



**AALBORG UNIVERSITY**  
DENMARK

**Aalborg Universitet**

## **Planning broadband infrastructure - a reference model**

Madsen, Ole Brun; Riaz, M. Tahir

*Publication date:*  
2008

*Document Version*  
Publisher's PDF, also known as Version of record

[Link to publication from Aalborg University](#)

*Citation for published version (APA):*

Madsen, O. B., & Riaz, M. T. (2008). *Planning broadband infrastructure - a reference model*. European Broadband Portal. <http://www.broadband-europe.eu/Pages/Download.aspx?title=Planning%20broadband%20infrastructure%20-%20a%20reference%20model&url=/Lists/Competences/Planning%20broadband%20infrastructure%20-%20a%20reference%20model.pdf>

### **General rights**

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

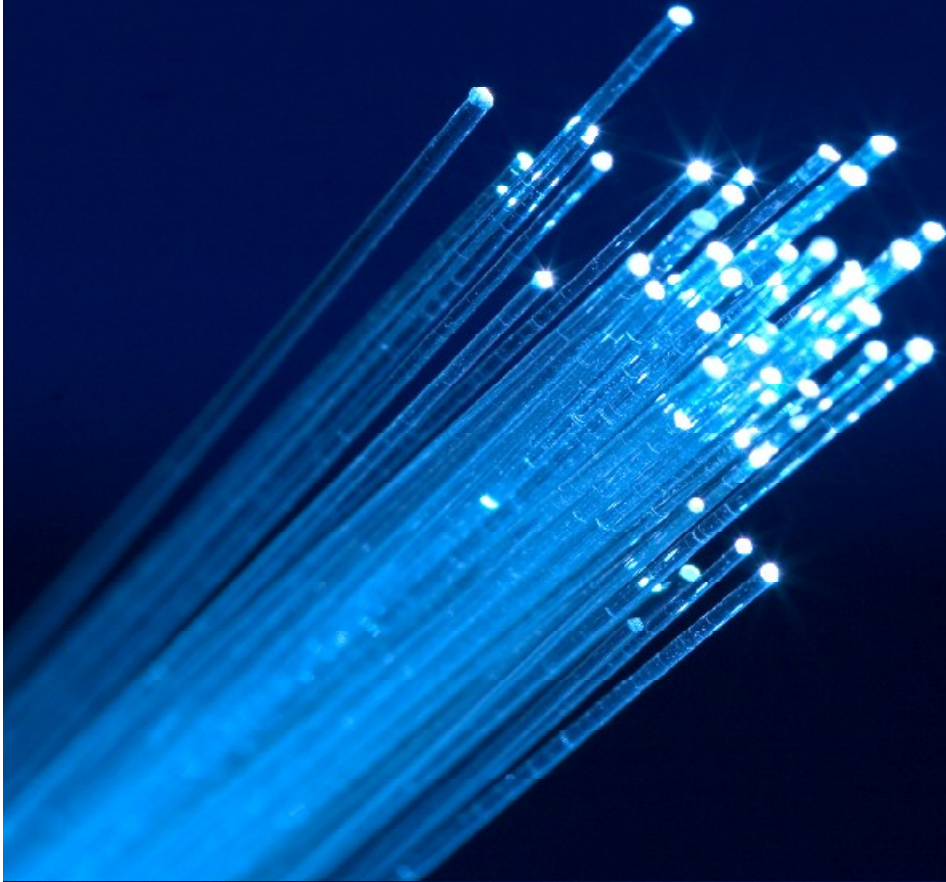
- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal -

### **Take down policy**

If you believe that this document breaches copyright please contact us at [vbn@aub.aau.dk](mailto:vbn@aub.aau.dk) providing details, and we will remove access to the work immediately and investigate your claim.

Aalborg University  
Department of Control Eng.  
Fredric Bajersvej 7C  
9220, Aalborg

*Planning broadband network infrastructure*  
- a reference model



Center for Network Planning  
by Ole Brun Madsen and Tahir M. Riaz



## Table of Contents

<b>1. Introduction</b>	<b>8</b>
<b>Background</b>	<b>8</b>
<b>Global and Local Situation</b>	<b>9</b>
<b>Main Objectives of the Report</b>	<b>10</b>
<b>Reading Guidelines</b>	<b>10</b>
<b>2. Network Planning Essentials</b>	<b>11</b>
<b>What is Network Planning</b>	<b>11</b>
<b>Network Planning Factors</b>	<b>11</b>
<b>Application Services</b>	<b>11</b>
<b>Economy</b>	<b>12</b>
<b>Technology</b>	<b>12</b>
<b>Planning by Level of Details</b>	<b>12</b>
<b>Administrative/High Level Planning</b>	<b>12</b>
<b>Technical Level Planning</b>	<b>13</b>
<b>Planning by Network Levels</b>	<b>13</b>
<b>Hierarchical Division of Network</b>	<b>15</b>
<b>Access Network</b>	<b>15</b>
<b>Transmission Networks</b>	<b>15</b>
Metro Networks	15
Long-Haul Networks	15
<b>Network Modeling</b>	<b>16</b>
<b>3. Infrastructure Planning</b>	<b>17</b>
<b>Main Goal and Strategic Objectives</b>	<b>17</b>
<b>Collecting General Information</b>	<b>20</b>
<b>Geographic location and its significance</b>	<b>20</b>
<b>Existing network infrastructure</b>	<b>21</b>
<b>Regulation issues</b>	<b>21</b>
<b>Population and related statistics</b>	<b>21</b>
<b>User groups</b>	<b>22</b>
<b>Network services and application</b>	<b>22</b>
<b>Bandwidth demand and traffic forecasting</b>	<b>23</b>

<b>Network Technologies and Trends</b>	<b>24</b>
<b><i>Network Structure Planning</i></b>	<b>24</b>
<b>Data Preparation</b>	<b>24</b>
<b>Node Locations</b>	<b>25</b>
Number of Main Nodes	26
<b>Network Structure</b>	<b>26</b>
Connectivity	27
Redundancy	27
Reliability	27
Cost	28
<b>Access Network Structure</b>	<b>28</b>
Including broadband wireless	29
<b>Metro Network Design</b>	<b>29</b>
<b>Long Haul Designs</b>	<b>29</b>
<b>4. Network Modeling</b>	<b>31</b>
<b><i>Network modeling introduction</i></b>	<b>31</b>
<b><i>Modeling Platform for Network Planning</i></b>	<b>32</b>
<b>Origin Data</b>	<b>33</b>
<b>Conversion Tools</b>	<b>33</b>
<b>Models and Modeling Tools</b>	<b>33</b>
<b>Result Data</b>	<b>34</b>
<b>Presentation Tools and Presentation Data</b>	<b>34</b>
<b><i>Network Modeling</i></b>	<b>34</b>
<b>Network Architecture</b>	<b>35</b>
<b>Network Components Definitions</b>	<b>36</b>
Nodes:	36
Lines:	36
<b>Digital Road Network</b>	<b>37</b>
Segment Table	37
Segment point table	38
Simplifying the digital road network	39
The Road Table	40
The Road Point Table	41
<b>Further reduction and manipulation</b>	<b>41</b>
<b>5. Planning Tools and Algorithms</b>	<b>43</b>
<b><i>Software application/tools for Network Planning</i></b>	<b>43</b>
<b>GIS tools</b>	<b>43</b>

Mapinfo _____	43
ESRI _____	43
IDRISI _____	44
Manifold _____	45
InterGraph GeoMedia _____	45
GRASS _____	46
<b>Network modeling and Planning Tools _____</b>	<b>46</b>
OPNET IT Guru _____	46
Shunra _____	47
NetRule _____	47
NS2 _____	48
QualNet _____	48
Mathematical Modeling Tools _____	48
<b><i>Algorithms for Network planning _____</i></b>	<b>49</b>
<b>Definition _____</b>	<b>49</b>
<b>Spanning Tree _____</b>	<b>49</b>
Algorithm _____	49
Steps: _____	50
Graphical Representation _____	50
<b>Finding Connection Node in Spanning Tree _____</b>	<b>53</b>
Rules _____	53
Algorithm _____	54
<b>Finding all CN in spanning tree and associating lines _____</b>	<b>54</b>
Rules _____	54
Algorithm _____	54
<b>Calculating the distance from a main node to all road points _____</b>	<b>55</b>
Algorithm _____	55
<b><i>Binomial Distribution _____</i></b>	<b>55</b>
<b>Theory _____</b>	<b>56</b>
<b>Using Binomial Distribution in Network Dimensioning _____</b>	<b>56</b>
<b><i>Network Availability _____</i></b>	<b>57</b>
<b>Equation 1 _____</b>	<b>57</b>
<b>Equation 2 _____</b>	<b>58</b>
<b><i>Network Fiber Length _____</i></b>	<b>58</b>
<b><i>Network Cable Length Estimation _____</i></b>	<b>59</b>
<b><i>Summery _____</i></b>	<b>59</b>
<b>6. Network Technologies _____</b>	<b>60</b>
<b><i>Wired Network Technologies _____</i></b>	<b>60</b>
<b>Fiber Optic based Network Technologies _____</b>	<b>60</b>

<b>Optical fiber transmission system</b>	<b>60</b>
Characteristics	60
Principle of Reflection	61
Existence of Modes	61
Multi mode Fiber	61
Single mode Fiber	61
The Light source	62
Optical Couplers	62
<b>Optical Network Architectures</b>	<b>63</b>
Introduction to SONET/SDH	63
Emergence of WDM/DWDM Technology	63
<b>How DWDM Works</b>	<b>65</b>
Techniques for multiplexing and demultiplexing	66
Add Drop Multiplexing (ADM)}	67
Evolution of DWDM Applications	67
<b>Introduction to Dynamic Packet Transport (DPT)</b>	<b>68</b>
Overview of DPT	68
<b>Passive Optical Network (PON)</b>	<b>69</b>
Advantages and Disadvantages	70
Multiplexing techniques	71
Types of PONs	71
<b>Copper Based Network Technology</b>	<b>72</b>
PSTN	72
xDSL	72
Symmetric DSL	73
CATV	75
<b>Wireless Network Technologies</b>	<b>75</b>
<b>Wireless LAN</b>	<b>75</b>
The Wireless LAN Architecture	75
802.11 Topologies	76
Current Standards	77
Current Capacity	77
Future standards	78
WLAN Security	79
<b>Third and Fourth Generation Networks</b>	<b>80</b>
<b>Wireless MAN</b>	<b>81</b>
HIPERMAN	81
802.16/802.16a standards	81
802.16e Standard	82
Mobile Broadband Wireless Access: 802.20 Standard	82
<b>Satellite Broadband Access</b>	<b>82</b>
<b>UWB</b>	<b>83</b>
<b>7. Broadband Services</b>	<b>85</b>
<b>Application Service</b>	<b>85</b>

Peer2Peer File Sharing _____	85
IP Telephony _____	85
Online Gaming _____	86
Web Browsing Related Activities _____	86
Storage Area Network _____	86
Broadcast TV and Radio _____	86
Video on Demand _____	87
E-learning and Tele Commuting _____	87
<b>8. Network Structures _____</b>	<b>89</b>
<i>Network Topology</i> _____	89
QoS _____	91
SQoS _____	91
<b>9. Case Study _____</b>	<b>93</b>
<i>Introduction</i> _____	93
<i>Infrastructure Planning for Municipality of Hals</i> _____	93
Main goal _____	93
Collecting General Information for Municipality of Hals _____	93
Interested Parties for Infrastructure _____	94
Service Providers _____	94
The Public Sector _____	95
The Private Households _____	96
The Businesses in Hals _____	97
Planning strategy _____	99
Network design _____	101
Operational step _____	101
Tactical step _____	103
Strategic step _____	105
<i>Summery</i> _____	106
<b>10. References _____</b>	<b>108</b>
<b>11. Acronyms _____</b>	<b>110</b>

## Table of Figures

<i>Figure 1: Planning by network levels</i> .....	14
<i>Figure 2: Network Hierarchical levels</i> .....	16
<i>Figure 3: Planning details with different levels and targets</i> .....	18
<i>Figure 4: Using grid to decide node location</i> .....	26
<i>Figure 5: A representation of physical and logical topologies shown in different layers</i> .....	27
<i>Figure 6: Modeling platform for network planning</i> .....	32
<i>Figure 7: Network Architecture</i> .....	36
<i>Figure 8: Binomial distribution with <math>n=30</math> and <math>p(\text{active})=0.2</math></i> .....	57
<i>Figure 9: Propagation of a ray in a multi mode fiber</i> .....	61
<i>Figure 10: Propagation of a ray in a single mode fiber</i> .....	62
<i>Figure 11: The optical spectrum</i> .....	64
<i>Figure 12: Evolution of WDM/DWDM</i> .....	65
<i>Figure 13: Transmission in WDM/DWDM</i> .....	66
<i>Figure 14: Evolution of WDM/DWDM Applications</i> .....	68
<i>Figure 15: Overview of an access network [20]</i> .....	70
<i>Figure 16: Broadcast PON [24]</i> .....	70
<i>Figure 17: Independent Basic Service Set</i> .....	76
<i>Figure 18: Infrastructure Basic Service Set</i> .....	77
<i>Figure 19: Spatial capacity comparison between IEEE 802.11, Bluetooth, and UWB</i> .....	84
<i>Figure 20: Different topologies of a network with six nodes</i> .....	89
<i>Figure 21: <math>N2R(p;q;r)</math>-graphs</i> .....	91
<i>Figure 22: Location of the municipality of Hals in Northern Jutland</i> .....	94
<i>Figure 23: The municipality of Hals with its villages and main roads</i> .....	95
<i>Figure 24: The public institutions in the municipality of Hals</i> .....	96
<i>Figure 25: The private households in the municipality of Hals</i> .....	97
<i>Figure 26: The distribution of the businesses in Hals exclusive the agriculture</i> .....	98
<i>Figure 27: The distribution of agriculture in the municipality of Hals</i> .....	99
<i>Figure 28: The backbone network in the municipality of Hals</i> .....	102
<i>Figure 29: Operational step ADSL/VDSL and FWA coverage</i> .....	103
<i>Figure 30: Tactical step ADSL/VDSL and FWA coverage</i> .....	105
<i>Figure 31: coverage for the strategic step of implementation</i> .....	106



# 1. Introduction

## Background

It had been realized soon after the invention of telephone by Alexander Graham Bell that the telephone should be under the reach of all members of a society in order to satisfy the basic need of interpersonal communication and the progress of society. This motivation gave a birth to communication infrastructure. Generally the first communication infrastructure was based on copper wire. The copper wired infrastructure has been successfully serving over several decades. The main application was the voice telephony. However, the communication infrastructure was not remaining limited to voice communication.

Later, advances in digital communication and emergence of computer based communication introduced with several new applications, such as video conference, video on demand and other data applications, start changing the overall shape of infrastructure. The amount of information sent through any communication channel is namely measured as bandwidth. As the amount of users and new applications accelerated the bandwidth demand of backbone and access network started significantly. One of great innovations in networks is an optical fiber transmission. The optical fiber broke the capacity and distance limitation of existing copper based infrastructure, and became a de-facto standard for the backbone networks.

Today, almost all the backbone networks are mainly based on optical fibers and can tolerate virtually unlimited bandwidth by just upgrading the electronic equipment. On other hand, access networks still mainly consist of conventional twisted pair copper wire. While there are several copper based broadband technologies introduced, but none of them is promising a long term solution for high demanded application services for today and future. In addition to that, in access network, wireless broadband technology is introduced too, mostly for the mobility and a temporary substitute for the wired network. The ultimate long term solution only lies in approaching by optical fiber to the end user - commonly known as Fiber To The Home (FTTH).

Considering the wireless technology, few decades ago it has been assumed that wireless technology will be dominating, both in local and large area loop, in near future. That assumption is however proven wrong with the large scale use of fiber optic technology. Now in the large scale network only the optical fiber technology is dominating. The wireless satellite link is used mostly for the very long distances and where the optical access is not available, expensive to deploy, or for the redundancy. In recent years broadband wireless is penetrating in the local loop and some times seen as a competitor. However, the physical limitation of wireless technology restricts to reach the capacity of optical fiber. A new kind of infrastructure is

emerging with the combination of wired and wireless technology. The wireless technology will be mainly supporting for the mobility, remote access areas where the wired infrastructure is unavailable and relatively expensive to deploy in a particular time frame, and redundancy.

Today communication infrastructure is confronting replication of infrastructure. Several new players jumped in after the de-regulation of telecommunication. This gave many positive impacts, but some negative as well. The deregulation enhanced the quality of service, new application services and cost benefits to customers. However, new services and customers demands spurred parallel infrastructure, for instance cable TV, private networks etc. It is being experienced that there passes many communication lines at the same place. It can be possible that all the different services can be transported at single fiber, since fiber optic provides potentially unlimited capacity.

The technological innovation and the social paradigm for the need of new services are both dynamic and inter-related. The necessity which kicks the innovation of new technologies and on other way around the innovation also invokes necessities for new services. History is evident for such phenomenon. It can be concluded that the new application services will be introducing along the better technology.

## **Global and Local Situation**

Upon the situation, described above, several countries have taken initiatives to build their IT infrastructure, which should be able to meet the communication requirements of next generation. Fiber optic network is found to be the best solution for the basis of IT infrastructure. Not so long, fiber optic was quite expensive to establish on the edges of network. Mass production and technological achievements made it possible to afford the infrastructure reaching with fiber optic at end users. Some of the leading countries in deploying FTTH include Canada, Sweden, South Korea, Italy and the USA etc.

In Denmark fiber based infrastructure has been tried out already a decade ago at a very small scale. However, it could not be able achieve its goal due to the fact that there was not such a service which delivered on a fiber can not be delivered on a copper cable. Other issues were the relative high cost of fiber and equipment. In December 1999, a storm with catastrophic consequences lead to a blackout in various places in Denmark due to the vulnerability of cables carried in pylons. One of the Danish power companies, NVE, had suffered great damages on their power infrastructure and it was decided to dig down the cables to avoid future mechanical damage caused by nature. In the same time it was decided to put down empty pipes, which later could be used to carry optical fibers. In 2002, after an extensive burying of pipes and fibers, NVE could as the first service provider in Denmark offer new and improved digital services on their fibers directly to the customers. This initiative has later on lead to many other similar projects in all over Denmark. Today several power companies are forming their own strategy concerning a new area of business as IT infrastructure providers.

## **Main Objectives of the Report**

This report will explain the network planning for establishing the Broadband IT Infrastructure. The main intention is to provide a comprehensive guideline to speed up the on going and intent planning of next generation IT infrastructure. This report intends for network planners, decision makers and other interested parties. It will be worthwhile to mention that the report will provide guidelines only at a higher level. The detailed or technical level planning process is out of the scope of this report.

## **Reading Guidelines**

First two chapters provide a general introduction and basics of network planning concepts. The chapter 3, Infrastructure Planning, gives comprehensive guidelines with some methods to plan network infrastructure. In this chapter we also have tried to avoid giving too much technical details of planning. The technical details, tools, algorithms, and some modeling details are mentioned in separate chapters. Network modeling chapter gives some examples how the modeling is used for the planning. Some of tools which can be used for the network planning are introduced in Chapter 6. In network technology chapter we provided a general overview of current and future's technologies. Both wired and wireless technologies in context of broadband are mentioned. The advances in network technology are very fast so it is always recommended to get updated with the new advances in technology.

In the end, a practical example with providing a case study of infrastructure planning for a municipality is given.

## 2. Network Planning Essentials

In this chapter we will shortly describe the essentials of network planning. Before entering into detailed planning it is suggested to get familiar with the basic terminologies and definition used in the network planning.

### What is Network Planning

The beginning of network planning can be associated with the telephone industry. The Most large telephone companies have had network planning departments for some times. Telephone companies have been joined in their need for a planning function by cable TV operators and computer network operators. The introduction of new technologies required new planning. This includes computer networks in general, ISDN networks, ATM and SDH networks, cellular radio networks, and FTTH or fiber optic networks.

In general, network planning can be said a composition of the certain activities which are carried out to achieve the defined goal. The activities are performed in a way that the goal is achieved in an economical or cost-effective and an efficient way. The efficiency and cost effectiveness are achieved by optimization planning processes. Network planning involves the efficient deployment and management of communication facilities over time. The time perspective is very important in network planning and acts an important role for planning decisions. Earlier, Network management was also regarded as an integrated part of network planning. But, as the network complexity grown network management is regarded a distinct field of network planning.

In the last two decades there has been a tremendous growth in the number, sophistication, and capacity of networks. The convergence of telecommunication and computer networks apparently noticed. Now the trend is towards a ubiquitous communication infrastructure where all the telecommunication and computer network applications can be delivered on a homogeneous network, particularly in the last miles of networks. This situation enhanced the importance of network planning in recent years where new IT-infrastructure is thought to be built.

### Network Planning Factors

There could be many factors which influence network planning. These factors can be divided into minor and major ones. Only the major network planning factors are discussed in the following sections.

#### Application Services

The end goal of infrastructure is to cater application demands of users. In the first step, the most important one, a network should be able to satisfy the contemporary

demands of application services. However, this is not only a goal of network planning. With time new applications are introduced - this is observed a continuous process. A planned network not only able to provision the current services but also in some extend should be able to fulfill the future demands of applications.

## **Economy**

Building a communication infrastructure is usually quite expensive. Investment done for network is mostly for longer term. Economy plays a vital role in network planning; It limits resources which are involved to build a network infrastructure. Economic consideration not only important at operators' side but also on users or customers. It is very important that the economical conditions of customers are taken into considerations. The declension of user economy will lead to lower demand of offered applications. The future situation of customer plays a big role for the decision of network infrastructure planning.

## **Technology**

Today's and future evolution of network technologies impacts on network planning decisions. Mostly, new technologies bring more capacity, increased reliability and reduced cost. It is crucial to choose the right technology. Along time, the old technologies are gradually replaced with the new technologies. The right decision for the selection of technologies is quite crucial. Examples of the gradual displacement of older technologies include the use of digital technology in place analog technology and the use of fiber optic links in place of copper or electrical links. Some older technologies can live alongside with new technologies. A claver planning can introduce the reusability of older technologies.

## **Planning by Level of Details**

New innovations in network technology and the increased complexity of network protocols made network planning a more complicated task. It is therefore considered to divide network planning into different levels in order to have better understanding, easier implementation, and simplicity.

### **Administrative/High Level Planning**

Administrative or high level planning is performed mainly for the decision making purposes. This includes the main goals of network plans. Planning a network infrastructure is quite a huge task, and also expensive to deploy. Before the network plan embarks into the deployment stage it is important to estimate and get a general overview of what the network will be offering, and what would be the returns. Financial policy is also described in this level. Available economical resources and the expected outcomes are evaluated. The economical resources are specified and allocated. It is however very important that regularity issues are elaborated at this level in order to avoid later complications. Examples of the regularity issues are government's deregulation policy, frequency used in wireless infrastructure, and

digging etc. The traffic, application and technology trend forecasting is a vital element in planning. In the strategic level network planning, an overall forecasting is done. However, a detailed forecasting and traffic estimation is left for the technical level planning.

## **Technical Level Planning**

After high level planning technical level planning is outset. Technical level planning is some times called fundamental level planning.

Detailed planning for network is exercised considering to the high level planning goals. Detailed level of switching, routing, addressing, signaling, operations, provisioning, and maintenance plans are described.

It should not be assumed that network planning is carried out implying waterfall model, herein the iteration is not allowed. In practice, strategic level planning and technical level planning work together iteratively. Several adjustments are made due to the new facts embraced at technical level.

## **Planning by Network Levels**

Networks are usually divided into different levels. They are usually composed by many different elements, such as ducts, cables, switching equipments etc. These elements work together to perform the network processes. In practice, planning all these together is relatively complex task, especially when the network size is considerably large. In order to achieve simplicity and ease of implementation network elements are virtually divided into levels. Network level concept follows the famous analogy of divide and rule.

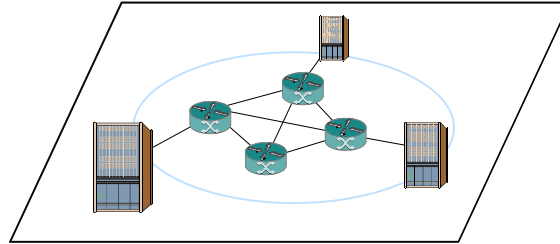
### Application Level

End equipment, programs  
databases etc.



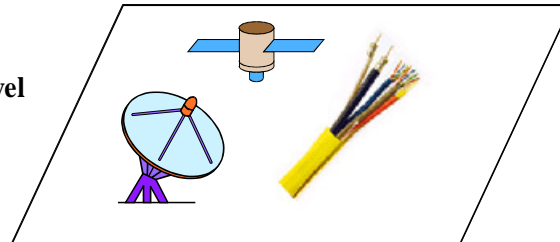
### Transmission Level

Several logical connection over  
physical connection, IP level  
communication etc.



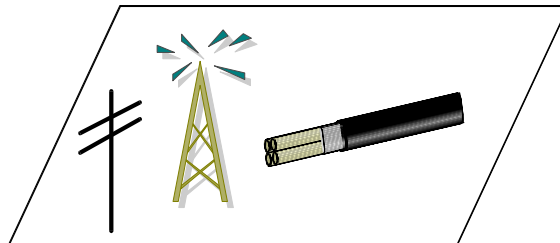
### Cables and Antenna Level

Cables (dark fiber ), and  
antenna systems.



### Duct and Mast Level

Duct for cables and towers for  
antennas and polls etc.



### Trace Level

Space allocation for infrastructure  
digging and cable layout on ground

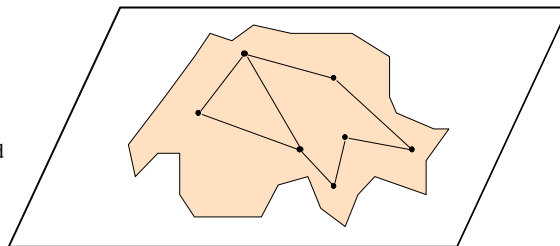


Figure 1: Planning by network levels.

## Hierarchical Division of Network

Hierarchical division is to separate the network in different levels or domains. There are several terminologies exist for the hierarchical divisions of network, and some time this causes confusion. However, the main idea to divide the network into different domains is to get a better control, understanding, manageability, and scalability. A negative side is that the capacity loss which can lead to a performance loss. We can divide the network into two main levels, Access networks and Transmission networks.

### Access Network

The lowest level of network hierarchy is called Access network. This is also commonly known as last mile network. Access network consists of end users or end equipment, usually called network termination (NT). These NTs are connected to higher level of network hierarchy. Access networks are mostly having low capacity lines, and usually no redundancy. The overall structure of the access network is tree. The distance from NTs to transmission network is shorter compare to its higher hierarchies, usually from some 100 meters to few kilometers. The technologies used in access networks are xDSL/Cable, Ethernet, ISDN, FTTH etc.

### Transmission Networks

Access network is connected to transmission network, where transmission network's job is transport the data collected from the access network. If each data switch, telephone exchange, or radio terminal called a point, then a transport network something that enables these points to be connected. The transport network provides the ability to carry traffic between the points. Transmission can be thought as plumbing in that each pipe is set up according to a certain size, and it remains the same whether the flow through it or not. In transmission networks resources are mostly allocated and reserved, without any facility overbooked. Transmission networks it self can be divided into two types; two different transmission scenarios—One for the metro environment and one for the long-haul environment.

#### Metro Networks

The geographical location of metro networks is limited to small area < 100km, which includes cities, town etc. Metro networks collect the traffic from access networks and transport to other users within the metro networks and also to other long distance areas through long-haul networks. Metro networks are mostly deployed as ring or interconnected rings structures. The dominant technology in metro networks is SONET/SDH. But, Gigabit Ethernet is also now being used coupling with the DWDM technology.

#### Long-Haul Networks

Broadly speaking, the long-haul is about creating big pipes, which means the capacity of long-haul networks is very high. The type of service is not numerous unlike the metro side. The network shape is relatively stable; however, as traffic



grows dramatically, the size of the pipes must be able to grow easily, too. Other significance of long-haul networks is the distances. The distances between nodes are usually quite long, normally  $> 100$  km. Long-haul networks are usually deployed as point to point mesh structure.

