FTTH Handbook

Edition 4.1

D&O Committee

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Fibre to the Home Council Europe

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Foreword

The publications of the FTTH Council Europe play an important part in our mission to accelerate the roll out of fibre access networks to homes and businesses throughout Europe. These documents help to meet the increasing thirst for knowledge about fibre-to-the-home (FTTH) networks, particularly among the new entrants and alternative operators who form an important part of the FTTH scene in Europe.

The FTTH Handbook was the first major publication produced by the FTTH Council Europe. Originally issued in 2007, its purpose was to provide an impartial source of information about the options available for deployment of optical fibre cable. The scope of the book was later expanded to include the technical options for lighting up the fibre, including both passive optical network and Active Ethernet systems, and the customer premises equipment.

Last year the entire document was revised, and extensive new sections were added on the subject of FTTH network testing, including qualifying networks during construction, service activation and troubleshooting.

For this, the fourth edition of the FTTH Handbook, the sections on current and future developments in active equipment for FTTH networks have been updated to include the latest passive optical network solutions with 10Gbps capacity and wavelength-division multiplexing. There is also a new section on quality grades for fibre-optic connectors.

As an industry organisation, the FTTH Council Europe represents fibre, cable, equipment and installation companies all over Europe. The cooperation of more than 150 members ensures that the FTTH Handbook provides vendor-neutral information based on the latest developments in the industry. The Deployment and Operations Committee has done a great job of co-ordinating the different contributions in order to create such a comprehensive document.

Chris Holden, President of the FTTH Council Europe

Contents

1 Introduction

Optical fibre is now recognised as the main building block for future high-capacity home broadband networks. The transmission capacity of fibre is almost unlimited and is unconditional compared to existing copper cabling systems.

Numerous financial models have shown little difference between the deployment costs of optical fibre and copper cable systems of equal capacity. However, the advantages of fibre – high bandwidth over long distances, future upgrade potential and significantly lower maintenance and operational costs – make fibre the sensible, long-term choice.

The FTTH Handbook has been written in order to provide a straightforward and impartial description of the important elements and various possible construction methods for a fibre-to-the-home (FTTH) network infrastructure.

In these pages, you will find details of the different infrastructure deployment options that can be considered when planning and building an FTTH network in Europe. The scope of this document is to provide an overview of existing technologies; it should not be taken as a design guide.

All deployment options discussed in this Handbook are based on a complete optical fibre path from the network operator's active equipment right through to the subscriber premises. Hybrid options involving part fibre and part copper infrastructure networks are not considered.

The FTTH Council Europe accepts that all existing solutions have a place in today's networks. A important part of designing a network is choosing the most appropriate build methodology. It is up to the network designer to decide which methodology is the most appropriate solution for the specific circumstances.

All of the equipment, services, and deployment methods described are currently available and have been successfully deployed throughout Europe and elsewhere. They can be used either in isolation or in combination with the other options to form the most efficient overall solution for specific network circumstances.

Pierre Pigaglio, Chair of the Deployment and Operations Committee

2 FTTH Network Description

A fibre to the home (FTTH) network constitutes a fibre-based access network, connecting a large number of end users to a central point known as an access node or point of presence (POP). Each access node will contain the required electronic transmission (active) equipment to provide the applications and services over optical fibre to the subscriber. Each access node is served by a larger metropolitan or urban fibre network, which connect all the access nodes throughout a large municipality or region.

Access networks may connect some of the following:

- fixed wireless network antenna, for example, wireless LAN or WiMAX
- mobile network base stations
- subscribers in residential houses, terraces or blocks of flats
- larger buildings such as schools, hospitals and businesses
- key security and monitoring structures like surveillance cameras, security alarms and control devices

A FTTH network may be considered to be part of the wider area or access network.

2.1 FTTH network environment

The deployment of fibre closer to the subscriber may require deployment of fibre infrastructure on public and private land, and also within public and private properties.

