

# Fibre optic access to end-user — A guideline to building of FTTX fibre optic network

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# National foreword

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English version

**Fibre optic access to end-user -  
A guideline to building of FTTX fibre optic network**

This Technical Report was approved by CENELEC on 2007-07-06.

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**CENELEC**

European Committee for Electrotechnical Standardization  
Comité Européen de Normalisation Electrotechnique  
Europäisches Komitee für Elektrotechnische Normung

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## **Foreword**

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## Executive summary

FTTX normally refers to networks that deploy fibre directly into the customer residences, which can be either single dwelling units (houses) or multi dwelling units (blocks of flats).

Most FTTX networks are designed without any active equipment in the external network and are therefore classified as passive optical networks. The only active equipment is at the central office and the customer premises. FTTH - PON networks can be designed around different architectures.

The purpose of this Technical Report is to be a first guideline for those considering to install a high bandwidth (high bit-rate) FTTX-network. After studying the Technical Report operators, communities, energy companies, installers and other will understand the necessary steps to take to plan and install FTTX-networks with high quality and cost effectiveness, and to secure a uniform structure and a high quality level on such networks.

The main part of this Technical Report describes the FTTX-networks, but Clause 1 also contains more general information to give an understanding how these networks fit into the planning of the fibre infrastructure.

FTTX has for many years been regarded as the most future-proof technique for transmission of broadband multi-media applications. The building of FTTX-networks has previously been prevented by high costs. New investigations show, however, that the cost to install a new fibre based network (100 Mbit/s) is a little less than to install a new copper network. The FTTX-network is also the only structure, which with certainty can offer both the present and the future needs, which broadband access services require. At the same time the technique allows efficient operating maintenance and cost savings.

The networks to be presented used to be called FTTH, but with the strategy described here fibre networks can reach anywhere (X). The end-user can be separate homes, houses, office environments, optoelectrical transitions in equipment for alarms, surveillance, monitoring devices etc.

The Technical Report also describes recommendations and gives basic requirements to be fulfilled by a fibre installation in an FTTX-network to satisfy present and future requirements on capacity, transmission distance and quality. As a target, the minimum capacity is set to 1 Gbit/s (1 000 Mbit/s) up to 10 km distance; for certain access applications (e.g. flats or multi-tenants buildings) a shorter distance can be targeted, e.g. 500 m to 2 000 m. Relevant types of optical fibres (single-mode and multimode) are specified in EN 60793-2-50 and EN 60793-2-10. However, in the industry a single-mode fibre is typically called by its ITU terminology (e.g. G.652). The physical network should have an expected lifetime of 25 years.

The recommendations are written for a general audience, but in particular for people involved in private and public enterprises, people responsible for broadband decisions, planning and installations.

The Technical Report is divided into six independent clauses:

- Clause 1 is an introduction and gives a view of the IT-infrastructure and a survey of the basic structure for the fibre optical broadband.
- Clause 2 describes system solutions for FTTX including requirements on capacity and installation techniques.
- Clause 3 is a guideline on how to create a network and gives an overview of applicable network topologies.
- Clause 4 gives basic information about installation and planning before installation.
- Clause 5 treats measurements and documentation.
- Clause 6 treats quality issues.

A number of annexes are included to give deeper knowledge in certain areas. They are broad examples and can be used to give a better view on the principles for installation of FTTX-networks with cables, microduct optical fibre cables, microducts and microduct fibre unit cables (blown fibres). To some extent these annexes are company specific, which the reader should be aware of. Annex A (reference [1]) gives a comprehensive list of standards. References [2], [3] and [5] give a good overview of the present status in both ITU-T, IEC and the general CENELEC view.

Some of the requirements put forward in this Technical Report are unique for an FTTX-network and should not be used in a general sense for optical networks.

## 1 Network Structure and Nodes – A guideline

### 1.1 Introduction

This Technical Report describes the FTTX-network. As a guideline other parts of the fibre optic infrastructure are given in this clause.

First some basics: sound, pictures, voice, data carried by networks are digital data expressed in terms of bit, bytes and their multiples (kilo (k), mega (M), giga (G), tera (T)). A bit (binary digit) is the smallest digital unit and has only two values: 0 or 1. A byte includes 8 bits and defines the size of a data file. Transmission capacity of networks and terminals is not expressed by using bytes, but using bit per second (bps). When a data file is transferred in a network two supplementary bits are necessary. It means that 10 bits are required for 1 byte.

In the case of a VDSL subscriber with 10 Mbit/s, who wants to upload a pdf data file, the Web provider indicates for instance the following size: 20 Megabytes. It should then take 20 s. However, for any Mbit/s subscription the fact is that the real final data flow is about a quarter of the notified data flow, because the data flow is shared between subscribers and its quality depends on the activity of the other subscribers. It means that the 20 Megabytes data file will need 1 min 20 s to be uploaded. For instance a 15 Mbit/s ADSL system gives only 1 Mbit/s for uploading. The following table gives some further examples of transmission times for uploading a quality DVD-movie, if there is no data flow sharing.

| Transmission speed | Uploading time |
|--------------------|----------------|
| 0,128 Mbit/s       | 5 days, 8 h    |
| 10 Mbit/s          | 8 h            |
| 100 Mbit/s         | 0,8 h          |
| 1 000 Mbit/s       | 50 s           |

We do not know the new tools that will be created by the real high bit rate networks. New applications (not invented today) will appear and applications originally dedicated to professionals will be extended to all in a similar way as it happened with the mobile phone.

It is important to define the meaning of « low, medium and high bit rate transmission ». One possible classification is presently the following:

- low bit rate transmission: up to 1 Mbit/s
- medium bit rate transmission: 1 up to 10 Mbit/s
- high bit rate transmission: 10 up to 100 Mbit/s and more.

## 1.2 Levels

For a level-designed view on the components in the build-up of the infrastructure, see Figure 1.

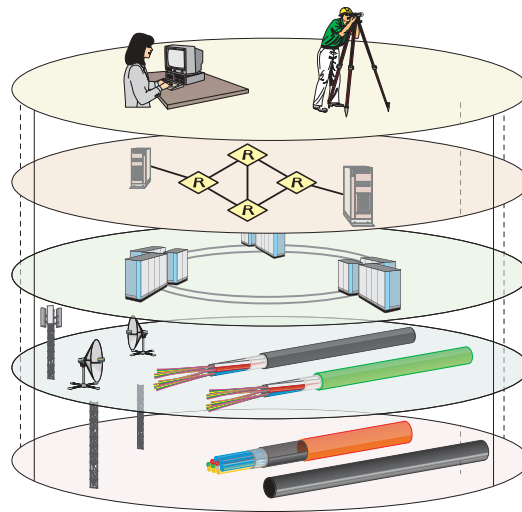


**Figure 1 – Network levels**

From the bottom up, Figure 1 shows:

- Physical routing: Duct for cables, for microduct optical fibre cables, and for microduct fibre unit cables (blown fibre products) and for structures for antennas
- Passive transmission and interconnecting media: optical fibre cable, connectors, antennas, boxes, closures and their physical interconnections
- Active transmission systems: Logical connections over a physical connection
- IP: The internet operator network service to the user
- Application: Equipment, program and data bases of the user

Designing the infrastructure in levels makes it possible for different ownership of individual levels. This creates possibilities for open networks and competition, but also presents risks regarding responsibilities and long-term interaction.

### 1.2.1 Physical routing

The lowest level in the physical network is the physical routing. It consists of ducts in standard dimensions, antenna structures, network material and microducts among others. Also existing infrastructure tubing as sewer-, gas-, and drinking water tubes may be used. It should have an expected lifetime of 25 years.

A large part of this level belongs to the FTTX and will be thoroughly described in this book. Most of the cost for a broadband network is in the planning and installation of the routing layer. It is therefore important to be accurate in planning, installation and documentation, and that the material of the parts is of high quality. Normally the network owner owns this level.

### 1.2.2 Passive transmission media

Level 2 contains optical fibres and cables, interconnecting devices (connectors, splices, closures, ...), copper cables (not treated here) and antennas (also not treated here) for radio networks (FWA, WLAN, 2G, 3G, 4G, LMDS).