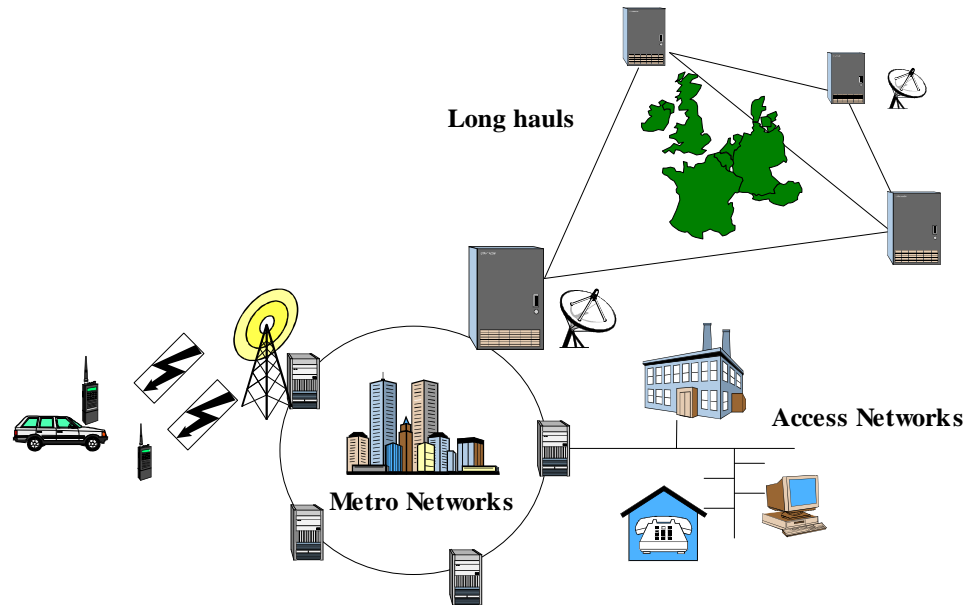


Figure 2: Network Hierarchical levels

## Network Modeling

Modelling is about the representation of real world at the abstract level. Network modelling is a very comprehensive concept in network planning. Planning and designing a network is a huge and complex task. A careful and intelligent planning makes the implementation more effective. As it is discussed earlier that networks are often very expensive to deploy. In the planning and design process different modelling techniques are used to analyse how the network would be performing before the actual deployment. Modelling not only helps in the design process but also useful in the running network to improve the network performance.

# 3. Infrastructure Planning

In the previous chapter a brief introduction to basic concepts of network planning is presented. We introduced different types and levels of network planning. This chapter will lead to the planning into further detail of network planning with different methods and guidelines for particularly focusing on infrastructure planning. In the start of the chapter we will describe which initial information is necessary in order to begin the empirical level of planning. Strategic goals and requirements are also explained and also their importance why it is needed to specify. The outset of the network structure planning is the modeling and preparation the data. And then, we will start the planning by describing how the node location can be decided. Moreover, to find the number of nodes in transmission network will be explained. When the node locations and their number are decided, the next step is to obtain a structure or topology of network. Some guidelines also will be provided for the selection of fiber optic cables and also about the ducts. To estimate the cost of IT infrastructure methods and guidelines will be provided as well.

## Main Goal and Strategic Objectives

Main goal of network planning is about the expectations and targets set to obtain the desired network. First and foremost, the main goal of network planning must be specified. It is essential and most important that the main goal is defined and understood clearly. A well-defined goal makes the planning more effective. What is the main intention to build an infrastructure, what services will be provided, what is the time frame of network planning and its implementation, such questions should be answered.

To achieve the main goal the sub goals are defined. These sub goals are usually called strategic objectives or strategic goals. The strategic goals are the targets which are approached in a way that the main goal is obtained in an efficient way. To realize the strategic goals strategic steps are formed. The strategic steps are the processes which guide what should be done in order to achieve the strategic goals. In Figure 3 the relation between main goal, strategic goals and strategic steps is represented with respect to the time. The time scale is divided into three phases. The division let us know which level of planning detail has to carry out. The time scale is not specified. However a general time scale is listed later. This should be kept in mind that the time scale is not strictly followed by this. This highly depends upon the main goal.

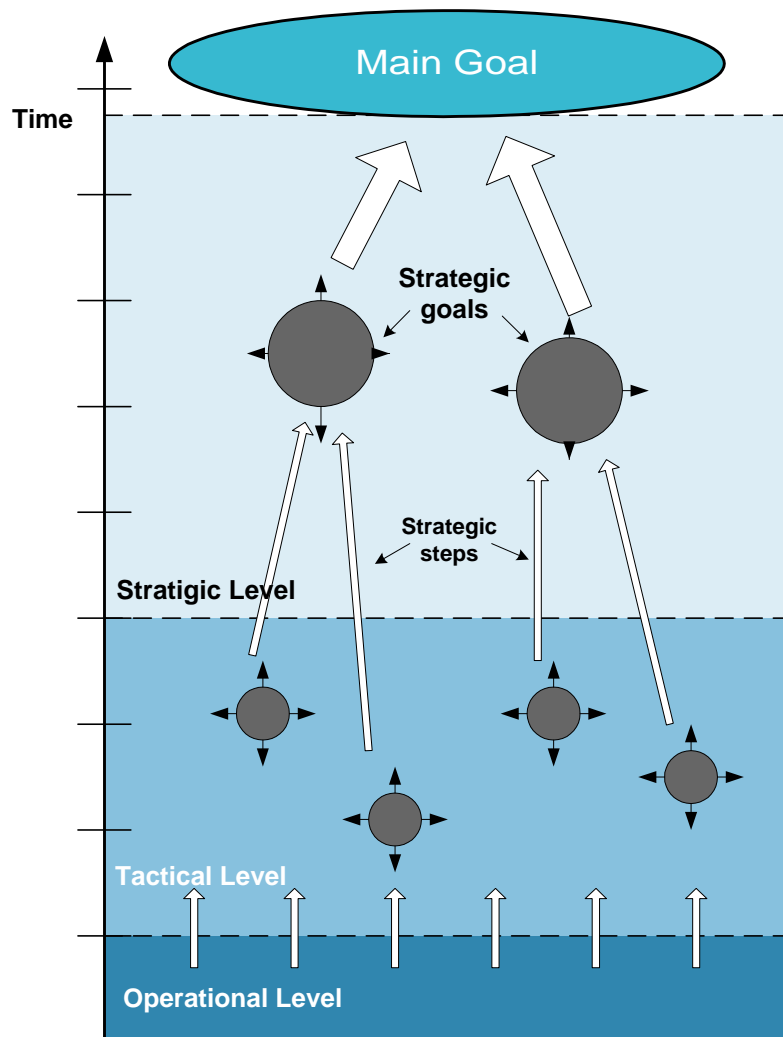


Figure 3: Planning details with different levels and targets.

The main intension for making such division and grouping is the nature of nature of network equipments, their life cycle, costs, and expansions etc. In telecommunication the technological developments are very fast, which tends to network equipment life cycle shorter. The electronic equipment, also called as active equipment, have mostly a shorter life cycle, usually 3 to 5 years. However, the passive equipment like fiber cable, ducts etc. have relatively very long life cycle. Considering this the planning levels are divided in different time scale. The division is listed as:

- **Strategic Level:** In this level the planning is exercised for long term, usually 5 to 20 years. The network elements which have long life time are

considered with priority. In the strategic level physical structure of network planned with more focus. As mentioned earlier that physical structure has long life time, a full scale structure is planned. The tasks which support to decide the network structure are performed. The tasks included in this level are: defining higher level of strategic goal, application and services evaluation offered by network, long term forecasting, and the most important planning physical network structure. Furthermore, policies like how the network would be scaled and upgrade milestones policies are discussed as well.

- **Tactical Level:** This level normally deals with 3 to 5 years of network plan. This level usually has much more detail compare to strategic level. In this level switching network is also included. The decisions of which switching equipment will be used are also made. Since the dimensioning of network also involved the traffic estimation and forecasting are tried with more reliable fashion. In the tactical level the strategic goals specified should be supporting to achieve the goals specified at the strategic level. Moreover, the goals specified at this level better have co relation with the goals at operational level.
- **Operational Level:** operation level consists of 1 to 3 years. This level includes the initial legislation issues, access priorities, transition from existing network infrastructure to new infrastructure, documentation system, business establishment, and related goals are specified. Operational step forms the basis to achieve the end goal of network planning. It is important the basis should be supporting the evolution of network infrastructure to achieve the main goal of the network.

It is recommended that the planning should be done with an integrated fashion, considering the long term demand and goal of the network and achieving it step by step with a cost and performance efficient manner. The division of planning sometime confuses and may lead planner to think that these steps are practiced as stair model where each step has to be planed in the sequential manner. But, in fact the aim is here to do the planning such an integrated way the overall cost of network could be reduced by achieving the strategic goals at each level, and also enhance the overall performance.

To make this concept clearer, we explain this by giving an example. For instance, the main goal is set to build an IT infrastructure for a particular area. The goal is to provide the broadband access reaching across very individual of the society, broadband for all. The goal yields a very comprehensive meaning and not clearly defined with detail. A planning task at this level would be, first of all, specifying clearly and describe the main goal with more detail. The questions like what would be the main network technology used for the network infrastructure. Would it be the wired or wireless? Should it be a fiber optic based or cooper, or even a hybrid one? Which technology is more future-proof. These details go further. The point is to get

the detail of main goal as much as possible, and relate it with the technological evolution and user demands for network services. A good idea would be to make a requirement analysis, which can identify which technologies can help to fulfill the demands. These tasks will help to define the strategic goals.

When the main goal is specified with its detail, the next step is to look at how it should be achieved. A good idea is here to start planning with the end goal. End goal meaning that make a full plan fulfilling the requirements of main goals. However, it is very difficult and complex to plan for long term if the time scale is more than 5 years. The uncertainly level would be very high especially for the active equipment. Since passive equipment have a long life cycle they can be considered first, which as mentioned the fiber optic and ducts etc. A full structure is planned. This is also called the trace level planning. The nodes and line locations are identified. Since fiber optic cable and mast for wireless antenna have very long life ~30 to 40 years the planning for the physical structure is conducted.

Going further down to lower levels, the tactical and operational level planning is conducted. These levels of planning have much more detail than the strategic level of planning. In this level the active equipment are considered. The switching level of planning is conducted. Traffic estimation and forecasting are conducted with greater detail as well. The strategic goals and steps are defined with more detail compare to strategic level planning. These two levels have much more detail and could the most time consuming task of network planning. It also depends what is goal of planning. As here planning is done for the decision making it is carried out with less technical detail. More the detailed planning done more the decision would be precise.

## **Collecting General Information**

Before the network structure is planned, it is necessary to collect necessary initial information. This information, described later, is immensely useful in the later process of planning. It should be noted that all the required information to deploy the network is not available most of the times. There are sometimes assumptions have to be made, many things are calculated by approximating. However, it is always useful to obtain maximum information which will make the planning more accurate. The most important are elaborated and discussed in the following sections:

### **Geographic location and its significance**

A detail study of geographic location, where the network is supposed to be planned, is the prerequisite of a network planning. Information about the area and what is the significance of the location compared to the other locations should be analyzed. Moreover, the information about the potential of network paths for laying ducts and placing wells are analyzed. The distribution over the geographical location of difference classes of network users is also useful.

Geographical information can be obtained and analyzed with the assistance of computer based Geographic Information System (GIS). The information in GIS can be represented both in two dimensional (2D) and three dimensional (3D), depending upon the available data. Normally 2D representation is adequate for the wired network planning but in some cases 3D is very useful too. For example, if the elevation of area is quite irregular, consisting of mountains etc., or inside the buildings etc., then the 3D GIS assists better. If the wireless is included in the network then 3D GIS is strengthened the planning in a greater extent.

## **Existing network infrastructure**

It is always found quite useful to investigate the existing network infrastructure. The information such as what is the service level of existing infrastructure, What is the coverage of existing infrastructure, which technologies are being used, What are their future plans, and similar others. The information of existing infrastructure can be useful in many ways: it maybe possible to use the existing infrastructure with new infrastructure, the services offered by the existing infrastructure, and impact of the replacing or including the new infrastructure, competition level, and other related.

## **Regulation issues**

To avoid the later complications of regulations issues it is recommended they are confronted in the early stage. Regulations have a great impact to realize the network and also the economical impacts. The examples of regulations issues are infrastructure ownership, digging and placing the antenna, radio frequency, etc. The regulation issues should be given special attentions. As wrong assumption leads to wrong results, if, for instance, a certain level of radio frequency is not allowed in the region the planning based on such technology would be wasted, therefore it is very important to get the necessary regulatory information in order to avoid the later complications.

## **Population and related statistics**

The main target to build a network infrastructure is the inhabitant of the society itself. It is recommended to collect various information about population. Different of statistics which can be used in planning are listed below:

- Total population
- Urban and rural population
- Age groups
- Population growth
- Male and female population ratio
- Literacy rate

- Unemployment rate
- Others related

The use of these statistics can have many dimensions. They are helpful to understand the requirements of building an infrastructure affected by the population trends. To know the total population is certainly interested and required, it will let planner know the number of the potential users of network. It is also useful to get the statistics of urban and rural population. The general trend is the urban population is given more priority than the rural population. This leads to a digital divide. Generally speaking, rural population should also have an equal opportunity to access the communication infrastructure. A good strategy is to give an equal attention. This can be achieved by a long term strategy where gradually all the member of society participate.

Different age groups have different interests and that also leads different ways of the network use. Therefore, by getting the information of different age groups can help to understand better the use of network.

The growth of population cases by different reasons. In general population growth is measured by birth rate. But, this is not only the reason. There are other population growth factors like moving in and moving out to other areas. If the industry is growing the rate of population growth is increased.

Other statistics like male and female population ratio, literacy rate, unemployment all reflect some how the use of network infrastructure. This kind of information is not mandatory but help for the effectiveness of planning.

## **User groups**

The user of network infrastructure can be divided into different groups. The division or grouping helps to identify their QoS and also other related demands like redundancy. Some of the most used grouping is listed below:

- Households
- Businesses
- Public Institutions

The households are usually the largest group in infrastructure. Business and public institutions are also having quite a big proportion and demanding higher availability of network. There can be made further sub-grouping, like in Business; important business and ordinary business can be sub-grouped.

## **Network services and application**

The buildup of every network is to offer certain kinds of services and applications. In early days of networks were planned to offer just a single service, for telephony a

separate network, for TV a cable TV network and list goes on. The emergence of data networks the services and applications offered by a network became numerous. Today networks can be built for multi purpose services and supporting variety applications. Today fiber optic based network are capable to offer all the services on a single network.

A detail analysis must be performed on the services and applications which the network will be offering. In addition, it should be investigated that what would be the potential services and applications in future. The most expected broadband applications are discussed in Chapter 7.

## **Bandwidth demand and traffic forecasting**

Different applications have different bandwidth demands. As it is important to know what applications will be used, it is also important to evaluate the bandwidth demands applications. Over the two decades it has been apparently observed that an increase in computer performance has been leading to new applications and also increasing the bandwidth demands. The traffic in backbone network is increasing exponentially causing by the use of higher bandwidth demanding applications.

Different group of network users have different bandwidth demand. For instance, business had been requiring higher bandwidths than rest of the user groups. However, the situation is changing at user side because of multimedia applications i.e. video on demand, file downloading etc. But, on other hand there are certain businesses which demand very high bandwidth due to the nature of applications being used. Therefore, a differential bandwidth demand has to be estimated.

In a future proof network the most important element is forecasting the bandwidth demand. The forecasting is to estimate the bandwidth demand in future. According to the past experience bandwidth in network does not a static behavior, it has been experienced increasing over the time. However, it is difficult to get a precise overview how the traffic will grow in coming years. A lot of research is done on the traffic growth. For instance, K.G. Coffman and A.M. Odlyzko [4] estimated the traffic from 2000 and in the following ten years. They predicted that traffic will be double every year. It is however suggested from [5] that this trend at a certain time will decrease and the needed bandwidth for an ordinary user will be stabilized around 100Mbs. This is due to the fact that the development of new services will start decreasing.

Traffic or bandwidth demand estimation and forecasting are important elements in network planning. Networks are usually expensive to deploy and equipment are relatively quite expensive. If the network is dimensioned on the contemporary traffic demand then it would not be able to handle the future's increasing traffic demand and end up with replacing equipment. On the other hand if network is dimensioned too optimistically then it would be quite expensive too. Therefore, it is important to find a compromise.



Different method can be employed to forecast and estimate the traffic in network. Some of the most used are explained in Chapter 5.

## **Network Technologies and Trends**

This is all the technological advances which made it possible to indulge the human desire of such an advance communication available today. In the early days of communication networks there was not much or almost no choice of other alternative technologies. Today, the communication technology is so versatile that to achieve one goal there exist several choices. However, each option has its own advantages and disadvantages. We can divide network technologies into two main domains, they are listed as:

- Wired technologies
- Wireless technologies

Both are generally discussed earlier in the report. A comprehensive description of these technologies can be found in Chapter 6.

Apart from the specification, it is also important to evaluate the future trend of a certain technology. A proper evaluation of a technology trend will give a comprehensive overview of the future of network infrastructure.

## **Network Structure Planning**

Network structure planning corresponds to the physical level of network structure planning. In this level node and line locations are explored. Different modeling techniques are used, described in Chapter 4, in order to obtain the network structure. In the network structure planning sections the guidelines/methods will be provided. The guidelines will outset with data preparation in order to benefit the computer added tools. The approach will not only automate the planning process but it would be possible to establish different scenarios which will lead the decision space bigger.

### **Data Preparation**

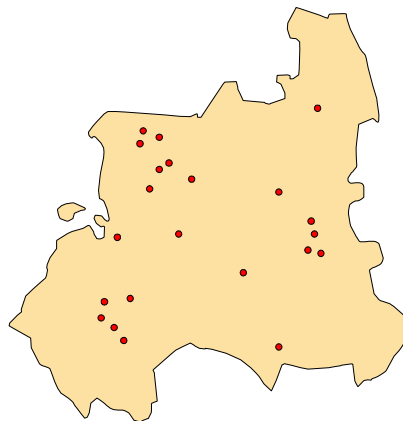
To support and make the planning process robust, GIS can be employed. GIS is a computer based system which is used to capture, retrieve, process, represent, and analyze both spatial and non spatial data of maps. Spatial data includes the points, lines and polygons etc., whereas non spatial data consist of textual information. This information can be stored in separate databases and can be accessible by the GIS tool. There are two major methods of representing maps, raster maps and vector maps. Raster maps consist of bitmap form, and vector maps consist of points, lines and polygons. Vector maps are more useful for supporting various calculations for planning. There are several GIS tools available, the description of some of them can be found in Chapter 5.

Several tables created to support the GIS data and also for the other planning tasks. Basically, two tables are required in the start: one containing the information about segments and second containing the information about segment points. However, these tables present only the potential of the network. Those tables usually called the road tables, containing most of the road map information in digital form. But, there are other potential of the network can be included as well, such as rail roads, footpaths and cycle paths etc. These tables are usually processed many times before they are able to use for the further network planning. The detail description and methods how these tables are created, their attributes and description can be found in Chapter 4.

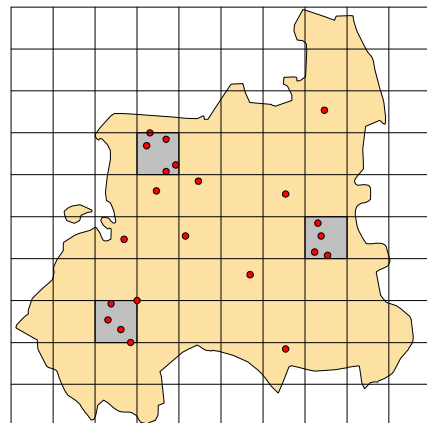
## Node Locations

The node location in access networks is not a problem - buildings, houses etc. can represent the node locations. However, it is a fundamental problem in the transmission network. There is no fully automatic solution available, which can find an optimal location. With experience, guidelines and together with systematic approaches a nearly optimal solution can be obtained.

One of the systematic approaches is described here first. As mentioned earlier that end users or Network Terminations (NTs) locations represents node locations in access network. These locations can be a base to decide the node locations. A solution is to make a grid on the location and then count the number of NTs within it. The grids containing the highest distribution of NTs can be a potential of node location. Figure 4.a shows the locations of NTs on the map and Figure no. b shows the map with grid. The grids for potential locations are highlighted. However, still we can not be certain about the location within the grid, but at least this gives a first approximation.



(a)



(b)

*Figure 4: Using grid to decide node location.*

To find the optimal location only guidelines can be provided. A compromise is made in most cases. Theoretically a best location is that where the distance to connected NTs is least. But, in practice the compromised is made on the location cost, reusing the existing infrastructure, and electric power availability.

### **Number of Main Nodes**

After finding the potential locations of node, the problem is to know the number of main nodes. In order to decide it a detailed analysis is required. Too many nodes and too few nodes can both impact greatly on cost and performance of network. Another issue is the contemporary distance limit of Passive Optical Network (PON) in access network. It is recommended that a distance between NT and main node should not exceed 10 km. Within 10 km of distance optical signal can be transported without any electrical equipment and expensive fiber. However 10 km is not a hard limit of PON. This will be improving over the time; latest developments and future trend should be investigated while planning.

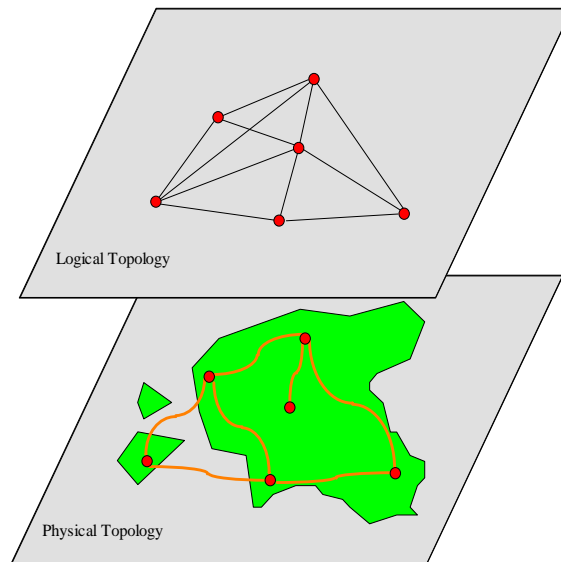
The amount of NTs per main node is also analyzed. Too many NTs can cause a difficulty to dimension the capacity of node. Moreover, fiber per cable also increases in case of low number of nodes. Besides that, the increment of number of nodes can cause the average hop distance to other NT, which decreases the performance. The issues which are important to consider while deciding the number of nodes are listed below.

- Limitation of fiber length in PON
- Total distance of fiber length and digging
- Node and line Redundancy
- Amount of fiber in duct
- Cost of nodes
- Amount of NTs per node
- Capacity of node
- Hop distance

### **Network Structure**

The planning of Network structures concerns how the nodes should be interconnected. A common terminology for network structure is network topology. Network structure or topology can be classified into two main categories: physical and logical. Figure 5 is a representation of physical and logical topologies in different

layers. On a single physical line several logical connection can be establish. Therefore, the physical structure of network should be given importance in term of reliability and performance. Here, the primary focus will be the physical structure of network.



*Figure 5: A representation of physical and logical topologies shown in different layers*

Network structure affects network performance in many ways. The most common performance parameters are explained here.

### **Connectivity**

Connectivity is considered most important while a planning network structures. In the physical structure, roads, power-lines, railway tracts all provide a mean of connectivity. Generally, the connectivity of a physical structure is established within the structural demand and the traces for connections.

### **Redundancy**

Redundancy in structure means to provision an alternative connection or path from one node to other node. The redundancy enhances reliability in network.

### **Reliability**

Reliability ensures network that in case of failure network is still operational without loosing the defined performance. The reliability in network is very much dependent on physical connectivity and redundancy in network. If the physical connection is lost, and there is not redundancy available then up on that all logical connections are lost, and can not be restored unless physical connection is establish.

## Cost

Cost plays a major role in the planning of physical structure. It is obviously nice to have maximum connectivity and redundancy which makes the network more reliable, but to obtain it apparently expensive. The physical structure of network is often most expensive element in network infrastructure. But, on the other hand, it has a very long life span. However, the planning task is to obtain an optimal structure with the limited economy.

## Access Network Structure

Traditionally, the access networks are provided without any redundancy and special protection. With the advent of new applications and the importance of reliable communication this scenario is changing. Starting from homes, we typically have a single connectivity, where the applications like security alarms (e.g., fire and burglar alarms), remote medical care, and home e-office are demanding high reliability. This is even more critical for the business sector, and the public institutions. Some of the businesses are even totally relying on networks, known as e-commerce, and the consequences of failure could be huge. Since, the physical structure of network is planned for longer term the reliability in case of line or node failure should be paid some attention.

The structure of Access network has mostly based tree topology. In tree topology there is only single connectivity offered. But this is not the requirement of access network. The tree topology is offered because of least cost. But, the disadvantage of tree topology is no redundancy and therefore in case of line or node failure no restoration is provided. The access network is not limited to tree topology or a providing a single connectivity.

If the size of Access network grows larger then another network structure can be included, called as ***Distribution Network***. The distribution network can be thought as a mini Metro Network.

To obtain the access network structure using an automatic scheme we can employ a modified spanning tree algorithm, explained in Chapter 5, which finds the shortest path between main nodes and NTs, and along that some planning heuristics. As it is described earlier the potential paths, roads, rail track etc., are processed as small segments while preparing GIS data. The structure of access network usually contains quite a big size, more number of nodes and lines compare to higher hierarchies of networks. Manual techniques of access network planning require significant time. Automated planning is most demanding at this stage.

Wells in networks are holes in the ground consisting 1 to 4 meters deep, depending on the circumstances and the amount of cables passing through, an equipment to be placed. The used of wells in networks infrastructure has various purposes. Wells can be used to place the equipment; the equipment can be both passive and active. The use of equipment depending upon the architecture decided to use. Wells, also can act as nodes in the network, when they are containing equipment. There is special protection should be provided for the well containing equipment.

### **Including broadband wireless**

In recent years wireless technology has embraced with many advances and becoming a complimentary part of wired infrastructure. Wireless has advantages of providing mobility for network access. Other advantages of wireless technology are it is easy to deploy, no need for time consuming digging, large coverage area, could be a cheaper solution etc. Since Access network is lacking the redundancy because of higher cost, the wireless connectivity can be used for the redundancy. In case of wired link failure the wireless can be a temporary substitute. Today various broadband technologies are available. Some of the most interesting broadband technologies are discussed in Chapter 6. Despite the advantages there are disadvantage too; it does not provide enough bandwidth compare to broadband wired technologies. The bandwidth limitation of wireless technologies is foreseen and it is therefore not considered the future proof technology. The limitation of wireless technology gives a stronger argument not to adapt it as a main access technology for the infrastructure. Wired and wireless technologies both complete the picture of broadband infrastructure by providing mobility and redundancy. The combination of wired and wireless technology gives a concept of *combined wired and wireless infrastructure*.

As the cost of infrastructure is usually very high and the deployment of wired technology is also very a slow process due to its deployment nature, the broadband wireless can be a strategic part of the deployment of the infrastructure, keeping the cost low and giving the access most of the part of infrastructure. This can be done by giving the wired access to most prioritized places and wireless access to remote rural places where the network access priority is usually. The gradual deployment of wired technologies reaching to every part of infrastructure and then adapting the wireless technology for the redundancy will complete the picture of infrastructure.

### **Metro Network Design**

Metro Networks are the next tier in the three layer approach of classifying the network. Metro network is distinguished from the access area by its size. Typical metropolitan area regional networks are 50–300 km in total transmission length. Most deployed metro networks are ring-based topologies because of their migration from Synchronous Digital Hierarchy (SDH) rings. There is no automated planning scheme available. Some systematic approaches are used. We have discussed earlier how the number of nodes and their location can be found. When the nodes are decided the problem is how they should be connected by links. The simplest form of structure in metro networks is ring, which provides redundancy. But not always ring structure is an optimal choice. The discussion about different structure is presented in Chapter 8.

### **Long Haul Designs**

The final tier in the layer classification of the network is long haul network. Traditionally Long hauls networks were the first fiber optic networks on account of that that fact that signal can go far long distance with very few errors compare to the old cooper based networks. The long haul networks are usually regional and international level networks. The design of long haul network is out the scope of this

report. However, it is important to know how the connectivity will be provided with metro networks to long haul networks.

