Introduction to requirements, models, topology and design of large (FTTx) networks

Hans Eric Sandström[1], Stefan Gistvik[2]

[1] Dpt. of Information Technology and Media ITM, Mid Sweden University, Sundsvall, Sweden, E-mail: hes@xinit.se

[2] Fiberson AB, Hudiksvall, Sweden, E-mail: stefan.gistvik@fiberson.se

ABSTRACT – Fiber to the end-user (FTTx) a generic term for all network architectures that uses optical fiber to deliver broadband services. In recent years we have seen the broadband market changing from delivering IP-services over a Telecom infrastructure to pure IP-only architectures. One of the driving forces behind this change is the cost of network components. Building broadband infrastructures, as shown in the picture, using off-the-shelf IP-network equipment is much cheaper than using dedicated telecom equipment.

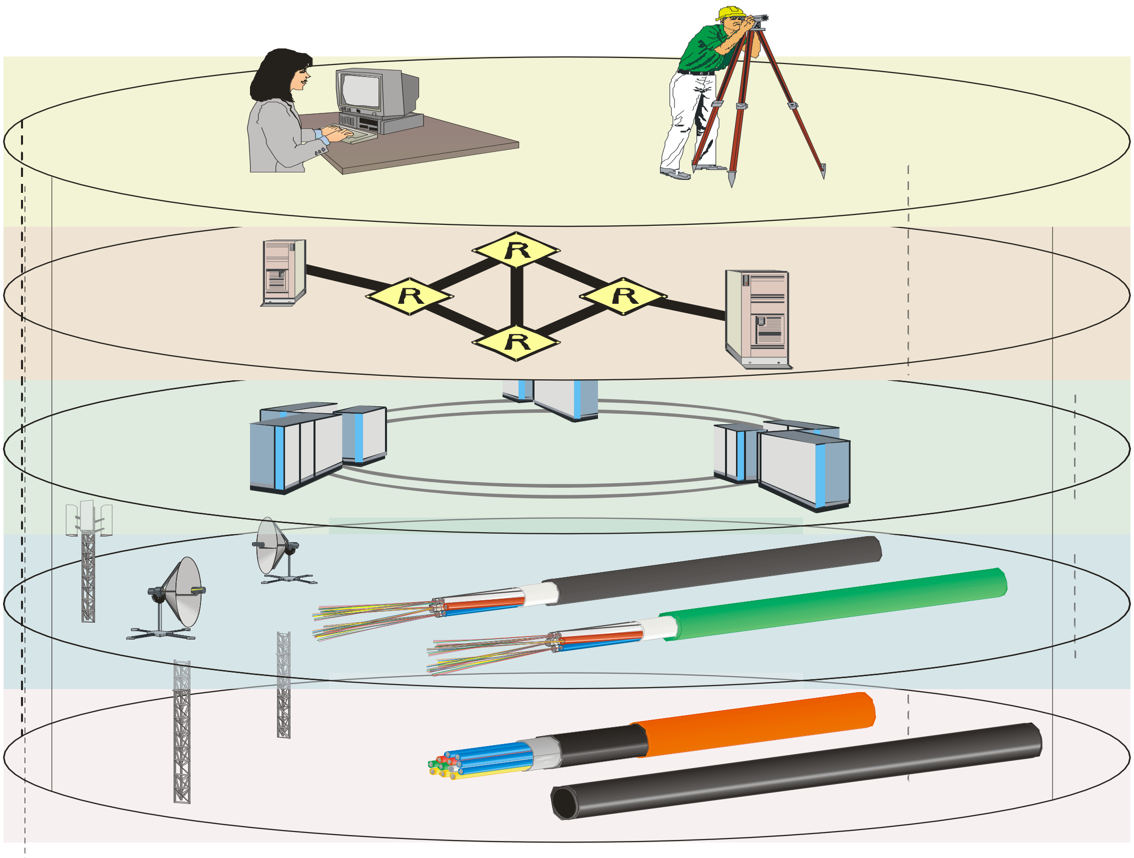

Figure 1: Network Infrastructure

Introduction

Cost effective design of FTTx networks has to start with known facts such as the end-user requirements and characteristics of the physical and active network components. Fiber is a long lasting investment; the resulting design has to be able to cope with the changes in end-user demands and technology development of active components over a long time period, 30 years or more. Using a modelling phase will help identifying conflicting requirements and give insights on the dynamic behavior of the model and thus the resulting network. The result will be a design that will meet all requirements and also deal with the trade offs of conflicting demands. This document will focus on design issues in the physical infrastructure and in the lower levels of the network architecture.