The optical fibre and cable have a mechanical lifetime that corresponds to the ducting level. However, the transmission lifetime depends on required future services on the fibres. These future requirements may demand more capacity compared to present planning prediction. If that is the case, the fibre may need to be replaced by a fibre with better transmission performance. It is therefore proposed in this guideline to use single-mode fibre in the FTTX-networks, since it has by far the largest capacity well above the 1 Gbit/s over long distances up to 40 km. In cases where the length is limited to 500 m – 2 000 m (e.g. multi-tenant buildings) also multimode fibres can be considered. By installing optical fibres and cables in ducts the costs for replacements and repair are substantially lower than without ducts. The network owner normally owns cable and fibre.

### 1.2.3 Transmission-, IP- and application level

Transmission-, IP- and application level will not be described in this Technical Report.

### 1.2.4 Ownership, operating and maintenance

When all parts in the infrastructure fulfil specified quality requirements regarding transmission and installation, different ownerships could be possible. Ownership and operation could be split by different governmental or community companies, jointly owned companies between different communities, energy companies, building enterprises. Housing co-operatives, house-owner associations, private persons and landowners may also own the local network closest to the end-users.

Considering operation and maintenance the network level owners have to specify acceptable downtimes.

## 1.3 Network topology – Terminology

### 1.3.1 Infrastructure parts

To get an overall picture about optical fibre networks it is necessary to explain some of the terminology and concepts used.

The higher the network is in a network topology, the higher traffic volume, capacity, requirements on function and availability and therefore also the strategic significance and need for protection and security in the network. All IP-traffic can be distributed, which means that this hierarchy may be flattened in a few years. The present network is a combination of a traditional telephone- and a future IP-network, which can be described as in Figures 2 to 7. This means that the information can find the best route when alternative routes are available.

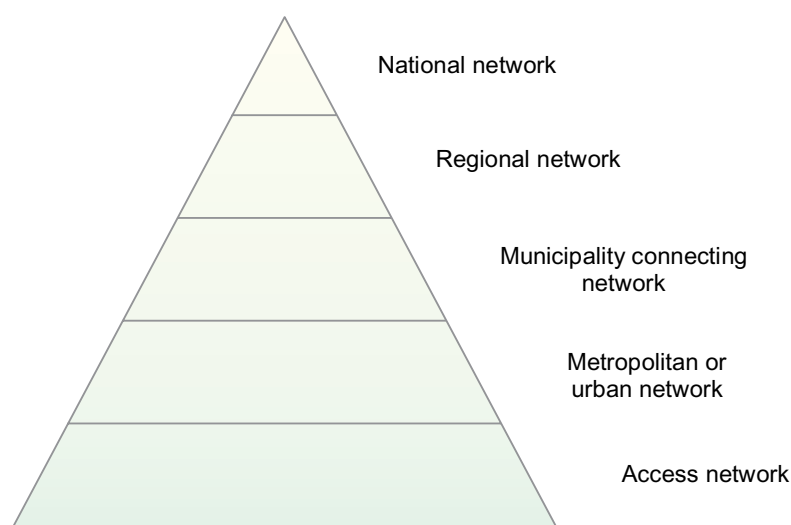


**Figure 2 – The new infrastructure is based upon both old and new network hierarchy**

The highest level is the national network, see Figure 2 and the lowest is the network for connecting end-users or subscribers.

### 1.3.2 National network

The national network connects all regions in the country and is connected to international networks. This type of network has a very high security level. A national network has normally few owners.

### 1.3.3 Regional network

A regional network or a community-connecting network connects networks within a region. Networks within a region often consist of municipality-connecting networks from different communities. A regional network is then connected to the national network.

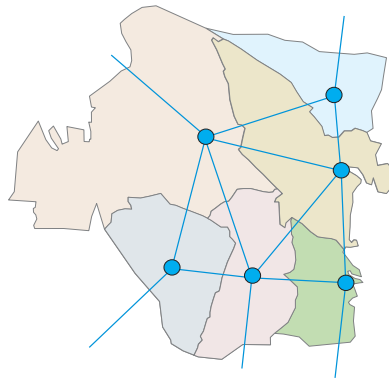


**Figure 3 – A regional network, e.g. in a county**

Some of the main communities can be connected to nearby regions (Figure 3).

### 1.3.4 Municipality connecting network

Municipality-connecting networks connect different municipalities (places) within a community. These networks are in turn connected upwards to regional networks or community-connecting networks and downwards to access networks. The connection is made through the community main node.

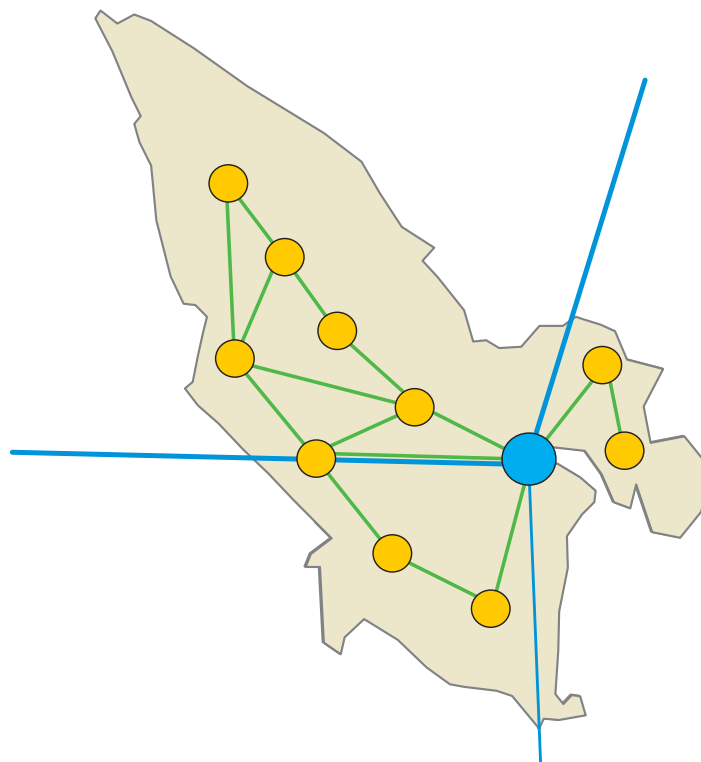


**Figure 4 – The municipality-connecting network connects the larger places within a community**

In each place there are one or more nodes, access nodes (possibly also distribution nodes), which connects the end-user – the subscriber (Figure 4).

### 1.3.5 Metropolitan or urban network

City (metropolitan) or urban networks are networks within a city or in a sparsely populated area. The function is to give a broadband infrastructure, which can satisfy a long-term need. It shall be easy to establish cost-effective solutions of access networks to reach subscribers. This can be achieved by using existing or planned networks of different kinds. These networks are directly connected to the main node or to a distribution node (redundancy), which could be a possible fibre optic cross-connect node (fccn) to another main node, if so required.



**Figure 5 – The metropolitan or urban network, the red lines, connects areas in a thinly populated area**

Access nodes are connected along the ring structure (Figure 5).

### 1.3.6 Access network

The access network connects subscribers or group of subscribers to an access node. Earlier described networks have normally been installed on public land. The opposite is normally valid for the access network. A large number of the access networks will be installed on private properties or land. Subscribers from houses, terraced houses, blocks of flats, companies, hospitals and authorities can be connected to the access network. Also masts for FWA (Fixed Wireless Access) or WLAN (Wireless LAN) and antennas for the mobile network can be connected. Furthermore equipment for security, surveillance, fire-alarms and control equipment can be connected.