## Economics

- Prices issues

Digging Prices

Laying Fiber

Pipe prices

Fiber prices

Blowing Fiber

Housing

Equipments

Switching Equipment

Splitters and Wells

- Budget Estimation

# 4. Network Modeling

## Network modeling introduction

In chapter 2 a short introduction to network modeling is presented. In this chapter networking modeling will be looked into further detail with connection to the last chapter Infrastructure Planning. The key to network modeling is the ability to closely match the generated network model and map it to the real network. In a network model all the elements of the real network can be represented at an abstract level. The modeling is usually done by mathematical models and simulated with the help of computer-aided tools.

In modern network planning Network Modeling is playing a more and more important role. Some of the reasons are:

- **Fast introduction of new technologies** mostly comes with enhanced performance and functionalities. Sometimes, it may be found several technologies to solve one kind of problem. This puts the planner in a difficult situation for the selection of the technology. One way is the planner takes the benefit of his/her past experience of the technology, and on the basis of that makes the decision. Conversely, if he/she does not have experience or enough knowledge, particularly in case of totally new technology, then the modeling approach is very helpful. The network is modeled and simulated in order to analyze if the technology is appropriate for the targeted network.
- **Fast introduction of new services** is a challenging part to network service providers. Where the introduction of new services helps network owners making more revenue, there it is also not always possible to provision the new services with the available network. If the network is designed considering the available services, it would be difficult to provision the new services, and need the upgrade in network. The often upgrades would lead to the network lowering the profit. Furthermore, it is also important to analyze if the available network can provision the services before its actual provision on the network. Modeling is therefore often used to see the consequences on network with testing new services.
- **Short reaction time** in competition on new market segments. After the liberalization of telecommunication, the competition became a key issue to make profit and even survive in the market. The decision time is usually very short to extend the business for new market segments.
- **Exponential growth in capacity demand** is observed in the network for many years. The capacity growth leads to the upgrade of network equipment. Network is planned usually considering this fact. However, both over dimensioned and under dimensioned networks are not the optimal choices.



Different network modeling techniques are used to dimension the network according to the growth of capacity demand.

- **Increased complexity** caused by network integration tends to use different modeling techniques to overcome the complexity problem. An example is the network layering model. Network is divided into different layers which helps to understand, deployment and manage the network.

Long term field trials are not appropriate in the very competitive market and with decreasing life-time periods for new technologies. As mentioned earlier that the life time of network technology is usually short. It should not be confused with expiring the equipment due to faults etc. It is mainly due to the introduction of new technologies. Network modeling helps to make the decision for the selection of technology by avoiding the field trials of it.

## Modeling Platform for Network Planning

Network modeling itself is not a single task. Networking modeling is usually done with the combination of different sub modeling elements of network. The network integration and interworking makes it mandatory to establish a modeling platform for handling a multitude of tools and data. In Figure 6 the modeling platform for the infrastructure planning is represented. Relationships between the sub-modeling element is shown. These elements are explained in the following subsections.

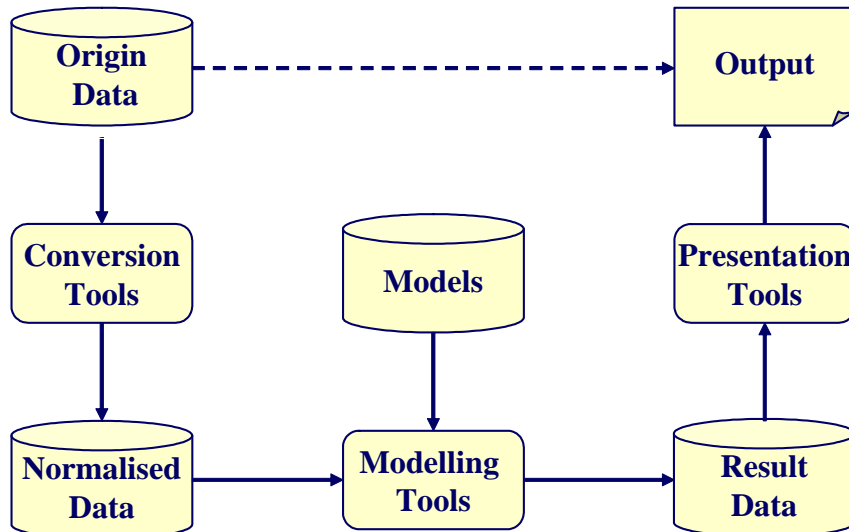


Figure 6: Modeling platform for network planning.

## Origin Data

The available data as base for the modeling process (Origin Data) will often come from various sources in many different formats.

- The types of data can be prognoses or factual information:
- Customer base (Size, geographical distribution, ...)
- Traffic and capacity demand (Volume, Tariffs, ...)
- Equipment evolution (price, performance, ...)
- Existing Network parameters (structure, topology, configuration, ...)

Part of the modeling work can be a complementary research for data in order to establish the necessary base.

## Conversion Tools

As the Origin Data can come from various sources in many different formats it will be necessary to adapt a set of Conversion Tools to the modeling platform to generate a common Database with Normalized Data in order to facilitate the modeling process.

An important part of the conversion process is to keep track of the relations between the Origin Data and the Normalized Data in order to maintain the possibility of back-tracking in the modeling process and to validate the input data. Some of the origin data may be periodically generated data or data representing the same information from different sources imposing an additional set of release and version identification. Similar the same set of data may occur as both a prognoses, a actual measured set or as a later revision of the same set.

A well structured and consistent database of Normalized Data is the key issue.

## Models and Modeling Tools

A variety of relevant Modeling Tools are available, some general purpose some specialized towards specific applications or problem areas. Many tools provide an associated application oriented program and model libraries.

Most tools are purely technical but the techno-economical modeling tools plays an increasing role as part of general decision support tool systems. There are literally no commercial available platforms combining the various tools in order to provide a total modeling system for the complex multi-layer network types.

Tools with associated scenario handling play an important role in this context.

The formulation and validation of the models are the key issues in the process of selecting and applying the appropriate modeling tools.

A general group of Modeling Tools deals with Mathematical Programming and covers optimization model types which can be formulated as:

- Linear programming problems
- Mixed integer programming problems
- Quadratic programming problems
- General non-linear programming problems

## **Result Data**

The Result Data contains the results of a modeling process including the relevant linkage information back to the normalized data as well as the involved model(s) and parameters.

Experience shows, that the lifetime of the results in a modeling process on a specific network problem often is relative short, as data changes rapidly, but may be needed at a later stage for documentation purposes.

A key problem is the housekeeping of the often very large amount of data generated in the modeling process. Some tools are associated scenario management, but for modeling in complex systems involving a set of tools this problem have to be solved outside the individual tools applying e.g. database systems.

## **Presentation Tools and Presentation Data**

In the total modeling process, the post-processing and presentation of the results requires special attention, as the potential audiences often are non-specialists.

In global networking the presentation tools apart from reports including more ordinary graphs and summarizing pictures need linkage with Geographical Information Systems (GIS).

GIS systems may also be needed in the creation of input data in order to generate information on distances, area coverage, and topographical bindings etc. as parameters to the modeling process.

## **Network Modeling**

To be able to input data in the described modeling platform data definition are required. It is necessary to describe network architecture for the modeling part of modeling platform. Definitions of all the network elements are required too. In later sections we will give an modeling example of network architecture. We will also

give some examples of establishing definition of network components. We will give some examples of input data. How the data can be transformed to more useful data will be explained.

## Network Architecture

Communication networks can be modeled mathematically as a graph  $G$  consisting of a finite set of pairs  $G = (V, E)$  where  $V \neq \emptyset$  and a set  $E$  of two-element subsets of  $V$ . The elements  $V$  are called Vertices. An element  $e = \{a, b\}$  of  $E$  is called an edge with end vertices  $a$  and  $b$ . Any network can be composed with the set of vertices and edges. The terms vertex is synonym to node and edge is to lines or links. The terms vertex and edge mostly used in the graph theory. But in the normal network planning language we use nodes and lines. We can define the network architecture using these basic tools.

We already have mentioned about the hierarchical division of network in Chapter 2, where the network is divided into different levels. In order to make the planning model more effective to use we will also keep the hierarchical division.

The network architecture for infrastructure planning is defined as:

- Backbone Network is called the highest level of hierarchy. The nodes correspond to this hierarchy called Main Nodes (MN). The lines are called as backbone lines.
- Distribution Network is an extension of backbone network. It extends the backbone network. The capacity of and span of distribution network is usually short. The nodes of distribution network are called Distribution Node (DN).
- Access Network The last mile network, explained in detail in chapter 2, consists of end users of networks. The nodes of Access network are represented as Network Termination (NT).

The architecture model is illustrated in Figure 7. Each Network class is represented with different color.

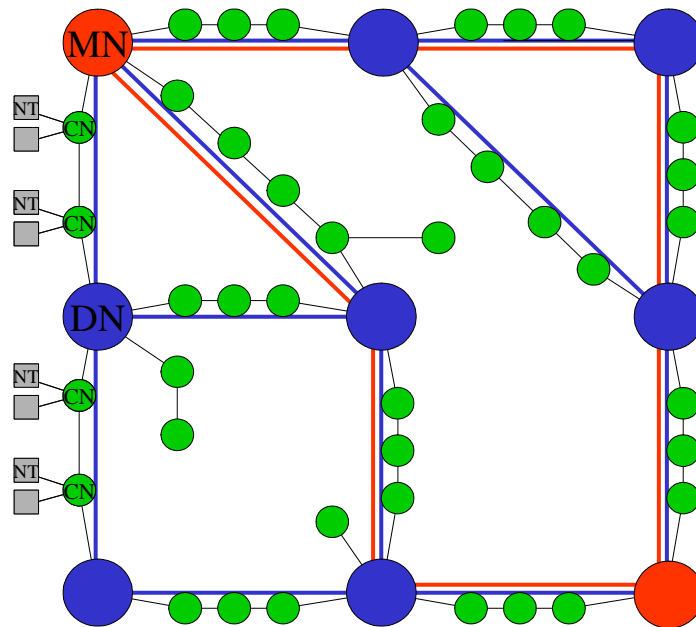


Figure 7: Network Architecture.

## Network Components Definitions

Here are some examples how the network components are defined.

### Nodes:

NT: Network Termination point (end user)

CN: Connections Node

DN: Distribution Node

MN: Main Node

### Lines:

NT - CN: max 800 - 1000 m

NT - MN: max 10.000 m

guideline: independent paths to 2 MN

CN - CN: max 1000 m

CN - DN: guideline: independent paths to 2 DN

DN - DN:

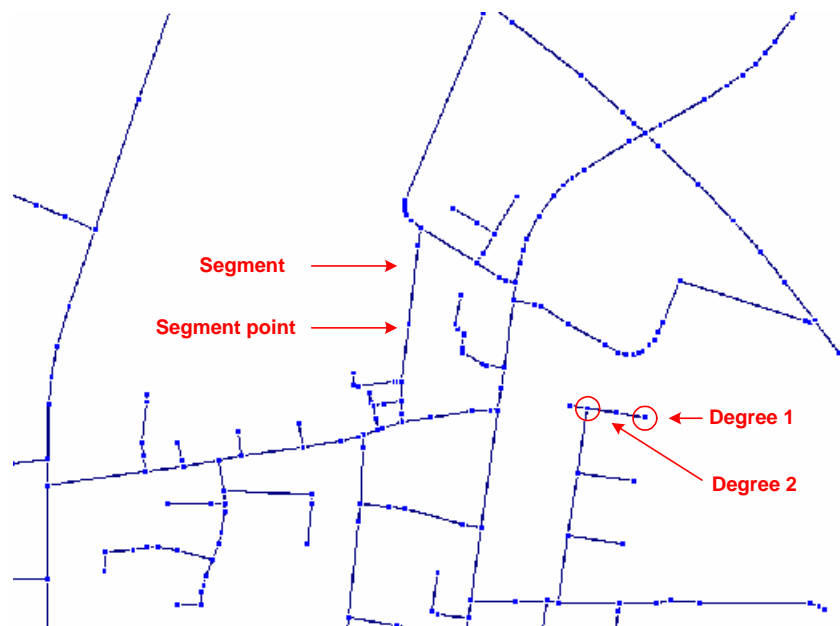
DN - MN: guideline: independent paths to 2 MN

MN - MN: guideline: min. 2 independent paths

## Digital Road Network

One type of digital road map describes the middle of the road as a set of interconnected line segments, associated a set of attributes like:

- Road number
- Municipality id
- Address guideline information



## Segment Table

The Segment table <S>:

obj\_type text <ref\_S>

S\_id integer segment id

R\_id integer road id  
S\_nr integer segment number counted from first Road Point RP1  
deg1 integer number of segments connected at SP1  
deg2 integer number of segments connected at SP2  
direction integer 0 = unknown; 1 = forward; 2 = backward  
level integer 0 = unknown; 1 = original level; >1 = level in reduction hierarchy  
length integer segment length in meter  
SP\_id1 integer Segment endpoint id for first endpoint SP1  
SP\_id2 integer Segment endpoint id for second endpoint SP2  
x1 integer x-coordinate for first endpoint SP1  
y1 integer y-coordinate for first endpoint SP1  
x2 integer x-coordinate for second endpoint SP2  
y2 integer y-coordinate for second endpoint SP2  
mun\_id \*) integer municipality id  
road\_id \*) integer road id, unique inside municipality  
\*) optional

### **Segment point table**

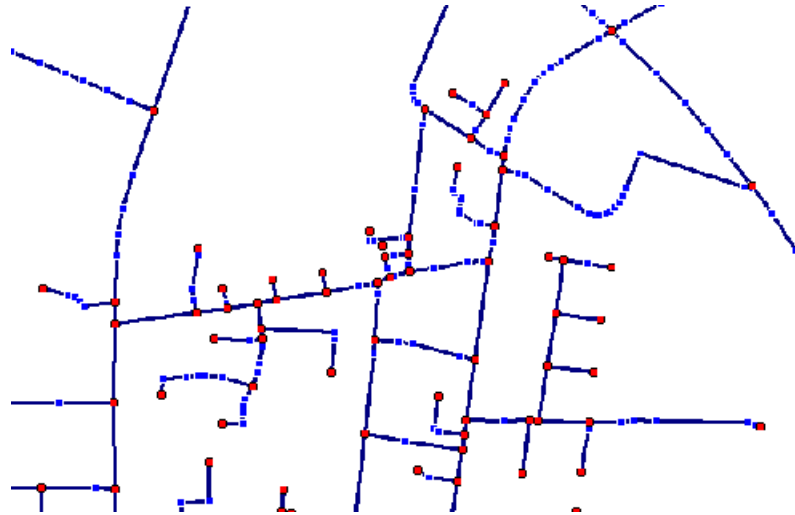
The Segment Point table <SP>:

obj\_type text <ref\_SP>  
SP\_id integer segment endpoint id  
x integer x-coordinate  
y integer y-coordinate  
deg integer number of segments connected at the SP  
level integer 0 = unknown; 1 = original level; >1 = level in reduction hierarchy  
mun\_id \*) integer municipality id

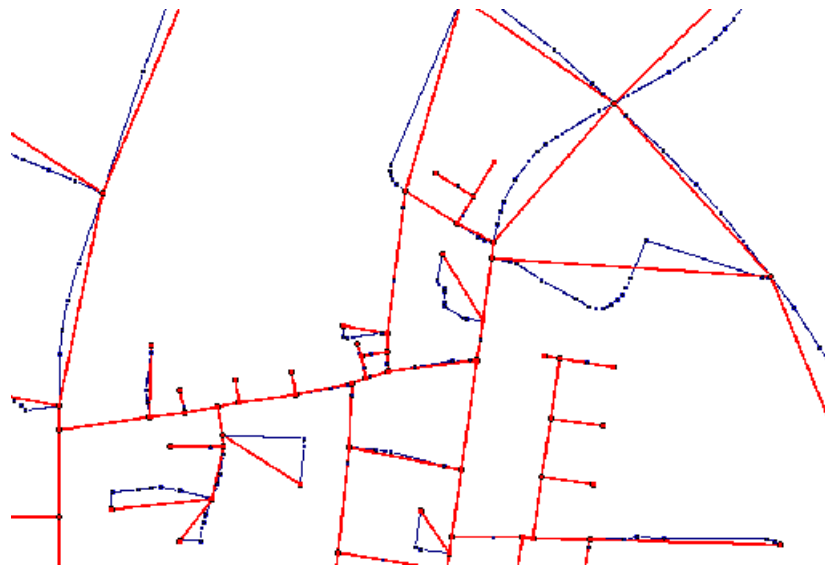
\*) optional

### **Simplifying the digital road network**

To simplify the analysis of the trace network generated by the segments, a new simplified representation, can be generated on the base of the S-table only including endpoints with degree 1 or degree  $> 2$ .

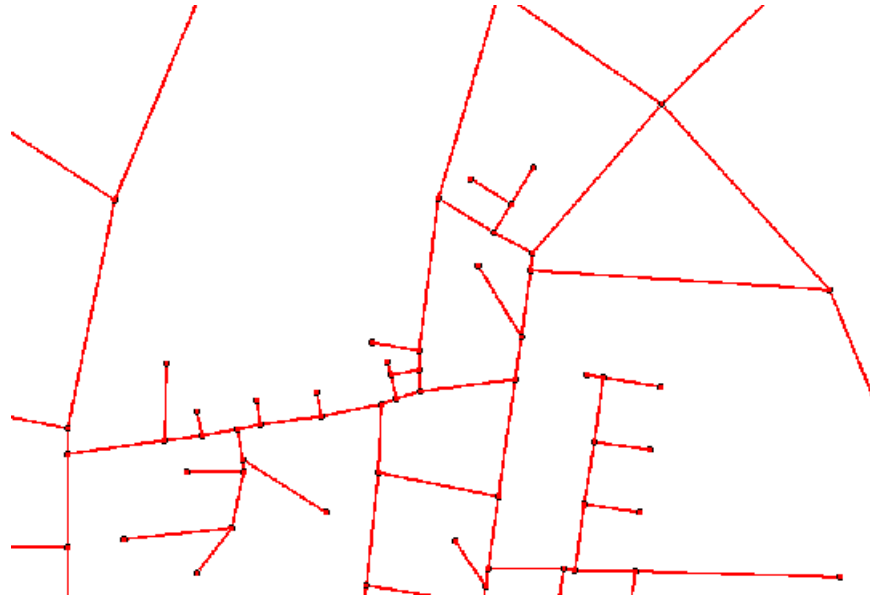


To simplify the analysis of the trace network generated by the segments, a new simplified representation, can be generated on the base of the S-table only including endpoints with degree 1 or degree  $> 2$ .





To simplify the analysis of the trace network generated by the segments, a new simplified representation, can be generated on the base of the S-table only including endpoints with degree 1 or degree > 2.



### The Road Table

The Road table <R>:

obj\_type text <ref\_R>

S\_id integer segment id of last segment on the road

R\_id integer segment id of first segment on the road

S\_nr integer number of segments

deg1 integer number of segments connected at RP1

deg2 integer number of segments connected at RP2

direction integer 0: unknown; 1: forward; 2: backward

level integer 0: unknown; 1: original level; >1 level in reduction hierarchy

length integer segment length in meter

RP\_id1 integer Road endpoint id for first endpoint RP1

RP\_id2 integer Road endpoint id for second endpoint RP2

x1 integer x-coordinate for first endpoint RP1

y1 integer y-coordinate for first endpoint RP1

x2 integer x-coordinate for second endpoint RP2

y2 integer y-coordinate for second endpoint RP2

### **The Road Point Table**

The Road Point table <RP>:

obj\_type text <ref\_RP>

RP\_id integer road endpoint id

x integer x-coordinate

y integer y-coordinate

deg integer number of segments connected at SP1

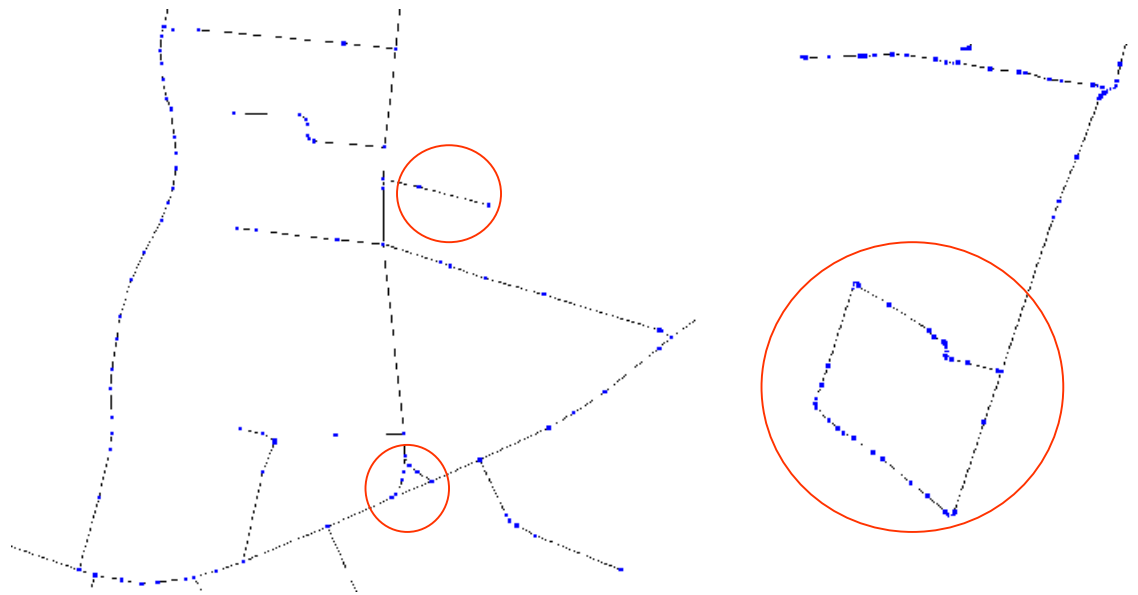
level integer 0 = unknown; 1 = original level; >1 = level in reduction hierarchy

mun\_id \*) integer municipality id

\*) optional

### **Further reduction and manipulation**

In order to transform the digital road map into a viable platform for the trace level a set of reductions can be considered.



In order to transform the digital road map into a viable platform for the trace level a set of amendments can be considered, based on additional information on potential areas to place the trace, like railroads, paths in the field etc.

# 5. Planning Tools and Algorithms

## Software application/tools for Network Planning

There are various networks planning software applications/tools exist. However, there other non specific network planning tools are used too. In this section we will described and discuss different tools which can be used for the network planning.

### GIS tools

#### Mapinfo

MapInfo is one of the leading GIS solutions, it lets perform sophisticated and detailed data analysis. The use MapInfo can be:

- Create highly detailed maps to enhance presentations and aid in decision making
- Reveal patterns and trends in the data
- Perform sophisticated and extensive data analysis
- Manage geographically based assets, such as people and property
- Detailed Plan logistics etc

Mapinfo is relatively simple to use, powerful and easily integrates with other mapping applications. The latest release is: MapInfo Professional v7.8. More information can be obtained from the following Mapinfo official website:

<http://www.mapinfo.com>

#### ESRI

ESRI is the GIS industry leader. The group of ESRI tools known as ArcGIS. ArcGIS tools further can be divided for three platforms: Desktop, Server, and Mobile. For the network planning the Desktop ArcGIS is most interested.

ArcGIS Desktop is a collection of software products that runs on standard desktop computers. It is used to create, import, edit, query, map, analyze, and publish geographic information. There are four products in the ArcGIS Desktop collection; each adds a higher level of functionality.

- **ArcReader** is a free viewer for maps authored using the other ArcGIS Desktop products. It can view and print all maps and data types. It also has some simple tools to explore and query maps.

- **ArcView** provides extensive mapping, data use, and analysis along with simple editing and geoprocessing capabilities.
- **ArcEditor** includes advanced editing for shapefiles and geodatabases in addition to the full functionality of ArcView.
- **ArcInfo** is the full function, flagship GIS desktop. It extends the functionality of both ArcView and ArcEditor with advanced geoprocessing. It also includes the legacy applications for ArcInfo Workstation.

All ArcGIS Desktop products share a common architecture, so users working with any of these GIS desktops can share their work with others. Maps, data, symbology, map layers, geoprocessing models, custom tools and interfaces, reports, metadata, and so on, can be accessed interchangeably. In addition, maps, data, and metadata created with ArcGIS Desktop can be shared with many users through the use of custom ArcGIS Engine applications and advanced GIS Web services using ArcIMS and ArcGIS Server. Further detail information can be found from the official ESRI website link:

<http://www.esri.com>

## **IDRISI**

IDRISI also provides quite extensive set of GIS and Image Processing tools in a single and affordable integrated package. Backed by a dedicated university-based research program, IDRISI provides research-grade tools that are at the forefront of the industry, yet are approachable and accessible to all. The latest version of IDRISI is known as IDRISI Kilimanjaro, the 32-bit version designed for Windows NT and above, now in its third release. With over 200 modules, IDRISI Kilimanjaro provides an unsurpassed depth of capability. Here are some of the major features of the system:

- Display and Map composition
- Database and Query functionality
- GIS modeling
- Distance and Spatial Context Operation
- Decision Support
- Image Analysis
- Statistics
- Surface Modeling and Geostatistics

The detail information of available packages are available on the following IDRISI website:

<http://www.clarklab.org>

### **Manifold**

Manifold System is quite powerful and the easiest to use GIS and mapping system. Manifold System is an integrated system that simultaneously works with vector drawings, satellite and aerial photos, other raster images, raster data, multichannel remote sensing images, 2D and 3D surfaces and terrain simulations, multilayered maps, user supplied or automatically generated labels and a vast range of database table formats. Manifold can do it all in one seamlessly integrated, high performance package. Manifold includes a sophisticated, fast, powerful Internet map server that's built right into Manifold so it could be possible to publish maps to the web for browsing by anyone.

More information about the product can be obtained from the following website:

<http://www.manifold.net>

### **InterGraph GeoMedia**

Providing the data integration, GeoMedia enables to bring data from disparate databases into a single GIS environment for viewing, analysis, and presentation. No translation of data is usually required. It avoids problems with redundant and out-of-date data because everyone is getting their information from the source. GeoMedia's data server technology supports open standards, providing direct access to all major geospatial/CAD data formats and to industry-standard relational databases.

GeoMedia provides a full suite of powerful analysis tools, including attribute and spatial query, buffer zones, spatial overlays, and thematics. With its data server technology, you can easily apply your analysis across multiple geospatial formats. And GeoMedia is uniquely suited to perform what-if analysis because it enables you to string together multiple operations in an analysis pipeline. Changing any of the data along the pipeline automatically updates the results.

For many applications, the ultimate goal is a map presentation. GeoMedia's layout composition tools give you the flexibility to design maps to meet your organization's unique needs. Using easy-to-use, standard tools, it can help to create aesthetically pleasing maps with quick turnaround time when necessary, or focus on high-quality cartographic output. Whether you want to distribute on the Web, with printed copies, or by simple file transfer, GeoMedia provides the tools which are need to share the maps.

For further information the below web link can be visited:

<http://imgs.intergraph.com/>

## **GRASS**

Geographic Resources Analysis Support System, commonly referred to as GRASS GIS, is a Geographic Information System (GIS) used for data management, image processing, graphics production, spatial modeling, and visualization of many types of data. It is **Free Software/Open Source released under GNU General Public License (GPL)**.

Grass was originally developed by the U.S. Army Construction Engineering Research Laboratories (USA-CERL, 1982-1995), a branch of the US Army Corp of Engineers, as a tool for land management and environmental planning by the military, GRASS has evolved into a powerful utility with a wide range of applications in many different areas of scientific research. GRASS is currently used in academic and commercial settings around the world, as well as many governmental agencies including NASA, NOAA, USDA, DLR, CSIRO, the National Park Service, the U.S. Census Bureau, USGS, and many environmental consulting companies.

### **GRASS Features**

GRASS (Geographic Resources Analysis Support System) is a raster/vector GIS, image processing system, and graphics production system. GRASS contains over 350 programs and tools to render maps and images on monitor and paper; manipulate raster, vector, and sites data; process multi spectral image data; and create, manage, and store spatial data. GRASS uses both an intuitive windows interface as well as command line syntax for ease of operations. GRASS can interface with commercial printers, plotters, digitizers, and databases to develop new data as well as manage existing data.