Correctly designed FTTx networks must be designed in such a way that the final network will offer a much lower total cost of ownership (TCO) than any other alternative. In this document we will show how to utilize the advantages of a fiber-only deployment to build such a broadband network.

Historically all new technology has been hampered by our tendencies to build new infrastructures the same way as we have always done. This means that we tend to build broadband networks much the same as we have built our data networks and we are hampered by the shortcomings of the old technology. In fact the new fiber optic infrastructure is very similar to the old telephone network. The old telephone networks could only deliver one advanced service – telephony, the new fiber optic infrastructure will in fact only deliver one service to, sufficiently fast and reliable IP-traffic.

One of the most prominent mistakes done when designing (single-mode) FTTx networks is the assumption that the distance from the customer to the access equipment is the same as for copper. This leads to designs which require active access equipment to be placed very close to customers. This is costly since all active equipment requires maintenance and is also replaced more than once during the lifetime of the passive fiber network.

Another common mistake is to model the physical infrastructure based on the current requirements of the available active equipment, thus creating a slim design with very little flexibility and redundancy and often no spare ducts for extra fiber. Configuration mistakes like point-to-point routing configurations that block the transparency on the data link layer, making it impossible to create end-to-end VLAN’s, are easy to fix but physical layer mistakes are very costly.

Background

Broadband networks has come a long way from its humble beginnings and has evolved from point to point connections where data was transmitted over telephony infrastructures to the now dominant fully transparent Ethernet/IP-only infrastructures. Technology development has been driven by the success of Ethernet and the TCP/IP protocols and the price drop for Commercial Of The Shelf (COTS) equipment in this area makes it possible to deliver affordable 100/1000 Mbps broadband to end users.