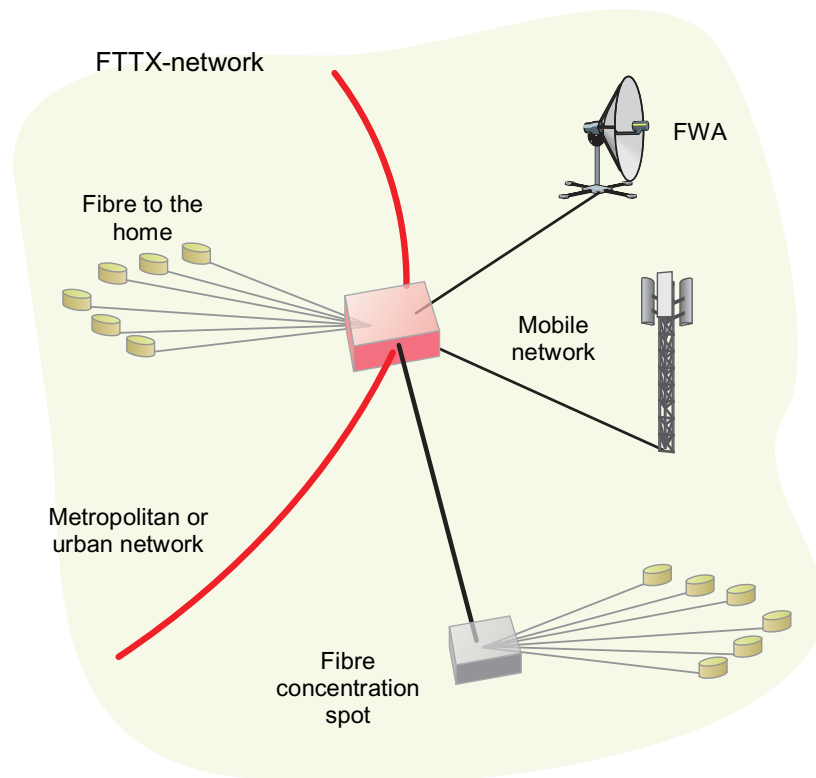


**Figure 6 – The access network connects a large number of end-users**

#### 1.4 Node topology – Terminology

There are a number of junctions (also known as nodes) in a broadband network, where single traffic flows are mixed, multiplexed and de-multiplexed to create an efficient flow through the network. In the nodes data packages are given a choice of route to make the distribution. Joint traffic between different network owners or operators is also possible. The largest number of nodes will be used for the connection of the end-customers.

The nodes are spaces filled with transmission equipment, cross-connect devices, splice boxes, uninterrupted power supplies and equipment for climate control.

The design of the access node will be briefly described in the following but other types of nodes will not be discussed, except for a few comments.

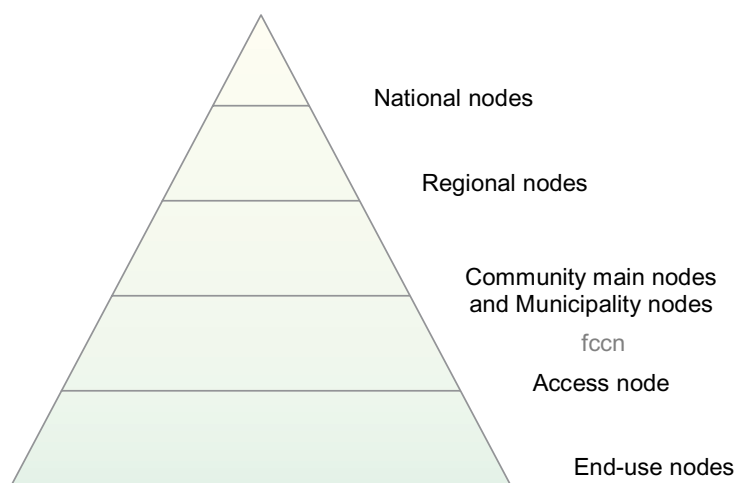


**Figure 7 – Node hierarchy**

### 1.4.1 National node

A national node is connected to several national and international networks.

The security level is very high.

### 1.4.2 Regional node

A regional node is connected to a national network, regional and municipality-connecting network.

### 1.4.3 Community main node

The main node in a community is connected to a regional network, municipality-connecting network in the same community. This node should always be redundant.

### 1.4.4 Municipality node

The municipality node is connected to the municipality-connecting network and the metro/urban network.

In small places the end customers may be connected directly to the municipality node through the access network.

### 1.4.5 Fibre cross connect node (fccn)

This is not a node in the true sense. It is more like a cross connect field to create redundancy in the premises network in case the main node will not function. In the distribution node the metro and municipality networks can be relocated to other main nodes, which will replace the original node. The distribution node can be localized next to the community main node or to the municipality node as a cross connect node, but not in the same room as the main node.

### 1.4.6 Access node

The access node is connected on one side to the metropolitan network and on the other side to the access network and can be connected directly to the end-user.

It will be described more in detail later in the Technical Report.

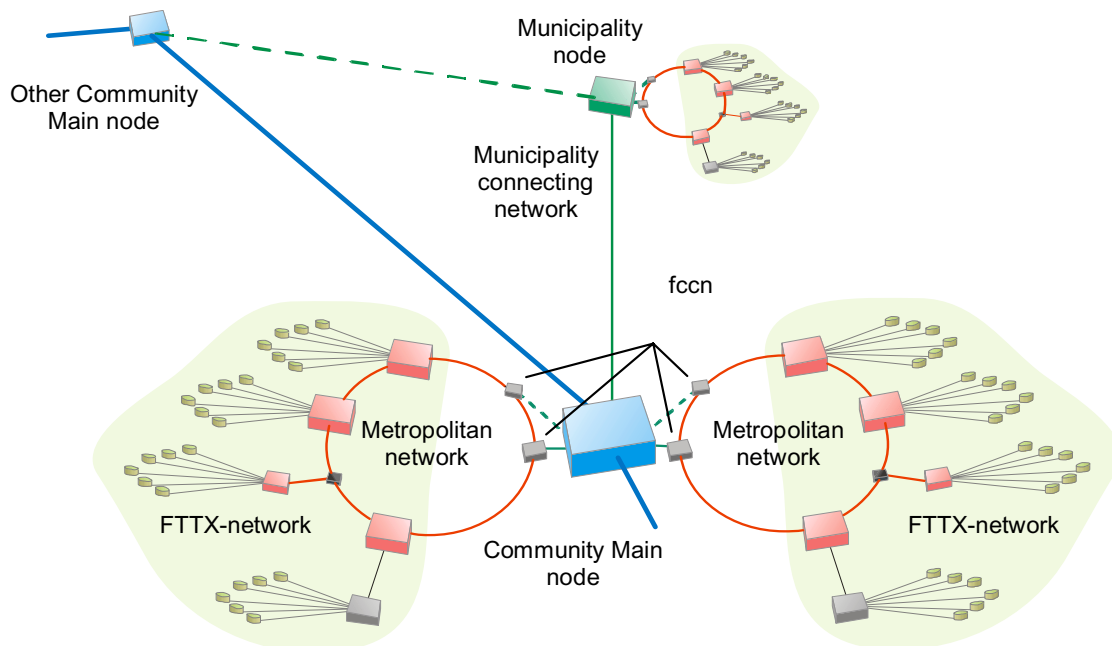


**Figure 8 – A comprehensive picture over a community network –  
The access network is here defined as FTTX**

## 1.5 Examples of FTTX topologies

The following four pictures give some simple illustrations to point-to-point (PTP) and passive optical networks (PON). PTP is in general passive, where one fibre from central office is routed directly to the customer and does not use splitters. For PON (in general point to multi point) one fibre from the central office is shared among a number of customers (usually 32) by the use of one passive splitter located within the network. For example, in a “converged PON” a number of passive splitters are located together, whilst in a “distributed PON” each passive splitter is located separately within the network.

The pictures are examples from different countries in Europe. See also the Glossary. PON can also be explained as power splitting point-to-multipoint.

