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Fiber Network Topologies Connecting VDSL Networks

S-38.128 Special Assignment (2 cr)

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Abbreviations

ADSL	Asymmetric Digital Subscriber Line
ADSL Lite	Asymmetric Digital Subscriber Line, light version
AN	Access Network
ANSI	American National Standards Institute
BRI	Basic Rate Interface
CAP	Carrierless Amplitude-Phase Modulation
DMT	Discrete Multitone
DP	Distribution Point
DSL	Digital Subscriber Line
DSLAM	DSL Access Multiplexer
E1 connections	European basic multiplex rate of 2.048 Mbit/s
ETSI	European Telecommunication Standards Institute
FP1	Flexibility Point 1, primary crossconnection
FP2	Flexibility Point 2, secondary crossconnection
FTABCDE	Fiber to A, B, C, D and E, in the access network model
FTTC	Fiber to the Curb
FTTLex	Fiber to the Local exchange
HDSL	High bit rate DSL
HDSL2	High bit rate DSL, second upgraded version
ISDN	Integrated Services Digital Network
ITU	International Telecommunications Union
LE	Local Exchange
LT	Line Termination
MDF	Main Distribution Frame
NT	Network Termination
OLT	Optical Line Terminal
ONU	Optical Network Unit
PBX	Private Branch eXchange
POTS	Plain Old Telephony Service
QAM	Quadrature Amplitude Modulation
TE	Terminal Equipment

U-ADSL	Universal Asymmetric Digital Subscriber Line
UDSL	Universal Digital Subscriber Line
UNIs	User Network Interfaces
VoD	Video on Demand
VDSL	Very high speed Digital Subscriber Line
xDSL	Generic term covering all Digital Subscriber Line technologies

1. Introduction

Very-high speed Digital Subscriber Line (VDSL) technology utilizes the final few hundred meters of the existing twisted copper pairs for broadband data transmission. Introduction of VDSL into the present copper access network requires radical changes to the network topology, since the remaining copper loop length needs to be shortened significantly. From the present Fiber to the Local exchange (FTTLex) architecture a transition to Fiber to the Curb (FTTC) architecture will have to be made. This means that fiber end points also called Optical Network Units (ONU) containing active electronics are placed in the approximate vicinity of the subscribers. New fiber network needs to be built in order to connect ONUs to data networks. There are some options concerning the topology of this fiber network. Especially when the number of ONUs is big and the fiber reaches close to end-users the applied fiber topology starts to be important. Additional fiber links may be required for protection. The present topology of the telephone access network may be inadequate for the new active devices.

This paper is a continuation of the work done with my master's thesis [Män99]. Background material presented in chapters 2 and 3 is partly based on the material of the master's thesis. The other chapters consist of completely new material that is not covered by the thesis.

2. Digital Subscriber Line (DSL) technologies

DSL or xDSL is a general term for digital technologies utilizing more of the transmission capacity of the twisted copper pair than the analog telephone systems have used so far. Analog connections only use the audible spectra of 4 kHz, which is just a fraction of the entire spectra transmittable over copper pair [Hum97].

In the following standardized technologies and the ones being standardized are presented. In addition to these there is a number of other proprietary DSL solutions from various companies that are not presented here.

2.1 ISDN

The digitalization of the telephone access network formed of passive twisted copper pairs began with ISDN that was developed in the 1980's. The basic rate ISDN (BRI) consists of two 64 kbit/s B channels for voice or data and one 16 kbit/s D channel for signaling (2B+D). By using both B channels 128 kbit/s data rate is achieved, about three or four times more than is achieved with analogue modems. At the moment ISDN is a good choice for residential users who need a faster, but still economical, connection. For bandwidth hungry multimedia services the transmission capacity of ISDN is too low. Newer DSL technologies, developed during the 1990's, offer significantly higher data rates.

2.2 HDSL

High bit rate DSL is the most widely deployed DSL technology that has been available since the beginning of the 1990's. HDSL offers a symmetrical 2 Mbit/s connection over two or three copper pairs. Typically HDSL is used to transmit 2048 Mbit/s E1 connections over two copper pairs. With HDSL the provisioning of E1 connections is cheaper than with older technologies. HDSL operating distance is about 3.5 km over 0.5 mm cable depending on the cable quality [Che98].

2.3 HDSL2

HDSL2 is developed from HDSL to offer the same service as HDSL does but over a single copper pair. The achieved operating distance is about 3 km, slightly shorter than that of HDSL [Che98].

2.4 ADSL

Asymmetric DSL was originally intended for providing video-on-demand (VoD) services to residential subscribers. Later Internet usage became the driving force for ADSL as it was realized that highly asymmetric data rates provided by ADSL are ideal for loading multimedia content from the Internet. Offered range of data rates in the downstream direction varies from 1 to 8 Mbit/s and in the upstream from 16 to 800 kbit/s. The operating distance may be up to 5 km depending on the quality of the cable. This long operating distance makes it possible to apply ADSL to the existing network without changes to access network topology.