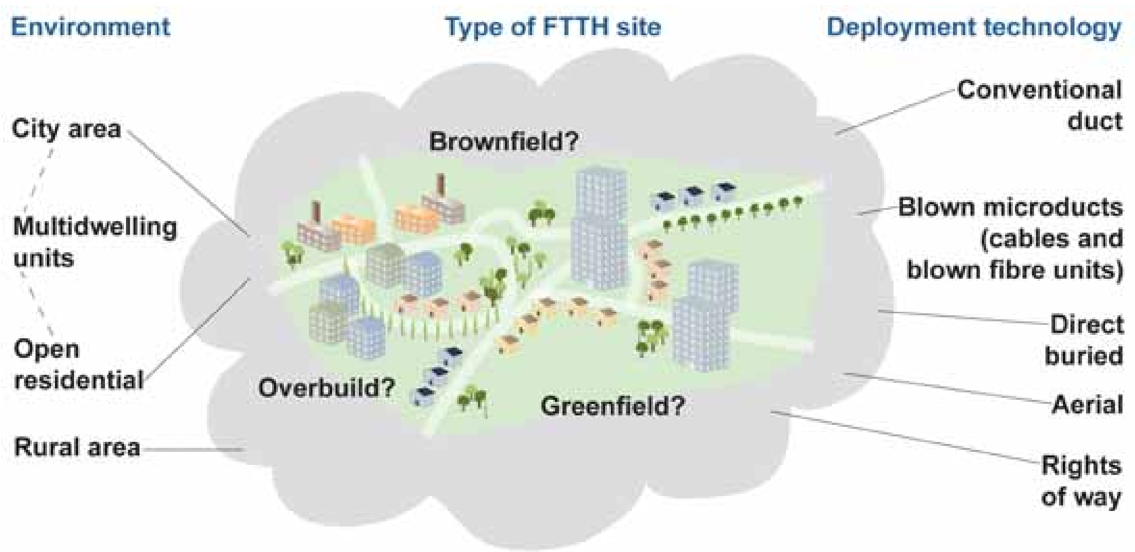


Figure 1: Type of FTTH site.

The environment can be broadly split into:

- city

- open residential
- rural
- building type and density – single homes or multi-dwelling units (MDUs)

Not only does each environment offer different customer densities (per sq km), but this also varies by country.

The type of site will be a key factor in deciding the most appropriate network design and architecture. Types include:

- Greenfield – new build where the network will be introduced at the same time as the buildings
- Brownfield – where there are existing buildings and infrastructure but the infrastructure is to a lower standard
- overbuild – adding to the existing infrastructure

The main influences on the infrastructure deployment methodology are:

- type of FTTH area:
- size of the FTTH network
- initial deployment cost of the infrastructure elements (CAPEX)
- ongoing costs for network operation and maintenance (OPEX)
- network architecture, for example PON or Active Ethernet
- local conditions, for example, local labour costs, local authority restrictions (traffic control) and others

The choice of fibre deployment technology will determine CAPEX and OPEX, as well as the reliability of the network. These costs can be optimised by choosing the most appropriate active solution combined with the most appropriate infrastructure deployment methodology. These methods, which are described in Section 9, include:

- conventional underground duct and cable
- blown micro-ducts and cable
- direct buried cable
- aerial cable
- "other rights of way" solutions

Key functional requirements for a FTTH network will include:

- provision of high bandwidth services and content to each customer
- a flexible network architecture design that can accommodate future needs
- connection by fibre of each end subscriber directly to the active equipment, to ensure maximum available capacity for future service demands
- support for future network upgrade and expansion
- minimize disruption during network deployment, to help fibre networks gain acceptance from network owners and to benefit FTTH subscribers

When designing and building FTTH networks, it is helpful to understand the challenges and tradeoffs facing potential network owners and operators. Some of these challenges may present conflicts between functionality and economic demands.

The FTTH network builder must create a profitable business case, balancing capital expenses with operating costs while ensuring revenue generation. Cost considerations are introduced briefly in Section 6, but for a more detailed analysis of the main influences on the business case for FTTH networks please read the *FTTH Business Guide*, which is also available from the FTTH Council Europe.

2.2 FTTH architecture

In order to specify the interworking of passive and active infrastructure, it is important to make a clear distinction between the topologies used for the deployment of the fibres (the passive infrastructure) and the technologies used to transport data over the fibres (the active equipment).

The two most widely used topologies are point-to-multipoint, which is often combined with a passive optical network (PON) architecture, and point-to-point, typically using Ethernet transmission technologies.

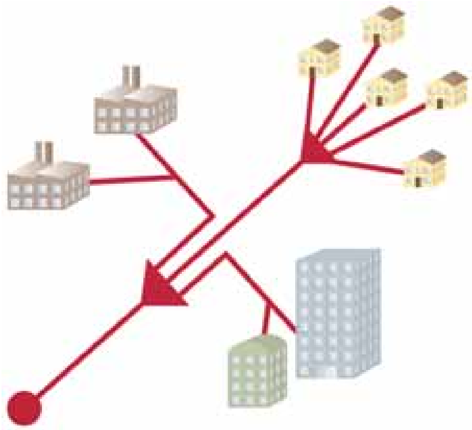


Figure 2: Passive optical network.

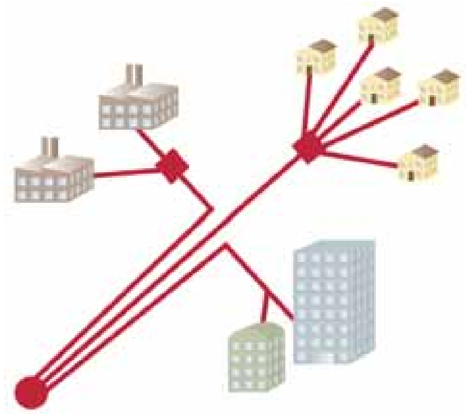


Figure 3: Active Ethernet network.