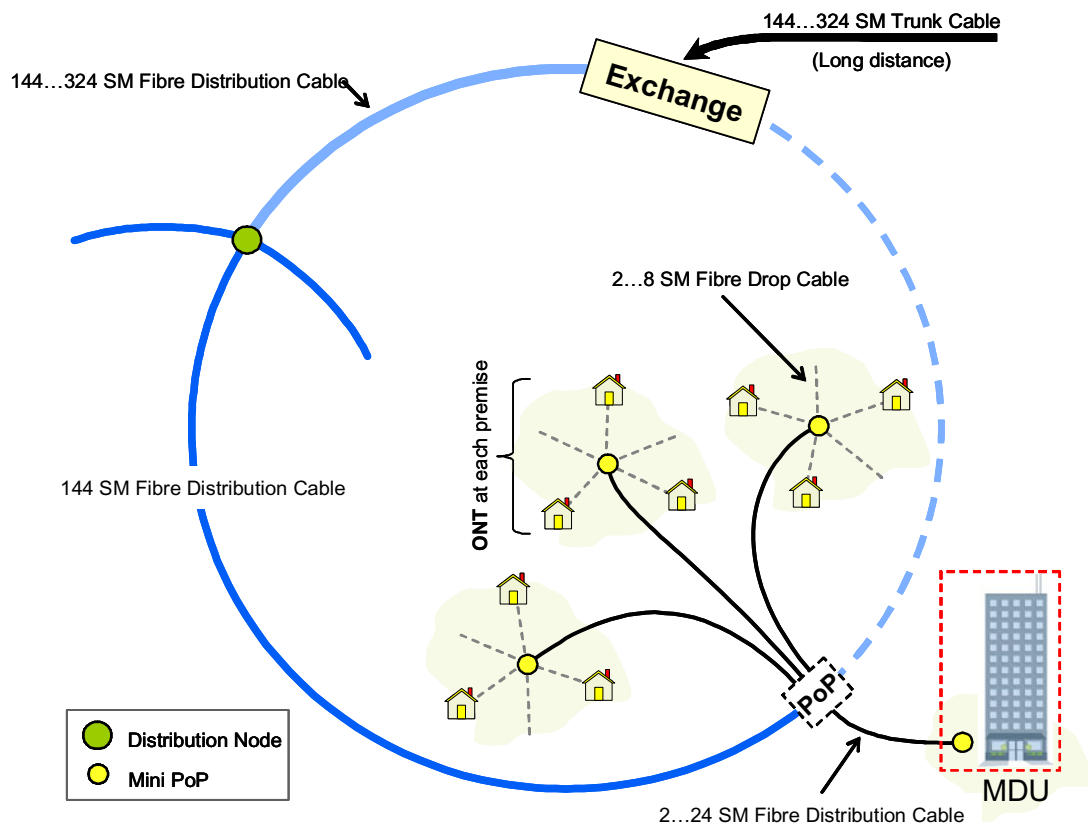


Figure 9 – Example for a Point-to-Point/Access Network

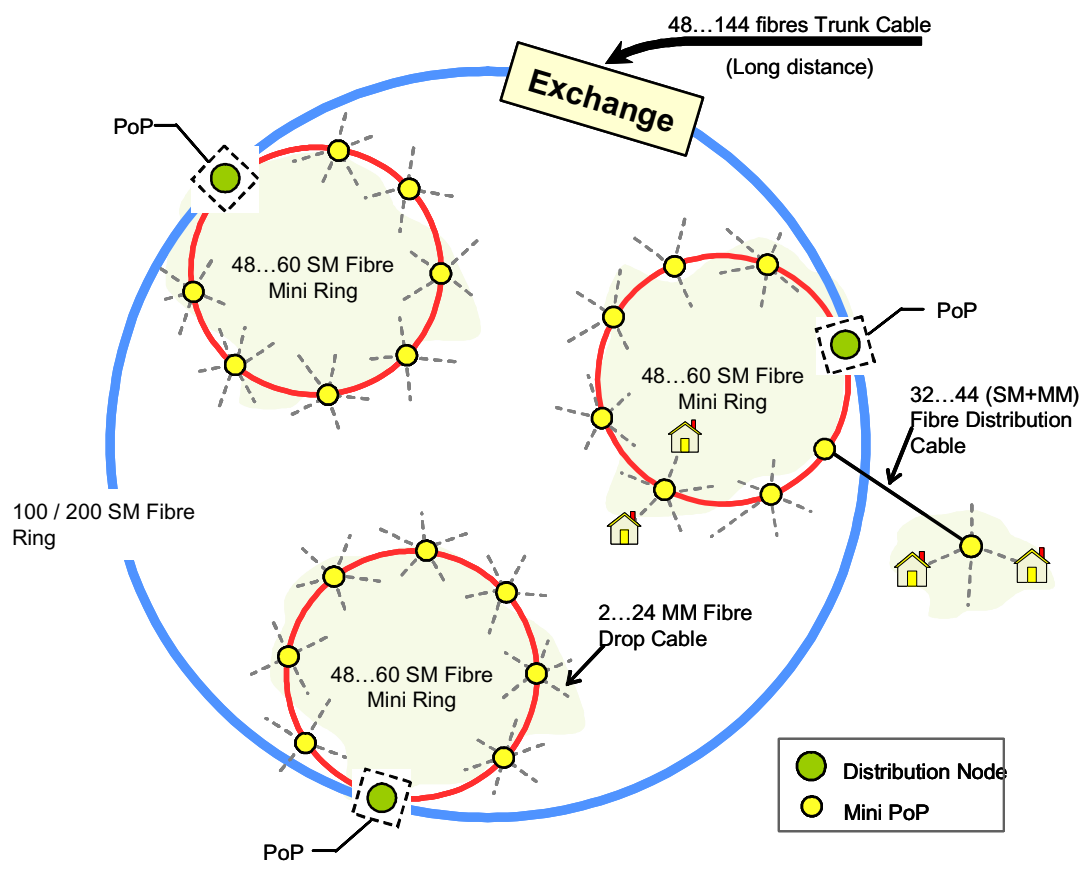


Figure 10 – Example of a Metro/Access Network

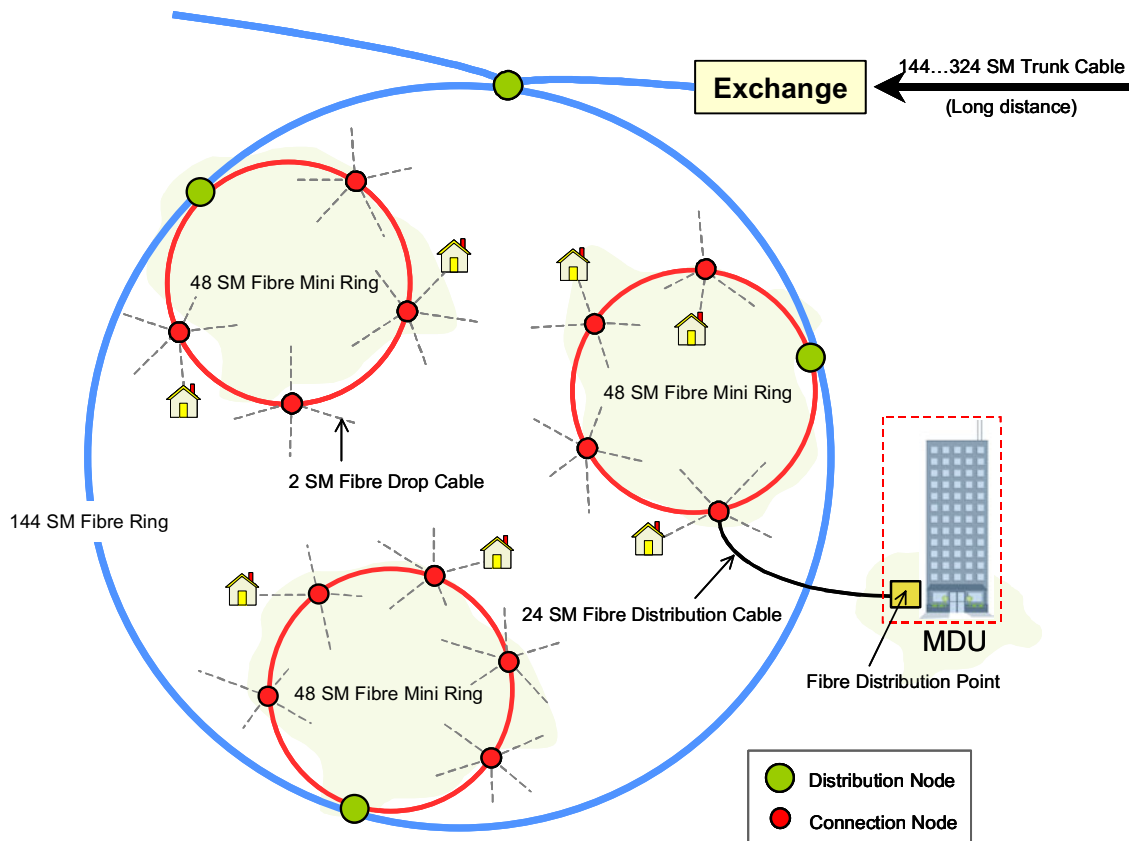


Figure 11 – Second example of a Metro/Access Network

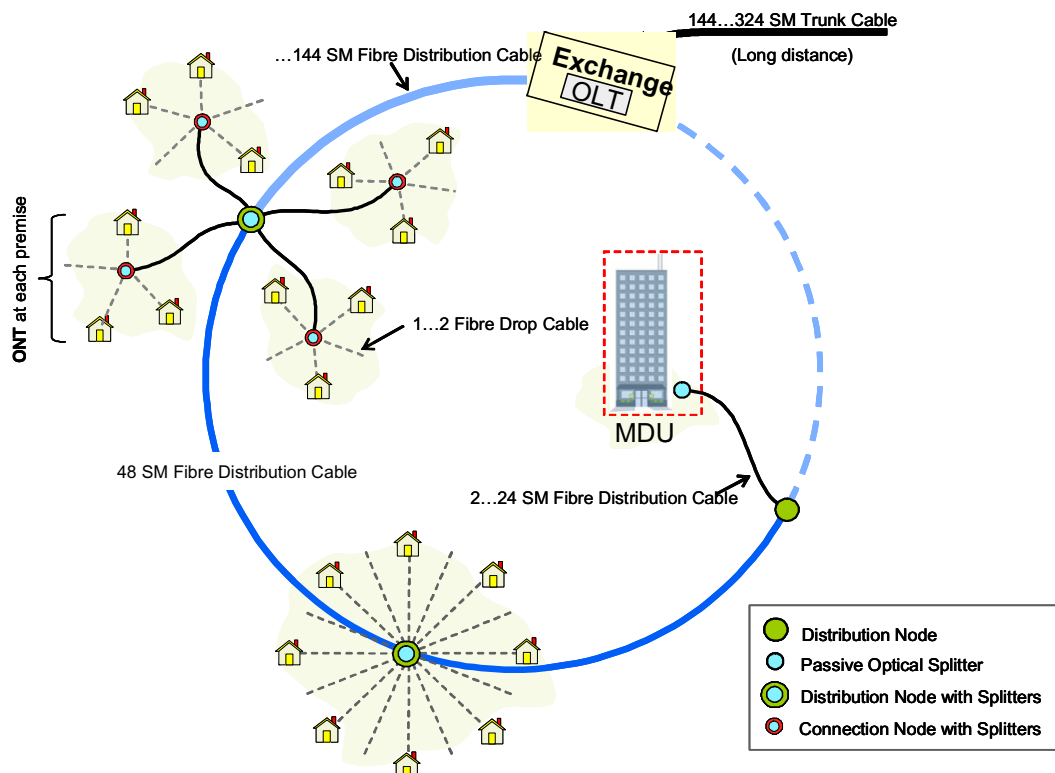


Figure 12 – Example for a Passive Optical Network (PON)

| Involved product standards (for details, see Annex A) |                         |
|-------------------------------------------------------|-------------------------|
| O. F. Cables                                          | EN 187105, EN 60794-x-y |
| Connectors                                            | EN 50377-x-y            |
| Closures/ODFs                                         | EN 50411                |
| Splices                                               | EN 61073                |
| Connector devices                                     | EN 61753                |
| RoW-solutions                                         | CLC/TS 50429 ... 50431  |

## 1.6 Access network

The network, which connects each end-user to the access node, is called the access network. The network is normally part of the real property. The access network may consist of a network inside a house and/or a network between several buildings. It can therefore include an area with block of flats, houses, industrial areas, schools, hospitals or offices.

The access network is the most complex network within the fibre optic IT-infrastructure. Each access network is unique and requires special planning to be optimised in all aspects. Anyway there are a number of solutions, which can be used as a base, see Annexes B, C and D.

### 1.6.1 FTTX in access networks

FTTX is often called the fibre access network. Here it is defined as the connection from a USER NODE in e.g. a private home to an ACCESS NODE. It is therefore the part of the IT-structure, where there is not a general redundancy requirement the fibres can be connected like a star from the access node to the user, see Figure 6.

Note that in many areas with privately owned access networks the active equipment is placed close to the building in a house property node. This network will therefore be rather short. A number of property nodes are then concentrated to an access node. This structure implies in many cases lower costs. Even working and maintenance expenses will increase for an area with active equipment in several nodes.

### 1.6.2 Size of an FTTX-network

The distance between the user and the access node can vary depending on the area from 10 m to 10 km. In most cases the FTTX-network varies between 100 m and 2 000 m.

To be able to handle these distances with desired capacity of 1 Gbit/s a single-mode fibre (SM) is required. Multimode-fibres can also be used in FTTX, but these networks are normally shorter, up to (500 – 2 000) m, and they need more active equipment. Multimode fibres can form sub-optimized solutions in particular for dense populated areas, like multi-tenants buildings, which can be compared in a way to business like LAN applications, where multimode fibres are the preferred fibre types because they offer cheaper active equipment.