ADSL modems are standardized to be rate adaptive so that it is possible to adapt the data rate according to line conditions. For residential users an important feature of ADSL is that it may be used simultaneously over the same copper pair with existing POTS or even ISDN if necessary. So called POTS splitters are required to separate the POTS and ADSL signals from each other. ISDN friendly mode of ADSL means a small decrease in achieved data rate since part of the bandwidth is reserved for ISDN [Rau99], [Dix99], [Max96], [Poi96].

2.5 ADSL Lite

ADSL Lite also known as Universal DSL (UDSL) or Universal Asymmetric DSL (U-ADSL) is a lower data rate version of ADSL. ADSL Lite is designed to be a mass market consumer version of ADSL and is supposed to work without the splitter in the customer premises making the installation process simpler. Some doubts have been expressed on the splitterless solution as the quality of POTS connection could be worsened too much [Dix99].

2.6 VDSL

Very high speed Digital Subscriber Line technology and especially the fiber network topologies connecting VDSL networks is the topic of this paper. Therefore VDSL technology is in the following presented in more detail than the previously presented other DSL technologies.

2.6.1 Standardization

VDSL is currently being standardized in ITU, ANSI and ETSI. Although many standard bodies are involved in the process, close co-operation is being done and the goal is to accomplish a common standard during this year.

The main issue in the standardization process at the moment is the choosing of VDSL line code. There are two candidate proposals, which are supported by two equally strong groups formed of participating companies. Single carrier technologies (CAP and QAM) are promoted by the so-called VDSL coalition group. The VDSL alliance group is the opposing group supporting discrete multitone (DMT) technology as the line code. There is strong disagreement between these two groups on which should be selected.

DMT is more complex to realize of these two, and therefore it seems that single carrier modems could be brought to the market faster if a single carrier was chosen as a standard. The performance of the two line codes is about the same and it seems that the disagreement is more of political nature than of technical. Big companies are behind each line code and big investments have already been made in these companies for the line code that they are supporting.

2.6.2 Defined Data Rates

VDSL technology is intended for transmitting high-speed data over short lengths of twisted copper pair. The bandwidth to be used by VDSL reaches up to 30 MHz, although the highest frequencies are usable only over very short cables.

Somewhat different VDSL data rates are presented in various standard proposals and drafts. Downstream rates going up to 52 Mbit/s and upstream ones up to 34 Mbit/s are suggested in [VDS98a], [VDS98b], [ANS98]. In Table 1 the payload bit-rates defined in the newest ETSI specification are presented.

Table 1 *VDSL payload bit-rates defined in [ETS99].*

Class of operation	Downstream (kbit/s)	Upstream (kbit/s)
Class I (A4)	23168	4096
Class I (A3)	14464	3072
Class I (A2)	8576	2048
Class I (A1)	6400	2048
Class II (S5)	28288	28288
Class II (S4)	23168	23168
Class II (S3)	14464	14464
Class II (S2)	8576	8576
Class II (S1)	6400	6400

2.6.3 Required Network Topology

Figure 1 shows the general VDSL reference model where the main parts of the VDSL network can be seen. The Optical Network Unit (ONU) must be placed into the access network close to the end-user. The ONU consists of the DSL Access Multiplexer (DSLAM), that contains the LT parts of the VDSL modem pairs, and of the fiber node that provides the connection to data network. Network terminal (NT) is the VDSL modem located in the customer premises. Network operators may choose whether they want to offer narrowband services over the same copper loop or not.