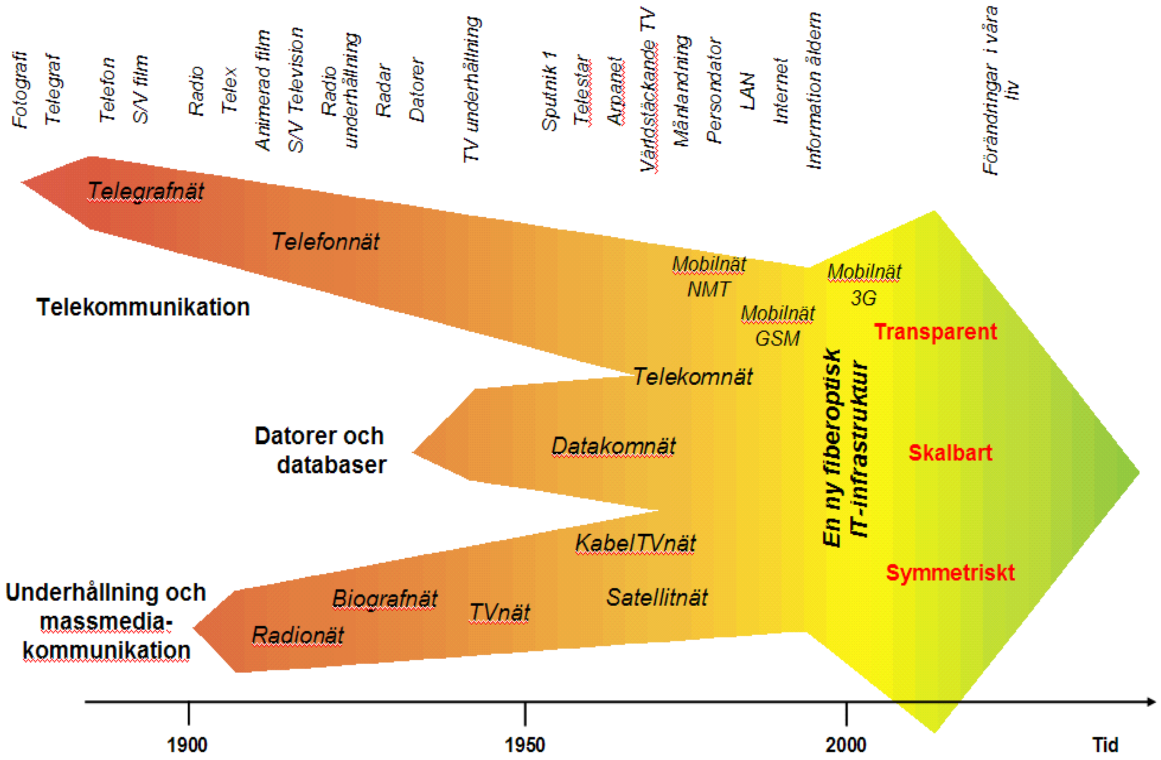

Figure 2: Network evolution

Requirements

Network design has to start with requirements and requirements have to be defined very clearly. Let us introduce a very simple network model, Fig 1. Using this model we can then form a set of basic requirements for a broadband network and the services it has to be able to carry. Note that these requirements are always end-to-end requirements for the whole network.

<u>Transparency</u>

A broadband network has to offer transparent delivery of packets from one customer to another. Or more exactly from one interface on one Customer Premises Equipment (CPE) to another interface on another or the same CPE. The standard interface for the customer today is 10/100/1000 Mbps RJ-45 and this will be the case for the foreseeable lifetime of CPE's delivered today. Transparent means that packets should not be blocked or altered by the broadband operator. There are some exceptions to the transparency rule to prevent network abuse, for example stateful dhcp snooping to block address resolution protocol (ARP) spoofing. A correctly designed multi layered network will be able to deliver this transparency on all network levels and also end-to-end over the whole network.

Closed Groups

A broadband network has to be able to create groups to restrict the delivery of packets to be only point to point or point to multipoint between CPE interfaces. On the data link level this is know as a VLAN and on higher network levels a Virtual Private Network (VPN). Network transparency is even more important in this case since all interfaces on all CPE's should be able to reach each other if they belong to the same group.

QoS

A broadband network should be able to offer guaranteed bandwidth rates on the CPE Interfaces within the limits of the interface capacity 10/100/100 Mbps and within the limits of the availability limits of the Service Level Agreements (SLA). For example if the Committed Bandwidth Rate (CBR) of an interface is 20 Mbps and the SLA availability is 99.5% then the customer should receive that bandwidth 99.5% of the time. This gives the operator some room for statistical over commitment of total available bandwidth. Given that his network offers an availability that exceeds 99.5%. The only other QoS mechanism suggested as shown by [1] is Explicit Congestion Notifier to handle Rapid Early Detection (RAD) in congestion situations. This means that the core of the network still is a very cost effective best-effort network and SLA is handled by over provisioning and statistical over commitment.

Network modeling and planning

The simplified network model introduced in the previous chapter does not give any hints on the topology of the network. So let’s add some more abstract network components to the model, Fig 2. The abstract components of this model are: Customer Premises equipment (CPE), Access Node Equipment, Core Network Equipment. The core node does not have any connections to CPE's. Core nodes can handle inter domain routing, that is traffic between independently managed networks. An inter domain link is just a core to core connection with some special protocols (like BGP). The arrows illustrate one to many or many to many relationships.

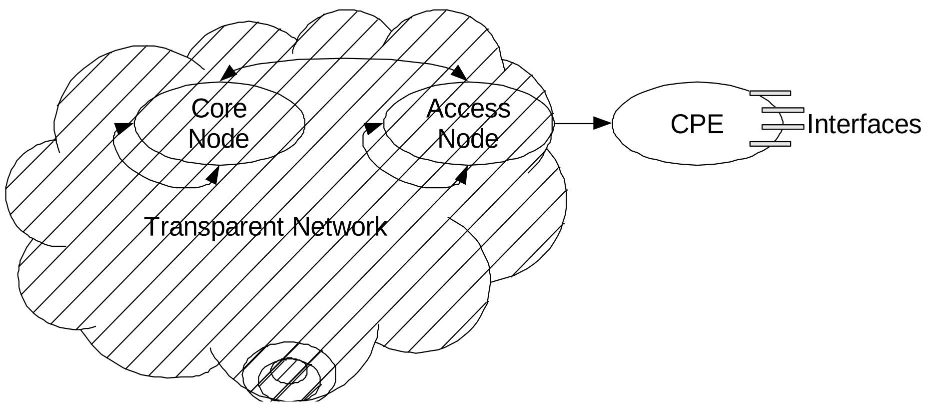

Figure 3: Network Design Model

We stated in the previous chapter that all network designs has to start with the end user demands so lets start the design from the end user equipment and end up in the core.

