. The project however was done in such manor that should new prizes become available it's only the matter of recalculation to view the new results. Also The digging problem remain a large factor as more digging would be required for the eartree topology in rural areas. But using the step wise approach of only making dense areas physically redundant first, should not increase these outcomes much, while covering most of the population.

Outlook

In chapter 4 on page 33 the scope of this project were set for both phase one and phase two. This still leaves unresolved issues which needs to be addressed in further work.

Digging

One of the larger problems still left is the calculation of the digging. Mainly as with the available GIS data it would have been quite a project to establish a method for calculate digging on both sides of the road. Since redundancy in most cases need independent path or even independent digging along side the same path, this should be fixed. An argument could be made that this is just an estimate, so getting a detail cost isn't a factor. But as this project focuses on the comparison of the different aspect each topology has, digging is surely one of them.
In hindsight it would have been possible for the rural digging problem to calculate the segments which did not have NT's on either side of the segment points. That would on its own also give faulty calculations as only measuring the double side digging for the eartree topology, would skewer the real results. Meaning since no double side digging is done for the tree topology it would not be fair to the results of the eartree topology.
Also more details regarding the digging could be included, as cost of digging differs between the different type of soil it has to dig.

Segment inaccuracy

Though this project was successful in shortening the segments and get the NT's closer to it's rightful entry point in the segment, a problem still exist regarding expanding again. The need for expanding the segments again is crucial as in a larger network it would be impossible for the algorithms to calculate all these point when creating a network. But it can be argued that the main part of this problem was solved, though not very help full.
In hindsight it the new distances could be used with the old data and the old segment points could be used but the NT's would have an updated distance.

Cost factor

As has been stated on several occasion the report only gives rough estimation as the project focuses on the network planning method itself. This accompanied with the fact that all the cost factors are based on old prices. Updating the prices, though hard, should be a priority to get a real view of what this might cost today.

Automation process

The program created for the automation process still needs lots of work to improve it's accuracy. The district creation part can use several optimization, mainly in dealing with large dead end neighborhoods and be more efficiency in rural areas. The splicing point placement is also an

issue as it bases it placement on choosing the point in the road network which has the least distance to all other points. This means that involvement of the NT's is missing as some district might have NT distribution on one side. By doing this fiber could be reduced even more.

The automation process is only based on the network planning method created here. Further work could be done in investigating different network planning methods.

Other AN redundant topology

It is of interest to suggest other possible topologies to be used in the access network. Wether it be adapting the ring topology to the access network or finding other concepts.

Other

Some calculation between the maximum number of NT scenario cost and the extra digging needed, should be considered. Meaning that as digging is more expensive it could be cheaper to use districts which cost more in fiber but less in digging.

Further investigation into the step wise approach, where dense areas are done with redundancies in the first step. Leaving the rural area non-redundant. This could decrease the initial cost and most of the population would be covered. Next step could then add the rural areas by making the splicing point redundant. This should be carefully planned so that only those district which would need much extra digging would fall into step two.

Finally it should be mentioned that there are still a lot more possibilities for improving on the automation of network planning. These mentioned here are the only one observed during this project.

Part

V

Appendix

Optical Fiber

A.1 Introduction

Light has been used as a signaling method for centuries and helped war being won with the signaling of light between towers in order to send and receive messages from greater distances. As we know light travels at the fastest speed known to men. Tough the principal optical communication has been available for quite some time now it wasn't until the late 60's some research begun into the use of optical communication as a transmission medium. It even took a decade longer to implement the first fiber optic system.

The main reason why this occurred is due to the fact that in that era electrical technology was rapidly growing so research and the use of electrical transmission medium was logical. In that being the development of the now well established copper network. With today's requirements and needs it's becoming clear that the copper network can not withstand the growth that is occurring. Therefore we are witnessing the upcoming of fiber. Today most of the previously copper operated backbones are now run with fiber networks in order to meet the demands of increased bandwidth need.

As the development is going towards a general purpose network that is to say that services previously offered through several networks and mediums are now converging towards one network. This means that the need for more bandwidth in the access networks is eminent. Today the market is slowly growing towards offering fiber to the home, the reason for it being slow is mainly due to the cost of a new infrastructure. Today the companies which already have a copper infrastructure are step wise trying to improve the their infrastructure by slowly moving fiber closer to the home in order to utilize the already available technology on the copper medium (like ADSL and VDSL).

There are companies offering fiber directly to the home, but because of the cost this is only done for large areas at a time which are interested in getting fiber. These cost factors may be reduced by careful planning of a whole network in advanced and even in a step wise approach [24].

A.2 History

In 1970 John Tyndall made the first experiment that shows how a light uses internal reflection to follow a specific path while a water flowed from one container to another when a beam of light is applied to it. See figure A.1 on the next page about Tyndall experiment. When the water poured out through the spout of the first container, Tyndall directed a beam of sunlight at the path of the water. The light, as seen by the audience, followed a zigzag path inside the curved path of the water. This simple experiment, illustrated in figure A.1 on the following page marked the first research into the guided transmission of light [7].
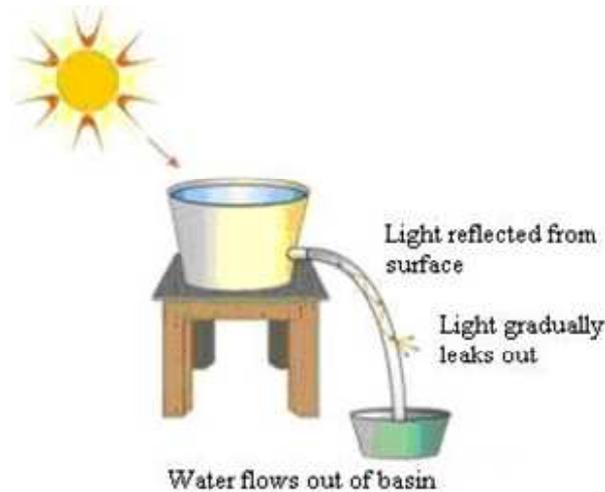
Figure A.1: The first fiber optic experiment.

At the end of 19th century, Alexander Graham Bell was the first person to attempt the transmission of information in the modern sense using light. His invention, the photophone, utilized the modulation of sunlight to send a message to a receiver located 200 m away. The sunlight reflected against a membrane vibrating with the sound of human voice [21].

Fiber optic technology experienced a phenomenal rate of progress in the second half of the twentieth century. Early success came during the 1950's with the development of the fiberscope. This image-transmitting device used the first practical all-glass fiber. But early all-glass fibers experienced excessive optical loss, the loss of the light signal as it traveled the fiber, limiting transmission distances. This motivated scientists to develop glass fibers that included a separate glass coating [7].

A.3 Technology

The term optical fiber is a glass or plastic fiber that has the ability to guide light along its axis. The optical fiber has three parts namely core, the cladding, and the coating or buffer. Figure A.2 on the next page, shows the three parts of the fiber. The innermost region of the fiber, or core, was used to transmit the light, while the glass coating, or cladding, prevented the light from leaking out of the core by reflecting the light within the boundaries of the core.

This concept is explained by Snell's Law which states that the angle at which light is reflected is dependent on the refractive indices of the two materials - in this case, the core and the cladding. The lower refractive index of the cladding (with respect to the core) causes the light to be angled back into the core as illustrated in figure A.3 on the following page.

The refractive index of the core is always greater than the index of the cladding. Light is guided through the core, and the fibre acts as an optical waveguide. The figure shows the propagation of light down the fibre optic cable using the principle of total internal reflection. As illustrated in figure A.3, a light ray is injected into the fibre-optic cable on the left. If the light ray is injected and strikes the core to cladding interface at an angle greater than the critical
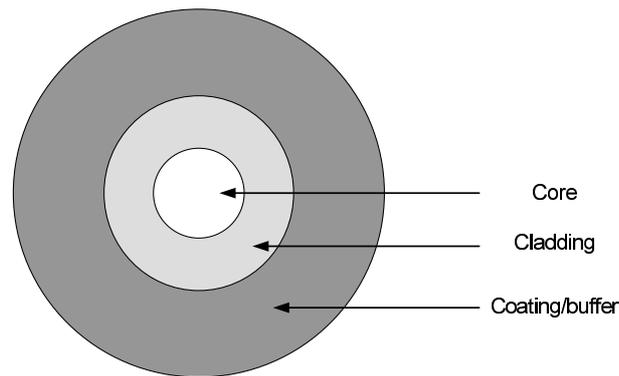
Figure A.2: Optical fiber cable parts.

angle with respect to the normal axis, it is reflected back into the core. Because the angle of incidence is always equal to the angle of reflection, the reflected light continues to be reflected. The light ray then continues bouncing down the length of the fibre-optic cable. If the angle of incidence at the core-to-cladding interface is less than the critical angle, both reflection and refraction take place. Because of refraction at each incidence on the interface, the light beam attenuates and dies off over a certain distance.
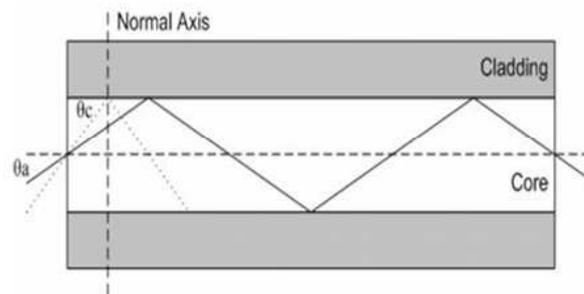

Figure A.3: Total Internal Reflection [7]

The critical angle is fixed by the indices of refraction of the core and cladding and is computed using equation A.1:

$$\theta c = \cos^{-1}(n2/n1) \tag{A.1}$$

Light must enter the core from the air at an angle less than an entity known as the acceptance angle θa which is shown in equation A.2:

$$\theta c = \sin^{-1}((n1/n0)\sin(\theta(c))) \tag{A.2}$$

A.3.1 Fiber Networks terms

There are several terms used in fiber networks to determine how much of the network is fiber. This is denoted FTTX where x stand for the location to where the fiber is. These terms are commonly used for companies which are still using their copper lines in co-operation with the fiber and use it to explain how much of their network is fiber. These are as follows

FTTN

Fiber to the node or FTTN is where fiber is in the network all the way to the distribution node and is mainly used in broadband architecture to offer high speed Internet to the customer but finishing off the last mile with ADSL or VDSL over the existing copper medium to the home. Though it can offer high bandwidth it isn't as good as FTTH or FTTP. This is explained in figure A.4.
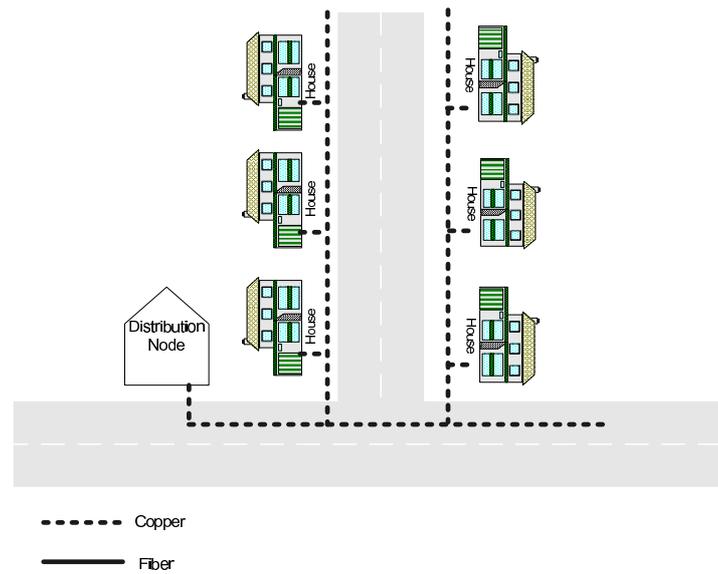

Figure A.4: Fiber to the node

FTTC

Fiber to the curb or fiber to the cabinet or FTTC is where in stead of having fiber to the distribution node fiber is now offered all the way to the area and serves only several costumers. This now offers possibility of greater bandwidth than FTTN with coaxial cable or twisted pair, but today ADSL and VSDL is mainly used with FTTC. FTTC is explained in figure A.5 on the following page.

FTTH

Fiber to the home or FTTH is where fiber is offered all the way to end users. With fiber to the home there are more possibilities due to high bandwidth availability. The possibilities includes triple play or TV, Telephone and Internet. This is like mentioned before with FTTH the transition can be made to one general purpose network. FTTH is explained in figure A.6 on the next page.

A.3.2 The Advantages of fiber optics

The advantages the fiber medium has over the already available copper medium are clear and it is the main reason why fiber is being thought as the medium to replace the copper with. The following list details the advantages of fiber over the copper [21].
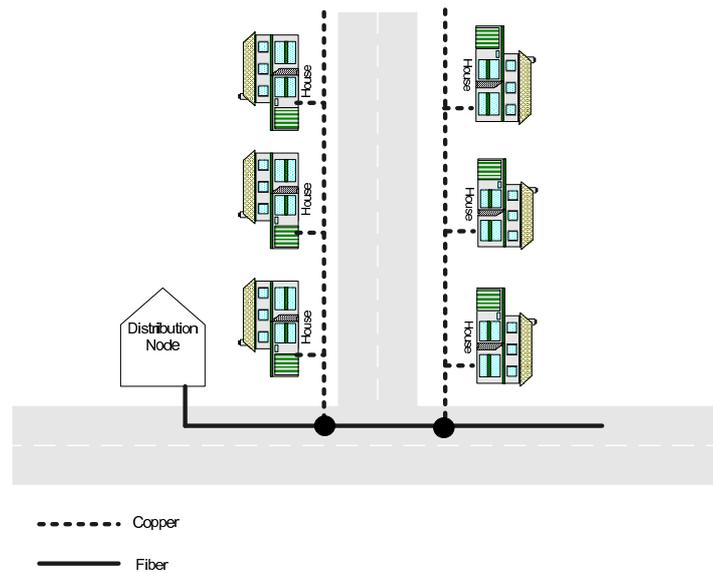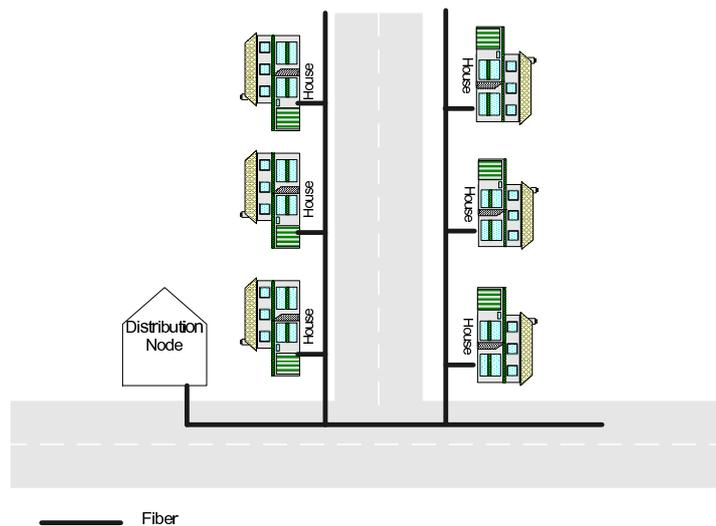
Figure A.5: Fiber to the curb

Figure A.6: Fiber to the Home

- The optical fiber is able to transmit over larger distances or 100km between equipments or repeaters. Electrical systems like copper however are only able to transmit over 2km between repeaters or equipments. Also with fiber optic amplifiers (EDFA) the optical signal can be amplified so it may transfer over several hundred kilometers before any electrical equipment needs to boost the signal. The amplifiers and receivers are to date still improving thus the distance in which the light can travel is increasing without interference.