Detailed information can be found on the official website of GRASS:

<http://grass.itc.it>

## **Network modeling and Planning Tools**

### **OPNET IT Guru**

OPNET IT Guru is the industry's premier network modeling and simulation software. IT Guru allows modeling an existing or planned network and then running simulations on the base model and on scenarios involving potential design changes to the base model. Simulation can shed light on design alternatives without the cost of building several real networks. OPNET IT Guru has a module, the Application Characterization Environment, which can be used to perform analyses on application quality of service parameters.

Cost: Typical configurations range from \$50,000 to \$150,000, depending on product module configuration [28]. Pros: Very scalable, powerful, sophisticated modeling, accepts configurations directly from popular network management packages such as

HP OpenView and CiscoWorks. Cons: Steep learning curve; features are overwhelming at first; pricey.

### **Shunra**

Shunra claims their products which avoid post-deployment firefighting, prevent finger pointing, and isolate intermittent problems by exposing applications to the production network before deployment. With the Shunra Virtual Enterprise, it can be seen exactly how the enterprise networks will function, perform and scale for remote end-users, and quickly, easily and cost-effectively find and resolve problems - before rollout.

Shunra promise by their products:

- Avoid initial network deployment problems and staggered rollouts
- Validate network health when applications or infrastructure change - before rollout
- Understand the impact of network changes on applications and infrastructure
- Plan capacity and right-size the network
- Troubleshoot and replicate network-related problems quickly and easily
- Ensure problem fixes do not negatively impact the rest of the system
- Build a baseline for consistent performance comparison

The Cost: \$47,800 form [28]. Pros: Real-time simulation, excellent for modeling WAN links, uses Microsoft Visio as the user interface. Cons: Less capable for modeling enterprise networks; very long reboot time.

More information:

<http://www.shunra.com>

### **NetRule**

NetRule is a modeling environment for large networks. It's scope of use extends beyond large network designing and planning to projects such as application rollout planning on networks.

NetRule claims modelers the capability to quickly obtain latency predictions. NetRule is also an information generating tool for making decisions about network mangement and changes. The net modeler can readily simulate and predict capacity loads, user delays, and failures in anticipation of changes such as application rollouts. NetRule can be used for monitoring networks by loading traffic snapshots, but is not a real-time data collecting program.



NetRule can be used to draw networks and visualize proposed changes. NetRule can model changes in message traffic over circuits and server workload, and provide predictions, almost immediately, how the network will perform. NetRule tool calculates component utilization and latencies as well as provides reports, diagrams, graphs, and traffic animations.

NetRule can be used for exploring alternative network designs and pretesting changes in the early planning and design stage, making your management process more effective and efficient.

Cost: \$25,000 from [28]. Pros: Easy to deploy, user-friendly interface, easy to learn. Cons: Lacks some of the features and capabilities required for modeling enterprise networks; no direct import from popular management packages.

Further Information can be obtained from the following NetRule official website:

<http://www.analyticalengines.com/>

## **NS2**

NS is a discrete event simulator targeted at networking research. NS provides substantial support for simulation of TCP, routing, and multicast protocols over wired and wireless (local and satellite) networks. Ns is developed by ISI, the Information Sciences Institute at the USC school of engineering. The tool including full source code can be downloaded and it can be compiled of multiple platforms, including most popular Unix flavors and Windows.

## **QualNet**

QualNet is a modeling tool for wireless and wired network,. The QualNet suite is composed of QualNet Simulator, which claims to be the fastest for real-time traffic modeling. QualNet Animator allows to graphically design the network model (using a wide library of components) and it displays the results of simulation runs. QualNet Designer also to create Finite State Automata to describe the behavior of network, while with QualNet Analyzer and Designer can interpret and make sense of simulation results.

## **Mathematical Modeling Tools**

**CPLEX** provides mathematical programming software and services for resource optimization (linear, mixed-integer and quadratic programming solvers)

**AMPL** is a algebraic modeling language for linear, non-linear, and integer programming problems.

**MPL** (Mathematical Programming Language) is a modeling system to set up complicated models, involving thousands of constraints for developing LP models.

**GAMS** General Algebraic Modeling System for modeling linear, non-linear and mixed integer optimization problems.

## Algorithms for Network planning

In this section we will present some of the useful algorithms which can be used to automate the network planning process. The most used one is the spanning tree. Furthermore, there are other similar algorithms are also described which can be used for the various planning tasks. The main idea of describing these algorithms is to show how the network planning task can be carried out in a robust way by using the graph algorithms.

### Definition

CN: Connection Node

DN: Distribution Node

NT: Network Termination point (end user)

NT\*: Network Termination point ( end user, road access point)

MN: Main Node

LN: Leaf Node

IN: Intermediate Node

RN: Road Node

SP: Segment Point

RP: Road Point

### Spanning Tree

Spanning tree algorithm can be used to automate the decision of laying ducts and fibers and other related calculations. The basic idea behind the spanning tree algorithm is to find the shortest path from any given nodes to other nodes in the network.

### Algorithm

#### Goal

*Calculate the shortest distance from a MN to all SP (or RP)*

**Steps:**

- Mark the MN
- Mark all SP with distance “infinity”
- Establish spanning tree SPT(MN, SP) from all MN in area Step by step
- Mark MN with the distance “0” and as a leaf-node LN

**LOOP**

Find one of the LN with lowest distance and find each SP successor

Mark the selected LN as Intermediate Node IN

Mark each SP successor with:

the actual LN as predecessor

the accumulated distance,

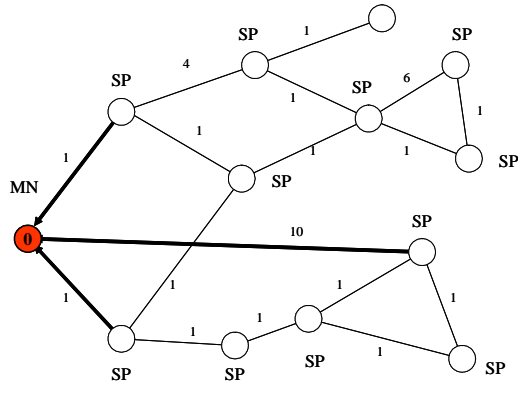
SP as a LN

Note that an IN can be re-marked as a LN

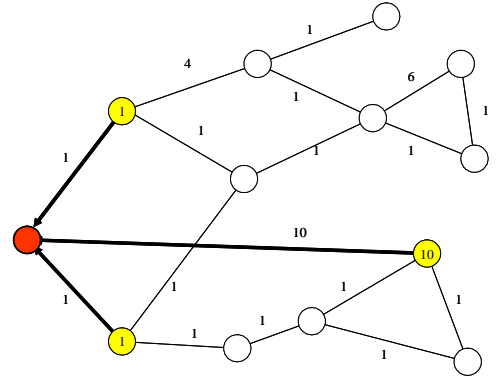
**UNTIL** {LN} is empty

**Graphical Representation**

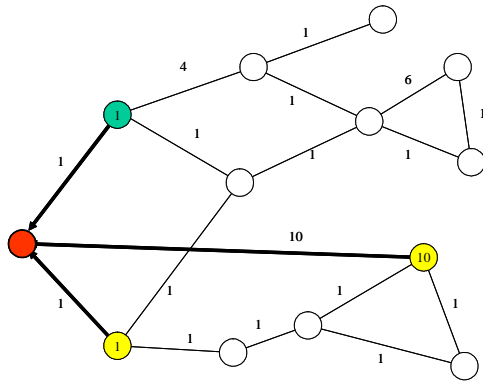
The graphical representation of spanning tree algorithm is shown in the figure. It is shown the how the algorithm establishes the spanning tree in the given network.



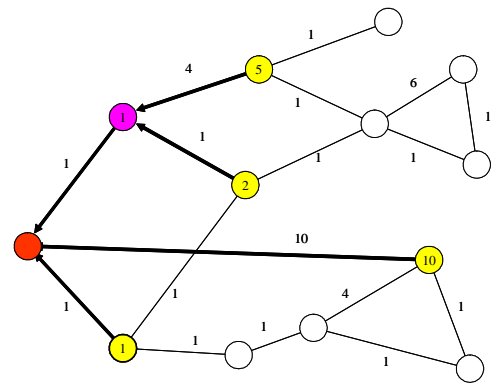
(1)



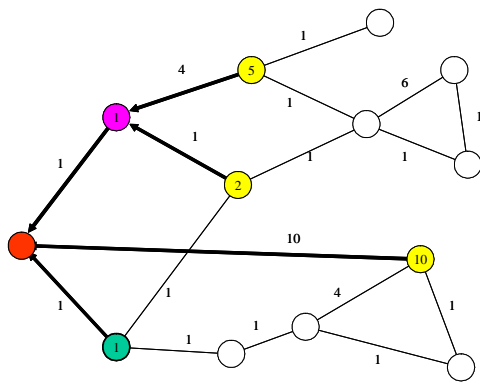
(2)



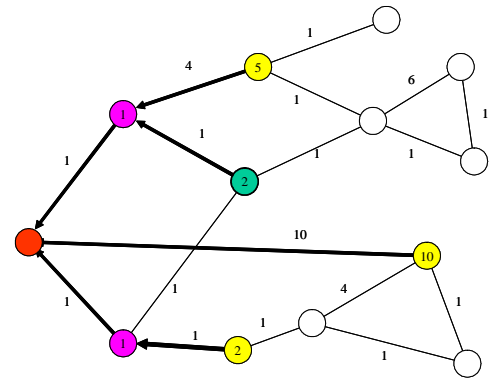
(3)



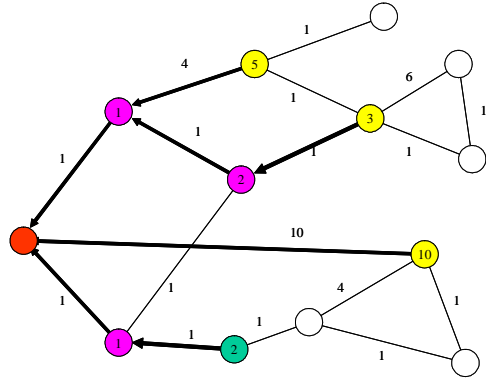
(4)



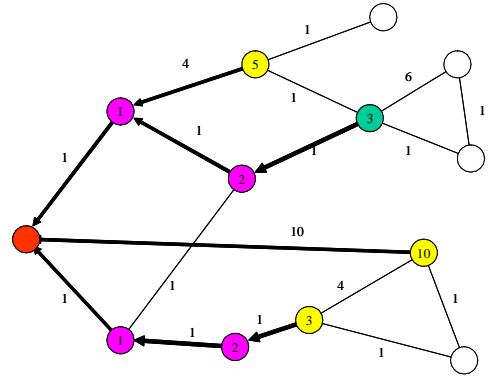
(5)



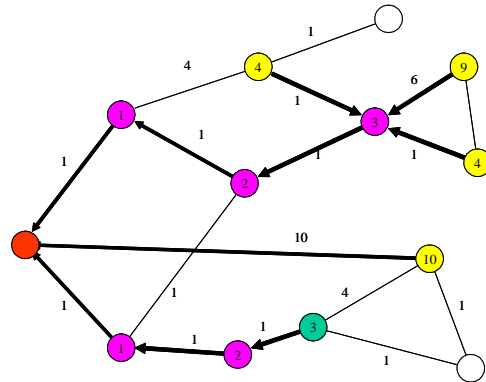
(6)



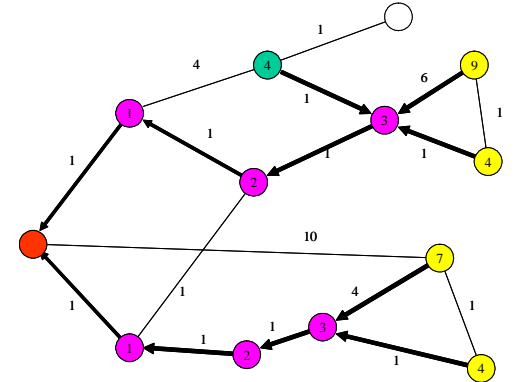
(7)



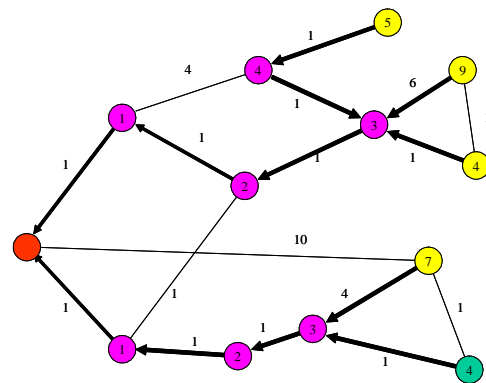
(8)



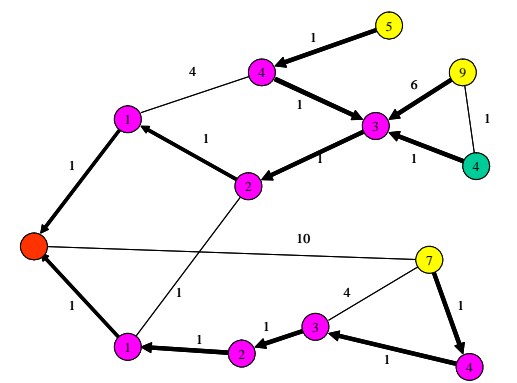
(9)



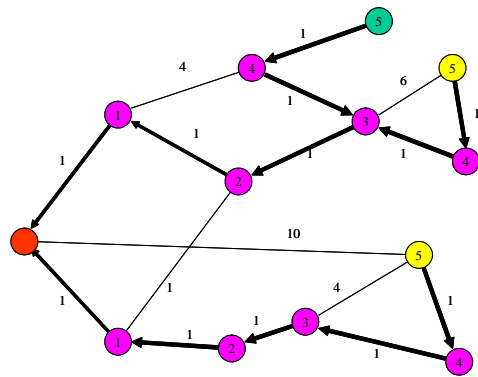
(10)



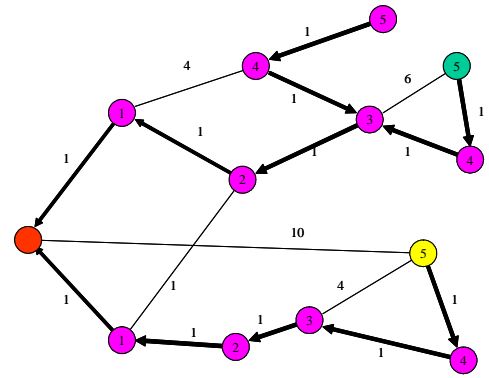
(11)



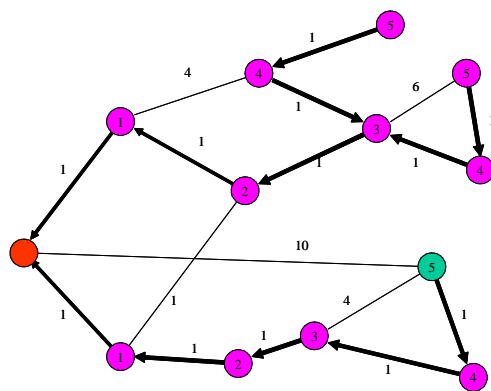
(12)



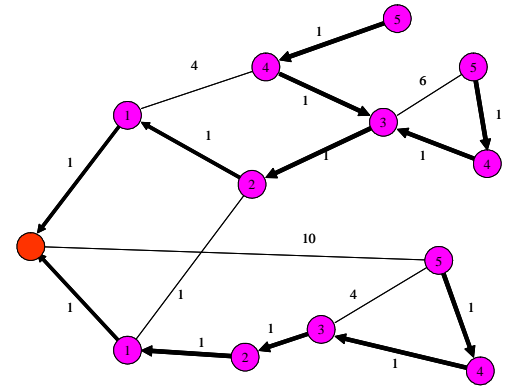
(13)



(14)



(15)



(16)

## Finding Connection Node in Spanning Tree

### Rules

Household: min 1 NT

Business: min 2 NT

NT - CN: max 1000 m

NT\* - CN: max 500 m

CN - CN: max 1000 m in spanning tree

CN - DN: guideline: min. 2 DN's, independent paths

NT - MN: max 10.000 m

guideline: min. 2 MN's, independent paths

### **Algorithm**

**Goal** Find all CN in a spanning tree and associated lines

### **Steps** Mark a MN

#### **LOOP**

Find one of the LN with lowest distance and find each RN successor

Mark the LN as Intermediate Node IN

Mark each RN successor with:

the actual LN as predecessor and the accumulated distance,

if the distance is less mark the RN as a LN

Note that an IN can be re-marked as a LN

**UNTIL** {LN} is empty

## **Finding all CN in spanning tree and associating lines**

### **Rules**

Household: min 1 NT

Business: min 2 NT

NT - CN: guideline: 500 m

NT\* - CN: guideline: 250 m

CN - CN: guideline: 500 m

CN - DN: guideline: 2 DN's, independent paths

NT - MN: max 10.000 m

guideline: min. 2 MN's, independent paths

### **Algorithm**

#### **Goal**

Find all CN in a spanning tree and associated lines

## Steps

### Mark a MN

#### LOOP

Find one of the RN with max distance to MN  
set the accumulated distance to 0 and mark the RN as IN  
Mark each unmarked RN connected to the actual node:  
As CN, if the accumulated distance is less mark the RN as a LN  
    Note that an IN can be re-marked as a LN  
UNTIL {LN} is empty

## Calculating the distance from a main node to all road points

### Algorithm

#### Goal

Calculate the distance from a MN to all RP

#### Steps

Mark all MN as MN, DN & CN  
Mark all RP with distance “infinity”  
Establish spanning tree from all MN in area Step by step  
Mark MN with the distance “0” and as a leaf-node LN

#### LOOP

Find one of the LN with lowest distance and find each RN successor  
Mark the LN as Intermediate Node IN  
Mark each RN successor with:  
    the actual LN as predecessor and the accumulated distance,  
    if the distance is  $<x$ , mark the RP as a LN  
    Note that an IN can be re-marked as a LN  
UNTIL {LN} is empty

## Binomial Distribution

Evaluating uncertainty of traffic networks is very important. In order to assess it theoretically, we need an equilibrium model that can estimate the probabilistic distributions of link travel times. While considering the dimensioning of the links and the nodes in a network, traffic estimation, bandwidth demands, and estimation of active users on the network are things to consider. The amount of active user can be



estimated by a binomial distribution, a user has two possible states, active and passive.

If a circuit switched network was to be designed, and a probability of 10 % was considered for and end used to be active, the estimated traffic considering all sending to all could be scaled by 10% before dimensioning the link and nodes. This is however not the case when considering a packet switched network, which is the case in this project. The number of users active in a packet switched network can be estimated by a binomial distribution model.

## Theory

In a binomial distribution there is two possibilities, namely success or failure. Let  $\pi$  be the probability of success and  $1 - \pi$  the probability of failure. In a sample of  $n$  observations, the number of

A success is  $x$  and the number of failures is therefore  $n - x$ . The probability of  $x$  successes and  $n - x$  failures can be calculated by equation.

$$p(x \text{ successes in } n \text{ trials}) = \binom{n}{x} \pi^x (1 - \pi)^{n-x}$$

$$= \frac{n!}{x!(n-x)!} \pi^x (1 - \pi)^{n-x}$$

The mean number of successors is found by following equation:

$$\text{Mean of } x = \mu = n\pi$$

And below equation finds the standard deviation of the number of successors.

$$\text{Standard deviation of } x = \sigma = \sqrt{n\pi(1 - \pi)}$$

## Using Binomial Distribution in Network Dimensioning

In order to use the binomial distribution to scale the traffic matrix for dimensioning the network, some general statistics have to be considered. The probability of a single user online has to be estimated. According to [29] there where 10 % online users at the same time in the United States in 1999, by this reason the amount of active users can be estimated to be 20 % in a short term view. In the middle term, the amount of active users is assumed to increase to 30%, and in the long term view it is assumed that more people will be online constantly, and [29] estimate that 40 % will be online at the same time. Figure 8 shows an example of a binomial distribution with 30 users, and a probability of 20 % for a user to be active.

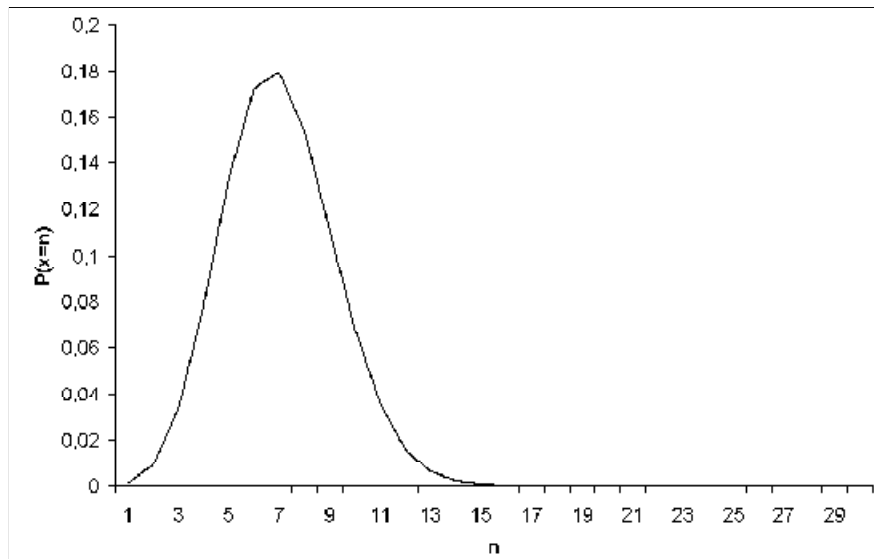


Figure 8: Binomial distribution with  $n=30$  and  $p(\text{active})=0.2$

According to equation, is the mean of  $x = \pi * n + 0,2 * 30 = 6$ , and the standard deviation of  $x = \sqrt{n\pi(1-\pi)} = 2.1999$ . If a significance level  $\alpha = 0.001$  is considered, and a function "Critbinom" in Excel is used, a critical value is found in the binomial distribution. In the example in Figure 8 this critical value is equal to 13. This "Critbinom" function is used to calculate the amount of active users which is used to scale the traffic matrices in order to dimension the network.

## Network Availability

The general requirement of network availability is about 99.99 percent or better. This means that the network work should be available for subscriber use all but 53 min or so per year. 99.99 of availability is not impossible to achieve with backup systems and quick maintenance procedures. Careful planning can reduce the chance that service operations will affect customers.

Availability is closely related to both the failure rate and the time it takes to repair them. There are several versions of availability equations to calculate availability. We will present two mostly used ones.

### Equation 1

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

Where  $A_i$  = inherent availability (a number less than 1; this is the theoretical limit of the fraction of time that the system is available for use)

$MTBF$  = mean time between failure ( including corrective actions)

$MTBR$  = mean time to repair

## Equation 2

$$A_o = \frac{MTBM + RT}{MTBM + RT + MDT}$$

Where  $A_o$  = operational availability ( a number that represents the practical limit on the availability of the system)

$MTBM$  = mean time between maintenance ( or preventive and corrective actions based on MTBF)

$RT$  = component average ready time per cycle ( available but not operating time per time period)

$MDT$  = mean down time = mean active corrective time / preventive maintenance time + mean logistic time + mean administrative time)

## Network Fiber Length

The general rule of thumb says that the required fiber length can be estimated from

$$\text{Fiber Length} = PDN$$

Where  $P$  = a redundancy constant, usually between 1 and 4

$D$  = distance

$N$  = number of required fiber links (  $N$  end switches )

The required length of fiber for a network is much more than the length of cable. This is due to redundancy. The above should be carefully considered when specifying a cable, the number of fibers, or the fiber cost, especially if it is an expensive or special fiber. The above also assumes that all the links have the same length. While obviously not universality true, this is a good assumption to begin with if we do not have all the details and merely need to estimate the kilometers of fiber needed.

## Network Cable Length Estimation

The rule of thumb says that the required fiber cable length can be estimated from

$$\text{Fiber cable length} = L * \sqrt{2}$$

Where  $L$  = direct distance between two nodes

The required length of cable for a network is much more than the direct length between two nodes. When node locations are known and the path for links are unknown, an estimation can be done by the above equation.

## Summery

For the network planning there are many simulations and modeling tools are used. However, there is no such a tool available which provides a full solution. We can divide tools, which can be used for network infrastructure planning, in two main groups: Network simulation and modeling, and GIS tools. Apart from that, additional algorithm can be employed as well, as an example the spanning tree algorithms mentioned in the chapter. In the end of chapter we gave some formulas which can be used for different planning purposes.

# 6. Network Technologies

## Wired Network Technologies

### Fiber Optic based Network Technologies

Optical fiber offers a high speed communication over great distances, and in backbone network designs. Fiber optic is an optimal medium considering the today's technology. In the modern telephone and data networks fiber optics are widely used in the backbone networks.

As more bandwidth is demanded in the access networks, the fiber optics has also become more common in this network level. FTTH is probably the only technology that will meet the future's bandwidth demands.

Passive Optical Networks (PON) can be used in the access networks in order to reduce the amount of fibers from the Central Offices (CO), instead of using home run to each NT. One fiber from the CO is in the network splitted into several subscriber lines by use of passive optical splitters. These components do not use any electronics, and no maintenance and power supply is required. More information about PON is given in later sections.

### Optical fiber transmission system

The optical fiber transmission systems are composed of three main elements: light source, optical fiber and photo detector. There are also numerous active and passive optical devices that perform complex networking functions in the optical domain such as signal restoration, routing and switching. Usually a LED or a laser diode launches the light into the fiber where it travels to the other end of the link. Here it is detected by a photo diode in the optical receiver, processed and amplified. Most of this chapter based on [20].

### Characteristics

The optical cable is made of glass and plastic, so it is electrically non-conductive, unaffected by moisture, and immune to the effects of external electrical interference. The principle of light propagation in an optical fiber is based on the principle of total reflection. The core of the fiber is cylindrical and composed of silica (silicon dioxide, SiO<sub>2</sub>) which has the particularly useful property: optimal reflectivity of 850, 1300 and 1500 nanometers wavelengths. The core is surrounded with cladding. According to the core size optical fibers can be classified as single-mode fiber and multi-mode fiber. The international standard for outer cladding diameter of most single-mode optical fibers is 125 microns (μm) for the glass and 245 μm for the coating. This standard is important because it ensures compatibility among connectors, splices, and tools used throughout the industry.

## Principle of Reflection

The refractive index of the core ( $n_1$ ) is always higher than that of the cladding ( $n_2$ ) to guide the light wave. Light injected into the core and striking the core-to-cladding interface at an angle greater than the critical angle will be reflected back into the core. Since angles of incidence and reflection are equal, the light ray continues to zigzag down the length of the fiber. The light is trapped within the core. Light striking the interface at less than the critical angle passes into the cladding and is lost.

## Existence of Modes

Rays of light do not travel randomly. They are channeled into modes, which are possible paths for a light ray traveling down the fiber. A fiber can support from one mode to thousands of modes. The number of modes in a fiber helps determine the fiber's bandwidth. More modes typically mean lower bandwidth, and the reason is dispersion. At high data rates, dispersion will allow pulses to overlap so that the receiver no longer can distinguish where one pulse begins and another ends.

## Multi mode Fiber

Multi mode fiber has a much larger core than single-mode fiber, allowing hundreds of modes of light to propagate through the fiber simultaneously. The larger core diameter of multi mode fiber facilitates the use of lower-cost optical transmitters (such as light emitting diodes [LEDs] at a wavelength of 850 and 1300 nanometers or vertical cavity surface emitting lasers [VCSELs]) and connectors. Multi mode fibers have core sizes of 50 or 62.5  $\mu\text{m}$  in diameter and cladding diameter of 125  $\mu\text{m}$  (by the standard ITU-T G.651). They are mainly used in local networks covering less than 3-4 km. They have a lower bandwidth (of the order of 500 MHz.km) which could be a problem in some networks. Their capacity is  $< 150$  Mbps.

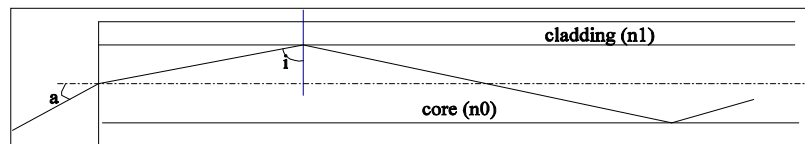


Figure 9: Propagation of a ray in a multi mode fiber.