Customer Premises Equipment – End-user node

The access network installation prices and costs for CPE's is still the single largest cost for a broadband operator (the pure installation, manpower and excavating). Thus there is very pressing needs to keep the costs for this equipment as low as possible. The simplest form of CPE equipment is just a simple media converter; A 1Gbps media converter costs less than 100 EUR, May 2007 and is only slightly more expensive then 100bps so we limit our calculus to 1Gbps equipment. The disadvantage of just using a media converter as CPE is mainly that it delivers all services on one single network port and pushes all other functional requirements into the end-user equipment. A more advanced CPE with more interfaces can, besides delivering different services on each port also off-load some functionality from the access equipment. This report will not focus on the in-house/apartment network and will only briefly deal with the CPE functionality.

Access nodes

Even the cheapest single mode transceivers can reach 10-15 km which gives us the opportunity to concentrate active access equipment to larger installations within this radius, Fig 3. Within rural areas a single access node installation will then service tens of thousands of end-users. With a port density of about 500 ports per 19' rack this means a 20 rack installation, add to this the racks for terminating the fiber optic access network. A 500 1Gbps port installation calls for an aggregated bandwidth of 500 Gbps, this is not unreasonable since there exists backbone switches that can handle up to 1 Tbps. Due to the fact that much of the traffic today is peer-to-peer statistical analysis on the access node will show that the backbone capacity between racks will be significantly lower than 500 Gbps. The total aggregated bandwidth for the access nod will be significantly lower than the total aggregated capacity of the CPE ports.

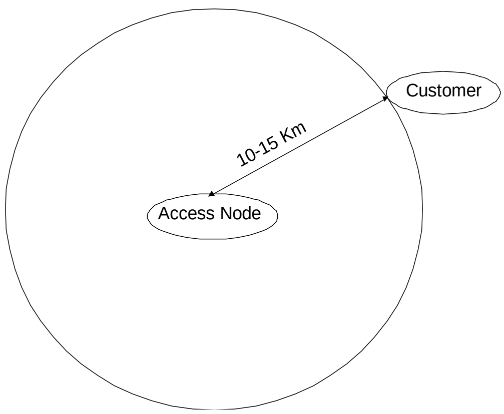

Figure 4: Access node radius

It can also be shown that it is economical to rebuild existing networks by replacing access nodes with a passive fiber cross-connect. The up link to the access node is then re-wired with high density trunk cabling. The added investment cost for the fiber trunk cabling can be compared to the savings in management costs when removing one active access node.

Will FTTH be a reality for everyone?

The picture (Fig 6) illustrates how an area (25 km × 30 km) covering about 100.000 households can be covered by just three (3) access nodes. In the very sparse populated areas of this picture 30 km fiber transceivers are utilized to concentrate traffic onto the 12km areas.

This means that even in a sparse populated country like Sweden we can achieve 50% coverage of the population utilizing less than 150 access nodes in the 30 largest cities. Doubling the number of nodes and also using 30 km transceivers for customers in remote locations we will cover 90% of the population. For the last 10% the cost is rapidly increasing due to the long distances and the fact that fewer households will share the same ducts.