- Since the fiber optics are only light being transmitted over glass which is electrically non-conducting. This means that the fiber is not affected by electromagnetic disturbances like thunderstorms and there's no chance of interference with other equipment or it interfering with other equipment. This also means that the fiber is not easily tapped.

- Due to it's special treatment the fiber is the most transparent material available today, thus

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greater distance between equipments is achieved due to the low transmission loss of the fiber. The low attenuation of 0.25 dB/km (at 1550 nm wavelength) in single mode fiber means that even after 40km 10% of the light remains.

- There is a huge theoretical transmission capacity available with the single-mode fiber. But due to the limitation of electronics equipment the capacity limit is at 2.5 Gbit/s for systems currently installed. So for 2.5 Gbit/s transmission means that it can simultaneously hold 31.000 (64 kbit/s) telephone conversation. Which is a great deal more then with the copper. However the surface has only been scratched with the possibilities of capacity through light and increase of 5, 10 and even 40 Gbit/s is thought to be around the corner. This would be done with Dense Wavelength Division Multiplexing or DWDM for short. Here within a fiber different transmission channels are created with different wavelength thus utilizing the fiber better.

- Compared to copper cables the fiber is much lighter, this is due to the fact that for 100km of fiber only 2.7 kg of glass is needed, and even with the protective coating the fiber is still lighter than the copper.

- Fiber optics are in general much cheaper than other more conventional solutions especially when the factors above are taken into account. And since modern telecommunication are requiring higher capacity over a longer distance fiber optics are a good solution.

A.4 Fiber Architecture

In this subsection a closer look at the two main types of fiber networking architectures that are used today are discussed. The architectures are:

- Synchronous Optical Network (SONET)

- Wavelength Division Multiplexing (WDM)

A.4.1 SONET

Developed by the Exchange Carriers Standard Association (ECSA), SONET is a standard for optical telecommunications transport. According to [20], the SONET standard is expected to provide the transport infrastructure for telecommunications for at least the next two or three decades.

SONET offers a bandwidth of OC-192 (9.925 Gbps) and it can carry a diverse range of information. SONET also features bit-error rates of one error in 10 billion bits, where Copper transmission will have a bit-error rate of one error in 1 million bits.

One of the chief benefits of SONET is its capability for use in the long haul networks (Network backbones), local networks (access networks) and loop carriers as well as in local CATV network.

A.4.2 WDM

The popular speed of SONET is 2.5Gbps, the next level speed that can be used in SONET is 10Gbps. And this 10Gbps is the limit that can be used by Time Division Multiplexing (TDM). That is TDM is the multiplexing technique used in SONET [20]. So to solve the problem of the bandwidth limit another technology called WDM is offered. WDM increased the carrying capacity of physical medium (Fiber) using a completely different mechanism

In WDM the incoming signals are assigned to specific frequency of light or wave length within a certain frequency band. One way to view it is that in WDM, each channel is different color of light. The ultraviolet region is beyond the human vision, and the visible spectrum. In optical networking, however, all the actions takes place between 700 and 1700 nm.

In WDM, all wavelength of the signal are entered into one end of the fiber, while on the other end a de-multiplexer separates the light. Like TDM, the resulting capacity is the sum of the input signal, but in WDM each signal is carried independently of others. Unlike TDM, WDM everything is carried simultaneously, while the TDM brakes everything into time slots.

One version of the WDM is called Dense Wave Division Multiplexing (DWDM) and the main difference is that DWDM puts the wavelength closer together than the WDM and therefore it carries more wavelengthes and has greater capacity. The limit of wavelengths space is exactly not known yet. Today there are up to 160 wavelength available [20][24].

A.4.3 PON

Access networks are part of a network that are directly connected to the subscribers. Then the access network been as important to telecommunications providers as they look for ways to deliver new high bandwidth services to their subscribers services that generate new revenues, help them retain existing customers, attract new ones and increase profits. Fiber is seen as the preeminent long-term alternative to today's broadband access technologies, one that not only allows providers to generate new services, but also provides them with significant and sustainable reductions in operating expenses and shifts their capital spending from older technologies to newer, less costly technologies [18].

Passive optical splitters are used to divide the bandwidth from a single fiber up to 64 users over a maximum distance of 10-20 km. In a PON, an OLT at the CO connects to customer premise located ONTs to terminate the fiber. The architecture is called passive because all splitters and intermediate equipment between the CO and the ONT is passive; that is, it has no active electronics and therefore does not need separate power.

A.4.3.1 PON for Access Networks

PON technology is getting more and more attention by the telecommunication industry as the 'first mile' solution. According to [15] advantages of using PON for local access networks are numerous:

- PON allows for longer distances between central offices and customer premises. A PON-based local loop can operate at distances of up to 20 km, which considerably exceeds the maximum coverage afforded by DSL.

- PON minimizes fiber deployment in both the local exchange and local loop. Only one strand of fiber is needed in the trunk, and only one port per PON is required in the central office. This allows for a very dense CO equipment and low power consumption.

- PON eliminates the necessity of installing multiplexers and demultiplexers in the splitting locations, thus relieving network operators from the gruesome task of maintaining them and providing power to them. Instead of active devices in these locations, PON has passive components that can be buried in the ground at the time of deployment.

- PON allows easy upgrades to higher bit rates or additional wavelengths. Passive splitters and combiners provide complete path transparency.

PON uses different kinds of multiplexing techniques. Time Division Multiplexing (TDM), Wavelength Division Multiplexing (WDM) and Code Divion Multiplexing (CDM).
TDM is a mechanism for dividing the bandwidth of a link separate channels or time slots. Then the ONT sorts out the data in the time slots than that are assigned to it. Wavelength Division multiplexing divides light signals into different colors. The electronic end equipment, ONT and OLT, has to distinguish the different signals by their colors.
CDM is a form of multiplexing where the transmitter encodes the signal using a pseudo-random sequence which the receiver also knows and can use to decode the received signal. Each different random sequence corresponds to a different communication channel.

A.4.3.2 Access Network Architectures

In this subsection access network architectures based on TDM multiplexing techniques will be presented. The classification for this type of TDM PONs are based on [15].

- **ATM PON:** It is a specification for a PON-based optical access network that uses ATM as its layer-2 protocol. Such systems were called APON, an abbreviation for ATM PON. The name APON was later replaced with BPON for broadband PON. The name change was reflective of the systems support of broadband services such as Ethernet access, video distribution, and virtual private line (VPL) / leased line services.

- **Ethernet PON:** In January 2001, the IEEE formed a study group called Ethernet in the First Mile (EFM). This group was chartered with extending existing Ethernet technology into subscriber access area, focusing on both residential and business access networks. Keeping with the Ethernet tradition, the group set the goal of providing a significant increase in performance while minimizing equipment, operation, and maintenance costs. Ethernet PONs became one of the focus areas of EFM.
  Ethernet PON (EPON) is a PON-based network that carries data traffic encapsulated in Ethernet frames as defined in the IEEE 802.3 standard [802.3]. It uses a standard 8b/10b line coding (8 data bits encoded as 10 line bits) and operates at standard Ethernet speed of 1 Gbps. Where possible, EPON utilized the existing 802.3 specification, including the usage of existing 802.3 full-duplex media access control (MAC).

- **GPON:** In the presence of ever-growing traffic volume and the emergence of 1 Gbps EPON specification, a new effort to specify a PON system operating at bit rates exceeding

1 Gbps is developed. This PON system is GPON that has several specifications like G. 984.1, G.984.2, and G.984.3. More on these specifications can be found at [15].

Network Topologies

B

The arrangement or mapping of the elements of a network gives rise to certain basic topologies which may then be combined to form more complex topologies (hybrid topologies). In the following section a summary of Network topologies based on [19] will be presented.

B.1 Bus Topology

The bus topology is a topology where a set of nodes are all connected to one central line called the bus which has a terminator on each end. As one central line is used some collision detection is needed so all the traffic won't collide when on the central line. Figure B.1 shows the bus topology and how the nodes are connected.
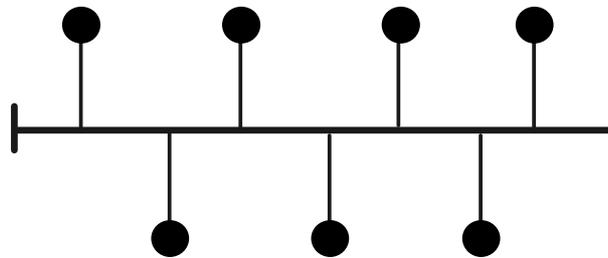
Figure B.1: Bus topology

Advantages:

- Easy to implement and easy to extend

- Is good for temporary networks

- Cheap to implement

- Does not need as much cables as the star topology

Disadvantages:

- If the central line breaks the entire network shuts down

- Administering and trouble shooting can become quite difficult

- Because nodes are not responsible for the traffic and listen only to the central line which causes low security as every node can read the data on the bus

- The performance degrades as more nodes are added

- Termination is required in both ends of the central line

B.2 Star Topology

The star topology is designed in such a manner that all nodes are connected to one central node. When data is sent from a node it is passed on to the central node which then sends it to the destination. Figure B.2 shows the star topology and how the nodes are connected.
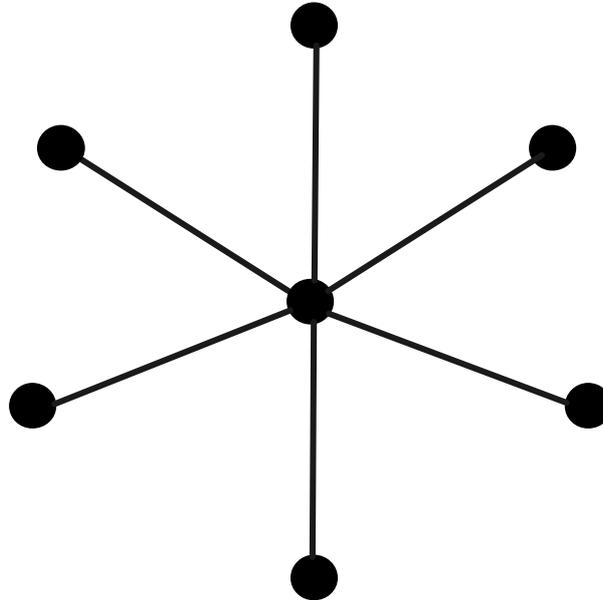

Figure B.2: Star Topology

Advantages:

- Easy to implement and easy to extend

- Is good for temporary networks

- Failure on any other nodes then the central node does not have great affects on the network

- No problem with collision as each node has its own line to the central

- Easy to administrate and troubleshoot

Disadvantages:

- Limited amount of users can connect and requires more cable

- Failure of the central node will disable the network

- More costly than the bus topology due to the central node

B.3 Tree Topology

The tree topology combines the bus topology with the star topology. The tree topology consist of having number of star topology where the central node connects to a bus. The network however is very expandable and is commonly used in todayï£¡s networks. Figure B.3 shows the
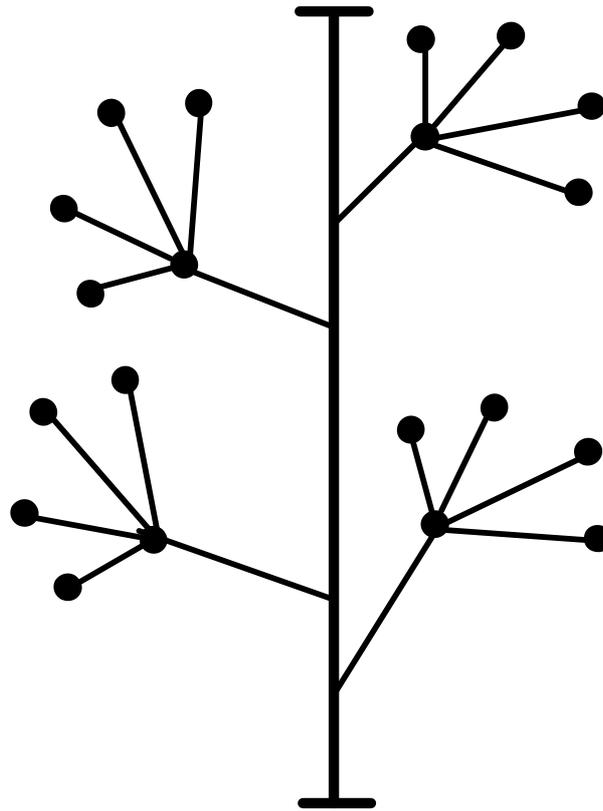
Figure B.3: Tree topology

tree topology and how the nodes are connected.

Advantages:

- Is supported by some hardware and software

- There is point to point wiring for each segment networks

Disadvantages:

- If the central line breaks the entire segments shut down

- The length of the cables are limited to the type of cable used

- More complex to configure and wire than other topologies

B.4 Ring Topology

The ring topology is fairly simple, here each node is connected to two other nodes, to create a ring network. Figure B.4 on the following page shows the ring topology and how the nodes are connected.

Advantages:

- The ring topology can have more distance as each node acts as a repeater in the network
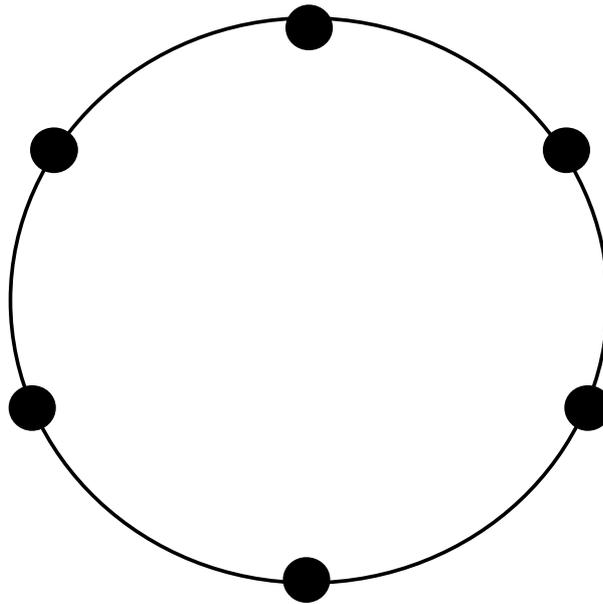
Figure B.4: Ring topology

- All the nodes in the network have equal access

- Manages easier then the bus topology

- Troubleshooting is much easier

- Because data travels only in one direction the ring topology is able to handle high volumes of data at a good speed

Disadvantages:

- Failure of one node may cause the whole network to go down provided that there is no protection in place

- Damage to the ring affects the whole network

- Can be quite difficult to install

B.5 Mesh Topology

The mesh topology can have many different shapes and connections between nodes. However to be considered as a mesh network two of the nodes must have at least two paths or more between them (minimum degree 2). The mesh topology is said to be self healing as in the case of a line or a node breaking down. The mesh topology is able to switch its traffic to another line making the mesh topology reliable.