## Single mode Fiber

Single mode fiber, on the other hand, has a much smaller core that allows only one mode of light at a time to propagate through the core. According to the ANSI the fiber has 8.5 micron core with 125 micron cladding. The advantages of the single mode fiber are a larger bandwidth, greater distance, and low attenuation. It also has some drawbacks as the core diameter is very small, so problems to access every home will arise. The narrow size of the core causes that other elements of the system, such as transmitters, connectors, and transceivers have to operate at slower tolerance, so their cost would be higher. Data transmission is handled by optical lasers emitting light at 1310 and 1550 nanometers, and by optical amplifiers located at regular intervals.

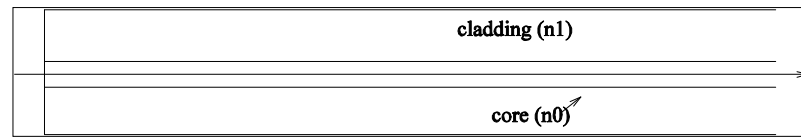


Figure 10: Propagation of a ray in a single mode fiber.

### The Light source

The light source is viewed as the active component in a fiber optic communication system. Its basic function is to convert electric energy into optical energy (light) in such a way that the light can be efficiently transferred to an optical fiber to transmit information through the fiber over long or short distances. There are three types of light source:

- Lamps: Broadband light sources with a continuous spectrum
- LED: monochromatic, non coherent light sources
- LD: monochromatic, coherent light sources.

These devices operate in the infrared portion of the spectrum, they are not normally visible to the human eye and the light they produce is very pure.

LED differs from the laser diode primary by, in a LED, there is no stimulated emission of light. Currently, the LED has a few disadvantages compared to the laser diode: lower power coupled into the fiber, relatively narrow modulated bandwidth (<50 MHz up to 150 MHz), broader optical spectral width. But its advantages can predominate in the choice of components for fiber optic communication: simpler manufacture, cheaper, longer life, less temperature sensitive. These advantages and disadvantages mean that the laser diodes are used mainly in systems for long distance communication and the LEDs have been used primarily in local area networks.

### Optical Couplers

Splicers and connectors play a critical role both in the cost of installation and in the system performance. The object of splicers and connectors is to precisely match the core of one optical fiber with that of another in order to produce a smooth junction through which light signals can continue without alteration or interruption.

There are two ways that fibers are joined:

1. Splicers form permanent connections between fibers in the system.
2. Connectors provide rearrangeable connections, typically at termination points.

## Optical Network Architectures

This section describes the main optical networking architectures which are prevalently used today. Contemporary the SDH/SONET and WDM/DWDM are the most famous one. However, there is also an emerging one, namely DPT from Cisco Systems which has becoming the competitor to SDH and WDM/DWDM.

### Introduction to SDH

SDH is the most basic and popular architecture. SDH is a standard for optical telecommunications transport. In a nutshell, SDH allows multiple technologies and vendor products to interoperate by defining standard physical network interfaces.

SDH was originally designed for public telecommunication system to carry information optically. Later, SDH has extended to carry data along voice calls. SDH offers top-end bandwidth OC-192 (9.952 Gbps) that can carry diverse range of information. Further, because of generous bandwidth of SDH affords the compression and encapsulation into IP packets is unnecessary. SDH is a self-healing network that recognizes fiber cuts and reroutes traffic before service is interrupted or degraded. All carriers that deploy SDH, follow the same set of standards. However, it is the network architecture and equipment over which SDH is deployed that makes the difference in survivability and restore times.

### Linear SDH

A linear SDH architecture is configured point-to-point. Traffic moving from point A to point B has only one route to follow. If there is backup cable in place, it usually follows the same route. In this design, a fiber cut or other service disruption requires rerouting traffic along other routes in the network, if capacity is available. Service stops while restoration is implemented

### Ring based SDH

One of the useful characteristics of SDH is that it supports the ring topology. Normally SDH uses double fibers in a ring but it can still work with one fiber and provide sufficient bandwidth. One of the rings is called working ring which is being used while transmitting the information, and other is called protecting ring. If working ring fails the protecting rings take over. However, this is more difficult in situation where both the rings are cut down between nodes. When the rings are cut down, the transmission switches to the back ring. Now, the only way to reach the node is going backward through other nodes in ring. Mostly, the time of connection restoration is very short, usually a fraction of second, if it is in small geographically networks. But if the nodes are situated cities apart, this can be more time consuming. This problem is handled with different synchronizing schemes. Because of this restoration characteristic SDH is also known as a self-healing network technology [21].

### Emergence of WDM/DWDM Technology

The emergence of SDH has given a significant boost to the network bandwidth which no one architecture has been able to offer before. SDH successfully passed the milestone of Gbps and reached to its 10 Gbps bandwidth limit. In the beginning no



one was aware that the limit of SDH will be its multiplexing scheme. SDH uses TDM, and 10Gbps is about the limit of TDM . The introduction of WDM was an attempt to break the SDH bandwidth limit. WDM increased the carrying capacity of physical medium (fiber) using a completely different from TDM that used in SDH.

In WDM the incoming signal are assigned to specific frequency of light or wavelength within a certain frequency band. In an analogy this can be explained as a radio station which broadcasts on different wavelength without interfering each other. Hence each channel is transmitted at different frequency, it can be selected with a tuner.

Another way to think is that in a WDM, each channel is a different color of light, and several channels together make a rainbow. The optical spectrum is depicted in Figure 11. In this section, the wavelength and channel are synonyms to each other.

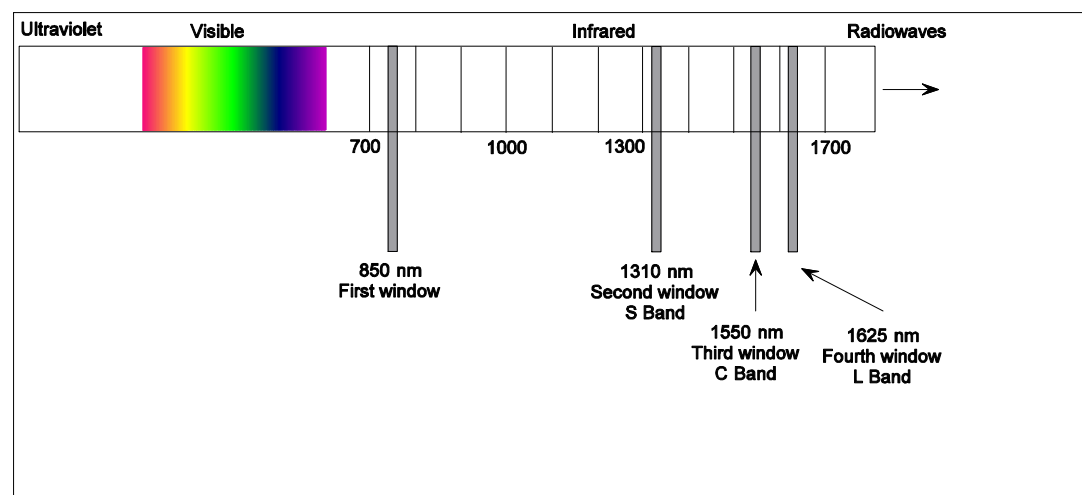


Figure 11: The optical spectrum.

The left half of Figure 11 is the ultraviolet region (which is beyond the human vision) and the visible spectrum. The visible spectrum contains all the wavelength of light that human eye can detect. In optical networking, however, all the action takes place on the right-hand side of the spectrum, particularly between 700 and 1700 nm. Within the region of the spectrum are certain areas where attenuation is low, this region, called windows, are little islands in an ocean of high absorption.

In WDM, all wavelength of the signal entered into the one end of fiber, on other end the signals are demultiplex. Like TDM, the resulting capacity is the sum of input signal, but in WDM each signal is carried independently of others. Each signal has its own dedicated bandwidth; all signals arrived at same times, rather than being broken up and carried in time slots.

The difference between WDM and Dense Wave Division Multiplexing (DWDM) is basically the degree. DWDM puts the wavelength more closely than the WDM and therefore it carries more wavelengths and has greater capacity. The limit of

wavelength's space is exactly not known yet. Today there are up to 160 wavelengths approached practically. The evolution of capacity and channels of WDM/DWDM is depicted in Figure 12 .

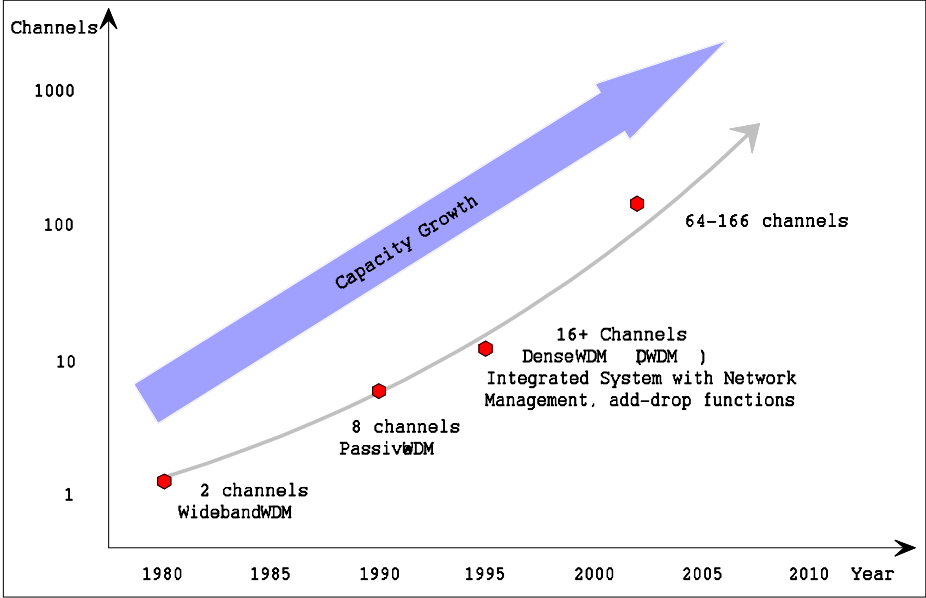
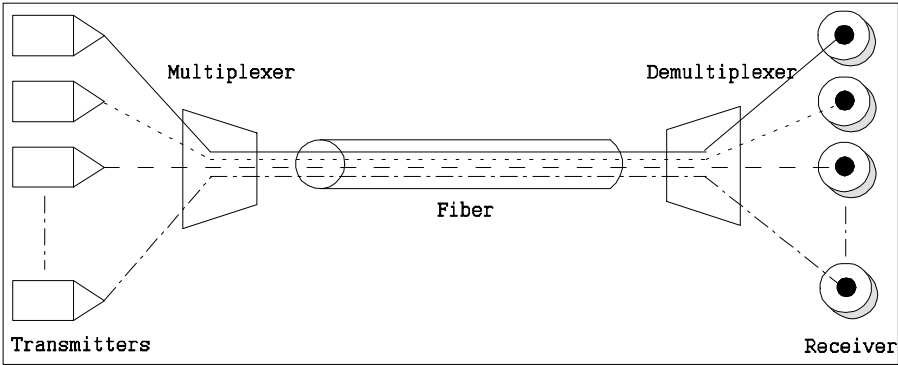


Figure 12: Evolution of WDM/DWDM.

### How DWDM Works

The main idea behind DWDM is to generate the signal in specific wavelength space using by solid state laser. These signals are then multiplexed together and transmitted through the fiber. In Figure 13 it can be seen that each channel occupies its own, unique wavelength.



*Figure 13: Transmission in WDM/DWDM.*

At different point in the network, different actions occur:

- Generating the signals: the source, a solid-state laser, must provide stable light within a specific, narrow bandwidth that carries the digital data, modulated as an analog signal.
- Combining the signals: modern DWDM systems employ multiplexers to combine the signals. There is some inherent loss associated with multiplexing and demultiplexing. This loss is dependent upon the number of channels but can be avoided by use of optical amplifiers, which boost all the wavelengths at once without electrical conversion.
- Transmitting the signals: the effects of crosstalk and optical signal degradation or loss must be considered in the fiber optic transmission. These effects can be minimized by controlling variables such as channel spacing, wavelength tolerance, and laser power levels. Over a transmission link, the signal may need to be optically amplified.
- Separating the received signals: at the receiving end, the multiplexed signals must be separated out, called as demultiplexing. Although this task would appear to be simply the opposite of combining the signals, it is actually more technically difficult.
- Receiving the signals: the demultiplexed signal is received by a photo detector.

The wavelengths are separated by each other to avoid fiber nonlinearities. Each wavelength is individually modulated, and the signal should be, in order to achieving best results, close to one another. One of the problems in DWDM is if any wavelength source fails. One solution could be to provide the redundancy but that becomes an expensive solution. There are tunable lasers developed to cope such problems. These lasers can be tuned to any wavelengths. This helps to reduce the number of spares lasers.

### **Techniques for multiplexing and demultiplexing**

There are different techniques used for combining (multiplexing) and separating (demultiplexing) the wavelength in DWDM. Each techniques has its own advantages and disadvantages. Demultiplexing is rather difficult compare to multiplexing. Some famous techniques are discussed below.

- Prismatic: a simple form of multiplexing and demultiplexing can be done by a prism. In prismatic technique the light is entered into one side of prism and reflexed to other side, where it is separated into different wavelength. The same process can be used for multiplexing as well.

- **Diffraction grating:** another way to demultiplex is to put the beam of light on a diffraction grating. A diffraction grating is an etched array of very fine lines that reflects light at different wavelengths. Each wavelength is diffracted at a different angle and then sent to a different point. By using a lens, these split wavelengths can be focused on individual fibers.
- **Array Waveguide Grating:** AWG is also based on diffraction principles. An AWG device, sometimes called an optical waveguide router or waveguide grating router, consists of an array of curved-channel waveguides with a fixed difference in the path length between adjacent channels. The waveguides are connected to cavities at the input and output. When the light enters the input cavity, it is diffracted and enters the waveguide array. There the optical length difference of each waveguide introduces phase delays in the output cavity, where an array of fibers is coupled. The process results in different wavelengths having maximal interference at different locations, which correspond to the output ports.
- **Thin Film Filters:** the last type of demultiplexer uses thin film filters in multilayer interference filters. By positioning filters, consisting of thin films, in the optical path, wavelengths can be sorted out (demultiplexed). The property of each filter is such that it transmits one wavelength while reflecting others. By cascading these devices, many wavelengths can be demultiplexed.

Thin Film filters and AWG are most promising of all. Thin film filters offer good stability and isolation between wavelengths at a moderate cost. AWGs exhibit a flat spectral response and low insertion loss. A potential draw back is that they are temperature sensitive, so they can be used in all environments. The advantage is that they can perform multiplexing and demultiplexing operation simultaneously.

### **Add Drop Multiplexing (ADM)}**

Add/drop multiplexing provides a good flexibility to DWDM. Generally, all wavelengths are multiplexed at the one end of fiber, and then demultiplexed on the other end of fiber. This technique is quite suitable for shorter distances. But for long distances sometimes it is needed to drop or add new wavelength from the other wavelengths. This can be conducted with an ADM. Rather than combining or unraveling all wavelengths; the ADM can add or remove specific signals while allowing others to pass through.

### **Evolution of DWDM Applications**

WDM emerged as to carry multiple wavelengths on single string of fiber, first started from 2 wavelengths. The possibility to carry more wavelengths on a single fiber has been evolving with time. Today WDM or more precisely DWDM can carry even more than 100 wavelengths.

In earlier days DWDM was only limited to long hauls. As the equipments and technologies became cheaper and more flexible, it started to be used for metro area networks and then for last mile or direct to residence networks. Currently, the DWDM is one of the most prominence technologies for the last mile networks. The evolution of DWDM applications is depicted in Figure 14.

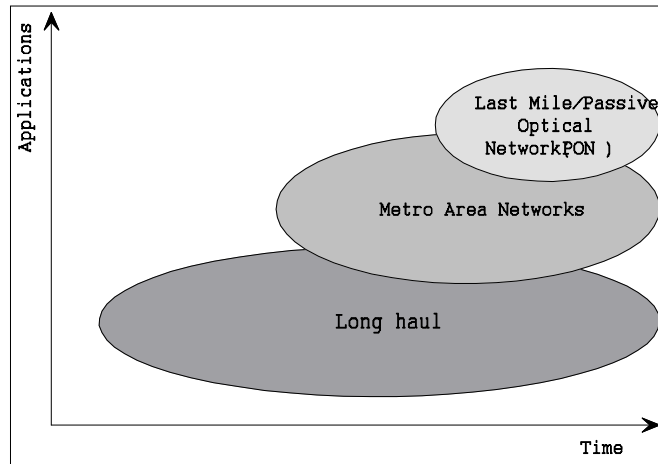


Figure 14: Evolution of WDM/DWDM Applications.

## Introduction to Dynamic Packet Transport (DPT)

SDH and DWDM are all technologies which are widely used and have technical specifications that have been developed and approved by the Institute of Electrical and Electronics Engineering (IEEE) or Institute of Engineering Task Force (IETF). This enables them standardized so that a range of vendors can use them.

Cisco Systems has introduced its own system for carrying information on optical networks. DPT is being positioned as a challenger to SDH. However, DPT is not a vendor standard.

### Overview of DPT

Like the SDH, DPT is also a ring based network technology. However, unlike the SDH, it allows to utilize the full bandwidth of fiber ring. DPT provides the potential evolution from multi layered infrastructure equipment to intelligent network services based OSI layer-3 (Internet Protocol [IP]/multi protocol label switching [MPLS] service and the optical transport layer).

DPT technology employs a new MAC layer protocol called the Spatial Reuse Protocol (SRP), which supports scalable and optimized IP packet aggregations and transport in LAN, MAN, and WANs.

DPT uses a bidirectional ring. The ring is composed of two symmetric, counter-routing fiber rings. Each of these rings can be used simultaneously to pass data and control packets. The difference between the two rings is that one ring is called the

inner ring and the other is called the outer ring. DPT sends data packets along the fiber in direction (downstream). By doing that, DPT is able to use both fibers simultaneously, maximizing the bandwidth.

## Passive Optical Network (PON)

In the access network it would be desirable to use Passive Optical Networks. This technology uses passive optical components to reduce the amount of fibers on the way from the subscribers to the COs. In the telecommunication literature, the elements of an access network can have many names. First a couple of words to make this clear. This section is mostly based on [20].

The access network itself is also known as 'the last mile' and 'the local loop'. It may consist of a feeder- and a distribution network. If there is used two levels of optical splitting, the distribution network is further divided into distribution- and final drop network. According to [23] if there is no splitting from OLT to ONT, like in the bottom of Figure 15, the access network is said to be Gigabit Ethernet, another name for such structure is Home Run.

In the provider's end, there is a Optical Line Terminal (OLT) in the CO which is also called Head-End (HE), Local Switch (LS) and HUB. Between the customer and the CO there may be an Optical Distribution Node (ODN) or Optical Remote Node (ORN). In the customers end, the NT, there is an Optical Network Termination (ONT), also called Optical Network Unit (ONU), Interface Network Unit (INU) and Customer Premises Equipment (CPE). A better view can be seen in Figure 15.

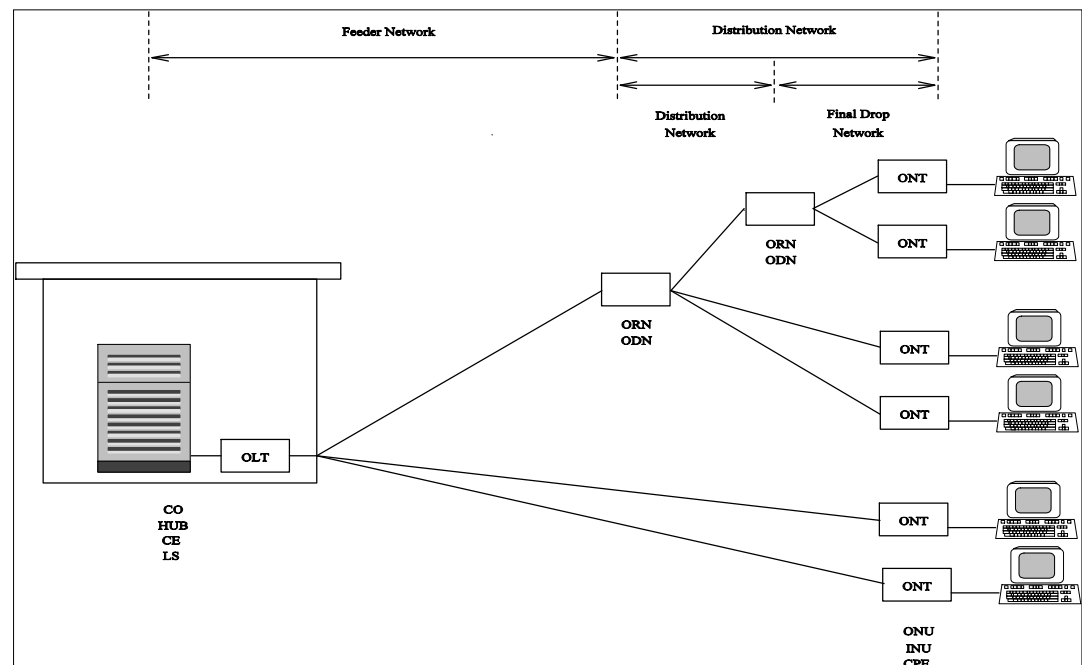


Figure 15: Overview of an access network [20].

The distribution network may be either broadcast or switched. In the broadcast version, the remote node sends all data it receives from the OLT to every ONT. - Even if the information is in different optical channels. This is done without any electrical process. In switched networks, the remote node only sends the data to the destination ONTs. This switching may be done optically if Wave Division Multiplexing (WDM) is done with Arrayed Wave Guide (AWG) devices. Then, one may conclude that security is better obtained in switched networks.

The feeder network may assign its bandwidth to the ONT in two ways. One possibility is to give all ONTs access to the whole bandwidth supported by the feeder network. This may be a good solution if the traffic to the ONTs is bursty. However, by using the other solution, where the ONTs is assigned a fixed bandwidth, it is easier to obtain a given QoS.

In a PON there are no electronics in the remote nodes, only passive optical components as splitters and couplers, and hence, the name. Typically the broadcast version is used, and each ONT has to sort out the data that is supposed to itself. The OLTs and ONTs are still active components, but these are placed in the CO and at the customer, and may then easily be supported with electrical power. Figure 16 shows an example of a broadcast PON.

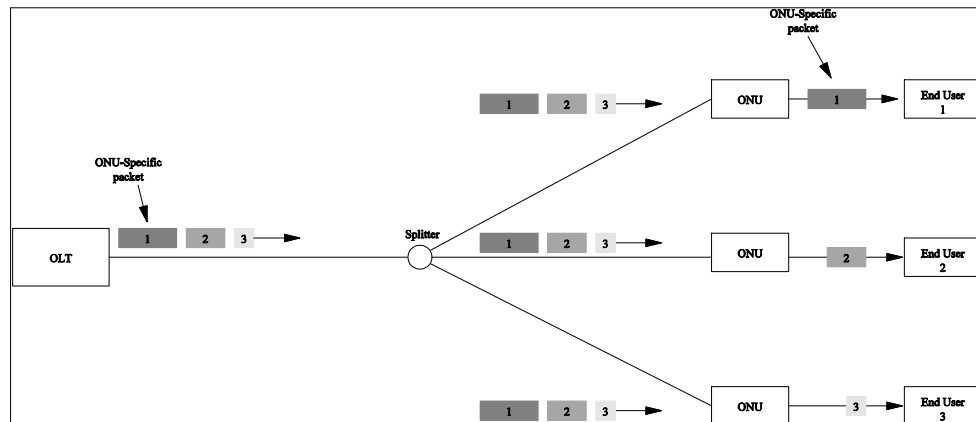


Figure 16: Broadcast PON [24].

### Advantages and Disadvantages

There are great advantages by not having electronics in the remote nodes. The passive couplers and splitters should just pass or restrict light, and therefore there is no need of processing power. Their mean time between failures can be considered as infinite. Since the price of passive components is lower, and the need of maintenance is practically eliminated, the cost of building and running the network is significant

lower, compared with using active components. The passive components can also with a suitable packing for protection be placed in the ground, and does not need an accessible location as active components. Scalability is also an advantage, PONs may easily be upgraded if new technologies should be invented, the only the end-equipment needs to be upgraded. The remote nodes are kept as they are.

Of course there are also some disadvantages compared to active networks. As mentioned above, the security is lower due to the broadcast. To obtain better security, heavy encryption algorithms may have to be used. There is no regeneration through the network, then the light signals lose their power. The reachability and transmission capability is reduced.

### **Multiplexing techniques**

There are different kinds of multiplexing techniques, Time Division Multiplexing (TDM), Wavelength Division Multiplexing (WDM) and Code Division Multiplexing (CDM) are used in PONs. TDM is a mechanism for dividing the bandwidth of a link into separate channels or time slots. Then the ONT sorts out the data in the time slots that are assigned to him. Wavelength Division Multiplexing (WDM) divides light signals into different colors (or wavelengths). The electronic end equipment, ONT and OLT, has to distinguish the different signals by their colors.

WDM is a technology used to expand fiber optic bandwidth by enabling signals from different sources to independently travel together on a single optical fiber. Fiber capacity is increased by mapping incoming optical signals to specific light wavelengths (colors) or optical channels. In WDM systems, each optical channel remains independent of other optical channels as if it were using its own fiber pair.

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.

### **Types of PONs**

APON uses the Asynchronous transfer protocol as their layer 2 framing protocol. It is a splitter based technology which today can achieve bandwidths up to 155 Mbps on a single fiber, and designed to reach 622 Mbps and beyond in the near future. Because of the inherently high QoS of ATM, APON is well suited to delivering bundled data, voice, image and video service offering.

EPON uses the Ethernet as their layer 2 framing protocol. Data is transmitted in various length packets up to 1518 bytes. It is well suited for IP data where the average packet length is between 500 and 1200 bytes. EPON uses different procedures for upstream and downstream transmissions. In the downstream the CO sends a stream of packets, each of which may be addressed to a different user. A passive splitter ensures each node to see all downstream traffic. The Ethernet protocol ensures that each node processes only packets intended for the user.



WDM PON using the same technology as in the long haul. BPON is the same as an APON, with extra overlay capabilities for broadband services like video. BPON is approved as International Telecommunication Union (ITU) spec G.983x. It supports data rates to 622 Mbps out to an endpoint (upstream) and back from the customer to the service provider's remote aggregation point (downstream).

GPON is the next wave of access networks being deployed by the carriers to meet their Ethernet and Voice and TDM services' needs. GPON uses a different, faster approach (up to 2.5 Gbps in current products, encapsulating traffic in a version of the SDH compatible Generic Framing Protocol (GFP). GPON is on track to becoming the ITU's G.984x. Copper based Network Technologies

## Copper Based Network Technology

This section describes copper based network technologies, namely copper, and coaxial cable. The classic copper technologies, as POTS and ISDN, have the advantage that there exist wires to each private household, but they are not offering the sufficient bandwidth demand predicted for the future.

### PSTN

Copper cables have for the major part of the 20th century been the main medium for wired network technologies. The oldest copper technologies making part from the Public Switched Telephone Network are POTS (56 kbps/s) and ISDN (from 128kbps to 2Mbps). They are mainly used for phone transmissions, but also data transmissions. The bandwidth of these technologies is quite small and becomes insufficient for the expected future network demands and applications [17].

### xDSL

The common for the xDSL technologies is that they utilize a modem and the standard twisted pair delivering high speed data connections [18].

### Asymmetric DSL

Asymmetrical variations include: ADSL, G.lite ADSL (or simply G.lite), RADSL and VDSL. The standard forms of ADSL (ITU G.992.1, G.992.2, and ANSI T1.413-Issue 2) are all built upon the same technical foundation, Discrete Multi Tone (DMT). The suite of ADSL standards facilitates interoperability between all standard forms of ADSL.