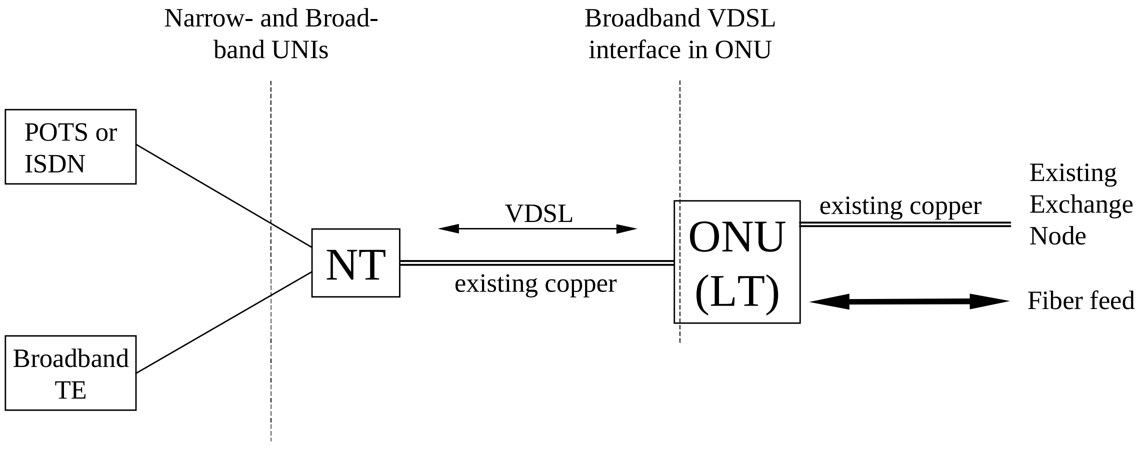

Figure 1 *VDSL reference model defined by ETSI [ETS99].*

2.6.4 Connecting of ONUs to Backbone

Often ONUs located in a certain LE area, are connected to Optical Line Terminal (OLT) located at the LE premises. Depending on the number of ONUs in the LE area it may also be possible that ONUs from multiple LE areas are connected to a single OLT. The ONUs are connected to backbone via a fiber network that may be either passive or active.

2.6.5 Obstacles

There are some technical and physical obstacles that may either result in lower transmission capacities or in some cases prevent the use of VDSL totally.

The problem with ONUs is that they require physical space that often does not exist in the current access network. Crossconnects that are located in the access networks would be the ideal places to locate ONUs, but the problem is that they often do not have any space for extra equipment. Also the powering required by ONU may be problematic, as the crossconnects of the passive copper network do not need any power. It may be that in many cases new locations must be found or built for ONUs, so that they could be placed in the immediate vicinity of the crossconnects.

Quality of copper cables and the disturbance caused by existing systems are also possible sources that may prevent VDSL usage [Hel99], [Liu99].

3. Access network topology

VDSL networks are typically built over existing copper access networks. Fiber is brought to the certain point in the access network and the final hop to the subscriber is realized with VDSL over existing copper pair. This chapter begins with the presentation of the topology of current copper access network after which the access network model is presented.

3.1 Current Topology

Present copper access networks consist of passive twisted copper pairs running from local exchanges (LE) to subscribers. A typical topology of this kind of access network is presented in Figure 2. From the main distribution frame (MDF) the copper pairs are lead via feeder routes to crossconnection points marked as flexibility points in Figure 2. The subscribers located close to LE are connected directly. Typically the distribution network from flexibility point to subscriber is short, compared to the length of the feeder cabling.