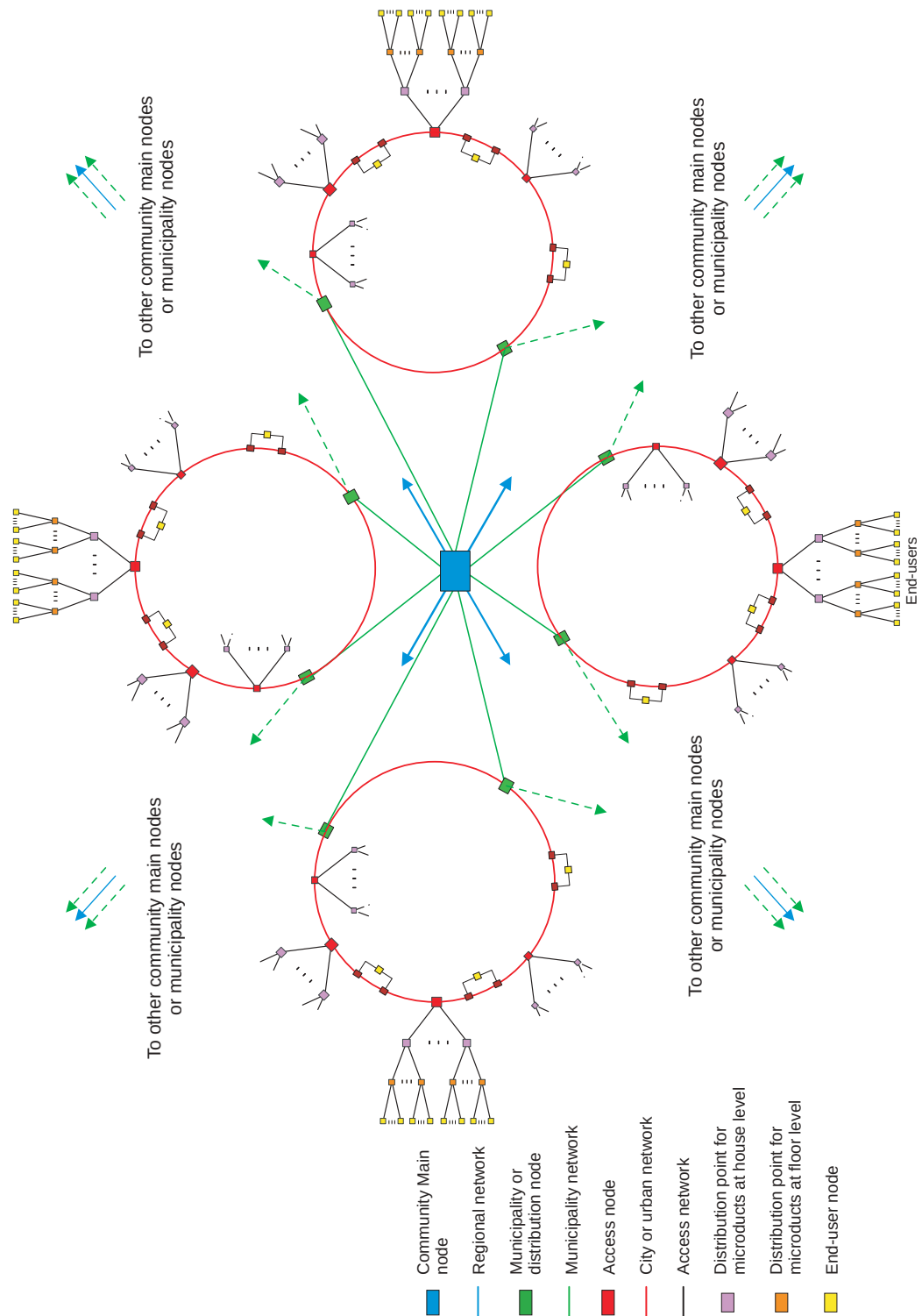


Figure 13 – A complex picture of a small community network with the main node in the centre

## 2 Passive network solutions

In this clause we will present some information about optical fibres, connectors, splicing, link designs and optical power budgets. Cable technology and various installation techniques will also be given. Although optical cables look similar to copper cables there are many differing details both in design and handling.

### 2.1 Choice of fibre type – Single-mode/multimode

The choice of fibre is determined by several parameters. The most important are:

- system costs,
- distance,
- transmission bit-rate.

The advantages of a single-mode fibre are high transmission capacity and low optical attenuation. If a single-mode fibre is used in FTTX, the same type can be used throughout the network, which gives transparency and uniformity. This also simplifies service, maintenance and new developments. Another advantage is that only tools and instruments for single-mode fibres need to be procured.

Multimode fibre allows simpler opto-electrical components and the costs for such networks will be slightly lower. However, such a fibre can only be used for shorter distances, depending on type, maybe 2 km, see more below.

NOTE Compilation of single-mode fibre types as defined in ITU and EN/IEC.

| Single-mode (SM)                              | ITU          | EN/IEC 60793-2-50 | Comment                          |
|-----------------------------------------------|--------------|-------------------|----------------------------------|
| Unshifted dispersion                          | G.652A,B     | B1.1              | Most common                      |
| Cut-off-shifted                               | G.654        | B1.2              | Low attenuation                  |
| Low water peak                                | G.652C,D     | B1.3              | Also common                      |
| Bending loss insensitive unshifted dispersion | G.657A,B     | - (tbd)           | New types for the Access Network |
| Dispersion-shifted                            | G.653        | B2                | Old, not recommended             |
| Nonzero dispersion-shifted                    | G.655, G.656 | B4                | Newer type for DWDM              |

For future developments in FTTX-infrastructures it is therefore recommended to use single-mode such as G.652B, C, D or G.657A, B, see more below.

The types G.652B, C and D are basically the same fibre type and allow CWDM. This is a cost effective way to transmit multiple signals in a fibre. Type C and D are fibres with low water peak attenuation at 1 383 nm (see Figure 15) and allow CWDM from 1 260 nm to 1 650 nm. The difference between C and D is the polarization mode dispersion (PMD) requirement, D has slightly lower PMD, but this is of minor importance for the discussed application FTTX.

The types G.657A, B fibres are specially designed for the Access Network in terms of reduced bending sensitivity (including applications inside buildings). Type A is fully compliant to G.652D for all other transmission parameters; type B may deviate from G.652D in terms of mode field diameter, chromatic dispersion and PMD, but its bending sensitivity is further reduced compared to type A.

Exception 1:

In densely populated areas with distances less than 500 m from the end-user to active equipment (e.g. in case of multi-tenant buildings) it may be possible to use multimode fibre, OM2 or OM3 [for an explanation of OM, see Table 2 and reference [1]].

Exception 2:

Another case is an area, where installations already have started with multimode fibres and where the same infrastructure is requested for the whole area.

In this particular case it is recommended to use multimode fibre of “giga”-type, i.e. (OM2 or OM3), to be able to further develop the network.

Please, note that most fibre manufacturers offer multimode fibre with higher performance than the standardized requirements for OM2- and OM3-specifications (see Table 2). Let the maximum distance be 1 000 m. This guarantees 1 Gbit/s.

Tables 1 and 2 below show some properties for recommended fibres.

**Table 1 – Example of properties for single-mode fibres for FTTX**

| Single-mode fibre    | Typical cabled attenuation (dB/km) |          |
|----------------------|------------------------------------|----------|
|                      | 1 310 nm                           | 1 550 nm |
| G.652B,C,D, G.657A,B | 0,36                               | 0,25     |

The basic difference is at 1 383 nm, the water peak, see Figure 15.

**Table 2 – Example of properties for multimode fibres for FTTX**

| Multimode fibre<br>EN 60793-2-10<br>type A1a and A1b | Attenuation (dB/km) |          | Bandwidth MHz × km (overfilled) |          |
|------------------------------------------------------|---------------------|----------|---------------------------------|----------|
|                                                      | 850 nm              | 1 300 nm | 850 nm                          | 1 300 nm |
| <b>OM2</b><br>(50 µm, 62,5 µm)                       | < 3,5               | < 1,5    | 500                             | 500      |
| <b>OM3</b><br>(50 µm)                                | < 3,5               | < 1,5    | 1 500                           | 500      |

A more complete table is given in EN 50173-1. A full description of multimode specifications is given in EN 60793-2-10.

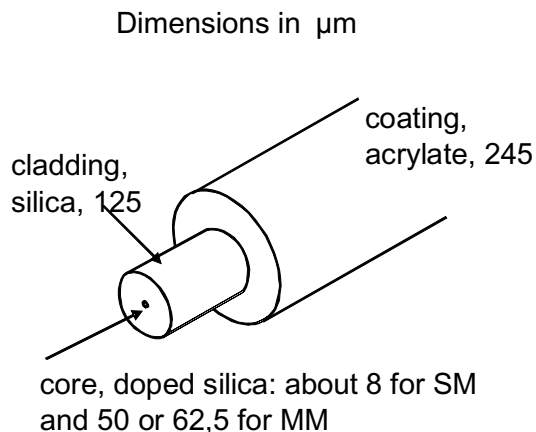


Figure 14 – Optical fibre, with single-mode (SM) core and multimode (MM) core examples

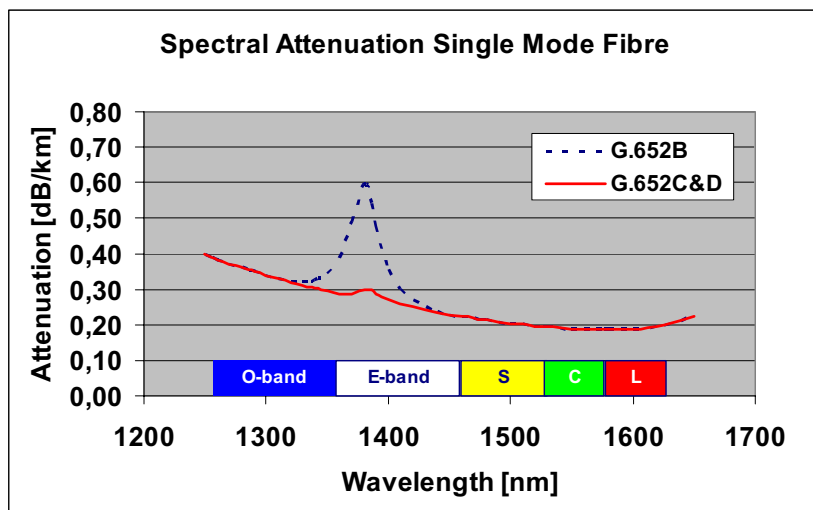


Figure 15 – Spectral attenuation curve for G.652B, C and D fibres with water peak at 1 383 nm  
O-, E-, S-, C-, and L-bands are defined in ITU-T

It is not only the low water-peak that differ G.652C and D from G.652B. There is also a specific hydrogen-test (EN 60793-2-50) to be fulfilled.