ADSL: enables voice and high-speed data to be sent simultaneously over the existing telephone line. ADSL offers different upload and download speeds enumerated in Table 1, where the distance depends on the wire diameter. This type of DSL is the most predominant in commercial use for business and residential customers around the world. Appropriate for general Internet access and for applications where downstream speed is most important, such as video-on-demand. ITU-T Recommendation G.992.1 and ANSI Standard T1.413-1998 specify full rate ADSL.

Distance[Km]	Data Rate [Mbps]
--------------	------------------

4.6 - 5.5	1.5 - 2.0
2.7 - 3.7	6.1

Table 1: ADSL data rates as a function of distance.

G.lite ADSL: was specifically developed to meet the plug-and-play requirements of the consumer market segment. G.lite is a medium bandwidth version of ADSL that allows Internet access at up to 30 times the speed of the fastest 56K analog modems ~ up to 1.5 Mbps downstream and up to 500 kbps upstream. G.lite is an International Telecommunications Union (ITU) standard, globally standardized inter operable ADSL system per ITU G.992.2.

RADSL: is a non-standard version of ADSL. Note that standard ADSL also permits the ADSL modem to adapt speeds of data transfer.

VDSL: is particularly useful for 'campus' environments like universities and business parks. VDSL is currently being introduced in market trials to deliver video services over existing phone lines. VDSL can also be configured in symmetric mode. The data rates are given in Table 2.

### Symmetric DSL

Symmetrical variations include: SDSL, SHDSL, HDSL, HDSL-2 and IDSL The equal speeds make Symmetrical DSLs useful for LAN (local area network) access, video-conferencing, and for locations hosting their own Web sites.

- SDSL is a vendor-proprietary version of symmetric DSL that may include bit-rates to and from the customer ranging of 128 kbps to 2.32 Mbps. SDSL is an umbrella term for a number of supplier-specific implementations over a single copper pair providing variable rates of symmetric service.
- SHDSL is state-of-the-art, industry standard symmetric DSL SHDSL equipment conforms to the ITU Recommendation G.991.2, also known as G.shdsl, approved by the ITU-T February 2001. SHDSL achieves 20 % better loop-reach than older versions of symmetric DSL, it causes much less crosstalk into other transmission systems in the same cable, and multi-vendor interoperability is facilitated by the standardization of this technology. SHDSL systems may operate at many bit-rates, from 192 kbps to 2.3 Mbps, thereby maximizing the bit-rate for each customer. G.shdsl specifies operation via one pair of wires, or for operation on longer loops, two pairs of wire may be used. For example, with two pairs of wire, 1.2 Mbps can be sent over 20,000 feet of 26 AWG wire. SHDSL is best suited to data-only applications that need high upstream bit-rates. Though SHDSL does not carry voice like ADSL, new voice-over-DSL techniques may be used to convey digitized voice and data via SHDSL. SHDSL is being deployed primarily for business customers.

- HDSL created in the late 1980s delivers symmetric service at speeds up to 2.3 Mbps in both directions. Available at 1.5 or 2.3 Mbps, this symmetric fixed rate application does not provide standard telephone service over the same line and is already standardized through ETSI and ITU (International Telecommunications Union). Seen as an economical replacement for T1 or E1, it uses one, two or three twisted copper pairs.
- HDSL2 (2nd generation HDSL) delivers 1.5 Mbps service each way, supporting voice, data, and video using either ATM (asynchronous transfer mode), private-line service or frame relay over a single copper pair. The ANSI standard for this symmetric service gives a fixed 1.5 Mbps rate in both up and downstream. HDSL2 does not provide standard voice telephone service on the same wire pair. HSDL2 differs from HDSL in that HDSL2 uses one pair of wires to convey 1.5 Mbps whereas ANSI HDSL uses two wire pairs.
- IDSL is a form of DSL that supports symmetric data rates of up to 144 Kbps using existing phone lines. It is unique by the ability to deliver services through a DLC (Digital Loop Carrier: a remote device often placed in newer neighborhoods to simplify the distribution of cable and wiring from the phone company). While DLCs provide a means of simplifying the delivery of traditional voice services to newer neighborhoods, they also provide a unique challenge in delivering DSL into those same neighborhoods. IDSL addresses this market along with ADSL and G.lite as they are implemented directly into those DLCs. IDSL differs from its relative ISDN (integrated The

Technology	Downstream [Mbps]	Upstream [Mbps]	Distance [km]
IDSL	0.128	0.128	6
HDSL	1.544 – 2.048	1.544 – 2.048	5.5
SDSL	0.128 – 2.048	0.128 – 2.048	3.6
ADSL	1.544 – 6	0.016 – 0.640	2.7 – 5.5
VDSL	13 – 52	1.544 – 2.3	0.3 – 1.5

Table 2: xDSL comparison table,[18] (\*) - requires three twisted pair line.

data rates for xDSL technologies are illustrated in the table. Such rates expand existing access capacity by a factor of 50 or more without new cabling. Thus ADSL will play a crucial role over the next ten or more years.

On a national basis, ADSL is now available for 95 % of the population. In the market for ADSL subscriptions, TDC has a growing market share, which was 79 % by the end of the first half of 2002.

### **CATV**

A cable television (CATV) network is based on broadband coaxial cables. It has a tree like structure which the signal is transmitted from the head-end and propagated through the coaxial cable to the users. The bandwidth on the cable is divided into channels. A channel on the cable can be used for analog TV or digital transmissions which can be used for e.g. digital radio, digital TV or Internet access. One channel can have a bit rate of 30 Mbps or more for the downstream and normally lower for the upstream, but the bandwidth is shared among all users connected to the head-end[19].

## **Wireless Network Technologies**

### **Wireless LAN**

Wireless LAN stands for wireless Local Area Network. In recent years the use of wireless LAN is increased significantly. The wireless LAN is mostly known as WiFi (Wireless Fidelity). It is also known as 802.11 networking and wireless networking. The big advantage of WiFi is its simplicity. You can connect computers anywhere in your home or office without the need for wires. The computers connect to the network using radio signals, and computers can be up to 100 feet or so apart. In the following section the detail architecture and different standards of Wireless LAN will be briefly introduced.

#### **The Wireless LAN Architecture**

The 802.11 architecture is comprised of several components and services that interact to provide station mobility transparent to the higher layers of the network stack.

#### **Wireless LAN Station**

The station is the most basic component of the wireless network. A station is any device that contains the functionality of the 802.11 protocol, that being MAC, physical layer, and a connection to the wireless media. Typically the 802.11 functions are implemented in the hardware and software of a NIC.

A station could be a laptop PC, hand held device, or an Access Point. Stations may be mobile, portable, or stationary and all stations support the 802.11 station services of authentication, deauthentication, privacy, and data delivery.

#### **Basic Service Set (BSS)**

802.11 defines the Basic Service Set (BSS) as the basic building block of an 802.11 wireless LAN. The BSS consists of a group of any number of stations.

## 802.11 Topologies

### Independent Basic Service Set (IBSS)

The most basic wireless LAN topology is a set of stations, which have recognized each other and are connected via the wireless media in a peer-to-peer fashion. This form of network topology is referred to as an IBSS or an Ad-hoc network.

In an IBSS, the mobile stations communicate directly with each other as shown in Figure 17. Every mobile station may not be able to communicate with every other station due to the range limitations. There are no relay functions in an IBSS therefore all stations need to be within range of each other and communicate directly.

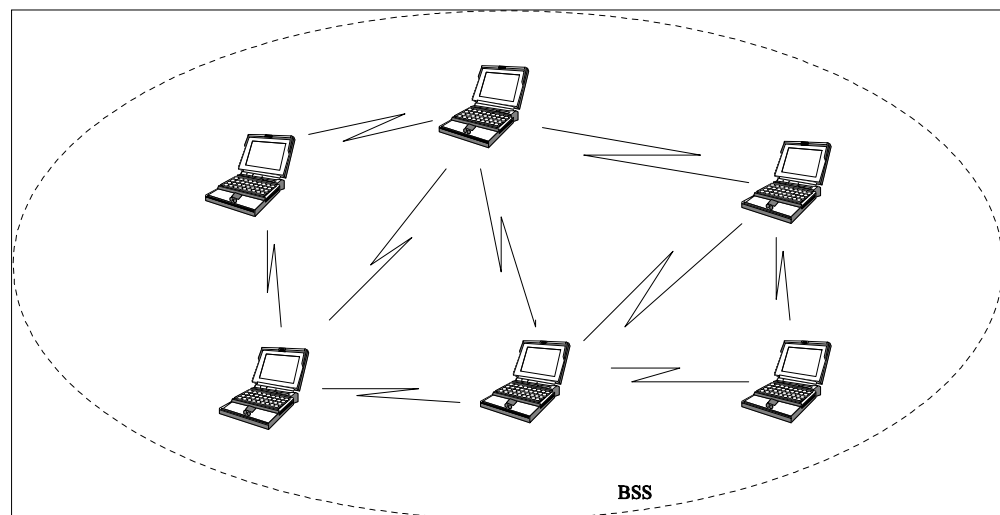


Figure 17: Independent Basic Service Set

### Infrastructure Basic Service Set

An Infrastructure Basic Service Set is a BSS with a component called an Access Point (AP). The access point provides a local relay function for the BSS. All stations in the BSS communicate with the access point and no longer communicate directly, as shown in Figure 18. All frames are relayed between stations by the access point. This local relay function effectively doubles the range of the IBSS. The access point may also provide connection to a distribution system.

The distribution system (DS) is the means by which an access point communicates with another access point to exchange frames for stations in their respective BSSs, forward frames to follow mobile stations as they move from one BSS to another, and exchange frames with a wired network.

As IEEE 802.11 describes it, the distribution system is not necessarily a network and the standard does not place any restrictions on how the distribution system should be implemented, only on the services it must provide. Thus the distribution system may

be a wired network like 803.2 or a special purpose box that interconnects the access points and provides the required distribution services.

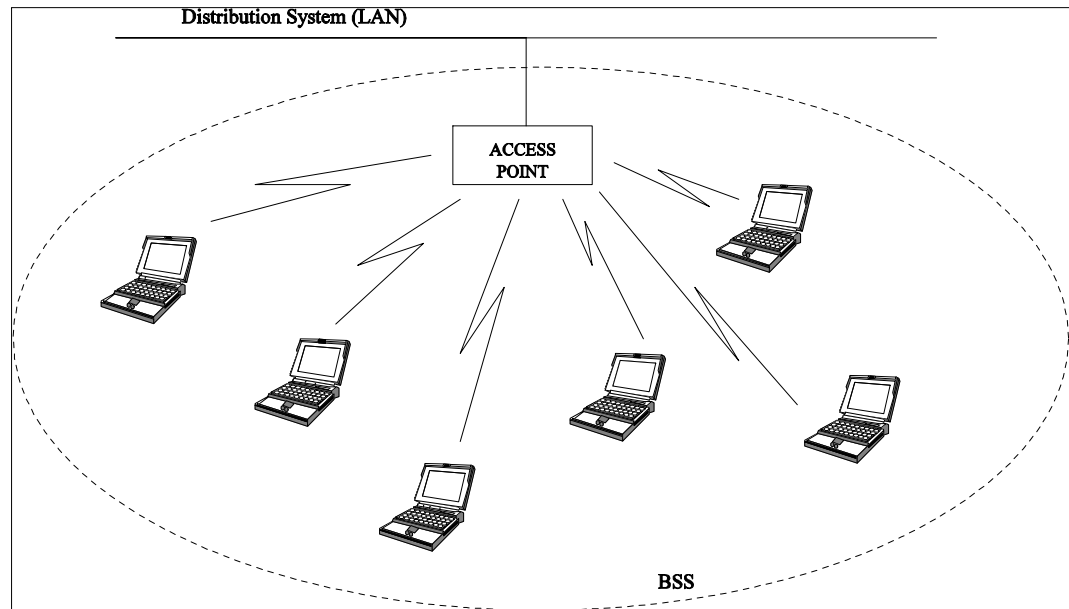


Figure 18: Infrastructure Basic Service Set.

## Current Standards

### 802.11b

This European standard operates in the 2.4 GHz spectrum and has a nominal data transfer rate of 11 Mbps. However, in practice the data transmission rate is approximately 4 to 7 Mbps, around one tenth the speed of a current wired LAN. The range is around 50m indoor and 100m outdoor.

### 802.11a

This American standard operates in the 5 GHz spectrum and therefore provides a higher data rate of 54Mbps. Because they operate in different frequencies, 802.11b and 802.11a are incompatible. The range is around 30m indoor and 60m outdoor.

### 802.11g

This standard has been finalized by IEEE and operates in the 2.4 GHz wave band, the same as the 802.11b standard. The advantage is it offers some degree of backwards compatibility with the existing 802.11b standard.

## Current Capacity

Planning a wireless LAN should take into account the maximum number of people who will be using wireless devices in the range of any access point. The recommended number of devices accessing each access point is 15 to 20. Where light usage of the network occurs, such as with web browsing or accessing applications that require little exchange of data, this could rise to around 30 users. It is relatively

easy to scale wireless LANs by adding more access points, but for an 802.11b network no more than three access points may operate in any one coverage area owing to frequency congestion. An 802.11a network can operate up to eight access points in one area, each using a different channel.

### Future standards

There are a number of standards in development, all of which have a nominal data transfer rate of 54Mbps.

#### 802.11h

This is a modification of 802.11a being developed to comply with European regulations governing the 5 GHz frequency. 802.11h includes transmit power control (TPC) to limit transmission power and dynamic frequency selection (DFS) to protect sensitive frequencies. Since this standard may supersede 802.11a, no new 802.11a equipment could be installed.

#### Hiperlan2

It is a European WLAN standard developed by ETSI and is significantly similar to 802.11a standard widely used in US. HiperLan2 WLAN systems are designed to operate within the 5 GHz frequency band, where 455 MHz part of the used spectrum is licensed. Radio coverage is intended to reach up to 60m in outdoor environment, and up to 30m indoor.

In a longer future, 802.11n standard should come out:

#### 802.11n

IEEE has informally assigned a group to investigate what needs and markets the next standard: 802.11n. Throughput of this standard hasn't been determined but is expected to be at least 100Mbps and could reach 320Mbps. However, 802.11n won't be in place before 2005 or even 2006.

The following table gives a brief overview of how the standards compare.

Standard	Nominal Data Rate [Mbps]	Actual Data Rate [Mbps]	Typical Range	Frequency [GHz]
802.11b	11	4-7	Up to 100m	2.4
802.11a	54	27-30	Up to 60m	5
802.11g	54	27-30	Up to 100m	2.4
802.11h	54	27-30	Up to 60m	5
Hiperlan2	54	42	Up to 60m	5
Bluetooth	1	1	Up to 10	2.4
UWB	100	N/A	Up to 10m	3-6

## **WLAN Security**

Anyone with a compatible wireless device can detect the presence of a wireless LAN. If appropriate security mechanisms are put in place, this does not mean that they can access the data, however. The wireless LAN should be configured so that anyone trying to access the wireless LAN has at least the same access restrictions as they would if they sat down at a wired network workstation. All the solutions below are practical steps to improve wireless LAN security.

- Wireless LANs that adhere to the Wi-Fi standard have a built-in security mechanism called Wired Equivalent Privacy (WEP), an encryption protocol. When wireless LAN equipment is supplied, the WEP encryption is often turned off by default. In order to be effective, it is essential that this security mechanism be turned on. Originally WEP encryption used a 40-bit or 64-bit encryption key and later a 128-bit key to increase security. All access devices must, however be set to use the same encryption key in order to communicate. Using encryption will slow down the data transfer rate by up to 30 per cent as it takes up some of the available bandwidth.
- SSID (Service Set Identifier) is the method wireless networks use to identify or name an individual wireless LAN. The default SSID (network name) and passwords should be changed. Access points may be set to broadcast the SSID to allow people to configure their own access.
- Utilize the Access Control List (ACL) that is standard in wireless LAN equipment. All devices have a unique MAC address; the ACL can deny access to any device not authorized to access the network. Use password protection on all sensitive folders and files.
- Install personal firewall software on all connected PCs and laptops.
- Avoid wireless accessibility outside buildings where it is not required; directional aerials can be obtained to restrict the signal to 180 degrees or 90 degrees from the access point.
- For the moment the installation of a VLAN is the most secure solution. VLANs have the same attributes as physical LANs with the additional capability to group end stations physically to the same LAN segment regardless of the end stations' geographical location. Traffic between VLANs must be routed. To interconnect two different VLANs, routers or Layer 3 switches are used. To segment traffic between two VLANs, an IT administrator must install two access points at each location throughout an enterprise WLAN network. A SSID defines a wireless VLAN on the access point and the bridge. Each SSID is mapped to a VLAN-ID on the wired side with a default SSID to VLAN-ID mapping.



However, WLAN security is not as efficient as wired security. For instance, some people had impression that WEP encrypts data end-to-end, not understanding that WEP is only a first-hop encryption solution. Once data is decrypted on the access point it keeps flowing through the Ethernet decrypted. And with that come all in securities that Ethernet brings. Moreover, since WEP is based on a shared key, all users associated on the same access point can sniff each other's data. Access point is just a wireless hub, not a switch.

### **Third and Fourth Generation Networks**

3G networks were proposed to eliminate many problems faced by 2G and 2.5G networks, like low speeds and incompatible technologies (TDMA/CDMA) in different countries. Expectations for 3G included increased bandwidth: 128 kbps in a car, and 2 Mbps in fixed applications. In theory, 3G would work over North American as well as European and Asian wireless air interfaces. In reality, the outlook for 3G is neither clear nor certain. Part of the problem is that network providers in Europe and North America currently maintain separate standards' bodies (3GPP for Europe and Asia; 3GPP2 for North America). The standards' bodies mirror differences in air interface technologies. In addition there are financial questions as well that cast a doubt over 3G's desirability. There is a concern that in many countries, 3G will never be deployed. This concern is grounded, in part, in the growing attraction of 4G wireless technologies.

A 4G or 4th generation network is the name given to an IP-based mobile system that provides access through a collection of radio interfaces. A 4G network promises seamless roaming handover and best connected service, combining multiple radio access interfaces (such as HIPERLAN, WLAN, Bluetooth, GPRS) into a single network that subscribers may use. With this feature, users will have access to different services, increased coverage, the convenience of a single device, on bill with reduced total access cost, and more reliable wireless access even with the failure or loss of one or more networks. At the moment, 4G is simply an initiative by 'R and D' labs to move beyond the limitations, and deal with the problems of 3G (which is having trouble meeting its promised performance and throughput).

At the most general level, 4G architecture will include three basic areas of connectivity: Personal Area Networking (such as Bluetooth), local high-speed access points on the network including wireless LAN technologies (such as IEEE 802.11 and HIPERLAN), and cellular connectivity. Under this umbrella, 4G calls for a wide range of mobile devices that support global roaming. Each device will be able to interact with Internet-based information that will be modified on the fly for the network being used by the device at that moment. In short, the roots of 4G networks lie in the idea of pervasive computing.

## **Wireless MAN**

### **HIPERMAN**

ETSI HIPERMAN (European standard) defines the requirements for an inter operable broadband fixed wireless access system operating at frequencies between 2 GHz and 11 GHz. Data Rates are up to 25 Mbps in a 7 MHz band and up to 100 Mbps in a 28 MHz band. The coverage is expected to be up to 15 miles range (around 20 km). The air interface will be optimized for Point to Multi-Point (PMP) configurations but may allow for flexible mesh deployments. HIPERMAN aims at having synchronization with the IEEE802.16a standard, such that worldwide standardized technology is available [27]. This standard is in draft mode. The real standard can be expected before the end of 2003.

### **802.16/802.16a standards**

802.16 standard is the wireless MAN equivalent of the 802.11 family of wireless LAN standards and it can be used to connect 802.11 hot spots to the Internet, provide campus connectivity, or provide a wireless alternative to cable and DSL for last mile broadband access. The base 802.16 standard is compatible with frequencies from 10 GHz to 66 GHz for fixed line-of-sight (LOS) high-bandwidth (up to 134 Mbps in a 28-MHz-wide channel) business-to-business wireless communications.

In January 2003, IEEE approved an extension to the 802.16 fixed LOS MAN standard-802.16a-to address licensed and unlicensed frequencies between 2 and 11 GHz that support non-line-of-sight (NLOS) communications more suitable for residential and small business

users. The 802.16a version has a range of up to about 50 kilometers (a typical cell could be up to 15 km) or more in point-to-multipoint configuration. 802.16a has a data rate per sector of up to 70 Mbps and can support around 60 users with T-1 speed (1.5 Mbps) connections or up to 400 homes at DSL rates. A typical BS has up to six sectors.

The ETSI's HIPERMAN standard will be based on a subset of 802.16a, so products based on either standard may achieve some level of interoperability. 802.16a-compliant products are expected to reach the market in significant numbers sometime in 2004.

In Denmark licenses are given to two frequency bands, 3,4-3,6 Ghz and 24,5-26,5 Ghz, known as the low and high band respectively.

Quality of Service: The IEEE 802.16a standard includes Quality of Service features that enable services including voice and video that require a low-latency network. The grant/request characteristics of the 802.16 Media Access Controller (MAC) enables an operator to simultaneously provide premium guaranteed levels of service to businesses, such as T1-level service, and high-volume "best-effort" service to homes, similar to cable-level service, all within the same BS service area cell.

Security: Privacy and encryption features are included in the 802.16 standard to support secure transmissions and provide authentication and data encryption. It is actually very close to an existing security protocol called DOCSIS, which is used in cable modems and requires heavy authentication.

### **802.16e Standard**

The IEEE 802.16e standard is planned to be an extension to the approved IEEE 802.16/16a standard and will operate in the 2-to-6-GHz licensed bands, with typical channel bandwidths ranging from 1.5 to 20 MHz. The purpose of 802.16e is to add limited mobility to the current standard which supports only fixed operation. One way to think of this future standard is Wi-Fi with a much bigger coverage range, and which allows people to use it while traveling in cars. A user will be able to move about in an 802.16a coverage area and-through use of a PC Card in a portable terminal device-remain connected. 802.16e mobile devices will of course be backward compatible with 802.16a fixed stations.

The target is to obtain a shared data rate of about 70 Mbps, but in practice 15 Mbps would for sure be achieved at range of up to 5 km. The final 802.16e standard is not expected before October 2004, and first 802.16e based systems before the beginning of 2005. Lastly, the cost of including the hardware for a 802.16e receiver into a laptop computer or PDA is expected to be affordable compared to the total cost of the device.

### **Mobile Broadband Wireless Access: 802.20 Standard**

The 802.20 working group (established by the IEEE in December 2002) aims to enable high-throughput data-rate NLOS links for motor vehicles and trains traveling up to 250 kilometers per hour (km/hour) in a metropolitan-area-network environment. The 802.20 proposed standard endeavors to optimize an IP friendly mobile wireless interface around today's packet-switching architecture.

The working group envisions that this standard will support data rates of greater than 1 Mbps at ranges of 15 km or more. It will operate in licensed bands below 3.5 GHz (500 MHz to 3.5 GHz) and incorporate global mobility and capability for roaming support between BSs. The standard will support real-time traffic with extremely low latency-20 ms or less. The low latency will help support voice over Internet protocol and typical channel bandwidth will be less than 5 MHz. Like 802.16, 802.20 will also likely see initial implementations using the PC Card form factor.

### **Satellite Broadband Access**

Satellite is another way to get broadband access. In recent years, satellite access has also become an option for broadband access. As the name implies, contrast to other explained technologies, satellite broadband access uses satellite which is located in space around 22,000 miles above from ground acts as hotspot. The satellite connected with both user and service providers. In other words satellite acts as a hub between the service providers and user. The User needs a satellite receiver called as satellite dish in order to get and send the radio signals.

There are two types of satellite access available. These are known as one-way and two-way satellite Internet access. In one way-way satellite access, a download link is available through satellite but upload is by some traditional ways e.g. using modem or xDSL connection; a subscriber requests the contacts to his satellite service provider and the service provides send the reply by satellite access. This is also known as hybrid satellite access. One-way satellite provides fast download speeds of between 400 Kbps and 1.5 Mbps. On other hand, in two-way satellite access both download and upload is achieved by satellite, instead of uploading by modem etc. This method provides more independence compared to one-way access. However, the compromise comes on speed, two-way provides around 200 Kbps upload and download speed. Other, the equipments used in two-ways are more expensive than the one-way satellite access.

Satellite broadband access still evolving, the bandwidth still not much offered compare to other bandwidth technologies. The equipments used for satellite access are also very expensive yet. Satellite access is useful for the remote areas where the cable option is not easily available. The performance for satellite is also degraded in bad weather conditions. Other issues are the QoS in satellite access; in one-way the delay of reply is quite apparent which is not suitable for application where QoS has highly demanded.

## **UWB**

An Ultra Wide Band (UWB) device is defined as one that utilizes a communication bandwidth of more than 500MHz or has a fractional bandwidth in excess of 20%. UWB technology operates in the 3 to 6 GHz spectrum. Traditionally, applications that require this much bandwidth were prohibited, as they would interfere with existing applications such as GSM and WLAN. UWB is unique as it is has the potential to co-exist with existing occupants of the frequency spectrum, with negligible interference to itself and others. This is because UWB devices transmit at extremely low power densities, in the order of 1,000,000 times lower than conventional transmitters such as mobile phones.

The very large bandwidth allows an high data rate transmission, 100 Mbps in a 10 m range. In a circle with a 10-meter radius, six UWB systems can operate simultaneously, each offering a peak over-the-air speed of 50 Mbps. The total aggregate speed of 300 Mbps, divided by the area of the circle, yields a capacity of approximately 1000 kbps per square meter.

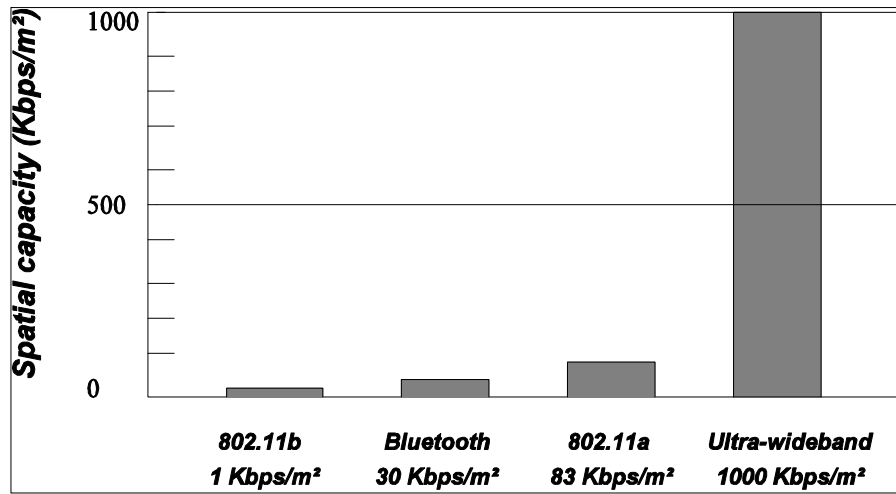


Figure 19: Spatial capacity comparison between IEEE 802.11, Bluetooth, and UWB

# 7. Broadband Services

In this appendix the broadband services will be looked in detail. What are the kinds of broadband services and their current and future trend will be discussed.

## Application Service

The essential motivation to establish the broadband IT infrastructure is the application services. The demand for broadband infrastructure thereby depends on the services offered. In the planning process of broadband IT infrastructure, the users' current and possible future demands of application services were focused closely. That would be worth-while to analyze what are the current application services for broadband available and what could be the potential future applications.

### Peer2Peer File Sharing

In recent years, the Peer2Peer (P2P) has become one of the most popular applications. P2P is actually a true broadband nature application; it demands very high bandwidth, depending upon the size of file being shared. Using P2P users can share almost anything, uploading and downloading with the connected party through P2P application.

In the future, the P2P demand will be higher and P2P will not only limit to only file sharing the data for collaboration research work.

### IP Telephony

IP telephony is gradually taking place of conventional telephony. IP telephony is also known as voice over IP (VoIP). IP telephony demands higher QoS, the inconsistent bit-rate can be a cause of jitter, it must be synchronous for both incoming and outgoing talks. The bandwidth standard for VoIP is either 56Kbps or 64kbps for uncompressed digital voice. However, using G.723 which is an international standard for compression of VoIP, the bandwidth can be reduced to only 6.4kbps or 5.3kbps with the overheads. Since IP telephony is a cheap way of calling, it is mostly used for long distance calls. The common way of IP telephony use is phone-to-phone, pc-to-pc, pc-to-phone and phone-to-pc.