The mesh topology has three types of formations, the mesh topology, the semi full mesh topology and the full mesh topology. They are as followed:

- **Mesh topology:** The most simple method of a mesh topology is the mesh topology. Here at least two of the nodes have two or more paths between them. The configuration of

how many nodes or which of them have more then degree 1 is based on the need of the network. Often the nodes who have the most traffic are degree 2 or more. Figure B.5 shows an example of a mesh topology.
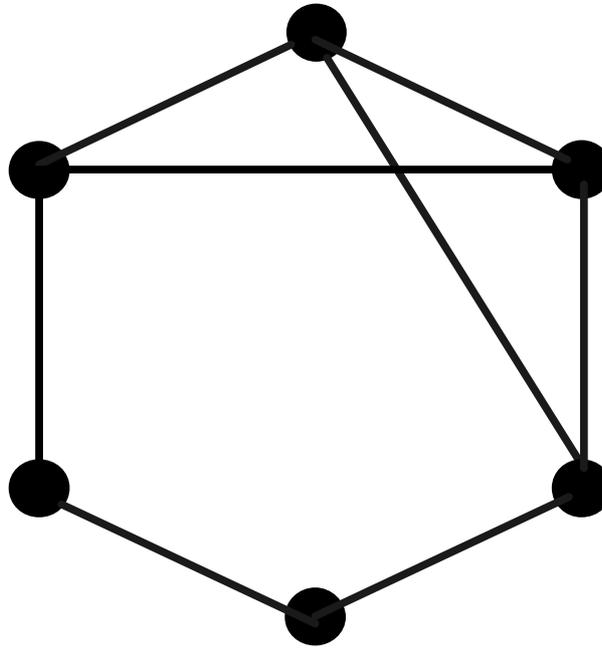

Figure B.5: Mesh topology

- **Semi full mesh topology:** In a semi full mesh topology some of the nodes have individual connections to each node. This is however a more expensive topology than the "mesh topology" as it physically requires more paths and lines. But instead it offers more reliability then the previous. Figure B.6 on the following page shows an example of a semi full mesh topology.

- **Full mesh topology:**

  A full mesh topology is the most reliable of them all as it has direct links between all pair of nodes. In a fully connected mesh network with n nodes there are $n(n-1)/2$ lines needed. Though the reliability is high with this kind of setup it is very expensive because of all the lines needed. Figure B.7 on the next page shows an example of a full mesh topology.

The mesh and the semi full mesh topologies are mostly used when creating a mesh network today, the sheer cost of the full mesh topology makes it unpractical to apply to a normal network. The full mesh topology is however mostly only used in military and other heavy dependant reliability application.

Advantages:

- Troubleshooting is easy as faults in the network can be singled out

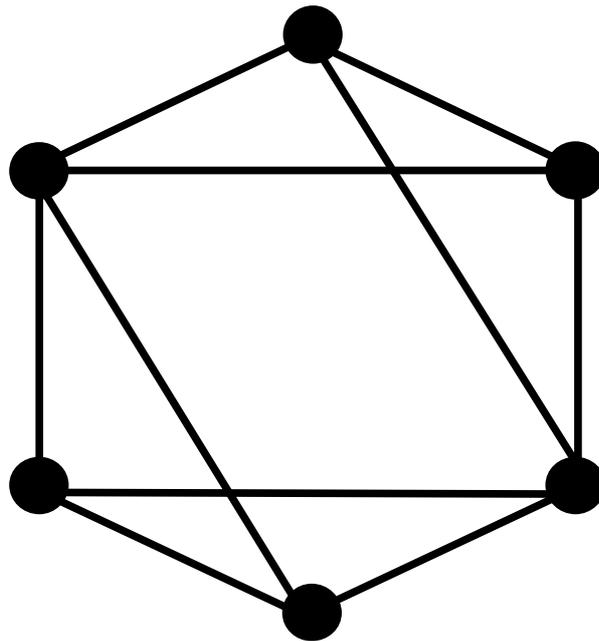- Separate links from each node ensure that different paths can be chosen for communication

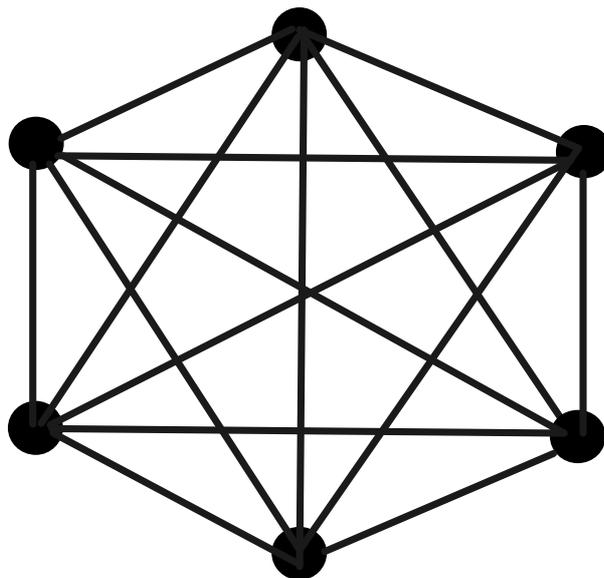Figure B.6: Semi full mesh topology

Figure B.7: Full mesh topology

Disadvantages:

- Because of the many links and possible distance it can be expensive

- Can be quite difficult to install

There are two types of information stored with GIS, those are:

- The geometry gives information about the location and shape of the object.

- The attributes that give a descriptive information about the object.

The geometry and the attributes of a digital map are shown in the following figure C.1.
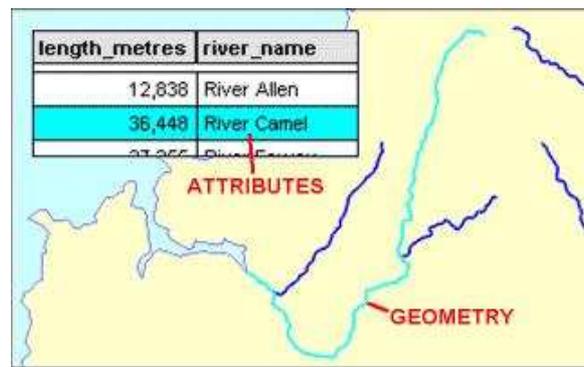

length_metres	river_name
12,838	River Allen
36,448	River Camel

ATTRIBUTES

GEOMETRY

Figure C.1: Digital information [27]

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C.1   Vector and raster data

In any digital system like a computer, it is obvious that every letter or number is represented in a sequence of bits. This forms a code for every possible letter or number. In the same way maps reference geographical locations on the surface on earth, through a system of coordinates like x and y coordinates.

C.1.1   Vector data

In vector data the features are recorded one by one, with shape can be defined by numerical values xy coordinates. Vector data can be represented as map objects (point, a line or an area).

For example, the following map represents a building as a simple red rectangle. In vector data the position and shape of the building is captured as a series of four pairs of numerical coordinates. To reproduce the building in a GIS the computer reads these values and draws a line linking the coordinate positions. Figure C.2 on the next page shows this.

C.1.2   Raster data

Map objects can be represented by numerical values in a grid of cells. That is by representing the type of object present in each cell [11]. For example a value is stored in each of these
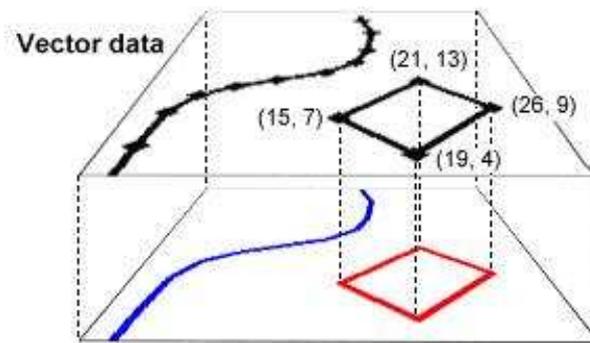
Figure C.2: Vector data [27]

.

cells to represent the nature of whatever is present at the corresponding location on the ground. These types of data are referred to as TIFF, JPEG, etc. They are used for visualization purposes.

In figure C.3 with figure C.2 in mind it is shown that the data records the color of the feature which occupies that part of the maps surface, the values recorded in the cells are either white, blue or red. To reproduce the image the computer reads each of these cell values one by one and applies them to the pixels on the screen.
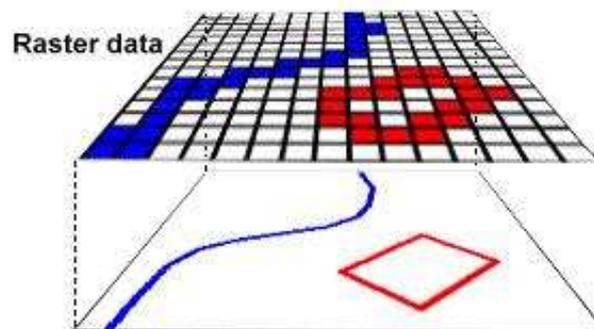
Figure C.3: Raster data [27]

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C.2 Use of vector data for planning a network

For planning an IT infrastructure the vector data is most useful because it is a strong form of representing spatial data in digital form. It uses coordinate pairs (x,y) to represent the features of interest on the landscape. The vector maps use geometrical segments such as points by coordinate pairs (x,y) and lines (series of point coordinates to represent the object)[25].

The GIS data that represent a road network is used to model a network in the trace level where it is the space allocation in the field for the infrastructure [17].

For example, the municipality of Hals geographic data can be found in terms of nodes, lines,

and this data can be represented using the vector data model. It is possible to store information on nodes and lines in a database applications like Ms-Access both as tables and meta data views.

C.3 Converting map information in to digital form

Geographical data can be placed in GIS (Geographic Information System) which is used for analyzing geography and information. The GIS is used for many purposes, e.g., the GIS can answer questions like "What is the shortest path between two locations in that area?" by using the GIS information regarding road structure. This again helps in planning a network where physical locations of duct nodes and other infrastructure components can be chosen based on the GIS data.

In a given map a number of information can be observed. For example, human beings can interpret some information from a map by simply from the pictorial content of the map for instance by using names of objects written on a map.

Like human beings GIS takes all the information and records this information in an electronic format.

The GIS must be able to store information about:

- *The geometry:* The shape and location of the objects.

- *The attributes:* The descriptive information known about the objects, normally displayed on a map through symbology and annotation.

C.4 Maps in bits

The first step in converting map information into a form that can be read by a computer is to describe the shapes and locations of features using a series of numbers. Computers store information in sequences of binary digits (bits), which form a code for every possible number or letter.

This fits with the way maps reference geographical locations on the earth's surface, through a system of coordinates. These coordinate systems can be local, national or international.

For example a grid can cover the whole map area of a location. Again a grid can be represented as a series of numbers. As shown in figure C.4 on the following page, all locations and shapes can be defined in terms of x and y coordinates from a given grid system: these are the numerical values which are used to translate map information into digital form.
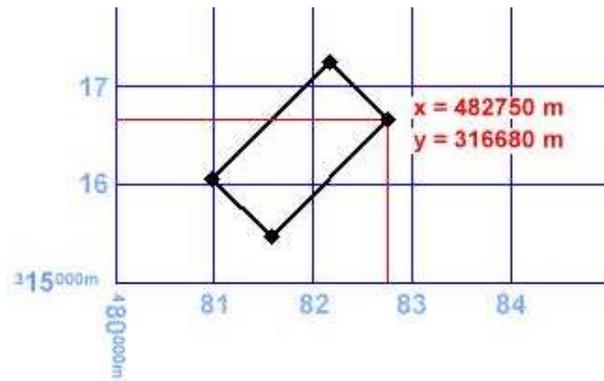
Figure C.4: A grid representing coordinates in a map [27]

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C.5 Mapinfo

Mapinfo is currently the market leader in affordable mapping software. Mapinfo provides a flexible tool for integrating attribute data with map data [11].

The key to understanding mapinfo is to consider a mapinfo database as a series of registered map layers or themes which represent a landscape or individual site.

On mapinfo, the data represented by a map layer is known as a table, which consist of two distinct components. *Tabular Data* this is also called attribute data that contains field values in a series of records, i.e a conventional data base table. For example the following C.5 shows a tabular data for the Hals Kommune digital map database. Tabular data are stored in mapinfo as

Figure C.5: Example view for a tabular data in mapinfo

conventional database tables like access database or MySQL database.

  Map data are also called graphical data that contain graphical objects related to some or all of the tabular data records. For example the following C.6 on the following page shows a map that is created from the tabular data.

  Therefore, using mapinfo for handling a GIS data for creating a map is a very important tool

Figure C.6: Example view for a map data in Mapinfo

for network planning. Once a tabular data in GIS is available it is possible to generate queries and find out the information is quite simple.

PHP and MySQL

There are two types of information stored in GIS. PHP is a server side scripting language designed specifically for web applications but it also used for other applications that need a dynamic update of information, for example in some applications PHP is used for applications like network planning. The PHP has given more interest to us because of it's high performance and due to offering interfaces to many different database systems.

One type of database system that can be used along with PHP is MySQL. MySQl is very fast, robust, relational database management system that is used to store, search, sort, and retrieve data [16].

D.1 Interfacing with MySQL using PHP

Before connecting to a database in MySQL, the first step should be creating the database. After the database is created the steps in using the database are following:

1. Setup a connection to the appropriate database

2. Query the database

3. Retrieve the results

Setup a connection to the appropriate database: To connect to MySQL, MySQL user name and password must be specified. Using the mysql_connect and mysq_select_db function, it is possible to connect and select a database to use for a scrip to create.

For example the following script shown in figure D.1 is used for setting up a connection to the database called, spt. To connect to the database a function is called, mysql_connect, in line

```
1   <?php
2   /*
3   * This script is used to connect to the database
4   */
5   $user = "root";
6   $passwd = "beloved";
7   $database = "spt";
8   /* connect to database */
9
10  $link = mysql_connect("localhost", $user, $passwd);
11  if(!mysql_select_db($database, $link))
12      echo "connection faild to database \n";
13  ?>
14
```

Figure D.1: Example of a script for connecting to a database [22]
.

10, here above it is used for opening a connection to the database called, spt, that can be seen here above in line 7. The script does a task by authenticating the users name and the password, that can be seen in lines 5 and 6. The connection closes when the script finishes it's execution.

Generally has the connection function in MuSQl the syntax: Mysql_connect (hostname, user-name, password) where the hostname is the name of the server, or hosten has a script running. Username is the name of the user who has the authentication.

Query the database: The other important function that is used for query the database is mysql_query function. Once connected to the database this function is used to send commands to the database to fetch the information from the database.