## 2.2 Number of fibres for each end-user

The total number of fibres for each end-user is depending on the use of opto-electrical components in the network and installation technique. Most systems for point-to-point connections are based upon two-fibre solutions with one fibre up- and one downlink.

Presently there are also systems based upon WDM-technique, where up- and downlink is on the same fibre, but different wavelengths. The fibre volume, splices and connectors are then only half.

When the network is dimensioned it is necessary to take into account future possible requirements such as new establishments, alarms, different providers et cetera.

Different systems in the future may need more fibres.

Therefore:

- If the installation is performed with a traditional optical cable for the last km, two-fibre cables shall be installed even if only one fibre is used initially.

- If blowing technique is used, a single fibre can be installed, since the advantage with blowing technique is that it is easy to add fibres if a microduct system is used.
- If a microduct system is used it is easy to add fibres.

It is not necessary to assemble unused fibres with connectors. They can be placed in splice boxes or panels.

### 2.3 Connectors in the FTTX-network

Fibre optic connectors are passive optical components in a fibre optic network. Connectors are used to couple two fibres together or to connect fibres to transmitters or receivers.

Connectors allow flexibility in case of reconnecting or reconfiguration of the fibre optic networks. Therefore, they are designed to be demountable and have the additional requirements of durability under repeated matings.

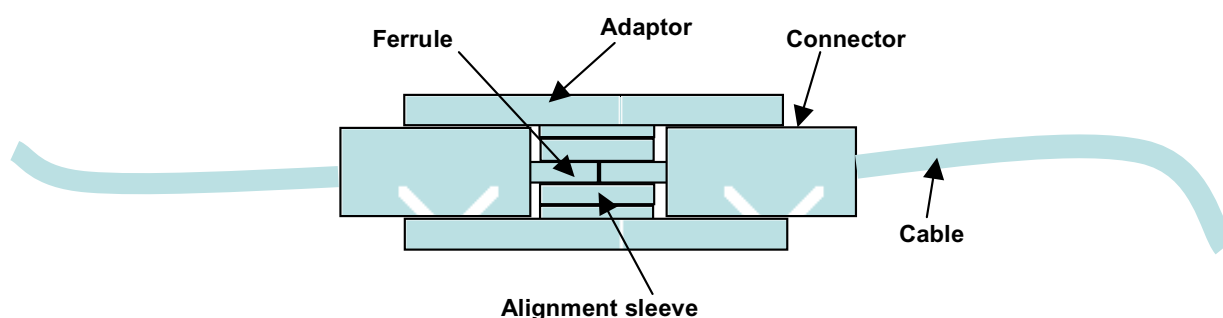
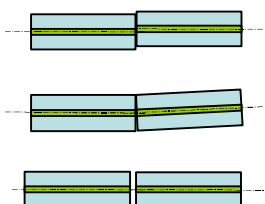


**Figure 16 – Functional elements of a fibre optic connection  
(two connectors aligned in the sleeve inside the adaptor)**

One fibre optic connection is defined with two connectors and one adaptor. Ferrules and alignment sleeve are the most important functional elements of the fibre optic connector. The required quality of the fibre optic connections is achieved by the alignment of the two fibre optic axes within submicron range and by the end face condition within specified requirements.

Connection loss is mainly caused by following factors:

- lateral offset of two aligned fibres
- angular mismatch of two fibre axes
- end face air gap

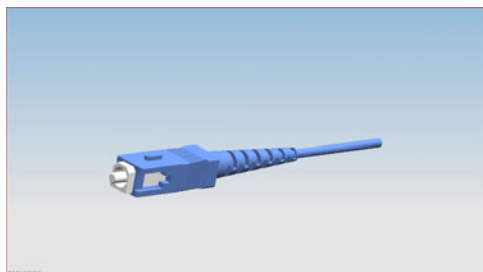


The following criteria and requirements are internationally agreed and published as standards:

- mechanical intermateability,
- optical intermateability,
- optical performance requirements,
- reliability requirements,
- end face geometrical requirement,
- end face cleanliness (dust, contamination, etc.) and polishing condition (scratches, pits, debris, etc.),

guaranteeing the required performance of connectors with plugs and adaptors from different suppliers.

A number of different connector types, characterised by the physical contact of the two fibre end faces, are defined in the related international standards and can be used in FTTX networks. They can be distinguished in the size, form and coupling mechanism. Normally the connectors of the different types cannot be mated together unless hybrid adaptors are used.



SC  
(ferrule diameter 2,5 mm)



LC  
(ferrule diameter 1,25 mm)

**Figure 17 – Examples of ferrule based connector types**

Connectors with 1,25 mm ferrule diameter are smaller and space saving.

All fibre optic connector types are available for single mode and multimode fibres.

All these connector types are available as simplex or duplex, with non-angled or angled end face polishing. Angled polishing technology delivers connections with improved high return loss <sup>1)</sup> ( $\geq 60$  dB) compared to non-angled polishing technology ( $\geq 45$  dB).

The deployment and the choice of the connector type depend on the following:

- type already installed in the network or deployed in the system,
- handling,
- application,
- availability from different sources,
- price.

Fibre optic connectors may be assembled in the field or be delivered as pre-connectorised pigtails.

Table 3 gives a summary of the optical performance requirements for connections in the FTTX-network with digital transmission specified for random mated connections:

**Table 3 – Proposed connection requirements for FTTX**

| Connection type                                                                                                                                                                                                                        | Optical attenuation,<br>typical<br>dB | Optical attenuation,<br>maximum<br>dB | Return loss<br>dB        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|---------------------------------------|--------------------------|
| Single-mode                                                                                                                                                                                                                            | $\leq 0,25$                           | $\leq 0,5$                            | $\geq 35$<br>$\geq 60^a$ |
| Multimode                                                                                                                                                                                                                              | $\leq 0,3$                            | $\leq 0,75$                           | $\geq 20$                |
| <sup>a</sup> Return loss $\geq 60$ dB: For a video overlay network (with analog RF modulation) APC (angled polished connector) are recommended. Higher reflections may result in a distortion or a poor S/N ratio of the video signal. |                                       |                                       |                          |

<sup>1)</sup> Return loss has the same absolute value as back reflection, but with a positive sign.

## 2.4 Fibre splicing

Traditionally optical fibres have been fusion spliced, however mechanical splices also offer a cost effective solution.

A good splice typically gives (0,05 – 0,2) dB in attenuation for single-mode fibres. The splice attenuation is not critical for many systems, but for optical budget reasons it is recommended to resplice, if the attenuation is higher than 0,3 dB for fusion splices or if the attenuation is higher than 0,5 dB for mechanical splices.

## 2.5 Link dimensioning

The following parameters are needed for a link dimension:

- maximum transmission distance,
- optical attenuation budget for the system,
- fibre type,
- connector attenuation,
- splice attenuation,
- maximum back reflection (return loss),
- type of connector,
- ageing and repair margin.

Some systems also need:

- shortest link distance,
- lowest optical attenuation.

## 2.6 Calculation of an optical budget

The fibre optic connection is dependant on the opto-electrical components in use. A general calculation of the maximum fibre length is given by:

NOTE The dispersion is here disregarded.

$$l_{\max} = (O_{pb} - a \times C_a - b \times S_a - n) / F_a$$

where

|            |                                                                              |
|------------|------------------------------------------------------------------------------|
| $l_{\max}$ | maximum fibre length in km;                                                  |
| $O_{pb}$   | optical power budget for the opto-electrical system in dB;                   |
| $a$        | number of connectors;                                                        |
| $C_a$      | average connector attenuation in dB/connector;                               |
| $b$        | number of fibre splices;                                                     |
| $S_a$      | average fibre splice in dB/splice;                                           |
| $n$        | margin for ageing and repair, on/off-ratio, temperature changes and similar; |
| $F_a$      | fibre attenuation in dB/km.                                                  |

This is a simple example of a link calculation without splitters.