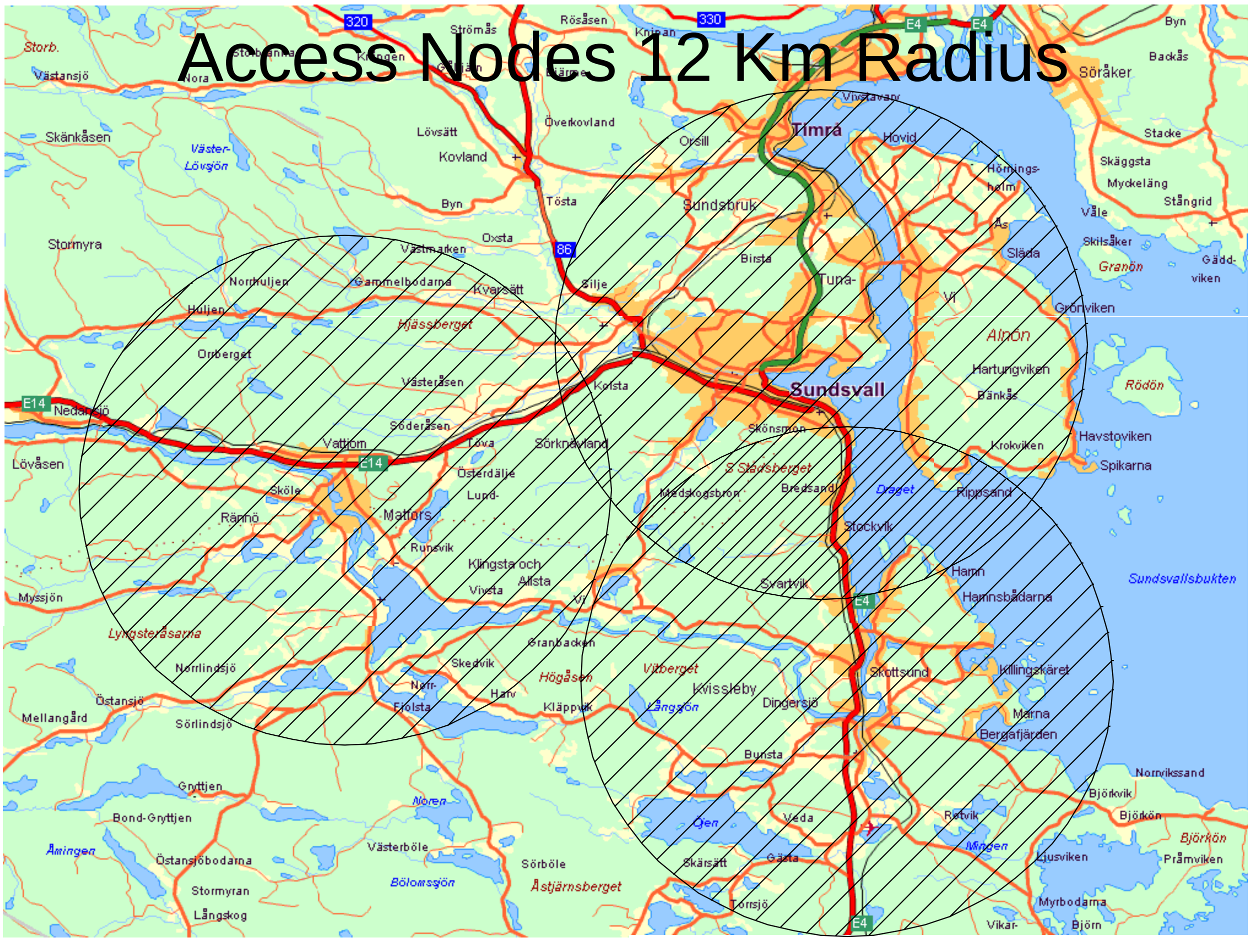

Figure 5: Access node service area

Core nodes

Just as we can have large numbers of customers per access node to reduce costs, we can do the same with core nodes. The number of core nodes is governed by the fact that these are used as exchange points for traffic between operators. All independently managed networks need at least two (2) core nodes for redundancy. This means we will have at least two (2) core nodes in each urban areacity with an independent access network operator. At the core nodes all operators can place equipment for peering of traffic between operators. Access and core nodes can also be collocated to reduce costs but equipment from different operators needs to be kept apart at least in different cabinets. Aggregated backbone capacity between core nodes can be rather huge in the future. The dominant link capacity today is 10 Gbps and trunking of multiple 10 Gbps connections will be an option for the foreseeable future, that is before 100 Gbps becomes a viable option.