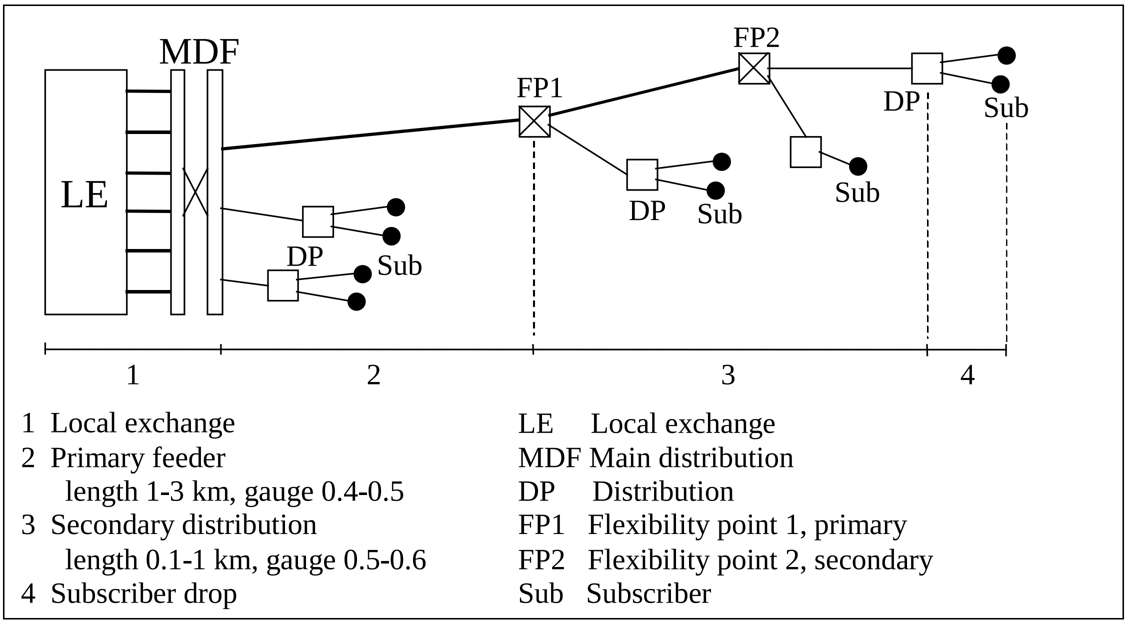

Figure 2 *Current access network topology [Poi98], [You95].*

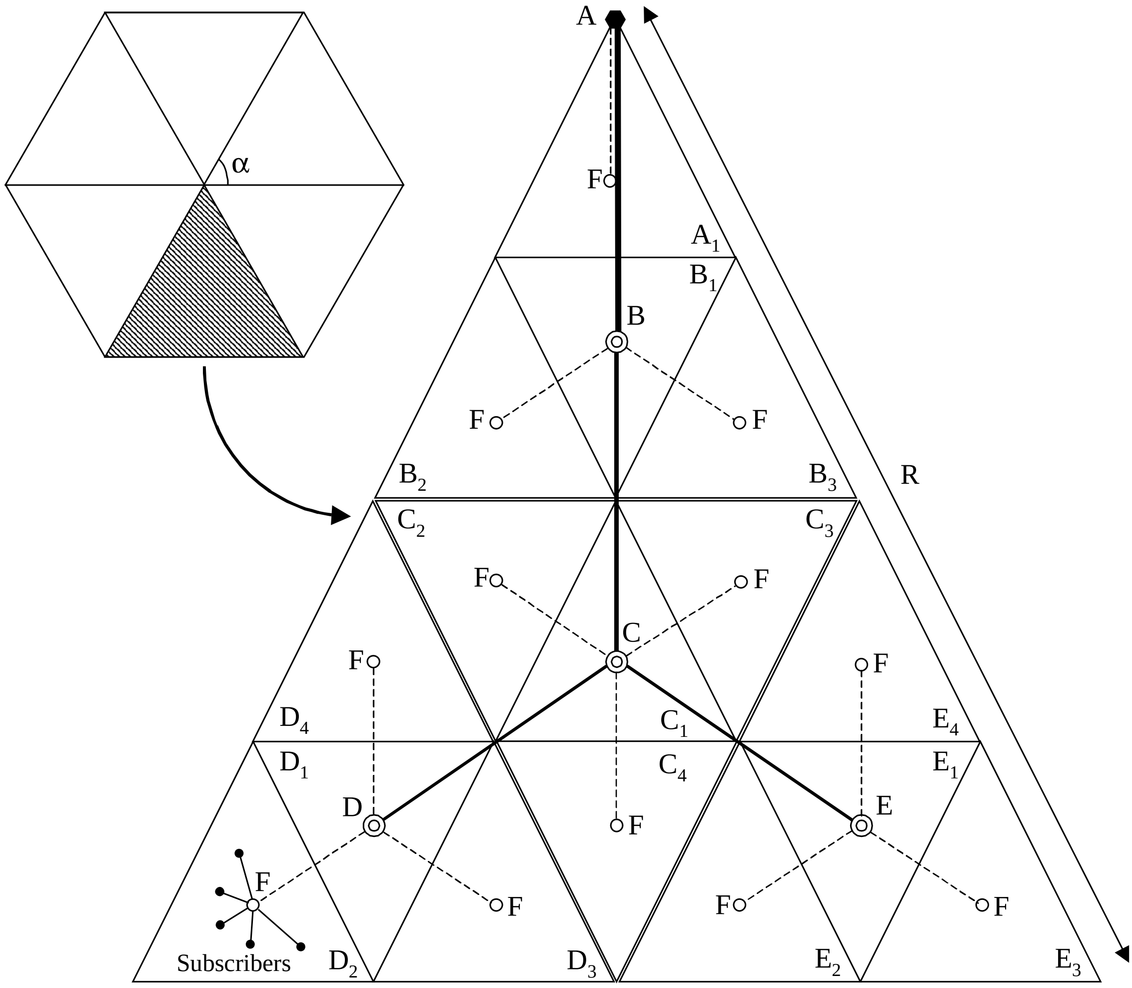

Figure 3 *The SYNTHESYS access network model [Wel98].*

3.2 Access Network Model

Access network models make it possible to perform calculations and evaluations of different upgrade scenarios in a simplified environment where all the needed parameters are known unlike in the real network. Different models have been developed for example in the RACE 2087/TITAN project [Wel98]. Here the SYNTHESYS model, a polygon based geometric access network model presented in Figure 3, was adopted because of its simplicity and general applicability. In more detailed models different network topologies, area shapes and subscriber distributions are included. However the general applicability is lost, as the complex models require defining of the parameters for each area separately. The TITAN model, also presented in [Wel98], is an example of a more complex model that enables modeling real areas more accurately.