Example: The following script shown in D.2 is used to fetch a query for creating a table called nodes that uses an SQL syntax for creating the table in the attributes given.

```php
1    <?php
2
3    include("create_db.php");
4    include("connect_db.php");
5
6    mysql_query("Create table nodes (sp integer, x_cord integer, y_cord integer)");
```

Figure D.2: Example of a script for fetching a query from a database [22]

.

Retrieve the results: There are a variety of functions available to break the results out of the result identifier in different ways. The result identifier is the key to accessing the zero, one, or more rows returned by the query.

For instance if a select command is used, mysql_num_rows() can be used to count the records returned in the result set. Then, to display the data that was found, mysql_fetch_array () can be used to get all the results during a loop and get them on a screen [14].

For example, the following function shown in the figure D.3 used for displaying the data in the src_node after the execution of functions mysql_query,mysql_num_rows and mysql_fetch array.

```php
39   function f_spt($start_node){
40
41       mysql_query("Delete from sptree");
42       mysql_query("Delete from sptree_temp");
43       mysql_query("Delete from segs_connected");
44
45       mysql_query("insert into sptree_temp(src, pred, level, dist)values($start_node, 0, 0, 0)");
46
47       $results = mysql_query("Select * from sptree_temp");
48       $rows = mysql_num_rows($results);
49       $array0 = mysql_fetch_array($results);
50       $src_node = $array0["src"];
51
```

Figure D.3: Example of a function used for displaying a data [22]

.

D.2   Project PHP

As mentioned throughout the report the GIS data is stored in databases. In order to create the scenarios some manipulation of this data is necessary in order to achieve the results needed with the help of some algorithm. There are a several ways of achieving this, but the method chosen here is to program the scenarios in PHP as it is good in interacting with SQL. In this project, we

desided to write the program in PHP.

This section will explain each phases program's process on manipulating and programming from the GIS data in order to achieve the results needed. However the section will not go into minor details, that explains every line of code, that is done in the code itself which is enclosed on the followed CD. We will rather explain the main parts of the code and the flow.

D.2.1 Phase 1

D.2.1.1 main.php

All the scenarios in both 1 DN location and 2 DN locations subscenarios we used the main.php as our main file where we call all the needed parts.

Flow of main.php

1. *Run create_db.php:* This runs the create_db script, which deletes the db if it is already created.

2. *Run connect_db.php:* This runs the connect_db script, which creates a connection between the php and the SQL database.

3. *Run preperation.php:* This runs the preparation script. The preparation extracts the needed data from the original GIS database and places it in the newly created database. There are two reasons, first we only extract the data needed from the original database. Second, is not to keep the original database intact. More detailed information can be found in D.2.1.2.

4. *Run create_DN.php:* This runs the create_DN script, creates our distribution nodes needed for the scenarios.

5. *Choose topology to run:* Because each topology scenario use the same database and as the programming of each scenario is similar, only one topology can be run at any given time. The scripts available to run are tree-topology.php, eartree-topology.php and ear-topology.php (for more see D.2.1.3).

D.2.1.2 preperation.php

Same as for main.php, preperation.php is identical in both 1 DN location and 2 DN location scenarios. The preperation.php is used for acquiring the needed data from the original GIS database and placing it in the newly created one. That is, it prepares the project database to be used for the scenarios created.

Flow of preperation.php

1. *Create SP_vh table:* Here a table is created where only the needed segment points are chosen. This makes it easier to run a spanning tree algorithm, as having all segment points available would be unnecessary and process hard.

2. *Create S_vh table:* Same is done to the segments themself as the segment point for the same reason.

3. *Run extra_S.php :* This runs the extra_S script, which creates the extra segments and segment point for the area which are missing from the original database. These are mainly town owned bicycle and walk roads which are available for the network creation.

4. *Create NT table:* Here an NT table is created where only the needed NT's are selected and placed in the new database. Also some extra NT's are excluded which where not chosen in the previous study. The NT's are then marked with which district it is a part of, again from the previous study. Finally some cleaning is done of the NT columns.

5. *Create NT2SP table:* Here a line is created from the NT's to the SP for visual purpose but also to mark the distance from the SP to the NT.

D.2.1.3 tree/eartree/ear-topology.php

Though they are all different topologies they all have almost the same flow and use similar methods. However some inner functions may vary for example the ear topology has two splicing points in each districts therefore two paths are created to each house rather than just one with eartree and tree. However the method of creating those paths is still the same just done twice for the ear topology from 2 locations. So in basic it is very similar but with some differences. As the flow is nearly identical between the topologies it will only be detailed once instead of 3 times. In the flow X will thus denote tree eartree and ear.

Flow of tree/eartree/ear-topology.php

1. *createXSpliceP():* This function creates the splicing points used in a scenario. This is manually done, but will later on be an automatic process where the splicing points are automatically created based on the set criteria. But for now this is manual as previously chosen splicing points where created.

2. *createTables():* A small function which creates tables needed by the scenario.

3. *createSPtree():* This is the most important function which creates the spanning tree for the scenario. The algorithm uses the segment points to create the spanning tree. The steps taken to created the spanning tree are:
   1. Starting point is chosen (DN's segment point).
   2. Check which segments are connected to that segment point.
   3. Those segments are then checked for the second segment point.
   4. The second segment point of each segment is then updated with who it's ancestor is and the distance (Ancestor distance + Segment distance). Also the level of the segment point from the starting point is updated.
   5. This is then done until each segment point has been updated.

4. *addSpliceP_dist():* This function adds the distance from the DN to the splicing point, there from to the splicing point table.

5. *Run X-topology-startrun.php:* In order to avoid clutter some of the function calls are moved to this script. This is mainly the spanning tree function call for every splicing point. Also the createSP_MNPath function and update NT() function explained in the next step of the flow.

6. *createSP_MNPath():* This creates the path segments for visual purposes for the splicing points to the DN's. The way this is done is explained in the following steps:

   1. Starting point is chosen (splicing points segment point).

   2. Segment points ancestor is checked and the path table is updated with the two points.

   3. The algorithm then checks which segment has both segment points and updates the path table with the segment.

   4. This is then done until the level reaches 1 again.

   (Each segment point has a level, that is to say how many segment points is between itself and the destination).

7. *updateNT():* This function updates the NT table with the splicing point id, Splicing point to SP distance and splicing point to NT distance.

Now this is basically the same for every scenario however there are two extra functions used in the ear topology with one DN location, these are:

1. *addSpliceP_dist_rerouteA():* This function reroutes the splicing point to DN for DN1. The reroute is necessary where the ear topology rule is broken. And then updates the NT table with the new distance.

2. *addSpliceP_dist_rerouteB():* Same as addSpliceP_dist_rerouteA() but only for connections from DN2.

D.2.1.4 Remark

Now though the program has been explained as one whole this should not be construed that the programming for each scenario is the same. On the contrary as can be seen on the cd each scenario has it's own programming code, the reason is that though the flow is similar the function differs in every scenario mainly because there are many different factor which play in each scenario making it necessary to program each function on it's own for each scenario. For more detailed analysis the code should be examined.

D.2.2 Phase 2

D.2.2.1 main.php

We use the main.php as our main file where we call all the needed parts. This is done for one distribution node at a time.

Flow of main.php

1. *Run marking_segments.php:* This runs the marking_segments script, which marks the segments with the distribution node it is connected to.

2. *Run create_db.php:* This runs the create_db script, which deletes the db if it is already there and then creates it.

3. *Run connect_db.php:* This runs the connect_db script, which creates a connection between the php and the SQL database.

4. *Run preperation.php:* This runs the preparation script. The preparation extracts the needed data from the original GIS database and places it in the newly created database. There are two reasons, first we only extract the data needed from the original database. Second, is not to keep the original database intact. More detailed information can be found in D.2.1.2.

5. *Run districts.php:* This runs the districts creation script. Depending on the criteria set this script will create districts for the GIS data.

6. *Run d_post.php:* This runs the d_post.php script, which is the post process script to the district.php. Because districts.php leaves behind several problems after it has been run, this script ensure to fix those problem.

7. *Run splicingpoints.php:* This runs the splicingpoints.php script. After the districts have been created we have to find where to place the splicing points.

8. *Run topology.php:* This runs the topology.php script. Unlike phase 1, we only do this in general as tree topology and ear tree topology are planned in same manor. And the only difference is the calculation.

9. *Run digging.php:* This runs the digging.php script. This script finds which segments are used and puts them in a database, the distance can thus be calculated by adding the length of these segments.

10. *Run calculations.php:* This runs the calculations.php script. Here the results from everything is gathered and calculated.

D.2.2.2 preperation.php

The preperation.php is used for acquiring the needed data from the original GIS database and placing it in the newly created one. That is, it prepares the the project database to be used for the scenarios created.

Flow of preperation.php

1. *Create SP table:* Here the segment point (SP) table is copied from the original database.

2. *Create S table:* Here the segment (S) table is copied from the original database.

3. *Create NT table:* Here the Network Termination's (NT's) table is copied from the original database.

D.2.2.3 districts.php

The districts.php is the main script in phase 2 as it creates the districts. A combinations of algorithms is used in order to acquire the results needed.

Flow of districts.php

1. *createTablesDist():* A small function which creates tables needed by the scenario.

2. *Add a start point:* A start point is added, mainly the location of the distribution node. And is placed in the district_j table (junction table used to identify next point to create a district from).

3. *districtLoop():* As one district is created at a time a loop is needed in order to create the districts until we have included every NT. The process is that it starts by running createSPtreeDist() to find the distance from the point we are using in the district_j table to all other points. From that we can then choose the points we want in the district based on the criteria's in the districtCreation().

4. *createSPtreeDist():* Same as createSPtree() in phase one, where we find the distance from one point to all other. Used to map the surroundings from the point we are working with at the moment.

5. *districtCreation():* This function views the result gotten from the createSPtreeDist() and based on the criteria's set chooses it's district, it then marks the segments, SP's and NT's with the district. And finally creates new junction points based from the new district.

6. *Remove the the used junction point:* After we have finished we now have to remove the point from the district_j table so we wont try to use it again.

7. *check_junction():* Finally we now run a function which checks the junction table and sets up for the next loop run.

D.2.2.4 d_post.php

In the process of making the districts, we encounter some problems of small districts. This meaning that the criteria's set in the district creation can cause small districts to form inside dead end roads. Another problem which can occur is that because districts are created in spanning tree manor, empty district can form. This only happens when traveling to rural areas where empty district are created as the spanning tree is traveling trough rural areas.

Flow of d_post.php

1. *district_recalc():* This function starts of by opening the newly created district_nt table and check if there are district's with fewer NT's then the criteria set. If so it then check if the combined segment length of this district is less then the criteria set. If both criteria's check out it then searches for the district closest to it and adds this small district to it. By checking both NT's and distance we ensure that rural districts with small amount of NT's

but large distance are not combined. And that districts in dense areas with large amount of NT but small distance are not combined.

2. *removeNullDistricts():* This function checks that if any of the districts created do not have any NT's. IF so it is removed from the list, so that it will not be calculated as a district.

D.2.2.5 splicingpoints.php

When we have created the district we need to find where to place the splicing points within the district. This script finds that point and places it in a splicing point table.

Flow of splicingpoints.php

1. *findSplicingPoints():* This function determines which segment point is best suited for a splicing point placements. This function checks for one district at a time. Each segment point within a district is run through the spanning tree algorithm to check it's distance to all other segment points within the district. The segment point with least amount of distance to all segment points is chosen as the splicing point.

D.2.2.6 topology.php

Unlike phase 1, it is not necessary to have one script for each of the topology. Both the tree and the eartree topology are planned in the same manor, but only the calculation will be different. Because we have now automated all the process the difference is of this and phase 1 is somewhat. .

Flow of topology.php

1. *createTables():* A small function which creates tables needed by the scenario.

2. *createTreeSpliceP():* This function creates the splicing points used. Here the splicing points created in the spicingpoints.php script is prepared to be used with the topology. This meaning creating a table which includes the needed data to be used in this script.

3. *createSPtree() :* Is the same used throughout this project and is the spanning tree algorithm.

4. *addSpliceP_dist():* This function adds the distance from the DN to the Splicing Point to the splicing point table.

5. *splicingPoints():* This function creates the spanning tree tables for each of the splicing points.

6. *updateNTloop():* It loops the updateNT() function which adds all the necessary data to the NT's based on each district. That is the splicing point id, splicing point to nt distance, the whole distance and the district number.

D.3 Project DB

This section will focus on explaining the details of the database created for this project. Now after the programming is done we are left with a DB which contains our scenarios of network infrastructure, from that calculations can be made or the tables in the databases can be extracted to be used with a GIS visualization tool like mapinfo. However this database can be large and withhold a large amount of data. Now this section will explain the tables made by the project and explain what each table withholds. Following is the explanation on how the chapter is set up to ease the readability of the section.

Section structure:
Table name: *Explanation of the table*

- Column1 : Explanation of column1

- Column2 : Explanation of column2

- ...

Each scenario will however not be explained but as the programming is similar the database structure is similar so this section will explain all the tables in one. The program also creates some extra temporary tables which is used during the scenario creation and will not be explained.

NT: *This table withholds the information regarding the network termination points and the all relevant information.*
Where there is a difference between ear or eartree against ear topology it will be placed in (value in ear topology db).

- NT_id: Names the NT.

- NT_x: The x vector of the NT location.

- NT_y: The y vector of the NT location.

- NT_count: The number of NT's within the NT.

- SP_id: The id of the Segment point which the NT connects to.

- SP_dist: The distance of the Segment point to the NT.

- MN_id: The id of the MN the NT is closest to.

- MN_dist: The distance of the MN to the NT.

- kom: The numerical value of the commune.

- vejnr: The numerical value of the road the NT is on.

- prev_district: The numerical value of the district the NT adheres to in the previous study (Phase 1).

- (District: The numerical value of the district the NT adheres to in the previous study (Phase 2).)

- SpliceP_id(_A): The id of the splicing point (A) which the NT connects to (Phase 1 and 2).

- SpliceP_SP_dist(_A): Distance between Splicing point (A) and Segment point (Phase 1 and 2).

- SpliceP_NT_dist(_A): Distance between Splicing point (A) and NT (Phase 1 and 2).

- (SpliceP_id_B: The id of the Splicing point B which the NT connects to (Phase 1).)

- (SpliceP_SP_dist_B: Distance between Splicing point B and Segment point (Phase 1).)

- (SpliceP_NT_dist_B: Distance between Splicing point B and NT (Phase 1).)

- (SpliceP_NT_Total_dist: Total distance of both Splicing points to the NT's (Phase 1).)

S : *This table withholds the information regarding the Segments (roads).*

- S_id: Names the Segment.

- deg: Lists the degree which the segment is. Meaning how many other segments are connected.

- direction: The direction of the road.

- level: Details what level the segment is.

- lenght: Explains how long the segment is.

- SP_id1: This column holds the name of the segment point 1 connected with the segment.

- SP_id2: This column holds the name of the segment point 2 connected with the segment.

- SP_x1: The x vector of the Splicing point 1 location.

- SP_y1: The y vector of the Splicing point 1 location.

- SP_x2: The x vector of the Splicing point 2 location.

- SP_y2: The y vector of the Splicing point 2 location.