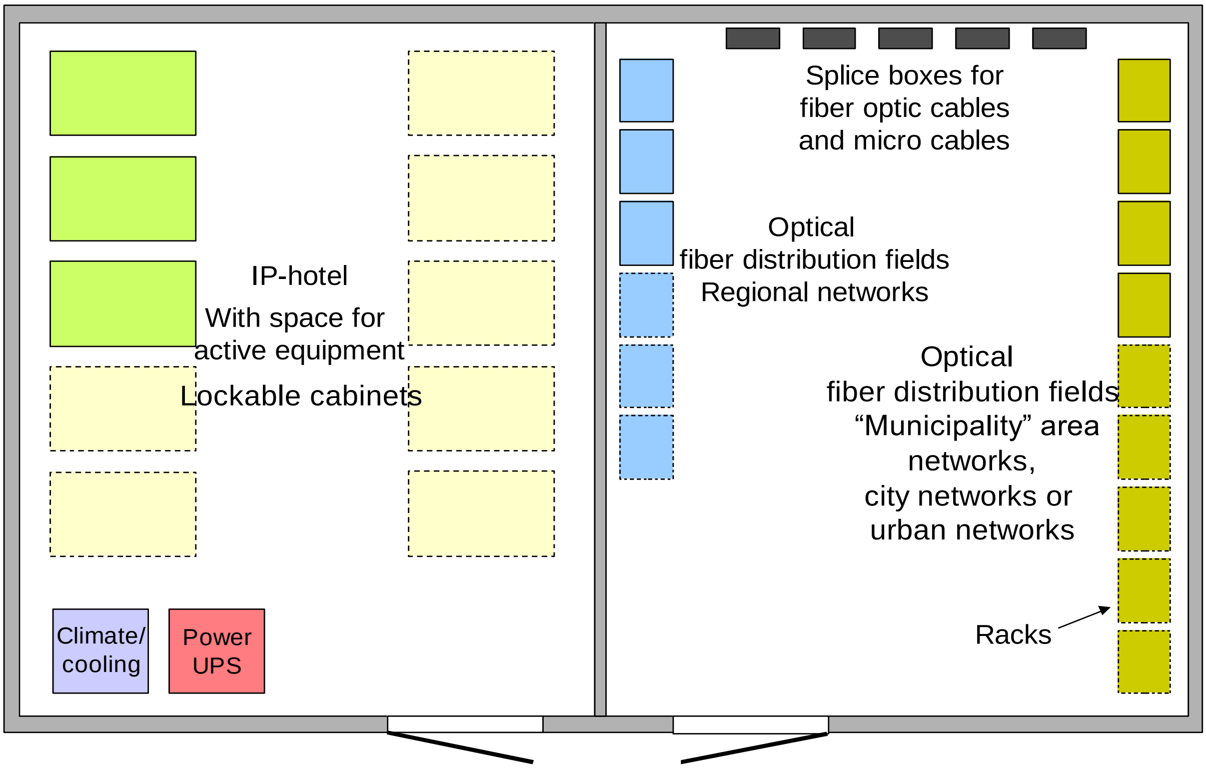

Figure 6: Node with multiple operators

Topology

The QoS requirements demand a topology with redundant routes to every access and core node. A multi level ring of rings topology is usually the best. Total number of nodes is given by this formula: $N=R^L$

Where R is ring size and L is the number of hierarchical levels. For example if we want to cover Sweden with a broadband network consisting of less than 400 nodes a two level hierarchy is probably sufficient. Giving us a top level consisting of about 20 connected rings each consisting of about 20 nodes.

Discussions & Conclusions

This document has shown how to create real cost effective FTTH networks. There are some rules of thumb to remember when doing real deponents. First rule is, Keep It Simple. All designs will fail when they face the real world, to smart and elusive designs will fail horribly making fault diagnosis difficult. Comparing your model behaviour with the real world probably gives a good clue on what went wrong and how to fix it. Without a model we would be totally clueless. The second rule is, Be very flexible. It is not possible to foresee all future demands given the long lifetime of fiber so we have to make ample room for future changes. For example there has to be ample room for expansion in ducts and physical installations.

References

[1] J. Crowcroft, S. Hand, R. Mortier, T. Roscoe, A. Wareld, “QoS's Downfall: At the bottom or not at all”, ACM 2003.

[2] Swedish Electrical Committee SEK 434, A guide on how to build fiber optic access networks – FTTX-networks.