In Figure 3 one segment of the whole polygon, presenting the whole LE area, is enlarged. The subscribers are connected to distribution points, letter F in the figure, located in the middle of the smallest triangles. Like in real access network also here individual segments are gathered together at flexibility points – B, C, D and E in the figure – and brought in big cable bundles to the LE location, presented by letter A in the model. Subscribers that are located near the LE, triangle A_1 in the model, are connected directly.

Lengths of the different links of the access network model can be derived from geometry. The calculations of link lengths are presented in [Wel98] and in [Män99]. The results are shown in Table 2.

Table 2 *Values for the access network model.*

Parameter	**Link length [*R*]**	**Value**
R		3000 m
α		60°
AB,BC,CD,CE	0.289 x *R*	866 m
AF,BF,CF,DF,EF	0.188 x *R*	564 m
$F \rightarrow Sub$	from 15 m to (0.093 x *R*) + 15 m	15 – 293 m
$A \rightarrow Sub$	from (0.188 x R) + 15 m to (1.147 x *R*) + 15 m	579 – 3456 m

The values presented in Table 2 are based on an example area with R = 3000 m and $\alpha = 60°$. This is a moderate sized area that could be realistic in urban or semi-urban areas.

4. Network topologies

A communications network is formed of separate devices, often called nodes, connected to each other. There are several different network topologies that can be applied to interconnect these nodes. Some examples of the possible topologies are presented in the following and shown in Figure 4 [Fre96], [Tel77].

Full mesh topology forms a fully connected network, where each node is connected to all others. There is a direct point-to-point connection between any two nodes of the network. The big number of needed links makes this topology very expensive. Partial mesh topology is formed if some of the links of the full mesh are left out. In most cases this is sufficient and a lot more economical to build and maintain.

Ring topology forms a continuous loop of the network nodes so that each node is connected to two adjacent nodes. Typically ring network is built in such a way that the network survives even if interconnection between one pair of nodes is lost.

Star topology forms a network, where all nodes are connected to one central node. Any connection from a node to another node always passes through the central node.

Double star is an extension of the star topology. Here sets of smaller star-connected nodes are connected to a bigger center. This idea can be taken further into a multi star topology. Star topologies are not as reliable as possible because a failure of one link may disconnect a whole part of the network.

Multipoint or bus topology interconnects three or more devices using the same line. Other topologies presented here use point-to-point connections between nodes. Multipoint is an option that is simple and economical to build. The shared capacity that is provided to connected nodes may however be inadequate in the long run.

In real networks different topologies are often mixed in order to achieve the most suitable solution. Major points to be considered are installation cost, communication cost, reliability and availability [Str98]. Some kind of compromise between cost and reliability has to be made since generally more reliable topologies also cost more because of the additional links needed. Usually networks are not fully connected,