- MN_id: The id of the distribution node associated with the segment (phase 2).

S_extra: *This table withholds the information regarding the extra Segments (roads) used in phase 1.*
Same columns are used here as for table S.

S_vh: *This table withholds the information regarding the Segments (roads) in the vicinity of the planning area for phase 1.*
Same columns are used here as for table S.

segs: *Temporary segment table used during the spanning tree algorithm.*
Is a reduced version of the S table.

SP(_vh): *This table withholds the information regarding the segment points used in this project.*

- SP_id: Names the Segment Point.

- SP_x: The x vector of the segment point location.

- SP_y: The y vector of the segment point location

- deg: The degree of the segment point. Meaning how many segments are connected to the segment point.

- MN_id: The id of the DN the SP is closest to.

- prev_district: The numerical value of the district the SP adheres to in the previous study (Phase 1).

SP_vh_extra: *This table withholds the information regarding the extra Segments points used in phase 1.*
Same columns are used here as for table SP_vh.

xSpliceP: *This table withholds the information regarding the splicing points.*
x in the table name denotes that we are talking about ear, eartree and ear topology. The ear topology also has two SpliceP tables, namely EarSplicePA and EarSplicePB, the columns how ever don't differ.

- District: Names which district the splicing point is in.

- SpliceP_id: Names the Splicing Point.

- SpliceP_x: The x vector of the segment point location.

- SpliceP_y: The y vector of the segment point location.

- dist1: Distance of the Splicing point to DN1 (phase 1).

- dist2: Distance of the Splicing point to DN2 (phase 1).

- dist: The total distance of the Splicing point to DN's (phase 1 and 2).

SP_DNx_tree or SP_tree(district nr): *This table withholds the information regarding the spanning tree from the DN's to all SP's.*
x in the table name denotes either DN1 or DN2.

- src: The Segment point id.

- pred: The Segment points predecessor.

- level: Explains the level which the SP is from the DN.

- dist: Distance from the SP to the DN.

SP_SplicePx_tree: *This table withholds the information regarding the spanning tree from the Splicing point to all SP's.*
x in the table name denotes the district in question. Has the same columns as SP_DN_tree.

SP_DNx_path: *This table withholds the information regarding the path from the DN's to all SP's.*
x in the table name denotes either DN1 or DN2.

- SP_id: Names the Segment Point.

- MN_id: The id of the MN the SP is closest to.

- SP_id1: This column holds the name of the segment point 1 connected with the segment.

- SP_id2: This column holds the name of the segment point 2 connected with the segment.

- SP_x1: The x vector of the Splicing point 1 location.

- SP_y1: The y vector of the Splicing point 1 location.

- SP_x2: The x vector of the Splicing point 2 location.

- SP_y2: The y vector of the Splicing point 2 location.

- level: The level the segment point is to the DN.

NT2SP: *This table withholds the information regarding the segment from the NT's to it's SP.*

- NT_id: Names the NT.

- SP_id: Names the Segment Point.

- dist: The distance between the NT and it's SP.

- NT_x: The x vector of the NT location.

- NT_y: The y vector of the NT location.

- SP_x: The x vector of the segment point location.

- SP_y: The y vector of the segment point location

Calculations: *This table withhold all the information needed for the calculations.*

- District: The district number.

- NR_of_NT: Number of NT's in that district.

- dist_SPDN: Distance from the splicing point to the distribution node.

- dist_SPNT: Distance from the splicing point to the NT.

NT2SP: *This table withholds the information regarding the segment from the NT's to it's SP.*

- NT_id: Names the NT.

- SP_id: Names the Segment Point.

- dist: The distance between the NT and it's SP.

- NT_x: The x vector of the NT location.

- NT_y: The y vector of the NT location.

- SP_x: The x vector of the segment point location.

- SP_y: The y vector of the segment point location

Digging: *This table withholds the segment ID's which are used in the project, from this digging can be calculated.*

district_j: *This table holds the segment point id of the junction point (sp_id) and the previous district it was created from (p_district) (phase 2).*

district_nt: *This table holds the NT id and the district it is in (phase 2).*

district_s: *This table holds the segment id and the district it is in (phase 2).*

district_sp: *This table holds the segment point id and the district it is in (phase 2).*

Guidelines

E.1   Types of fiber

Knowing the characteristics of different fiber types is used for understanding the applications for which they are used. For using a fiber optic communication properly relies on knowing what type of fiber is being used and why. Currently fiber is categorized into two groups namely, single-mode and multi-mode fiber. The mode refers to the path a photo takes in going from one side of the fiber to the other.

Multimode fiber: Multi-mode fibers are those with multiple pathways through which light travels. Within the core of these cables are several hundred layers of glass, each with a lower index of refraction as you move outward from the center. Since light travels faster in the glass with lower indexes of refraction, the light waves refracted to the outside of the fiber is speeded up to match those traveling in the center [6].

The most important thing to know about multi-mode fibers is that they are fine for distance of up to about a kilometer and slower bandwidths. That makes them suitable for data networks within buildings or between nearby buildings. That means this type of fibers are best designed for short transmission distances, and is suited for use in LAN systems and video surveillance [13].

Single-mode fiber: Single-mode fibers are considered the more appropriate choice when running cable longer than a kilometer, when putting through a signal of more than 2 or 3 Gbps, or when the system must be "future-proof."

The reason single-mode fibers have such a great capacity lies in their design. The core of a single-mode fiber cable is extremely small and usually between 8 to 9 micron (compared with 62.5 micron in the typical multi-mode fiber cable) and only one light wave at a time can be transmitted down the core. Because of quantum mechanical effects, the light traveling in the very narrow core stays together in packets, rather than bouncing around the core of the fiber [6].

While this enables single-mode fibers to handle far more signal over far greater distance than their multi-mode cousins, single-mode fibers are considered to be a bit more difficult to terminate than multi-mode fibers. Plus, single-mode fibers require lasers as their light sources, which are more expensive than the LEDs that are typically used with multi-mode fibers.

E.2   Choosing optical fiber cable

There are different areas of application for a fiber optic cable. Reaserach has been done for several years to identify the type of fiber cable that are important for different types of applications.

According to [21] standard cable designs have been developed for the following areas of appli-

cation:

- Indoor cable

- Rack cable

- Duct cable

- Arial cable

- Direct burial cable

- Submarine cable

From these six cables only four of them are usable outdoors, these are the: Duct cable, Arial cable, direct burial cable and submarine cable. Arial and submarine cable are not feasible in a city area. Thus the Duct and direct burial cable are the only cables which meet the requirements [8].

E.2.1 Direct burial cable

Having a good IT infrastructure planning is always necessary before installation can begin. Setting guidelines can be a good way to start the planning process. In laying an optical fiber cable in to the ground special guide lines should be maintained. An Optical fiber cable can be laid in the ground by two methods i.e plowing or digging.

Plowing: This is the quickest and cheapest way for laying an optical fiber. But plowing is not always used in all places, for example, if the soil is a swamp or marsh, ditch-banks or very stony ground, digging will be preferable.

When plowing is done the following guidelines are important:

- Pre -plowing has been done

- A sufficient amount of cable is being fed

- The cable is being fed without jerks

- The plow is not raised or lowered steeply

- The correct depth is maintained

- The plow is not tilted sideways

Digging: In laying an optical fiber digging is preferred in cities, towns, and places where cables have been laid plowing is a less suitable method. For laying an optical fiber by digging a 12-15 cm cable trench is required. The trench can be done with a tractor to first dig the trench, and then, with its wheels on either sides of the trench and lay the cables along the trench directly. The digging must incorporate all possible connections within the area, by doing so the cost of excavation and future upgrades is minimized.

E.2.1.1   Installation in cable ducts

In cities and towns it is a common practice to find pipes or tunnels. When laying an optical fiber it is also practical to use the existing pipes and tunnels. Detailed instructions for the installation must be prepared after careful on site research along the entire path of the cable.

But before installing the optical fiber in ducts it is advisable to do tasks like:

- Manholes in need of repair

- Cable racks required

- Cleaning of ducts

- Repair of damaged ducts

To expand the cable network without disturbing the previously installed cables the use of PVC (polyvinyl chloride) is important. The PVC can be use as to increase capacity of wide ducts as a subduct. The figure E.1 shows a fiber cable duct that is used to hold a number of cables. When
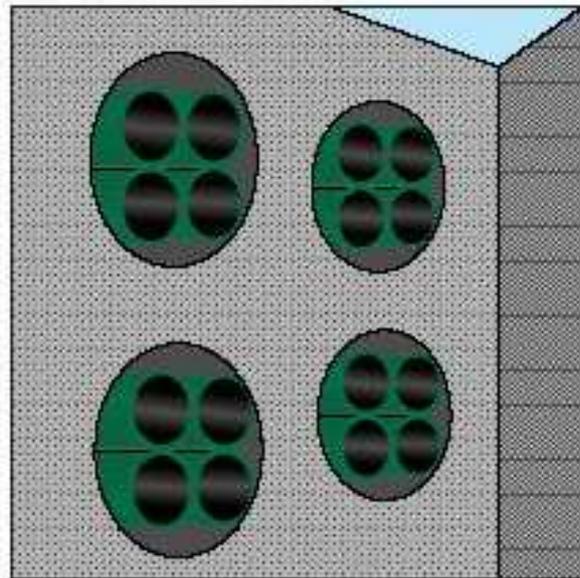

Figure E.1: Fiber cable ducts [21]

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using subducts, the maximum number of PVC tubes that can be inserted into a duct should be installed at the same time and secured at both ends.

There are different technique used to install the cable in to a duct. The most common ones are:

- Traditional pulling by using a pulling rope

- Blowing with compressed air

- Floating with water

Pulling by using a pulling rope: Pulling is done by having a drum of fiber on one side and a pulling vehicle on the other side (see Figure). This method only allows for pulling 1 km at a time, however there are methods for extending that distance **??** on page **??**. But this method can be very time consuming as the cable needs to be handled with care while pulling so it won't stretch. **Blowing with compressed air:** Blowing the fiber is the most conventional way to place
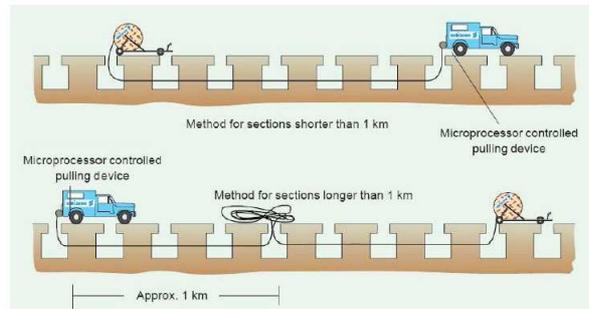

Figure E.2: Pulling a fiber optic cable [21]

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fibers inside ducts today. The method for blowing fiber depends on the fitting. With tight fitting the method is similar to the pulling where the air acts as the pulling rope. With loose fitting the stream of air will carry the cable through the duct, the pulling force decreases after 1-2 km offering the possibility of longer distances. The tools used for blowing fiber can be seen in figure E.3 below.

Figure E.3: Blowing a fiber optic cable [21]

.

Floating with water: Floating the cable with water is done nearly in the same manor as blowing the fiber, even almost identical equipment like (see figure E.3) is used. The method is gentler then blowing the fiber, however the floating method requires a large amount of water.

E.2.1.2 Installation of cable in ducts

There are a variety of cables intended for duct installation. The different types are:

- The concentric cable, GRHLDV, with upto 144 fibers in 12 loose tubes.

- The slotted core cable, GASLBDV-S, with 24 ribbonized fibers, intended for both outdoor and indoor use.

- The slotted core cable, GRSLDV, with 48 fibers in 6 loose tubes.

- The slotted core cable, GASLBDV, with 192 ribbonized fibers, intended for both outdoor and indoor use.

- The slotted core cable, GASLWLV, with 192 ribbonized fibers, intended for both outdoor and indoor use, this cable has also a corrugated street tape as extra protection against rodents etc.

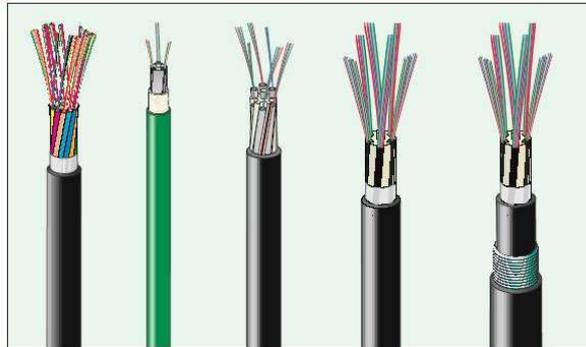Figure E.4 shows typical examples of different types of duct cables.

Figure E.4: Typical types of optical fiber [21]
.

E.3 Choosing splicing points and method

The splicing points are used in this project for connecting NT's to the main duct. With these kind of splicing points the access network becomes more manageable and adding extensions is fairly easy and cheap since for example adding a fiber requires only blowing from the NT to the splicing point. It should be mentioned that the reason for it being more manageable and cheaper is because the splicing points will be placed in the NT's district making the distance shorter. However that distance must not exceed 800-1000 meters from an NT to a splicing point due to blowing distance for NT's.

E.3.1 Splicing method

There are 2 methods available for splicing fiber cables together, these are:

- Permanent splice

- Semi permanent splice

The semi permanent splices uses connectors to splice (connect) the cables together. This means that semi permanent splices are mostly used in networks that are rapidly changing for example LAN's. Because the cables uses connectors there is greater loss than physically connecting them. And since we are splicing cables which should stand for the entire lifetime of the fiber, the semi permanent splices are not a good choice.

So the method which should be used is a permanent splice, there are two methods of creating a permanent splice, these are:

E.3.1.1 Fusion splice

In this method where the fibers are melted together, this is done with great precision to minimize the loss when connecting two cables. Splicing the cables with fusion is the most common method used today. However the method is time consuming and costly since the fibers need to be aligned with hair like precision.

E.3.1.2 Mechanical splice

There are a several different methods of mechanically splicing cables, however the mechanical splices are not as accurate as fusion splicing. Also in mechanical splices a special oil is used to splice, when the oil dries out after a few years it causes a lot of loss of the fiber. However mechanical splicing is not as time consuming and is much cheaper then fusion splicing.

E.3.2 Splicing points

The splicing points are the places where the main duct fiber is connected to the ducts going to the NT's. There are several ways to create a splicing point but there are two main points which are commonly used, these are:

- Manholes, shafts and wells

- Street box

Manholes, shafts and wells are mainly holes in the ground where the fibers are connected together. Since they are holes in the ground they provide more protection then street boxes, also the room for adding expansion is much greater then in a street box. Creating these holes are however expensive and thus more suitable for larger splicing points. Existing manholes, shafts and wells can though be reused bringing the cost down.

The street boxes on the other hand are boxes placed on the edge of a road, the street box offers easier access but are less protective. The street boxes are smaller thus have a limited space, however they do not cost as much.

Phase 1 results

This chapter will detail the results of every scenario, and is placed in it's own Appendix in order to improve readability as this is the main factor. First the chapter will list the results from the previous study to be used as a comparison between manual and automatic planning. Then the result from each scenario will be listed and the cost list mentioned in 6.5 on page 44 will be used to place cost on the fiber.