The video conversation/video-conference over IP telephony is rapidly emerging too, also called video-telephony. The bandwidth demand for video conversation is comparatively higher than the voice conservation. There is a much higher bandwidth demand to support the video conservation. For the higher quality video conference a bandwidth of 1,54Mbps is needed. For the very lower quality the bandwidth can be compressed to 28.8kbps . The desire for higher quality is always very demanding by users.

## **Online Gaming**

Online gaming is to play games over the network, two or more users/players play interactively with each other. There are many kinds of online games and they require different bandwidth depending upon the type of games, 3D games are the most bandwidth demanding one. The broadband has given a kick-growth to online gaming. According to , the worldwide online game market will grow from \$875 million in 2002 to over \$5 billion in 2008. The major factor driving online game growth is the increasing broadband penetration.

## **Web Browsing Related Activities**

The browsing is known as web page visiting related activities, and one of the most practiced applications of Internet. With the evolution of Internet, the web pages have also been improved a lot, from simple text based web pages to multimedia enabled web pages. In multimedia web pages the emergence of enhanced graphics e.g. 2D and 3D interactive graphics, video and audio made the browsing more bandwidth demanding. Since multimedia enabled web pages attract people, more web sites are including them into their web pages. Slower connection will make the multimedia browsing more frustrating because of the download waiting time. The good argument could be with the availability of broadband the web browsing experience will be more exciting and pleasant.

## **Storage Area Network**

A storage area network (SAN) is a high speed network that interconnects different kinds of data storage with associated data servers on behalf of a larger network of users. Typically, a storage area network is part of the overall network of computing resources for an enterprise. Today SAN is mostly used in large organization and market is growing rapidly with the deployment of broadband. SAN becomes more useful with higher bandwidth for both recovery of data and backup. For the private users, the SAN can be very useful, at the moment there are now many companies offering services to backup data and then access it from anywhere, also famous as Internet network drives etc.

In addition, today the storage has become quite cheap and this trend is going on. With the availability of higher bandwidth SAN is expected to be more popular.

## **Broadcast TV and Radio**

Broadcasting TV or Radio over Network is very similar to the conventional broadcasting of TV and Radio. The signal for TV or radio are encoded into digital compressed form (e.g. MP3, MPEG etc.) and transported over the network. TV or video broadcasting needs very high bandwidth ~1.5Mbps to 15Mbps depending on the quality. In future with the deployment of FTTH, a set-to-box can be connected for TV or Radio broadcasting which can provide the ubiquity, rather than providing separate TV cable connection.

## **Video on Demand**

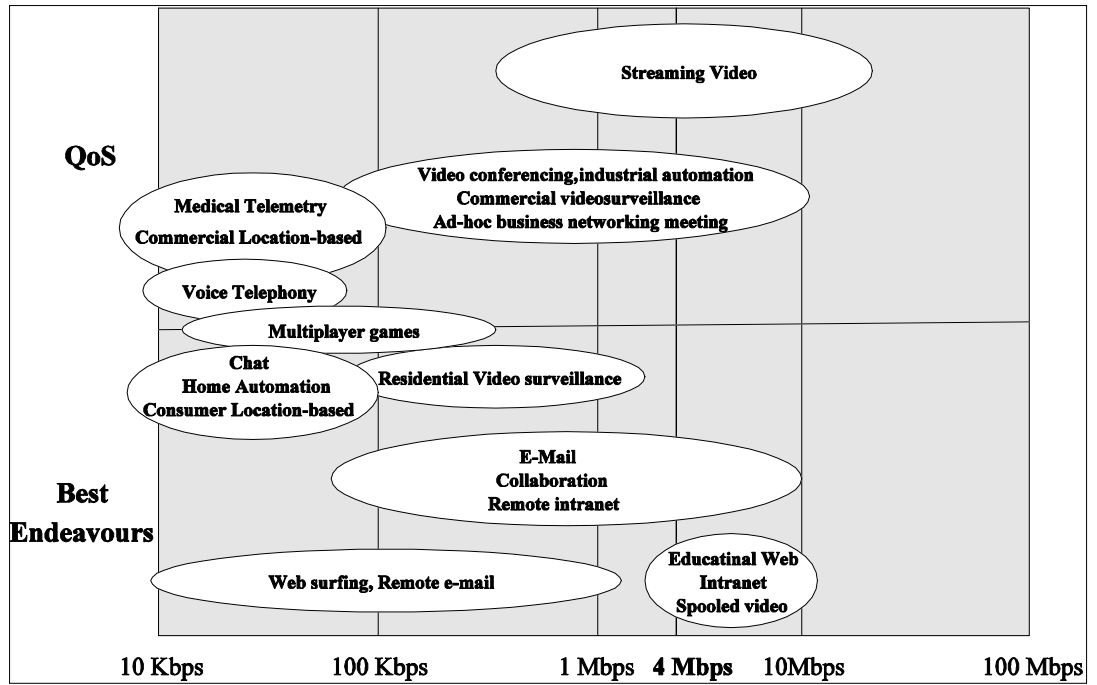
In video on demand (VoD) service a user asks desired video or movie to the digital video library. There are two possibilities to get the movies, either by downloading from the video server or by streaming it. Downloading and streaming is slightly different from each other. Streaming requires more or less constant bit rate, but for downloading that is not important. In the downloading case, user requests the video and then he is authenticated to download the movie in order to watch it whenever he wants, means pay one times and watch many times. On the other hand, while streaming video, user requests the video and then he is authenticated for streaming. User is not allowed to save the streaming video.

## **E-learning and Tele Commuting**

In the e-learning people can participate courses online. One of the exciting thing in e-learning is that the teachers not necessarily must meet at school, university or any institutions, it can be possible to perform the homework by sitting at home. Currently, there are many virtual universities which offer the courses online. In e-learning the lectures can also be broadcasted at real time. The e-learning is usually done by using email, file transfer, and video or audio based conference. For the large file transfer and good quality video conferences the demand of broadband is very high.

Tele commuting is very similar to the e-learning. In tele commuting, the user works at remote place instead of at working place using the similar ways of e-learning. Tele commuting is also called as virtual office. Today tele commuting is widely used in computer programming and development related jobs. Tele commuting or virtual offices can save a lot of revenue for work providers, they do not have to pay for the expensive offices and transports costs.





# 8. Network Structures

## Network Topology

The topology can be seen as the shape of the network, how the links are arranged between the nodes. Some topologies are shown in Figure 9figure. It should be noticed, that the sketches does not necessarily state the actual geographical arrangement of the nodes, the essential is how the links are arranged. Issues as network capacity, performance, redundancy and reliability are dependent of the topology.

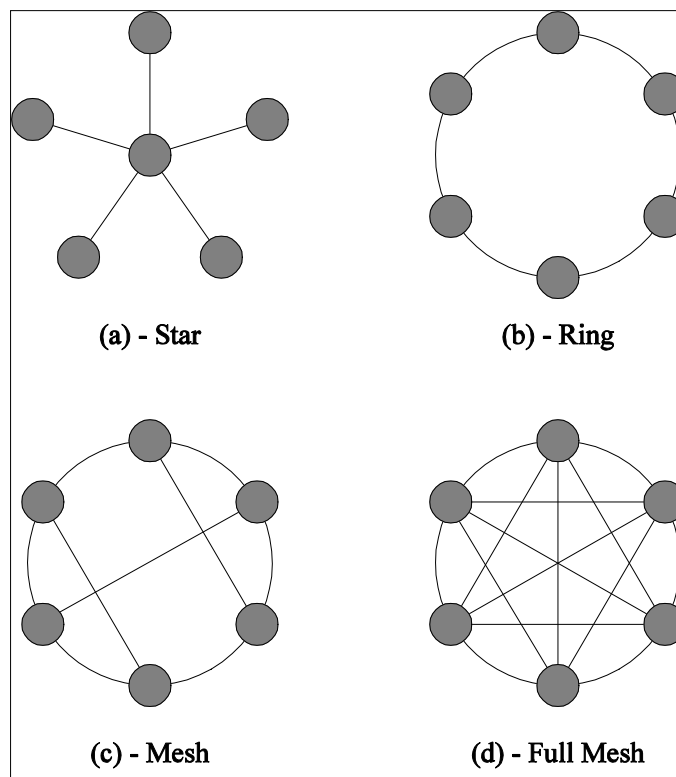


Figure 20: Different topologies of a network with six nodes.

In the star topology, Figure 20 (a), all other nodes are connected to one central node, also called a hub. A similar structure is the tree structure. From the root or hub, links branch out, and there may be several nodes along one branch. A node at the end of

one branch may be a sub root with several links branching further from this node. Such structures can easily be expanded, nodes can easily be added. They are also easy to map into real networks. However, they do not support any redundancy, no alternative paths are available, and are therefore not suitable for core structures.

A ring structure, Figure 20 (b), gives the simplest form of redundancy and is fairly easy to implement in practice. But also this is vulnerable. Only one protection path is present. To expand the structure, the ring has to be broken and a node inserted, hence less scalable than a star/tree structure.

Networks can be improved by the use of a mesh structure, Figure 20 (c). The capacity of the network will be increased for every line added between two nodes until all nodes are directly interconnected, giving a full mesh structure Figure 20 (d).

There are two kinds of meshed networks, ad-hoc and structured. The evolution of the WAN networks has gone an ad-hoc direction where nodes and lines have been added when needed. Consequently, no overall structure and complex routing algorithms and restoration schemes become a fact. Time consuming calculations of available capacity and support of real time QoS guarantees, are also consequences of ad-hoc networks.

Structural meshed network design aims to improve the structural performance. A key issue in this relation is the path length, or the number of hops, between two nodes. The full mesh structure will give the best performance for these criteria as the maximum distance in such structure is always 1. However, it is difficult to realize such a structure into wide-area networks. As the number of nodes grow, the amount of lines will increase significantly. For a given number of nodes  $n$ , the number of lines  $l$  in a full meshed structure can be calculated by the equation:

In this project, a structure for connecting 54 nodes is suggested. A full mesh structure would contain 1431 lines, hence clearly not cost efficient to realize. In order to provide some reliability, there should be at least two independent paths between every pair of nodes. With a minimum degree 3 for all nodes, there can be determined 3 independent paths between any two nodes. And in practice, 3 or 4 independent paths is the upper limit.

For large size "unstructured" ad-hoc networks, the regular routing algorithms have no problem finding the shortest path, also called the working path. Problems occur when finding the protection paths, that should be independent of the working path.

In [3], two approaches are considered to improve the structural qualities in mesh networks. The first one is based on a maximum spanning tree in order to minimize the path lengths. Only parameters for the root node according to the other nodes can be ensured in this approach, and not in between two other nodes. The second is using vertex symmetric graph structures. A vertex symmetric graph is a graph which looks the same viewed from any node. For this approach it is possible to obtain global properties. Studies have shown that structures of the N2R(p;q;r) family can give good structural properties close to the theoretical maximum. These are structures of nodal

degree 3, where the nodes are organized in two rings with  $p$  nodes in each,  $q$  and  $r$  indicates how the links are arranged in the inner and outer ring, or how many node jumps along the ring between two connected nodes, Figure 21. For further reading, see [3].

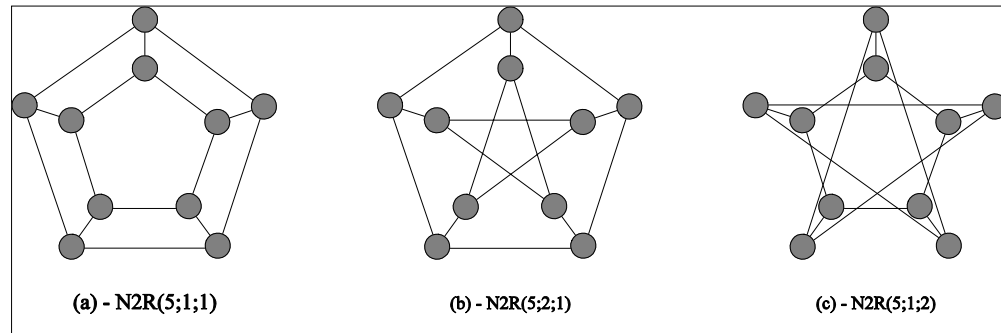


Figure 21:  $N2R(p;q;r)$ -graphs.

## QoS

Quality of Service (QoS) refers to the capability of a network to provide better service to selected network traffic over various technologies. The primary goal of QoS is to provide the priority including dedicated bandwidth, controlled jitter and latency, and improvement for loss characteristics. One important issue is to make sure, when providing the priority to a flow, that the other flows are not failing. The priority are given by either raising the priority of a flow or limiting the priority of other flows. This is basically done by congestion management tools where the priority of a flow is raised by queuing and servicing queues in different ways. QoS is very important in the real time transmission of voice and video services.

## SQoS

Structural Quality of Service (SQoS), or Sustainable QoS, is dealing with parameters primarily related to architecture and structural infrastructure properties in order to support QoS [3].

SQoS addresses reliability and scalability issues from a structural viewpoint. In QoS, certain network structures are analyzed in different situations of failures. Scalability in SQoS strives to find solutions if the network grows, what will be the impact on QoS. The concept of SQoS has been an effort to a base of reliability management in complex large scale communication network infrastructure. One typical example in SQoS is the number of hops in a network. There could be many network structures built using the same number of nodes, links and the degree. By changing the structure the network, performance can be optimized or vice versa.

Some applications like voice telephony or video conference etc. require a high level of QoS. Increasing the number of hops in a network leads to increased delay, and in such applications the delay decreases the performance. If the number of hops is minimized the performance can be increased.

As explained above, ad-hoc network can give complex restoration algorithms. Therefore most operators use structures with sets of interconnected optical rings, supporting fast restoration. On the other hand, if structured mesh networks are used, the restoration could be effective, even if more than one protection path is provided. Therefore, when designing a new network, these should be made future proof, and not only designed after the requirements today. The architecture should be structured, hence providing SQoS.

In addition, the network structure is also analyzed in failure of first path, in order to investigate if there exist second independent path and the same for the third path.

Using the properties of SQoS, the network can be optimized and the reliability can be increased.

## 9. Case Study

### *Strategy and Development Plan for Municipality of Hals*

#### **Introduction**

In previous chapters we have explained how the network planning tasks can be handled. In order to make the planning more understandable we will present a case study of strategy plan for the municipality of Hals [14].

#### **Infrastructure Planning for Municipality of Hals**

##### **Main goal**

This project is about to propose an analysis of elements in a long term strategy and development plan for a new IT infrastructure in the municipality of Hals. The goal is an overall coverage with fiber optic access and an extensive coverage with high-speed wireless access to support mobility. The high speed wireless access should also appear as a temporary substitute during the time to implement Fiber To The Home (FTTH).

##### **Collecting General Information for Municipality of Hals**

The municipality of Hals is located in the county of Northern Jutland in Denmark. More exactly, at the eastern coast of Jutland, north of Limfjorden. Figure 22 shows the geographical location of Hals and its surrounding municipalities.

There are about 3500 private households in Hals and as much as 3400 summer houses. The municipality has 6 villages: Hals, Gandrup, Hou, Stae, Ulsted and Vester Hassing. Hals is the most populated village in the municipality, but the City Hall and the municipality administration are located in Gandrup. The overall population in the municipality of Hals is 11,257.

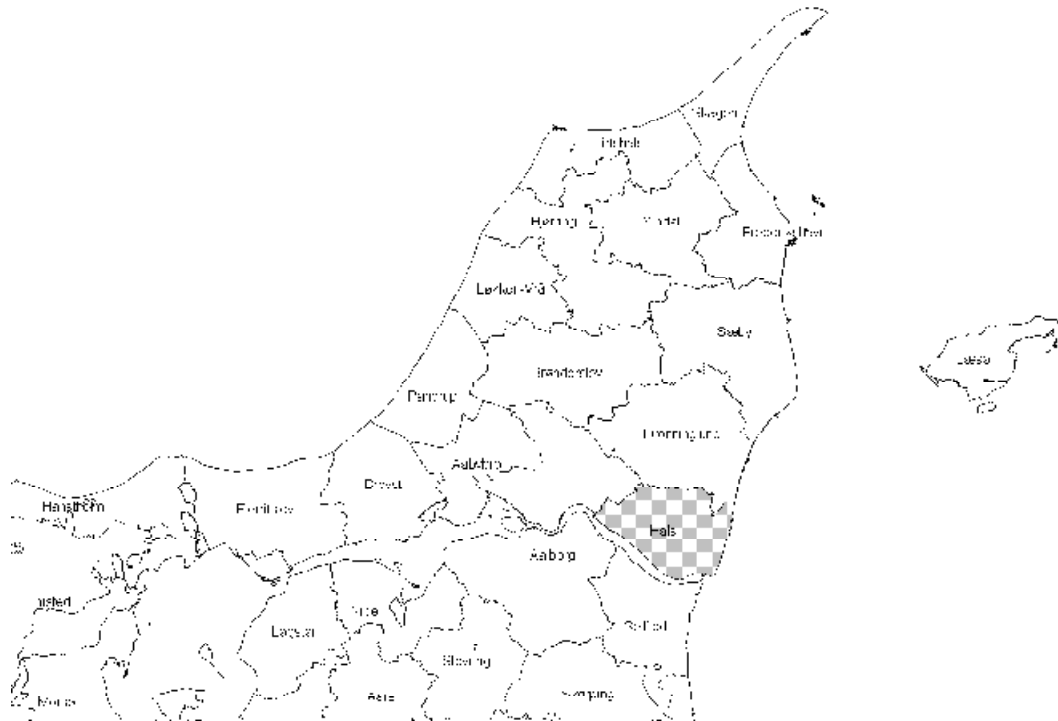


Figure 22: Location of the municipality of Hals in Northern Jutland.

The geographical location of the villages, together with the main roads and the summer house distribution, are shown in Figure 23.

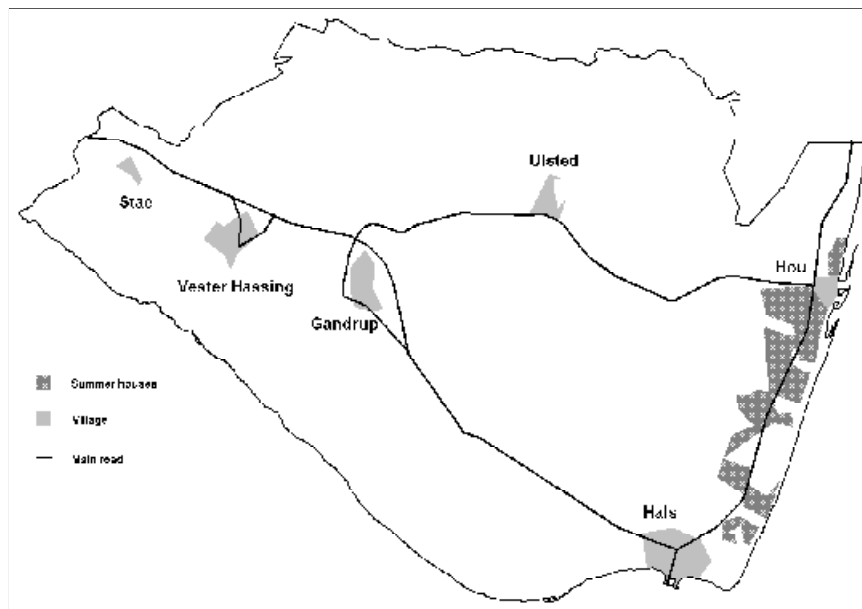
## Interested Parties for Infrastructure

In this section some information about interested parties will be provided. To obtain the following results, only assumptions have been made regarding the different parties current position in the municipality.

### Service Providers

From the service providers' view, they would lose some of the current market share if the new IT infrastructure is to be established in Hals. But the delivering of Internet access to the municipality is not covered by this infrastructure, and should be interesting for an existing or new service provider. IP Telephony and other application services to the private households and the business could also be a task covered by a service provider. Maintenance and management of such an IT infrastructure are other tasks which most likely can be covered by a service provider.

Many existing service providers do not own an access infrastructure, and have to rent connection from other providers. For such providers can a new IT infrastructure be an alternative to other existing network infrastructure.

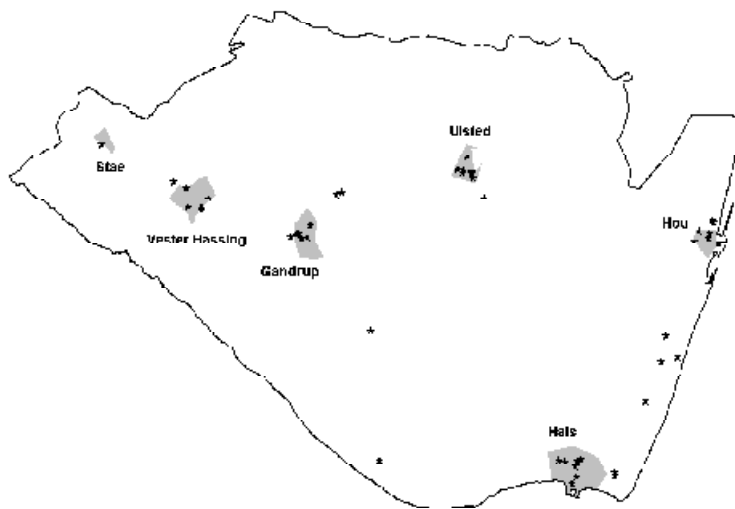


*Figure 23: The municipality of Hals with its villages and main roads.*

### **The Public Sector**

In Denmark, the national IT infrastructure is supposed to be market driven. Therefore a municipality like Hals could be interested of participating in an ownership of an IT infrastructure. The reason for this is that the municipality of Hals has sparsely populated areas and a lot of agriculture. The network operators are not interested in these areas due to high cost per customer of providing and maintaining an infrastructure. By participating in ownership of an IT infrastructure, an effective communication within the public institutions and interested neighboring municipalities can be established. Figure 24 shows the location of all public institutions in Hals.

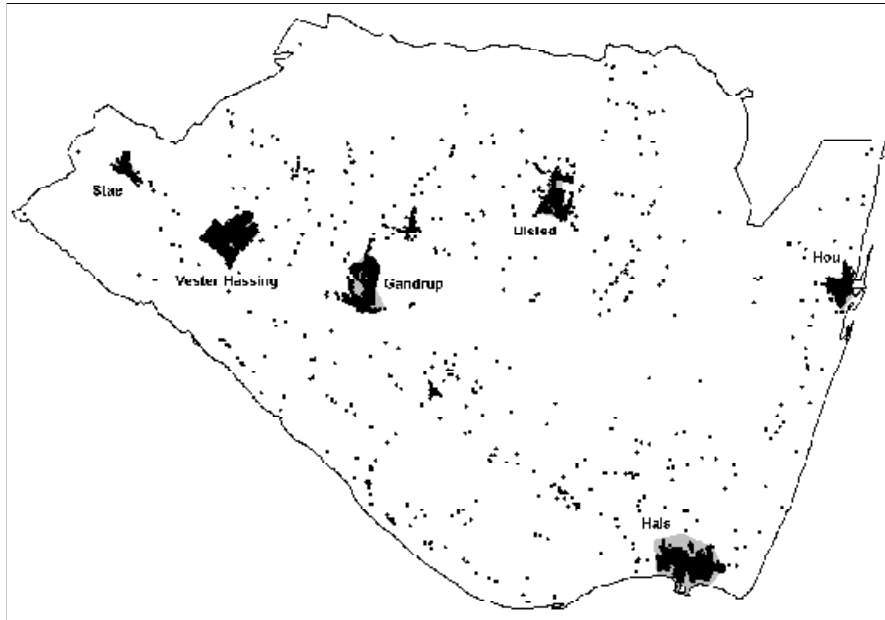




*Figure 24: The public institutions in the municipality of Hals.*

### **The Private Households**

When new and bandwidth demanding services become available in the future, broadband access offered by most of the today's network operators will not be sufficient. By this reason alone, the citizens in the municipality of Hals should be interested in a fast and cheap access to the Internet. This can be realized with a direct fiber connection. If the private households participate in a future IT infrastructure, the citizens also will be able to use services provided by the municipality as public health and security services, internal information; e-learning, etc. Figure 25 shows the distribution of the private households in the municipality of Hals.

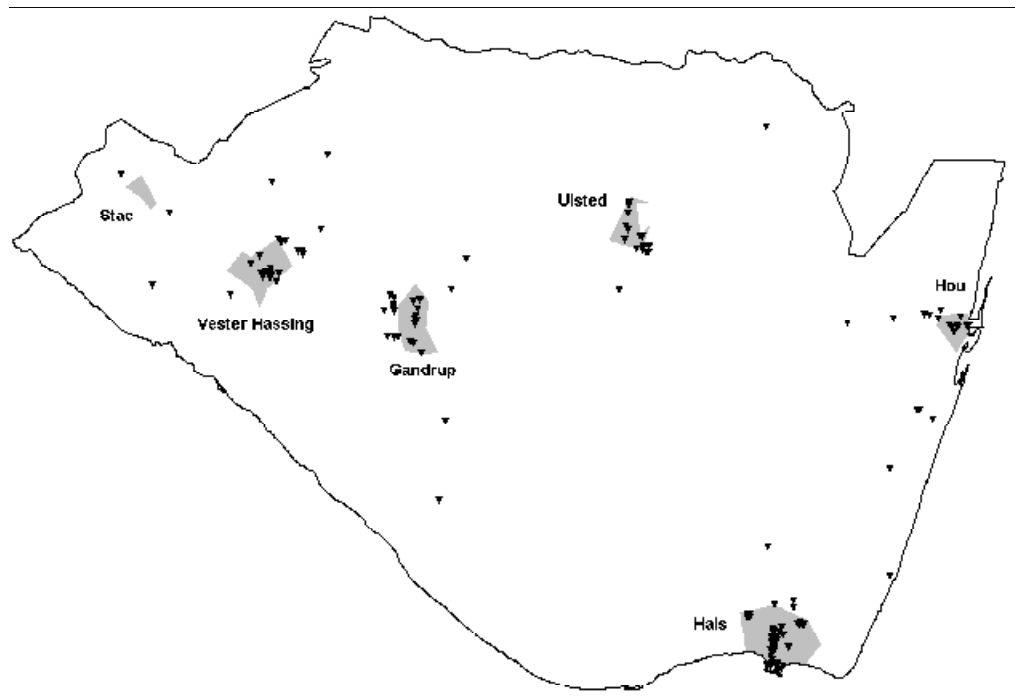


*Figure 25: The private households in the municipality of Hals.*

Some citizens may also be able to work at their homes with the increased bandwidth. This is especially interesting considering the municipality of Hals where the main part of the population has their daily work outside the municipality and uses a lot of resources for transportation.

### **The Businesses in Hals**

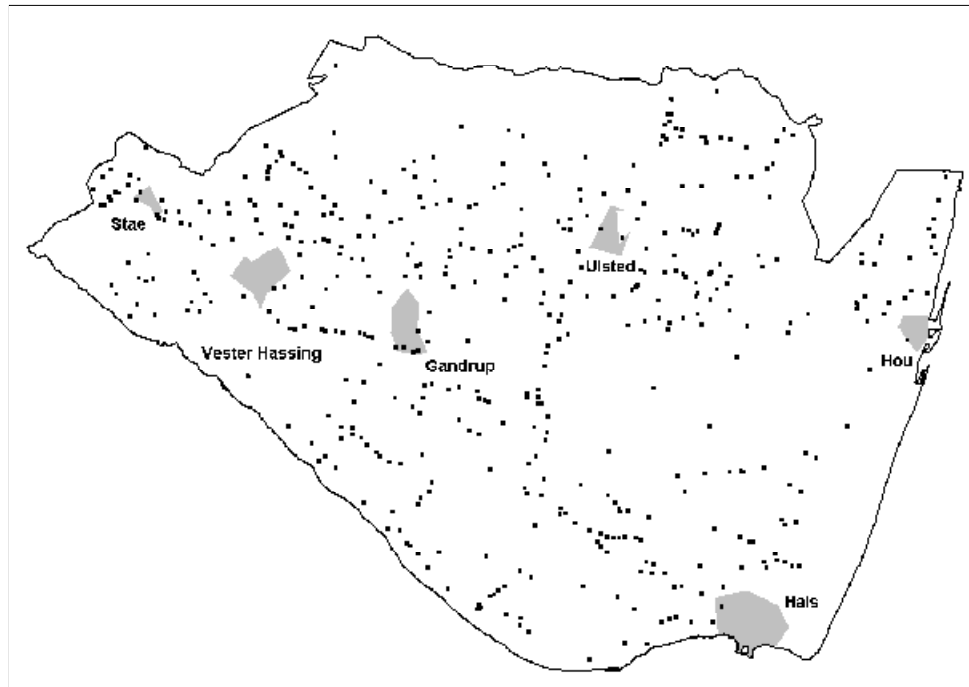
The businesses in Hals are located as seen in Figure 26.