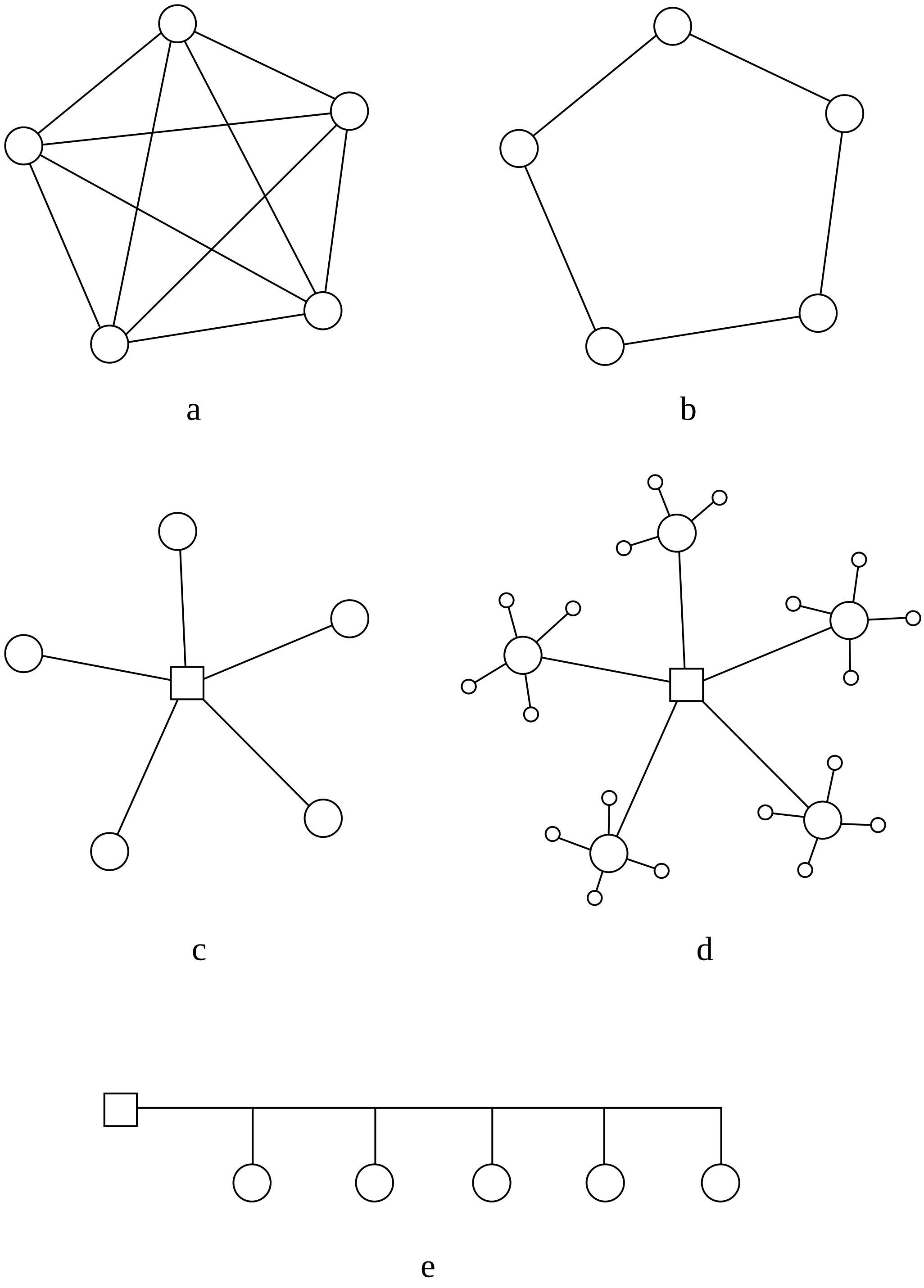

Figure 4 *Examples of network topologies.*

(a) full mesh

(b) ring

(c) star

(d) double star

(e) multipoint

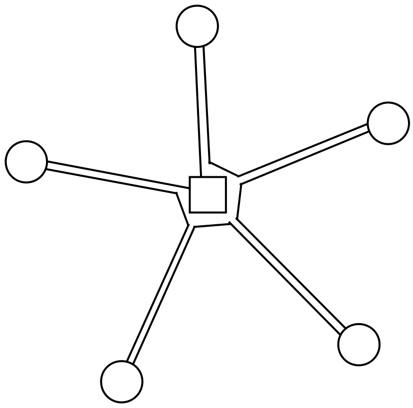

Figure 5 *Physical star, logical ring topology*.

although it is desirable to have more than one path through the network for each pair of nodes

Physical and logical topologies are not always the same. An example of this is shown in Figure 5 in which a physical star forms a logical ring. This way the number of required connections in the center node is reduced to only two. In case of fiber networks this may be of importance since the ending of each fiber introduces additional costs. In general possible logical topologies that can be applied depend on the existing physical topology.

5. Fiber network topology of the AN model

AN model, presented in Chapter 3.2, shows a simplified model of the present copper access network. This copper network needs to be upgraded as VDSL is introduced, since VDSL operates most efficiently over short copper loops of a few hundred meters. The average loop length in current network is approximately 1800 m. A few upgrade scenarios for the AN model are introduced in [Män99]. The scenario where fiber is brought to A, B, C, D and E (FTABCDE) is the first scenario in which VDSL can be offered to all subscribers located in the area of the model. With 25 ONUs the average loop length of circa 500 m is achieved. As the fiber network spreads this far a consideration of the best fiber topology makes sense. The whole AN model area for FTABCDE scenario is shown in Figure 6.