Calculate the maximum fibre length,  $l_{\max}$  for an FTTX-network from end-user node to access node, see Figure 18.

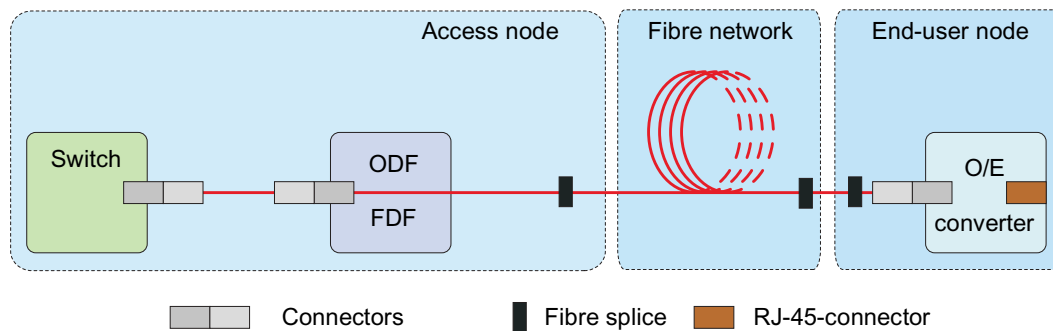


**Figure 18 – A model for calculation of optical attenuation**

In this example the network is built by using pre-connectorised fibres (pigtails), cords and cables from the end-user to the access node. In total this will give three connector connections ( $a=3$ ) and three fibre splices ( $b=3$ ) in the network.

An optical link at 1 550 nm with standard single-mode fibre has a typical attenuation,  $F_a$ , of 0,25 dB/km. The total fibre attenuation is therefore  $0,25 \times l_{\max}$ .

The network is connected with single-mode fibre connectors and assumed maximum attenuation,  $C_a$ , of 0,5 dB per connector. The total connector attenuation is therefore  $3 \times 0,5 = 1,5$  dB.

The fibre splice attenuation,  $S_a$ , is assumed to be max 0,3 dB per splice. The total fibre splice attenuation is  $3 \times 0,3 = 0,9$  dB.

The optical power budget in this example,  $O_{pb}$ , is assumed to be max 7 dB. The total attenuation from fibre, connectors and splices can therefore not exceed 7 dB. Margin for ageing is chosen to be 1,5 dB (this value is somewhat arbitrary). The maximum fibre length is then:

$$\text{Optical power budget (O}_{pb}\text{)} = \text{Fibre attenuation (F}_a \times l_{\max}\text{)} + \text{Connector attenuation (a} \times C_a\text{)} + \text{Fibre splice attenuation (b} \times S_a\text{)} + 1,5 \text{ (n)}$$

or

$$7,5 = 0,25 \times l_{\max} + 3 \times 0,5 + 3 \times 0,3 + 1,5$$

which gives  $l_{\max} = 14$  km

If the power budget is specified to 7,5 dB, the maximum distance is 14 km. To maximize future developments the optical power is presumed to be lower and the maximum distance should be shorter than 10 km. Then it is also possible to add more splices if necessary. Every new splice reduces the link length.

NOTE Substantially higher power budgets can be achieved for all types of application, which would make longer lengths achievable.

For a multimode fibre with higher attenuation, lower bandwidth and lower power budget the distance will be even shorter.

## 2.7 Fibre optic cabling

A fibre installation can be performed by:

1. Laying of direct buried type standard fibre optic cable in the ground.
2. Laying of HDPE ducts and consequently blow or pull in a standard fibre optic duct type cable.
3. Laying of a microduct system and consequently blow in a micro cable or a fibre unit.

For geographically spread access networks such as residential or industrial areas a combination of microduct fibre unit cables (blown fibres), microduct optical fibre cables and traditional cables are used. Microducts can be installed from areas/buildings to one or several concentration points. Depending on technique micro cable or fibre unit can be blown into the microducts from different directions. In the concentration point the fibre is spliced to a cable, typically installed in a duct, to the access node, see Figure 20.

In Figure 19 we find from top to bottom:

- primary coated fibre (Ø 0,25 mm),
- three different secondary coated fibre units – 4-fibre ribbon (1,1 × 0,4 mm), tight coated (Ø 0,9 mm) and loose tube (ca Ø 3 mm),
- microduct optical fibre cable in a microduct,
- standard cable with loose tubes,
- ribbon cable.

All of these can be part of the FTTX-network.

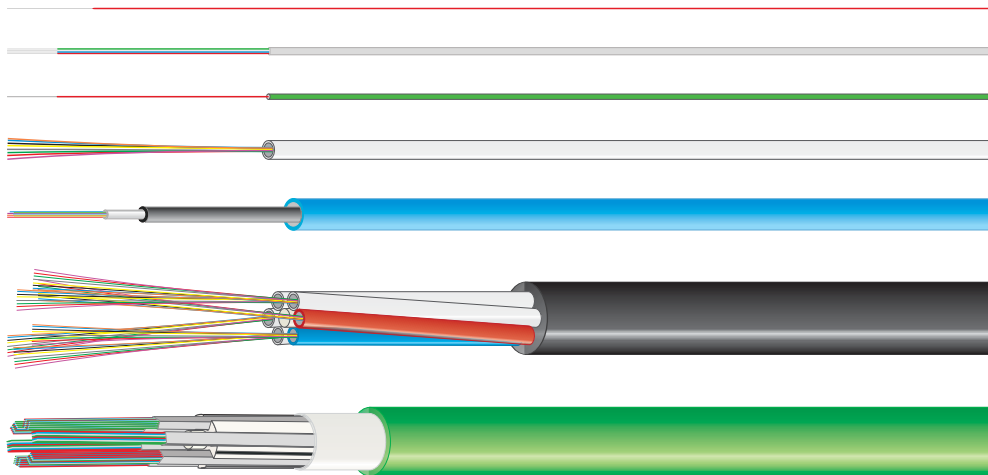


Figure 19 – From fibre to different cables

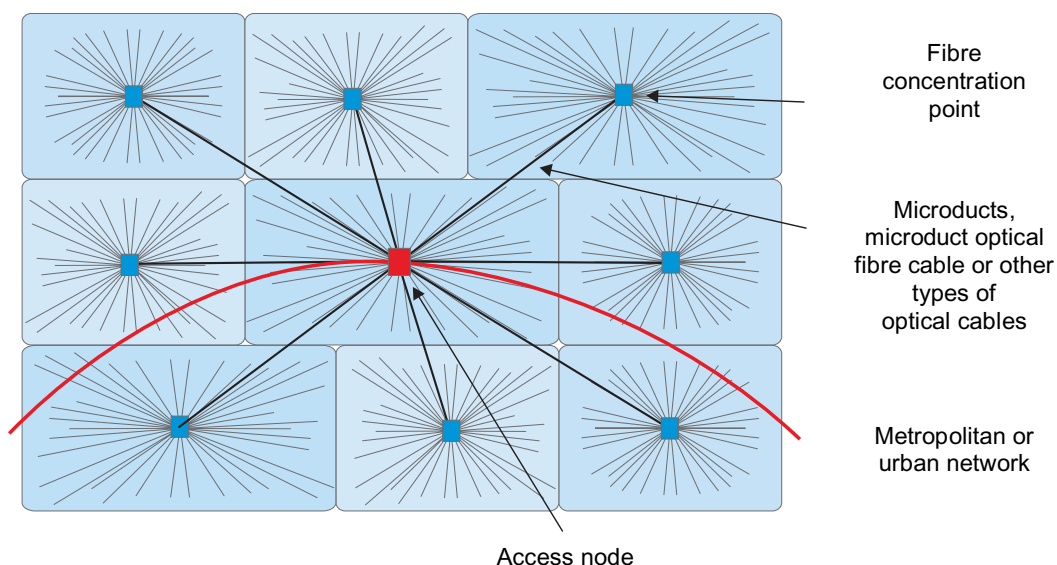


Figure 20 – Fibre installations planned in “cells” with the fibre volume focused to the access node