F.1 Previous project - Result

Like in this project the previous project [9] created scenarios with DN in one and two locations and both tree topology and ear topology was planned, however it was only done with home-run. Since the focus of this phase is only the fiber these results are only shown. In the previous study there where 4 scenarios which are showed in table F.1. All costs are in DKKR.

Scenarios	Explanations
Scenario 1A	2 DN locations, with traditional tree structured access network.
Scenario 1B	2 DN locations, with the new ear access network.
Scenario 2A	1 DN locations, with traditional tree structured access network.
Scenario 2B	1 DN locations, with the new ear access network.

Table F.1: Explanations of scenarios used in the previous study.

F.1.1 Scenario 1A

This previous study scenario is the traditional tree topology with two DN. The results are shown in table F.2.

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	7.756 [m]	54	418.824
Main duct: Blowing of fibers	7.756 [m]	7	54.292
SP to NT: Fibers	169.534 [m]	4	678.136
SP to NT: Blowing of fibers	169.534 [m]	7	1.186.738
Termination	830 [u]	300	249.000
Splicing	830 [u]	250	207.500
Street box	14 [u]	5.000	70.000
Total cost			2.864.490

Table F.2: Brake down of fiber cost variables in scenario 1A.

F.1.2 Scenario 1B

This previous study scenario is the ear topology with two DN. The results are shown in table F.3.

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	21.759 [m]	54	1.174.986
Main duct: Blowing of fibers	21.759 [m]	7	152.313
SP to NT: Fibers	532.269 [m]	4	2.129.076
SP to NT: Blowing of fibers	532.269 [m]	7	3.725.883
Termination	1660 [u]	300	498.000
Splicing	1660 [u]	250	415.000
Street box	28 [u]	5000	140.000
Total cost			8.235.258

Table F.3: Brake down of fiber cost variables in scenario 1B.

F.1.3 Scenario 2A and 2B

Because the network was planned in such a manor that the SP to NT stays the same between 1A and 2A and also between 1B and 2B. Thus the Main duct results are only shown. The difference between scenarios 1 and 2 is only that scenario 1 is DN's in two locations and scenario 2 is DN's in one locations. The results are shown in table F.4.

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct scenario 2A: Fibers	11.567 [m]	54	624.618
Main duct scenario 2A: Blowing of fibers	11.567 [m]	7	80.969
Main duct scenario 2B: Fibers	45.202 [m]	54	2.440.908
Main duct scenario 2B: Blowing of fibers	45.202 [m]	7	316.414
Total cost scenario 2A			3.096.961
Total cost scenario 2B			9.375.867

Table F.4: Brake down of fiber cost variables in scenario 2A and 2B

F.2 Phase 1 - Results

Following is the tables showing the results of phase 1. More information regarding these results can be found in Chapter 9 on page 59.

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	10.462 [m]	54	564.948
Main duct: Blowing of fibers	10.462 [m]	7	73.234
SP to NT: Fibers	169.571 [m]	4	678.284
SP to NT: Blowing of fibers	169.571 [m]	7	1.186.997
Termination	830 [u]	300	249.000
Splicing	830 [u]	250	207.500
Street box	14 [u]	5.000	70.000
Total cost			3.029.963

Table F.5: Brake down of fiber cost variables in scenario 1.HR.1

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	7.786 [m]	54	420.444
Main duct: Blowing of fibers	7.786 [m]	7	54.502
SP to NT: Fibers	169.571 [m]	4	678.284
SP to NT: Blowing of fibers	169.571 [m]	7	1.186.997
Termination	830 [u]	300	249.000
Splicing	830 [u]	250	207.500
Street box	14 [u]	5.000	70.000
Total cost			2.866.727

Table F.6: Brake down of fiber cost variables in scenario 1.HR.2

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	31.386 [m]	4	125.544
Main duct: Blowing of fibers	31.386 [m]	7	219.702
SP to NT: Fibers	169.571 [m]	4	678.284
SP to NT: Blowing of fibers	169.571 [m]	7	1.186.997
Termination	1660 [u]	300	498.000
PON splitters	42 [u]	200	8.400
Street box	14 [u]	5.000	70.000
Total cost			2.786.927

Table F.7: Brake down of fiber cost variables in scenario 1.PON.1

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	23.358 [m]	4	93.432
Main duct: Blowing of fibers	23.358 [m]	7	163.506
SP to NT: Fibers	169.571 [m]	4	678.284
SP to NT: Blowing of fibers	169.571 [m]	7	1.186.997
Termination	1660 [u]	300	498.000
PON splitters	42 [u]	200	8.400
Street box	14 [u]	5.000	70.000
Total cost			2.698.619

Table F.8: Brake down of fiber cost variables in scenario 1.PON.2

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	22.735 [m]	54	1.227.690
Main duct: Blowing of fibers	22.735 [m]	7	159.145
SP to NT: Fibers	480.244 [m]	4	1.920.976
SP to NT: Blowing of fibers	480.244 [m]	7	3.361.708
Termination	1660 [u]	300	498.000
Splicing	1660 [u]	250	415.000
Street box	28 [u]	5.000	140.000
Total cost			7.722.519

Table F.9: Brake down of fiber cost variables in scenario 2.HR.1

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	21.804 [m]	54	1.177.416
Main duct: Blowing of fibers	21.804 [m]	7	152.628
SP to NT: Fibers	477.379 [m]	4	1.909.516
SP to NT: Blowing of fibers	477.379 [m]	7	3.341.653
Termination	1660 [u]	300	498.000
Splicing	1660 [u]	250	415.000
Street box	28 [u]	5.000	140.000
Total cost			7.634.213

Table F.10: Brake down of fiber cost variables in scenario 2.HR.2

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	68.205 [m]	4	272.820
Main duct: Blowing of fibers	68.205 [m]	7	477.435
SP to NT: Fibers	480.244 [m]	4	1.920.976
SP to NT: Blowing of fibers	480.244 [m]	7	3.361.708
Termination	3320 [u]	300	996.000
PON splitters	84 [u]	200	16800
Street box	28 [u]	5.000	140.000
Total cost			7.185.739

Table F.11: Brake down of fiber cost variables in scenario 2.PON.1

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	65.412 [m]	4	261.648
Main duct: Blowing of fibers	65.412 [m]	7	457.884
SP to NT: Fibers	477.379 [m]	4	1.909.516
SP to NT: Blowing of fibers	477.379 [m]	7	3.341.653
Termination	3320 [u]	300	996.000
PON splitters	84 [u]	200	16800
Street box	28 [u]	5.000	140.000
Total cost			7.123.501

Table F.12: Brake down of fiber cost variables in scenario 2.PON.2

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	20.924 [m]	54	1.129.896
Main duct: Blowing of fibers	20.924 [m]	7	146.468
SP to NT: Fibers	169.571 [m]	4	678.284
SP to NT: Blowing of fibers	169.571 [m]	7	1.186.997
Termination	1660 [u]	300	498.000
EarTree splitters	N/A [u]	N/A	N/A
Street box	14 [u]	5.000	70.000
Total cost			3.709.645

Table F.13: Brake down of fiber cost variables in scenario 3.HR.1

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	22.899 [m]	54	1.236.546
Main duct: Blowing of fibers	22.899 [m]	7	160.293
SP to NT: Fibers	169.571 [m]	4	678.284
SP to NT: Blowing of fibers	169.571 [m]	7	1.186.997
Termination	1660 [u]	300	498.000
EarTree splitters	N/A [u]	N/A	N/A
Street box	14 [u]	5.000	70.000
Total cost			3.830.120

Table F.14: Brake down of fiber cost variables in scenario 3.HR.2

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	62.772 [m]	4	251.088
Main duct: Blowing of fibers	62.772 [m]	7	439.404
SP to NT: Fibers	169.571 [m]	4	678.284
SP to NT: Blowing of fibers	169.571 [m]	7	1.186.997
Termination	3320 [u]	300	996.000
EarTree splitters	N/A [u]	N/A	N/A
PON splitters	42 [u]	200	8.400
Street box	14 [u]	5.000	70.000
Total cost			3.630.173

Table F.15: Brake down of fiber cost variables in scenario 3.PON.1

Variable	Amount	Cost [m]/[u]	Total Cost
Main duct: Fibers	68.697 [m]	4	274.788
Main duct: Blowing of fibers	68.697 [m]	7	480.879
SP to NT: Fibers	169.571 [m]	4	678.284
SP to NT: Blowing of fibers	169.571 [m]	7	1.186.997
Termination	3320 [u]	300	996.000
EarTree splitters	N/A [u]	N/A	N/A
PON splitters	42 [u]	200	8.400
Street box	14 [u]	5.000	70.000
Total cost			3.695.348

Table F.16: Brake down of fiber cost variables in scenario 3.PON.2

Phase 2 results

This appendix is created to compliment the result chapter for phase 2. To ease readability of the result chapter all the details of each distribution node will be listed here. And the result chapter will only cover the scenarios as whole. For even more detailed results regarding the district scenarios it is recommended to view an excel file found on the enclosed cd. The file is called "CalculationNT.xls".

For more details regarding the complete scenarios the google KMZ file can be found on the enclosed CD. The file "hals.kmz" can be opened in the free tool called Google Earth. For even more details it is recommended to view the databases. First database folder includes every district scenario that is where the soft criteria maximum NT limit is from 30 to 150.

Each section in this chapter will represent each of the seven Distribution nodes used in this phase. Within each section, the result from the district scenario will be shown in a graph where the red stapled line marks the transformation from small to large district. From that, criteria's are chosen which show the best result for each distribution node. Following is a figure of the district creation for that distribution node.

G.1 DN: Uls

District scenarios

Figure G.1 shows graph of total cost result for each soft criteria maximum NT test.
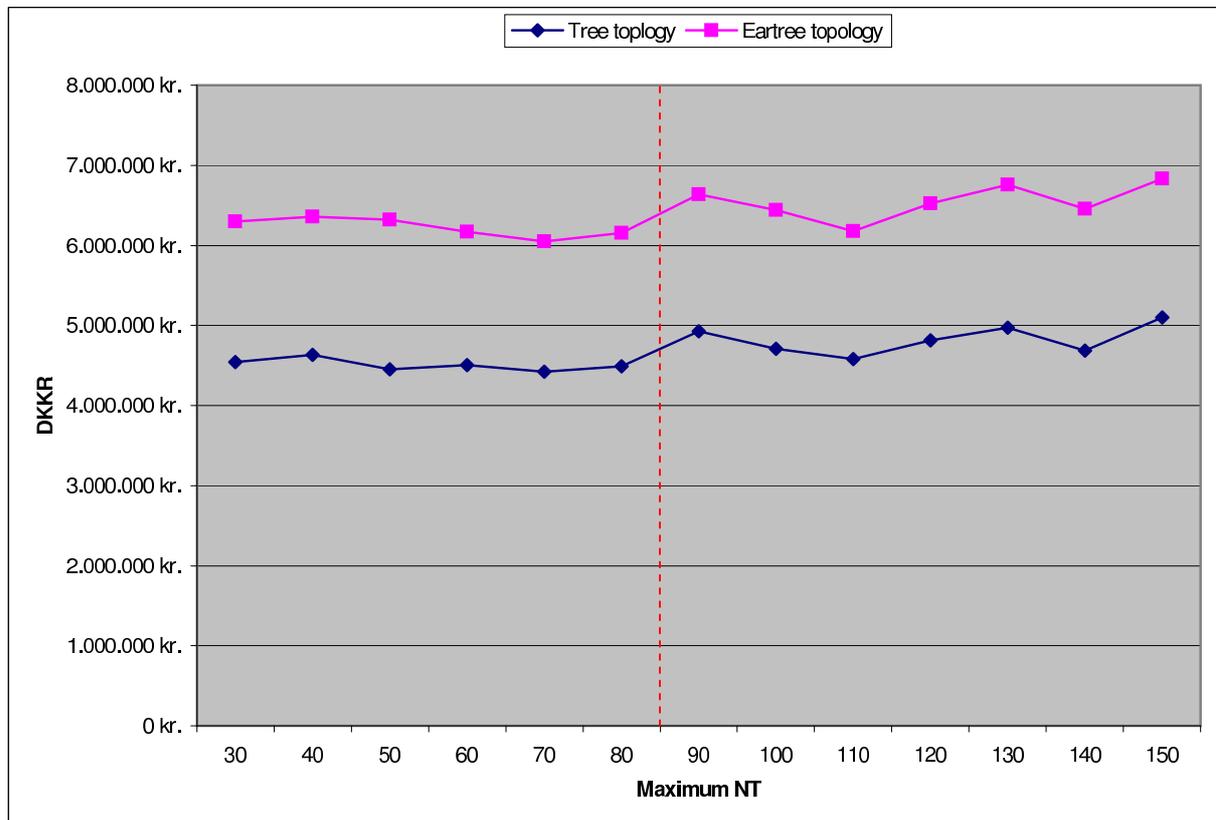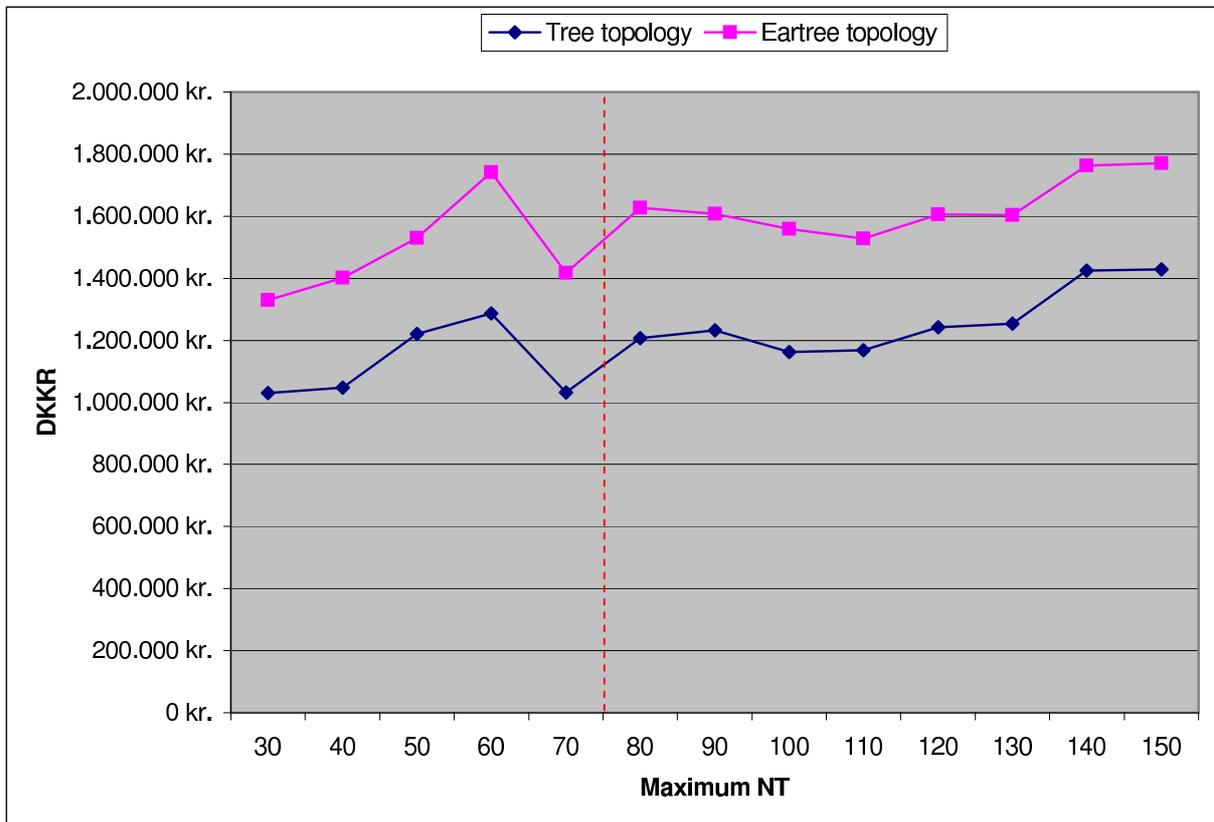

Figure G.1: Cost graph of district scenarios for Uls.