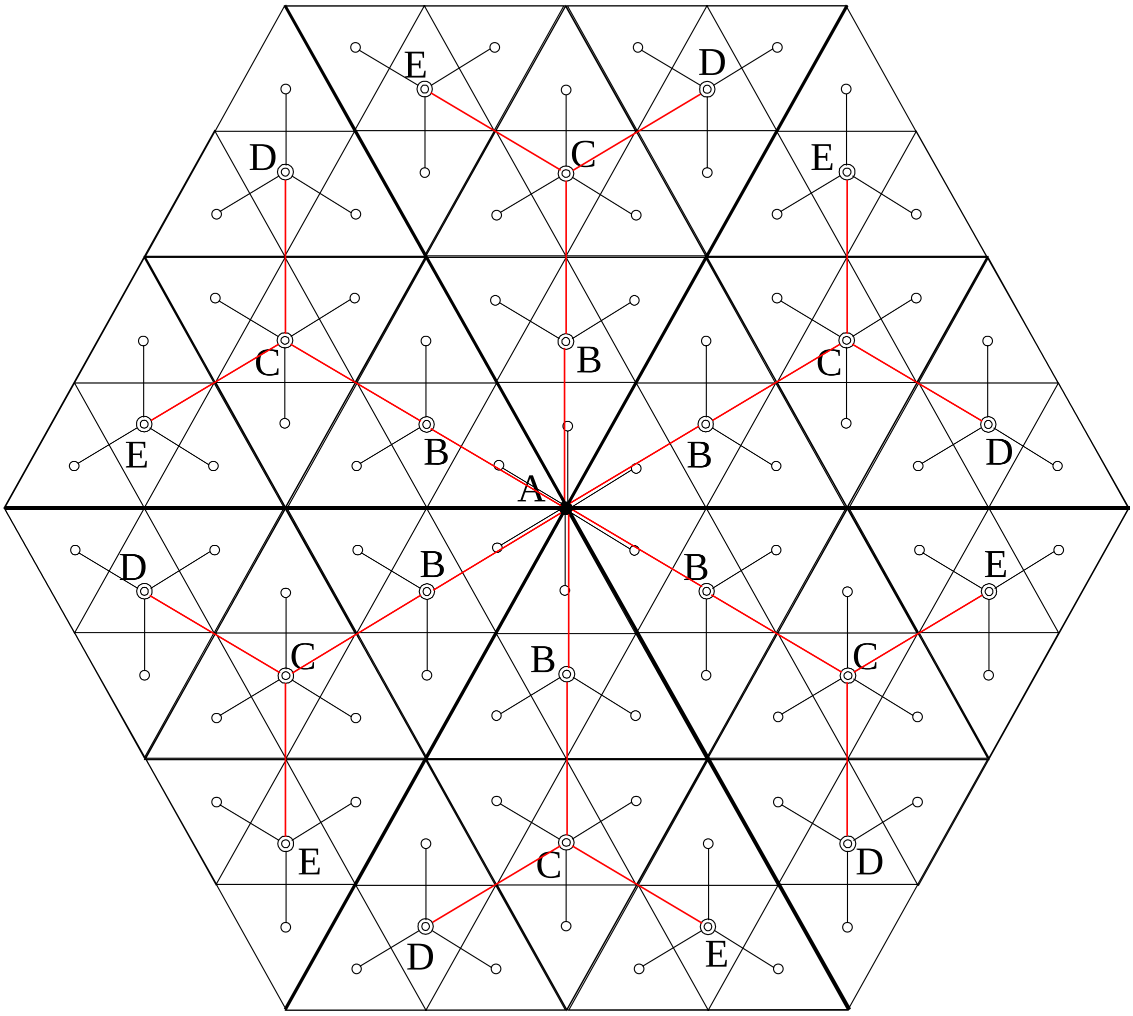

Figure 6 *Fiber to A, B, C, D and E (FTABCDE) scenario.*

In Figure 6 new fiber is routed along the existing cable paths. This is probably the most natural way for the fiber network to be built as new fiber is placed to the same cable paths as old copper cables. In the best case no new cable paths are required and in the worst case the old cable paths are so full that new cables have to be dug also in this case. The resulting topology is a star. Reliability of this type of network is not the best possible, as the links are not protected from failures. One failure near center location – A – could disconnect a whole segment. Possible capacity problems are also faced as all data generated from a segment passes through one link to A.

These problems can be solved partly by using multiple fibers in each link. Fiber cables that are installed typically contain 12, 24, 48 or possibly even more fibers. These would be enough to have a dedicated fiber to each ONU location in FTABCDE scenario if needed. Costs generated by a large number of fiber endings might prevent the use of this option. Another option could be to connect nodes to a logical ring, this way the number of fiber endings could be reduced significantly.

However, even more reliable solution would be to build crosswise links into the access network. In the current passive access network there usually has been no need for such links and therefore they do not exist. Connections to the PBXs of bigger companies are an exception, because they are often secured for example by connecting them to two separate LEs. For residential subscriber connections the paths through the access network are usually not secured.

As active ONUs are placed into the access network with introduction of VDSL it is a considerable option to build at least some crosswise links to make rerouting and recovering from failures easier. Figure 7 shows the first crosswise links that could be built to the network presented by AN model. Another option could be to interconnect B-nodes from adjacent segments. As the VDSL subscriber numbers grow bigger more crosswise links could be installed. This way rings connecting adjacent segments to each other would be formed. As in most of the real networks also here none of the earlier presented topologies fits this topology directly, a mixture of a star and a ring is formed. Partial mesh network could describe the new network topology also.

In real network the building of crosswise links is not as straightforward as in the AN model. Nodes in the adjacent segments may be separated by various obstacles, making the interconnection expensive. In most of the cases new fiber paths need to be dug. Also the number of VDSL subscribers and the amount of data traffic they generate may vary a lot depending on the area. Protection is required especially when VDSL take rate and the ONU sizes grow enough. Some prioritization needs to be performed, as the biggest ONUs need to be protected first.