*Figure 26: The distribution of the businesses in Hals exclusive the agriculture.*

A future proof broadband access to the Internet should be interesting for the businesses. Most of the businesses have few employees. By this reason the price for the IT infrastructure often becomes more important. A participation in the building of an IT infrastructure is expected to give the companies advantages on a regional, national and international business arena.

However, the main business in Hals is the agriculture, and the distribution of this can be seen in Figure 27.



*Figure 27: The distribution of agriculture in the municipality of Hals.*

Because of the geographical location, the agriculture is not often offered a proper Internet access. But the agriculture is often using the best access technology offered. The agriculture is often more dependent of a fast and reliable IT infrastructure than e.g. a bakery in a village.

New technologies available for the agriculture, like online control of feeding the animals, information when to harvest the crops, etc, are increasing the bandwidth demands in the future.

## **Planning strategy**

The final goal, to be obtained over time, is to provide every NT with a FTTH connection. FWA is established to cover the whole region and provide back-up paths for NTs requiring this. A backbone is also constructed connecting main nodes of the municipality with each other. One such main node is connected to the region backbone. As the backbone provides connectivity for both wired and wireless networks it must be established with sufficient redundancy to assure connectivity even in case of arbitrary failures.

The time perspective of the plan presented is 15 years. During this time three steps are considered: After 3 years the operational step should be implemented, after 5 years the tactical step should be implemented, and after 15 years the strategic step should be implemented. The aims of the operational and tactical steps are to implement the final solutions gradually and provide temporary solutions to the users

not yet connected by final solutions. In order to ensure a cost-efficient and fast deployment of the final solutions, temporary solutions are chosen such that they can form a part of the final solution. Redundancy is also added gradually.

Year	25%	50%	100%
2003	0.3	0.3	0.3
2004	0.3	0.4	0.5
2005	0.4	0.6	1.0
2006	0.5	0.9	2.0
2007	0.6	1.3	4.1
2008	0.8	1.9	8.2
2009	1.0	2.9	16.4
2010	1.2	4.4	32.8
2011	1.5	6.6	65.6
2012	1.9	9.8	131.1

*Table 3: Estimation of the future bandwidth demands in Mbps for each private household.*

It is of major importance that the networks can meet the QoS requirements demanded by the applications. This should be reflected in both temporary and final solutions. However, it is not trivial to predict the demands of the future, especially not 10-15 years or more ahead. Table 3 shows predicted bandwidth demands for private households (only the speed towards NTs are considered). A demand of 0.3 Mbps in 2003 is assumed as a base, and different increment rates considered. The growth is considered to be exponential, which is in accordance with Moore's law. This makes the predicted bandwidth demands highly dependent on expected increment rates and we will generally assume an increment rate of 50%. However, the importance of adjusting plans and choices of technology if the demands increase faster than expected should not be underestimated. Concerning redundancy, the current plan presented has the final goal of offering physically independent paths only for selected/important NTs, and the back-up paths are set up by wireless lines only. This is better than today where practically no physical redundancy is guaranteed, but it may not be sufficient: For users with a high bandwidth demand even in case of failures, the wireless connection may be insufficient, and it is not unlikely that even private users will demand redundancy. This is especially so if broadband connections become more widely used by medias such as television and telephony, or if they become used for applications like tele medicine and health monitoring.

Consequently, it may be necessary to establish physically independent fiber connections to selected NTs and to design wireless backup networks with a higher capacity than done in this study. Again, the development in demands must be observed, and the network planning strategy adjusted along the way.

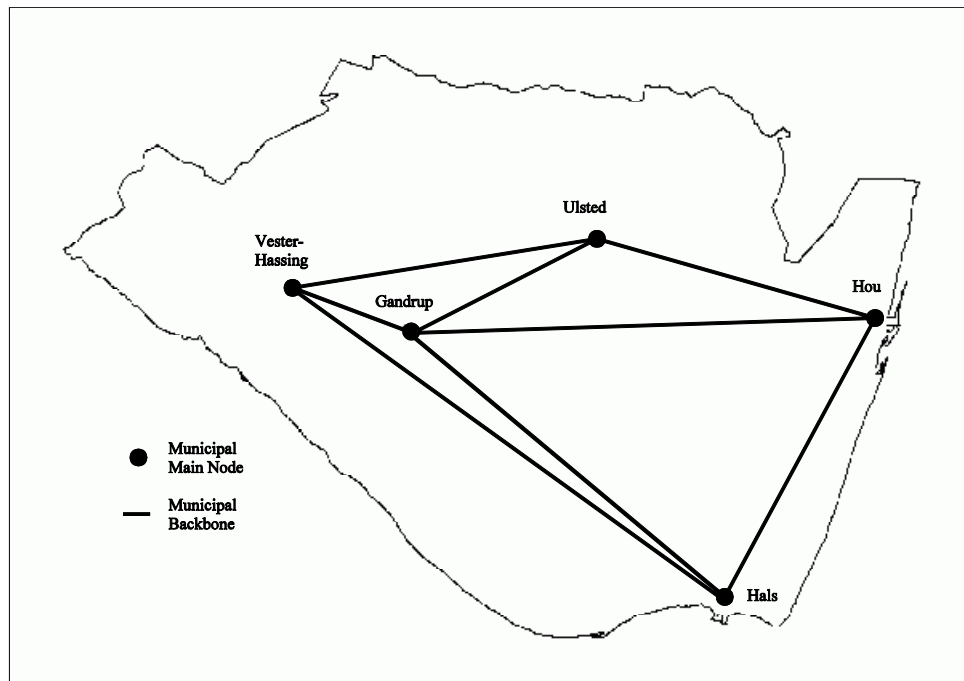
## Network design

### Operational step

During the operational step the following is obtained:

- A backbone is established.
- 56 selected NTs are served by FTTH.
- Every business is connected by at least 2Mbps.
- Every private household and summer house is connected by at least 512 Kbps.

The first step is to build a backbone providing connectivity and the next to connect the most important users to the backbone. As the most important users are considered to be the public sector together with the important businesses, the total number of NTs to be connected by FTTH at this point is 56.



*Figure 28: The backbone network in the municipality of Hals.*

The backbone consists of a number of nodes, called municipal main nodes, which are connected by a sufficient number of fibers. An important decision to make at this step is the location of nodes of the backbone. There is an obvious economical gain by placing these nodes near the existing TDC central offices since electricity etc. is supplied. Furthermore, this facilitates the use of the existing copper based infrastructure as a part of a temporary solution until FTTH is fully implemented. The number of main nodes, however, does also affect the cost of the backbone, and it is generally desired to keep the number of main nodes down. Further analysis based on the expected number of NTs connected to each main node indicates that four main nodes are sufficient, but in order to ensure sufficient redundancy, it is suggested to establish five main nodes. The suggested backbone design is shown in Figure 28. The main node in Gandrup is also connected to the region backbone, providing connection to the global Internet. It is not difficult to verify that the network remains connected even in case of two arbitrary failures and the availability of the backbone is estimated to be 99.999997 %. It is not necessary to establish redundancy in the backbone to make the network operational, and as such only 32.5 km of ducts are established in the operational step. The total duct lengths of the backbone sketched in Figure 28 is 84.1 km. of which the rest is gradually added during the tactical and strategic step. The fiber based access network, connecting the 56 selected NTs to the backbone, is estimated to have a duct length of 28.0 km.

In order to connect all NTs already in the operational step, an ADSL/VDSL solution is deployed for NTs located sufficiently close to the main nodes. As ADSL connections providing at least 2 Mbps are generally available as long as the copper cable length does not exceed 2 km, it is assumed that all NTs within a radius of 1.4 km from the main nodes can be connected by ADSL/VDSL. 1.4 km is chosen to take into account the fact that the cable length is often longer than the direct distance. ADSL/VDSL connections are available to approximately 3900 NTs at this step.

The remaining approximately 3600 NTs are connected by FWA. A number of trade-offs have to be made when designing such a wireless network, including trade-offs between coverage throughput and the number of base stations (BS). 802.16a is chosen as technology. Each BS defines a cell of coverage, and in order to ensure optimal connections for the end users, the radius of a cell should not exceed 5 km. Furthermore, the total data rate needed in one cell should not exceed 280 Mbps, which is the maximum throughput a BS with 4 sectors can provide. It is assumed that every NT has probability 0.2 of sending data at any given time, an important factor since the total data rate is shared among the users. Considering these geographical and traffic constraints, it is chosen to establish 5 BS. They are generally located at the main nodes, except for one (Gandrup), which is placed differently in order to obtain a homogenous coverage.

At this step NTs connected by FTTH or ADSL/VDSL can in principle use the FWA coverage for backup. However, as wireless and wired connections from a given NT often terminate in the same main node, and since redundancy is not yet established in the backbone network, no real redundancy is guaranteed yet.

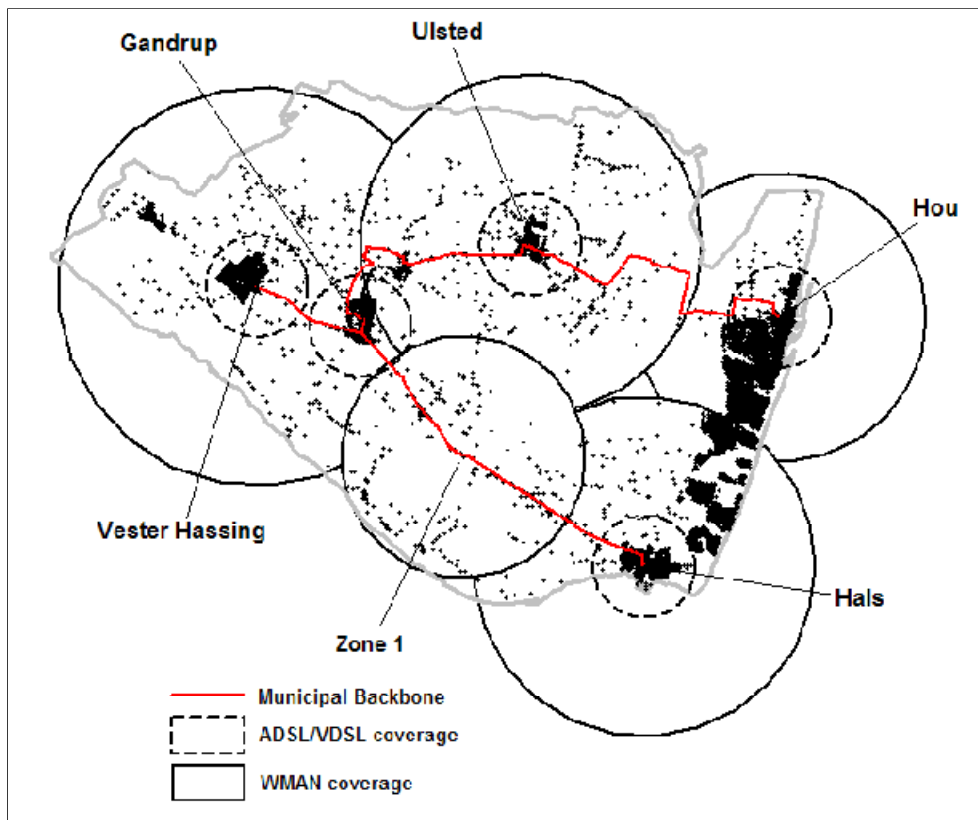


Figure 29: Operational step ADSL/VDSL and FWA coverage.

Figure 29 shows the complete implementation of the operational step. A backbone has been implemented and fiber access granted to public institutions and important business. For the remaining NTs 52 % are connected by ADSL/VDSL and 48 % by FWA.

### Tactical step

During the tactical step the following is obtained:

- Redundancy is added to the backbone.
- Approximately 700 NTs are connected by FTTH.
- NTs not connected by FTTH are connected by at least 4Mbps.



- Redundancy ensures that two physically line independent paths exist between any pair of nodes connected by wired connections.

In this step FTTH is extended to cover the small and medium sized business as well as the agricultural sector. Due to the expected increase in bandwidth demands it is unlikely that the previously established bandwidths of 512 kbps for private households will remain sufficient. As a compromise between cost and expected application demands, we have chosen to aim for a solution such that every NT is connected by at least 4Mbps when the tactical step is implemented. According to table 1 this should satisfy the bandwidth demands until 2010 with a growth of the traffic of 50% per year. When the tactical step is implemented 51.4 km of the backbone ducts been established as well as 219.4 km access network ducts. During the tactical step a total of 194 km ducts are established, of which 16.3 are shared between backbone and access networks.

The NTs not connected by FTTH in the tactical step remain connected by either wireless access or ADSL/VDSL. This is expected to be the case for approximately. 3700 NTs connected by ADSL/VDSL and approximately. 3200 NTs connected by wireless access. These NTs consist of private households and summerhouses, and their connections are upgraded to at least 4Mbps. We assume that most of the users connected by ADSL/VDSL will be able to obtain this speed through existing copper lines, in some cases by upgrading or changing the ADSL equipment in the central offices in order to support VDSL. In case some of these NTs cannot obtain 4Mbps by ADSL/VDSL they are connected by the FWA solutions described in the following.

The FWA coverage must be changed due to the changing number of NTs and different bandwidth demands. There are many summer houses located on the eastern coast between Hals and Hou, and consequently the density of NTs is highest in this area. The infrastructure established in the operational step did cover the whole municipality well enough to offer 4Mbps connections given that enough of the shared bandwidth is available. As the shared bandwidth becomes the bottleneck in the tactical step, the wireless coverage is improved by adding three more BS in the eastern part of the municipality, and consequently redefines the sizes and shapes of the cells. The new BSs are placed along the backbone in order to avoid additional duct costs, while the BSs established in the operational step remain unchanged.

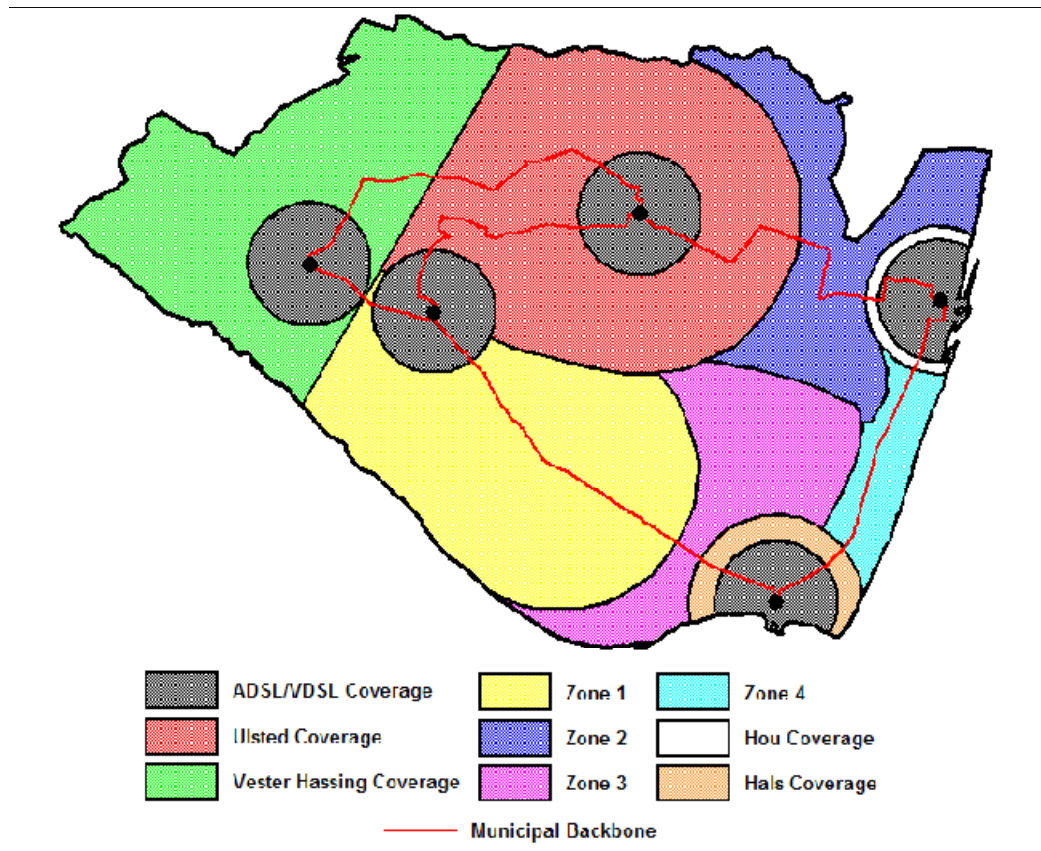


Figure 30: Tactical step ADSL/VDSL and FWA coverage.

Figure 30 shows the implementation of ADSL/VDSL and wireless networks in the tactical step together with the improved backbone. Redundancy is now guaranteed in the backbone such that it remains connected in case of any single failure, and line-independent paths exist between any two nodes connected by both wired and wireless solutions. However, the co-location of main nodes and BSs may still be critical. This can be handled by maintaining a high level of redundancy in the main nodes, including dubbing of equipment, electricity supply etc.

### Strategic step

During the strategic step the following should be obtained:

- Every NT is connected by FTTH.
- There exist two independent paths between any pair of nodes.
- Redundancy ensures that the backbone stays connected even in case of two arbitrary failures.

The ultimate and final solution is obtained by connecting every NT by FTTH. The ADSL/VDSL solutions become obsolete at this step, and so does the FWA

connections, except for their back-up functionality. When the strategic step is implemented the complete ducts of the backbone, 84.1 km, have been established as well as the total 381.4 km access network ducts. During the strategic step a total of 166.9 km ducts are established, of which 27.8 km are shared between backbone and access network.

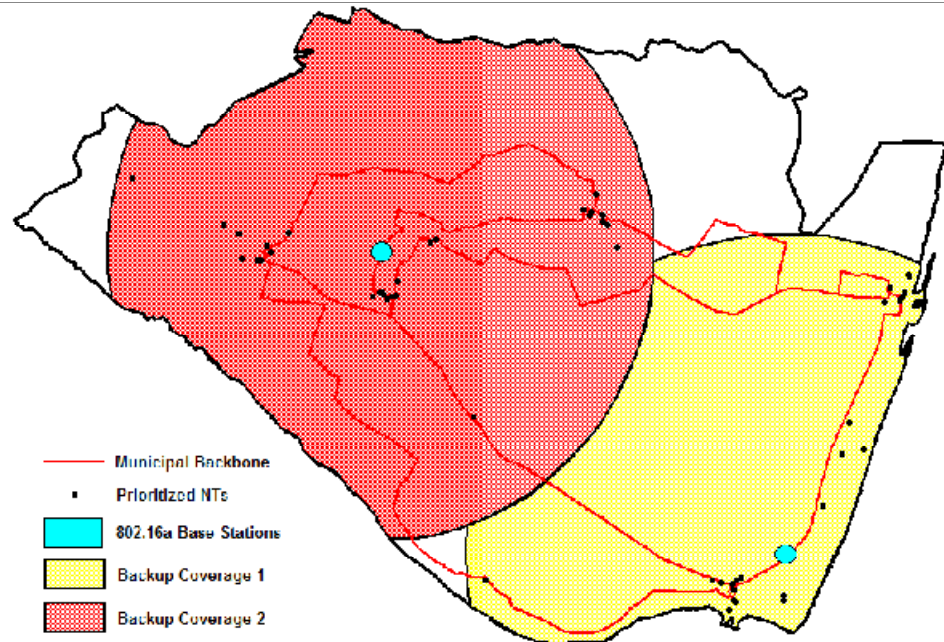


Figure 31: coverage for the strategic step of implementation.

Since the wireless access is now used only for back-up, the traffic that it is expected to carry is considerably smaller: Only the 56 NTs which was connected by FTTH during the operational step are considered for the fixed wireless backup. Assuming that a 10Mbps connection is sufficient for each of these NTs, only two BSs are necessary to cover the complete municipality. However, it is necessary to move the BSs to obtain a good coverage. Figure 31 shows the backup coverage as well as the placement of the prioritized NTs with backup access. The coverage area of BS1 is considerably shorter than the coverage area of BS2 in order to ensure that all prioritized NTs are assured 10Mbps despite the shared bandwidth. It is not difficult to provide backup-connections to more NTs by using more BSs.

## Summery

The cased study shown briefly how the network infrastructure is planned including both wired and wireless broadband technology. The strategic approach which is described in detailed in Chapter 3 is empirically shown in the case study of municipality of Hals. It is also shown that how the network can be planned with

taking different strategic steps in different time space in order to reach the main goal of planning the municipality's network infrastructure.

# 10. References

- [1] Ole B. Madsen, Jens D. Nielsen, Henrik S. Convergence. Proceedings of RTLIA 2002, Wien, 2002.
- [2] Jens M. Pedersen, Tahir M. Riaz, Ole Brun Madsen, Combining Wired and Wireless Networks for a QoS-Aware Broadband Infrastructure. QShine 2004, Dallas Tx 2004.
- [3] Ole B. Madsen, Thomas P. K. Jens M. Pedersen, SQoS as the base for next generation global infrastructure. Proceeding of IT&T Conference 2003, Letterkenny, Ireland, 2003.
- [4] K. G. Coffman and A. M. Odlyzko. Internet growth: Is there a “Moore’s law” for data traffic? AT&T Labs – Research July 2000.
- [5] Ole B. Madsen, Lecture Notes from the course; Network Planning Modeling & GIS. Aalborg University, 2002. <http://www.control.auc.dk/~obm>.
- [6] Ramaswami, Sivarajan, Optical Networks – A Practical Perspective, Second Edition, Morgan Kaufmann, 2002.
- [7] Hans Wallberg, General Guide to a Future-proof IT infrastructure. The Swedish ICT Commission 2001.
- [8] Stallings, High-Speed Networks and Internets, Second Edition, Prentice Hall, 2002.
- [9] Grover, Mesh Based Survivable Networks – Options and Strategies for Optical, MPLS, SONET, and ATM Networking. Prentice Hall, 2003.
- [10] John Lester Miller, Dr. Edward Friedman, Optical Communication Rules of Thumbs. McGraw-Hills 2003.
- [11] Thomas G. Robertazzi, Planning Telecommunication Networks. IEEE Press 1999.
- [12] Ron Olexa, Implementing 802.11, 802.16, and 802.20 Wireless Networks. Elsevier Inc. 2004.
- [13] Junming Xu, Topological Structure and Analysis of Interconnection Networks. Kluwer Academic publishers, 2001.
- [14] Tahir M. R., Frode F., Pedder H., Gebrial M, Pettia V. Strategy and Development Plan for IT infrastructure in the Municipality of Hals. Aalborg University, 2003.

- [15] Tahir M. R. Frode F. Pedder H. Michael P. Christian L., Simulation and Modeling Platform for Large Scale Networks, Aalborg University 2003.
- [16] Tahir M. R. Frode F. Pedder H., Transmission Network Planning for Sonofon. Sonofon, Aalborg University 2004.
- [17] National IT and Telecom Agency. Annual Report. National IT and Telecom Agency, 2002.
- [18] DSL Forum DSL Glossary. DSL Forum, September, 2004. [http://www.dslforum.org/about\\_dsl.htm?page=PressRoom/DSL\\_Glossary523.html](http://www.dslforum.org/about_dsl.htm?page=PressRoom/DSL_Glossary523.html).
- [19] CATV CyberLab. Cabel Speed. CATV CyberLab, 2004. <http://www.catv.org>.
- [20] J. Prat P.E. Balaguer J. M. Gene O. Diaz and S. Figuerola. Fiber to the Home Technologies. Kluwer Academic Publishers, 1 edition, 2002.
- [21] What you need to know about. Introduction to Sonet/SDH, 2003. <http://compnetworking.about.com/library/weekly/aa092800a.htm>.
- [22] Robert Elsenpeter with Toby J. Velte. Optical Networking . McGrawHill/Osborne, 1 edition, 2002.
- [23] Alcatel. Alcatel 6620 FTTU Outside Plant Product Family. Alcatel, 2004. [http://www.alcatel.com/doctypes/opgproductbrochure/pdf/a6620\\_fttu\\_pb\\_4q022.pdf](http://www.alcatel.com/doctypes/opgproductbrochure/pdf/a6620_fttu_pb_4q022.pdf)
- [24] Alloptic staff. Gigabit Ethernet Passive Optical Networks. Alloptic, 2004. <http://www.alloptic.com/products/whitepapers/031601.htm>.
- [25] Ict advice. Wireless Local Area Networks. Ict advice, October 2004. [https://www.ictadvice.org.uk/downloads/wirelesslan\\_technical.doc](https://www.ictadvice.org.uk/downloads/wirelesslan_technical.doc).
- [26] Tony Smith. IEEE preps 802.11n 320Mbps WLAN spec. The Register, 2004, <http://www.theregister.co.uk/content/69/30232.html>.
- [27] STRIKE. Synthesis report on current status of standardization of broadband FWA. STRIKE. <http://ist-strike.org>.
- [28] Jeffrey Fritz. Network Modeling Tools, Network Worlds 2004. <http://www.nwfusion.com/reviews/2004/1018rev.html>.
- [29] David Storm. The Coming Broadband Cogestion. Mappa and Mundi Magazine, 1999. [http://mappa.mundi.net/inform/archive/inform\\_0163.html](http://mappa.mundi.net/inform/archive/inform_0163.html).

# 11. Acronyms

ATM	Asynchronous Transfer Mode
ACL	Access Control List
AWD	Array Waveguide Grating
ADM	Add Drop Multiplexing
ADSL	Asymmetric Digital Subscriber Line
AP	Access Point
ANSI	American National Standards Institute
BS	Base Station
BSS	Basic Service Set
CPE	Customer Premises Equipment
CDM	Code Division Multiplexing
CDMA	Collision Detect Multiple Access
CDMA	Code Division Multiple Access
CN	Connection Node
CO	Central Office
DN	Distribution Node
DSL	Digital Subscriber Line
DPT	Dynamic Packet Transport

DP	Distribution Point
DWDM	Dense Wavelength Division Multiplexing
FTTH	Fiber to the Home
GPRS	General Packet Radio Service
GIS	Geographic Information System
GRASS	Geographic Resources Analysis Support System
GSM	Global System for Mobile Communication
Gbps	Gigabit per second
HE	Head End
IT	Information Technology
IP	Internet Protocol
IEEE	Institute of Electronics and Electrical Engineering
IBSS	Independent Basic Service Set
ISDN	Integrated Services Digital Networks
INU	Interface Network Unit
Kbps	Kilobit per second
LED	Light Emitting Diode
LAN	Local Area Network
LOS	Line of Sight
Mbps	Megabit per second
MBps	Megabyte per second
MBps	Megabyte per second
MPLS	Multi Protocol Label Switching
MAC	Media Access Control
MAN	Metropolitan Area Network
MHz	Mega Hertz



MN	Main Node
NLOS	None Line Of Sight
NS	Network Simulator
NT	Network Termination
NIC	Network Interface Card
OLT	Optical Line Terminal
ODN	Optical Distribution Node
ONT	Optical Network Termination
ONU	Optical Network Unit
PON	Passive Optical Network
P2P	Peer to Peer
PSTN	Public Switched Telephone Network
QoS	Quality of Service
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical Networks
SRP	Spatial Reuse Protocol
SDSL	Symmetric Digital Subscriber Line
SSID	Service Set Identifier
SAN	Storage Area Network
SQoS	Structural Quality of Service
TDMA	Time Division Multiple Access
TDM	Time Division Multiplexing
UWB	Ultra Wide Band
VCSEL	Vertical Cavity Surface Emitting Laser
VoIP	Voice over IP
VoD	Video on Demand

WAN      Wide Area Network  
WiFi      Wireless Fidelity  
WEP      Wireless Encryption Protocol  
WDM      Wavelength Division Multiplexing  
2D      2      Dimension