Scenario 1: Tree topology

- Digging : 76.272 Meters

- Number of NT's : 676

- Number of districts : 41

- Best maximum NT criteria : 70

Figure G.2 shows the district created for this distribution node for both tree and eartree topology. Each district has it's own color, and within each district a point is shown with a number illustrating the segment point placement and the district number. The purple star marks the distribution node placement.

Scenario 2: Eartree topology

Same as Scenario 1.

Figure G.2: District created for DN: Uls.

G.2   DN: Stae

District scenarios

Figure G.3 shows the total cost result for each soft criteria maximum NT test.

Figure G.3: Cost graph of district scenarios for Stae.

Scenario 1: Tree topology

- Digging : 20.010 Meters

- Number of NT's : 192

- Number of districts : 13

- Best maximum NT criteria : 30

Figure G.4 shows the district created for this distribution node for both tree and eartree topology. Each district has it's own color, and within each district a point is shown with a number illustrating the segment point placement and the district number. The purple star marks the distribution node placement.

Scenario 2: Eartree topology

Same as Scenario 1.

Figure G.4: District created for DN: Stae.

G.3 DN: Hoh

District scenarios

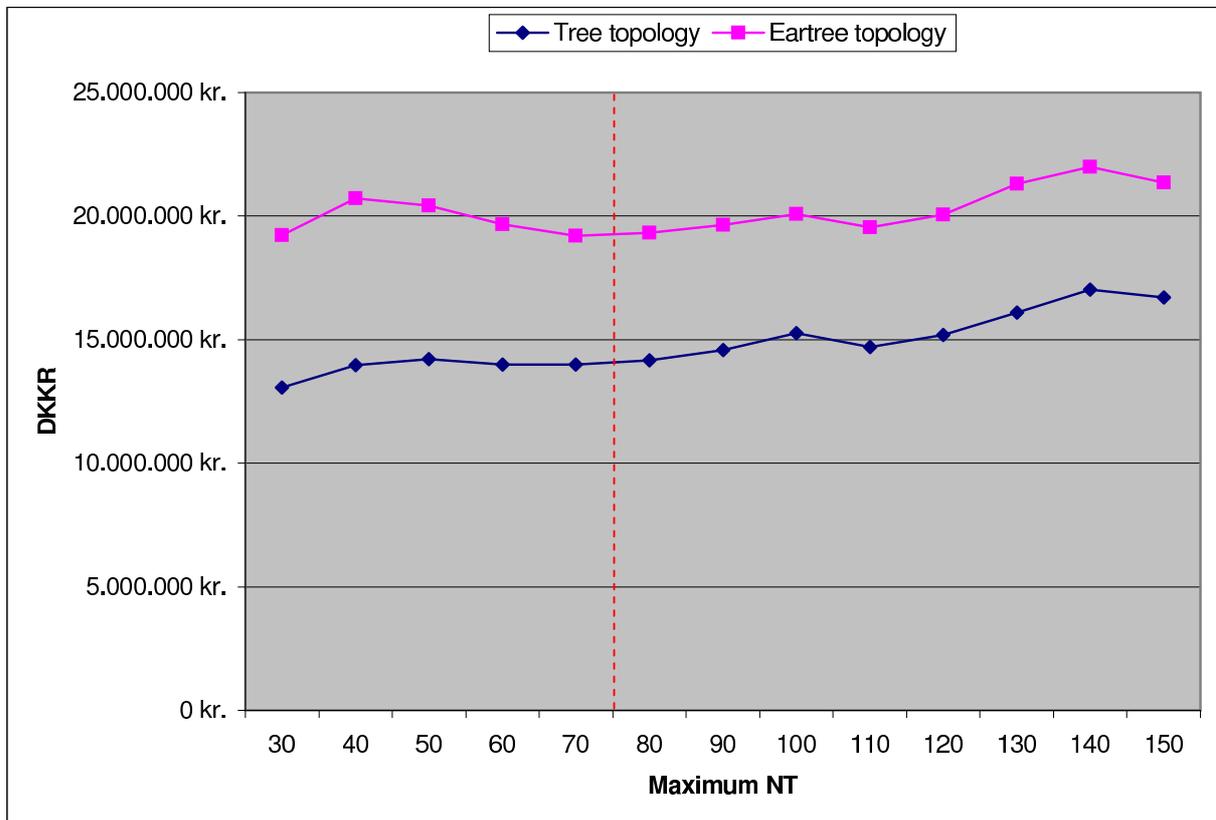Figure G.5 shows the total cost result for each soft criteria maximum NT test.

Figure G.5: Cost graph of district scenarios

Scenario 1: Tree topology

- Digging : 96.307 Meters

- Number of NT's : 2729

- Number of districts : 96

- Best maximum NT criteria : 30

Figure G.6 shows the district created for this distribution node for tree topology. Each district has it's own color, and within each district a point is shown with a number illustrating the segment point placement and the district number. The purple star marks the distribution node placement.

Figure G.6: Tree topology districts created for DN: Hoh.

Scenario 2: Eartree topology

- Digging : 97.099 Meters

- Number of NT's : 2729

- Number of districts : 60

- Best maximum NT criteria : 70

Figure G.7 shows the district created for this distribution node for eartree topology. Each district has it's own color, and within each district a point is shown with a number illustrating the segment point placement and the district number. The purple star marks the distribution node placement.
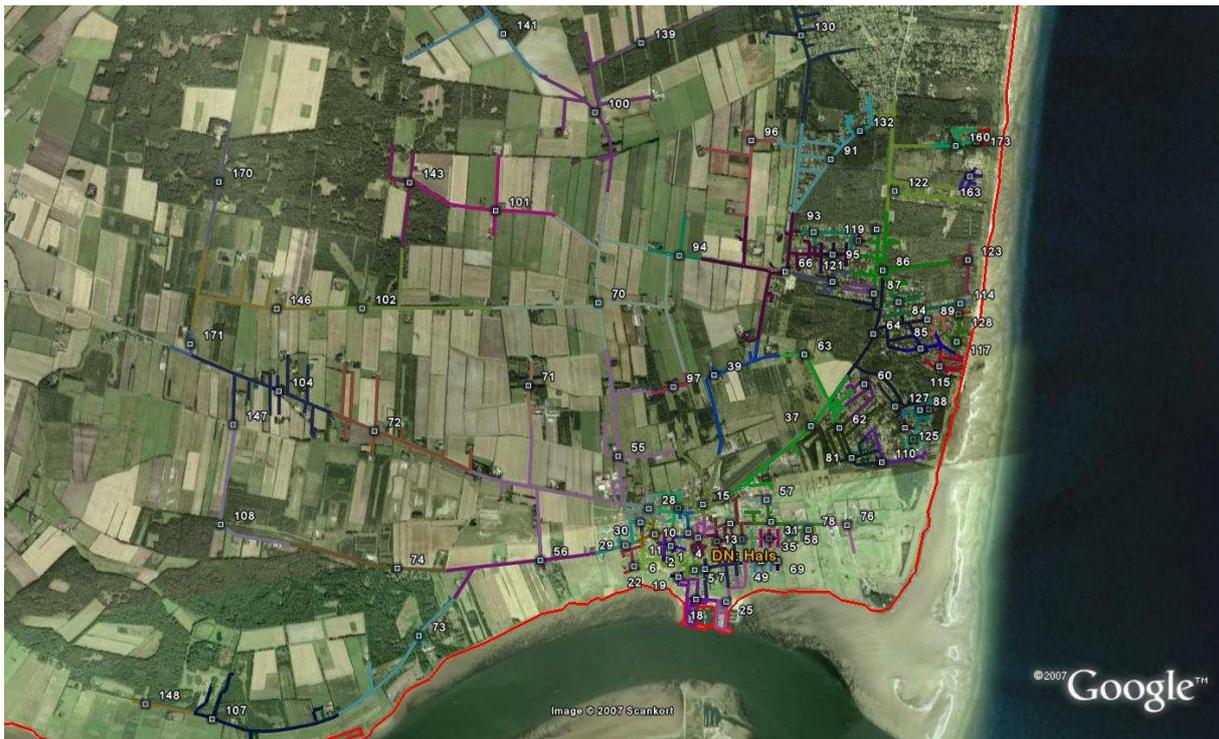
Figure G.7: Eartree topology districts created for DN: Hoh.

G.4 DN: Hals

District scenarios

Figure G.8 shows the total cost result for each soft criteria maximum NT test.
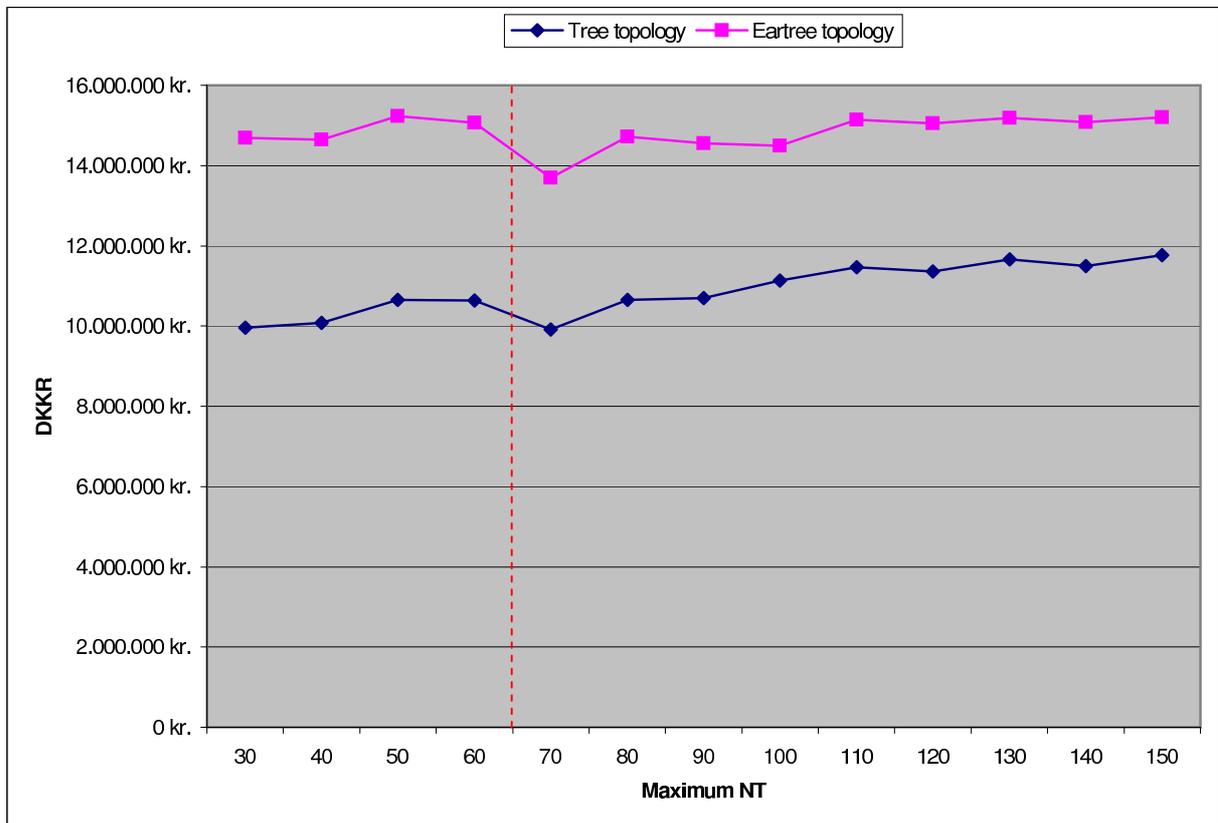
Figure G.8: Cost graph of district scenarios

Scenario 1: Tree topology

- Digging : 89.414 Meters

- Number of NT's : 2023

- Number of districts : 88

- Best maximum NT criteria : 30

Figure G.9 shows the district created for this distribution node for tree topology. Each district has it's own color, and within each district a point is shown with a number illustrating the segment point placement and the district number. The purple star marks the distribution node placement.

Figure G.9: Tree topology districts created for DN: Hals.

Scenario 2: Eartree topology

- Digging : 91.323 Meters

- Number of NT's : 2023

- Number of districts : 74

- Best maximum NT criteria : 40

Figure G.10 shows the district created for this distribution node for eartree topology. Each district has it's own color, and within each district a point is shown with a number illustrating the segment point placement and the district number. The purple star marks the distribution node placement.

Figure G.10: Eartree topology districts created for DN: Hals.