If the fiber is taken one step further in the AN model, to the smallest triangles, the number of required ONUs grows to 96. Crosswise links are an option for protection also in this case. According to needs based on the number of VDSL subscribers at each location more new links between adjacent segments could be formed.

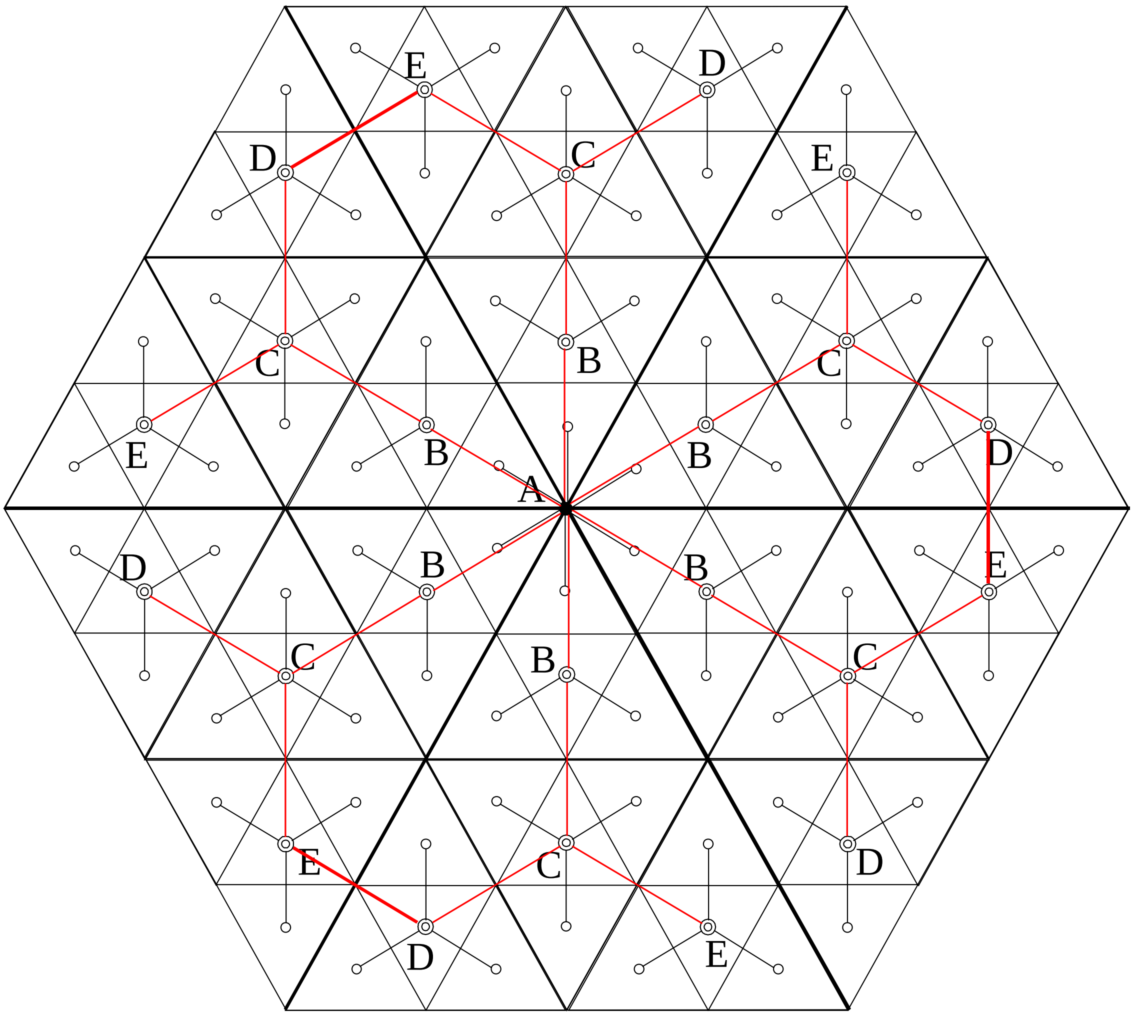

Figure 7 *First step of building crosswise links.*

6. Conclusions

As present copper access network is upgraded to hybrid fiber-copper network, a need for rethinking the utilized network topology becomes important. Protection of links connecting new active nodes placed into the access network requires additional crosswise links that do not exist in the present network. When adjacent segments of the access network are interconnected new rings can be formed and the reliability of the network can be raised to a higher level.

Probably the biggest problem is the cost. Upgrading of present network is very expensive even without extra connections required for better reliability. It must be thought very thoroughly which sites are the most important and should therefore be protected by additional links before other sites.

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