G.5 DN: Gaas

District scenarios

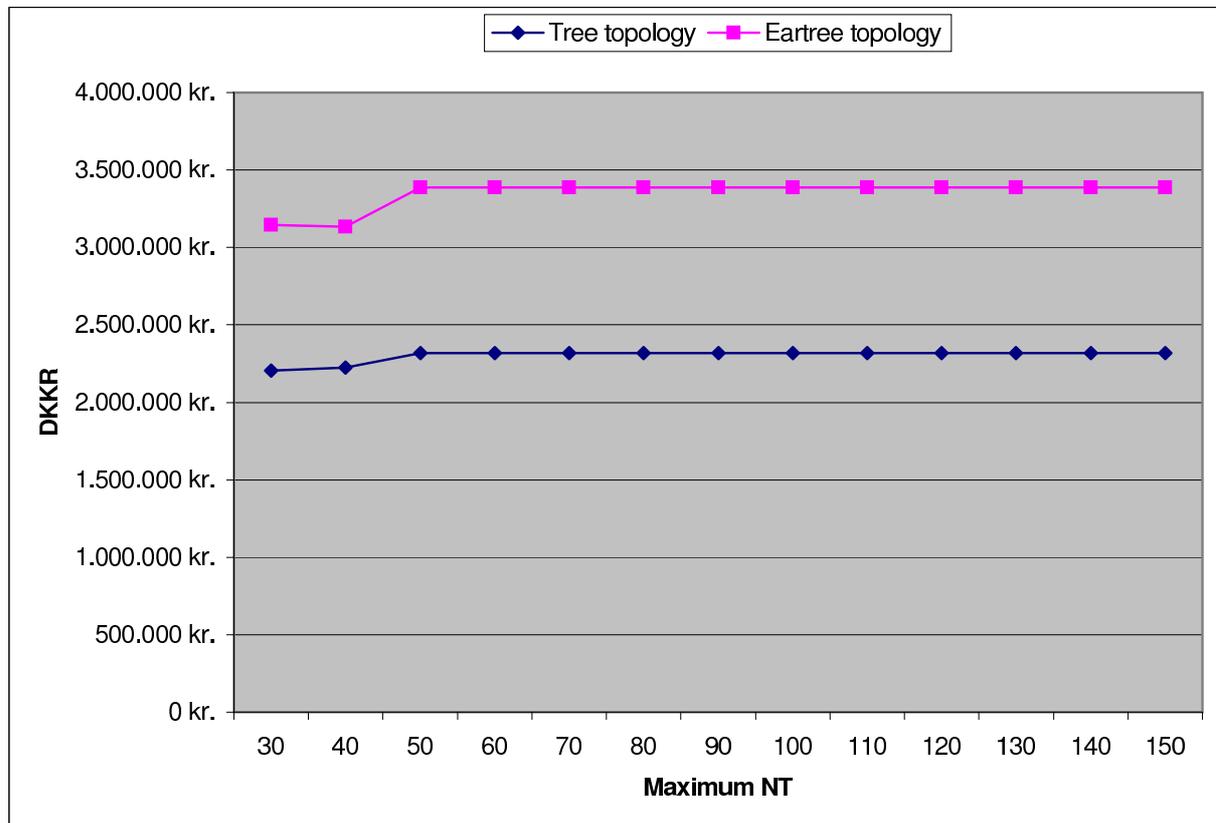Figure G.11 shows the total cost result for each soft criteria maximum NT test.

Figure G.11: Cost graph of district scenarios

Scenario 1: Tree topology

- Digging : 38.305 Meters

- Number of NT's : 221

- Number of districts : 20

- Best maximum NT criteria : 30

Figure G.12 shows the district created for this distribution node for tree topology. Each district has it's own color, and within each district a point is shown with a number illustrating the segment point placement and the district number. The purple star marks the distribution node placement.

Figure G.12: Tree topology districts created for DN: Gaas.

Scenario 2: Eartree topology

- Digging : 37.521 Meters

- Number of NT's : 221

- Number of districts : 19

- Best maximum NT criteria : 40

Figure G.13 shows the district created for this distribution node for eartree topology. Each district has it's own color, and within each district a point is shown with a number illustrating the segment point placement and the district number. The purple star marks the distribution node placement.

Figure G.13: Eartree topology districts created for DN: Gaas.

G.6 DN: Gad

District scenarios

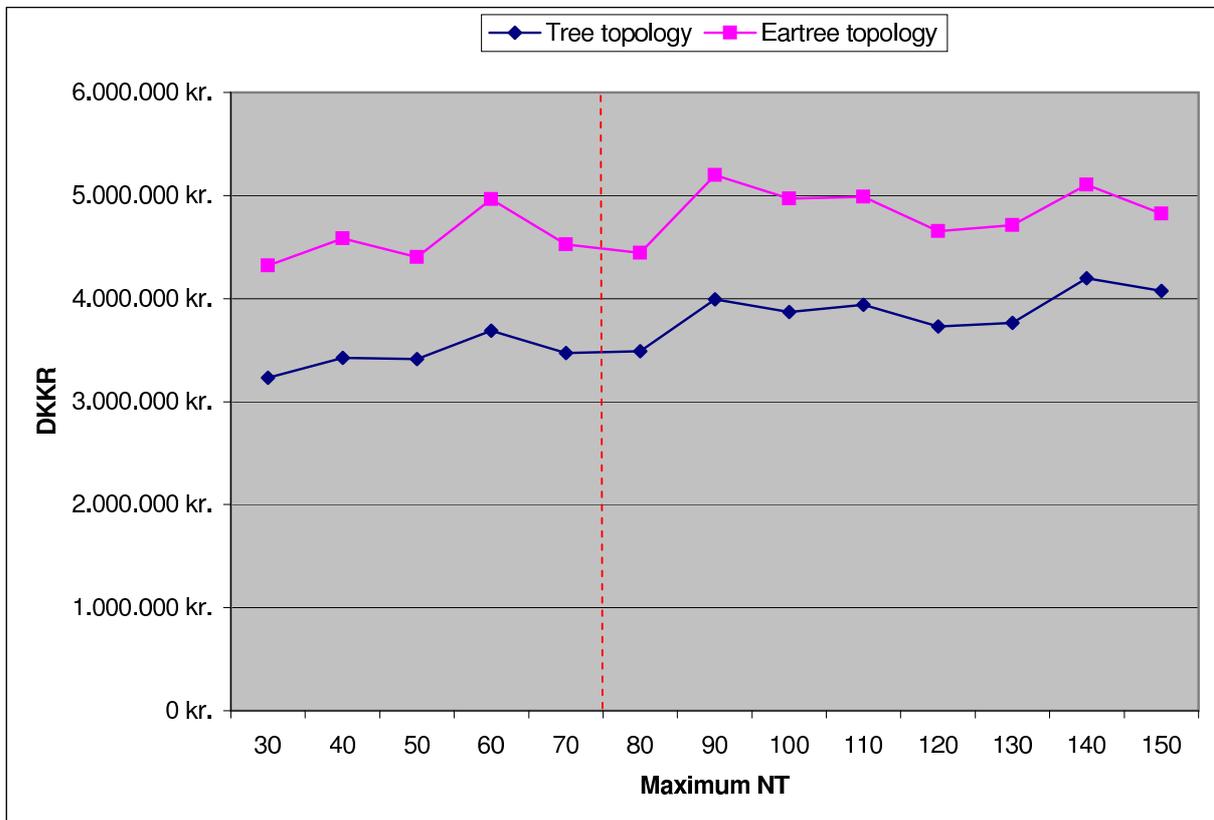Figure G.14 shows the total cost result for each soft criteria maximum NT test.

Figure G.14: Cost graph of district scenarios

Scenario 1: Tree topology

- Digging : 45.482 Meters

- Number of NT's : 765

- Number of districts : 36

- Best maximum NT criteria : 30

Figure G.15 shows the district created for this distribution node for both tree and eartree topology. Each district has it's own color, and within each district a point is shown with a number illustrating the segment point placement and the district number. The purple star marks the distribution node placement.

Scenario 2: Eartree topology

Same as Scenario 1.

Figure G.15: District created for DN: Gad.

G.7 DN: Vha

District scenarios

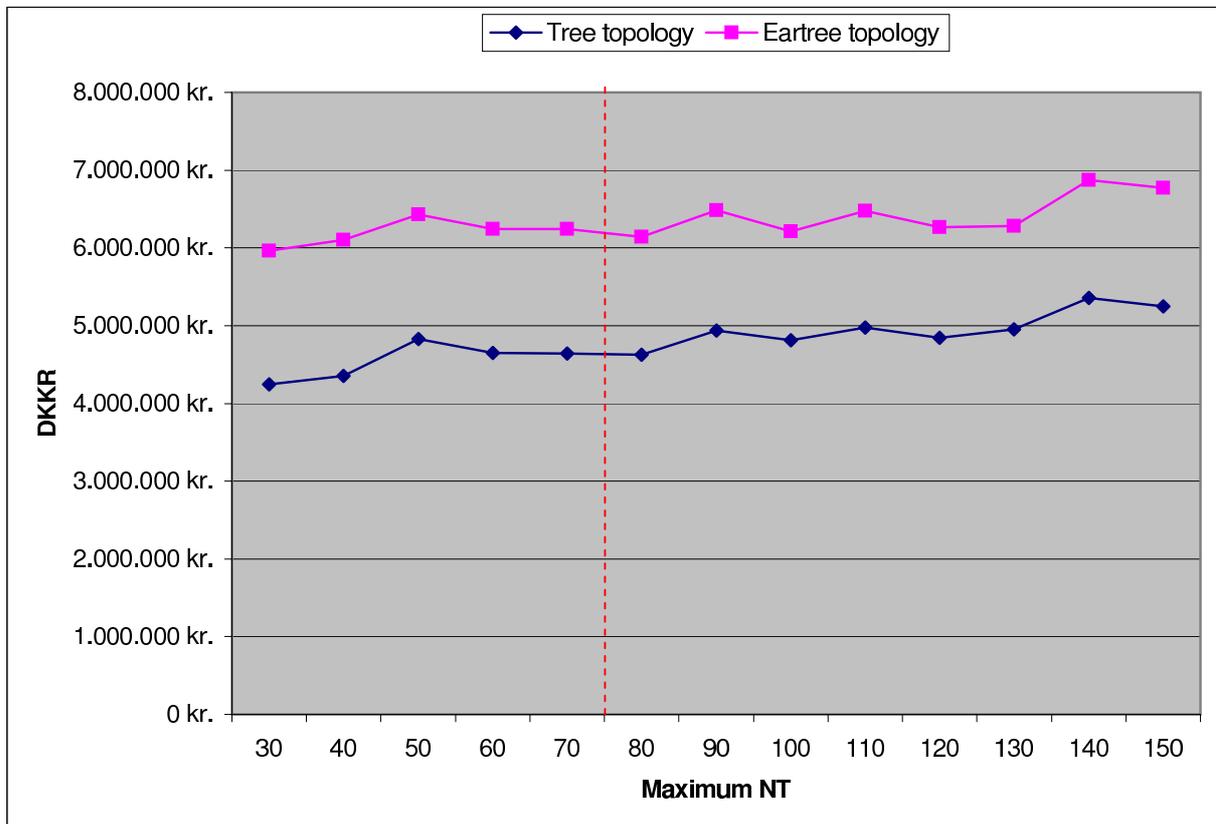Figure G.16 shows the total cost result for each soft criteria maximum NT test.

Figure G.16: Cost graph of district scenarios

Scenario 1: Tree topology

- Digging : 59.431 Meters

- Number of NT's : 991

- Number of districts : 54

- Best maximum NT criteria : 30

Figure G.17 shows the district created for this distribution node for both tree and eartree topology. Each district has it's own color, and within each district a point is shown with a number illustrating the segment point placement and the district number. The purple star marks the distribution node placement.
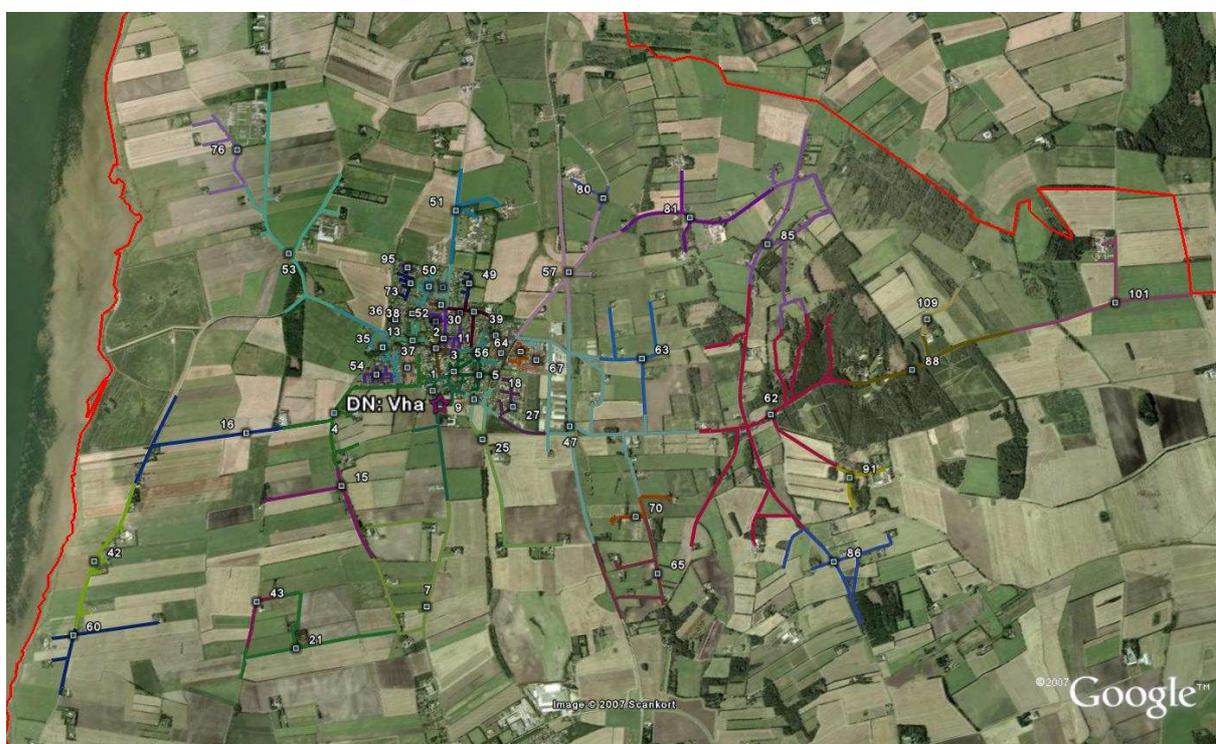
Scenario 2: Eartree topology

Same as Scenario 1.

Figure G.17: District created for DN: Vha.

Acronyms

ADSL - Asymmetric Digital Subscriber Line

ATM - Asynchronous Transfer Mode

CD - Compact Disc

CDM - Code Division Multiplexing

CN - Connection Node

CO - Central Office

DB - Database

DN - Distribution Node

DPT - Dynamic Packet Transport

DWDM - Dense Wavelength Division Multiplexing

ECSA - Exchange Carriers Standard Association

EFM - Ethernet in the First Mile

EPON - Ethernet PON

FTTC - Fiber to the cabinet

FTTD - Fiber to the Desk

FTTH - Fiber to the Home

FTTN - Fiber to the node

GIS - Geographic Information System

HDTV - High Definition Television

ICT - Information and Communication Technology

IEEE - Institute for Electrical and Electronic Engineers

IETF - Institute of Engineering Task Force

IT - Information Technology

KML - Keyhole Markup Language

KMZ - Keyhole Markup Zipped

LAN - Local Area Networks

MAC - Media Access Control

MN - Main Node

NTP - Netwrok Termination Point

OLT - Optical Line Termination

ONT - Optical Network Termination

OSI - Open System Interconnection

PON - Passive Optical Network

POTS - Plain Old Telephone System

PVC - Polyvinyl Chloride

QoS - Quality of Service

SDSL - Symmetric Digital Subscriber Line

SLA - Service Level Agreements

SONET - Synchronous Optical Network

SP - Splicing Point

SQoS - Structural Quality of Service

TDC - Tele Denmark

TDM - Time Division Multiplexing

VDSL - Very high bit-rate Digital Subscriber Line

VoD - Video on Demand

VoIP - Voice over Internet Protocol

VPL - Virtual Private Line

WAN - Wide Area Networks

WDM - Wavelength Division Multiplexing

WWW - World Wide Web

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