Point-to-point topologies provide dedicated fibres between the POP and the subscriber. Each subscriber is directly connected by a dedicated fibre. Most existing point-to-point FTTH deployments use Ethernet, but this can be mixed with other transmission schemes for business applications (e.g. Fibre Channel, SDH/SONET). This topology can also include PON technologies by placing the passive optical splitters in the access node.

Point-to-multipoint topologies with passive optical splitters in the field are deployed in conjunction with standardized PON technologies – GPON is today's frontrunner in Europe, while EPON has been massively deployed in Asia – using time-sharing protocols to control the access of multiple subscribers to the shared feeder fibre.

Active Ethernet technology can also be used to control subscriber access in a point-to-multipoint topology – this requires placing Ethernet switches in the field.

2.3 Different fibre termination points

Various access network architectures can be implemented:

Fibre to the home (FTTH) – Each device at the subscriber premise is connected by a dedicated fibre to a port on the equipment in the POP, or to the passive optical splitter, using shared feeder fibre to the POP. It uses 100BASE-BX10 or 1000BASE-BX10 transmission for Ethernet connectivity; mainly GPON (or EPON) in case of point-to-multipoint connectivity.

Fibre to the building (FTTB) – each optical termination box in the building (typically in the basement) is connected by a dedicated fibre to a port on the equipment in the POP, or the optical splitter, using shared feeder fibre to the POP. The connections between subscribers and the building switch can be fibre or copper based and use some form of Ethernet transport suited to the medium available in the vertical cabling. In some cases building switches are not individually connected to the POP but are interconnected in a chain or ring structure in order to utilize existing fibres deployed in particular topologies and to save fibres and ports in the POP. The particular case of bringing fibre directly into the apartment from POP or optical splitter onwards, without any switch in the building, brings us back to the FTTH scenario.

Fibre to the curb (FTTC) – each switch / or DSL access multiplexer (DSLAM), typically in a street cabinet, is connected to the POP via a single fibre or a pair of fibres, carrying the aggregated traffic of the neighbourhood via Gigabit Ethernet or 10 Gigabit Ethernet. The connections between subscribers and the switch in the street cabinet can be fibre or copper based, and use either100BASE-BX10, 1000BASE-BX10 or VDSL2. This architecture is also sometimes called "Active Ethernet" because it requires active network elements in the field.

This document will however concentrate on FTTH/B deployments because in the long term they are considered the target architecture due to their virtually unlimited scalability.

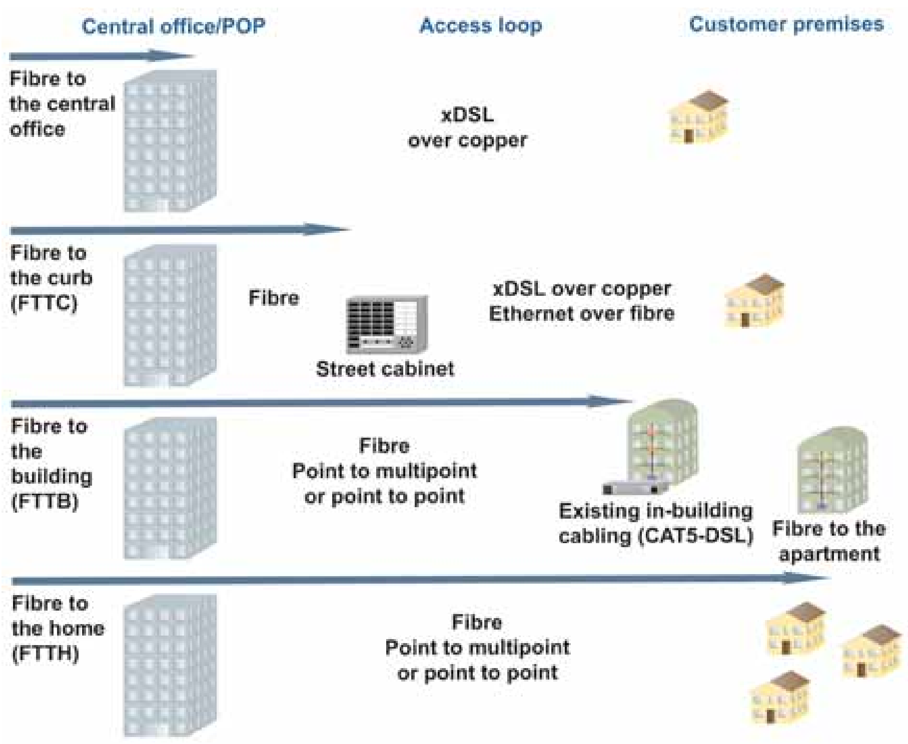


Figure 4: Different types of FTTx networks.

3 Active Equipment

Both passive optical network (PON) and Ethernet point-to-point solutions have been deployed worldwide. The choice of equipment depends on many variables including demographics and geographical segmentation, specific deployment parameters, financial calculations, and more. In particular, the choice is highly dependent on the ease of deploying the passive infrastructure. Clearly, in today's marketplace there is room for both solutions.

In a multi-dwelling unit (MDU), the connections between end-users and the building switch can either be copper or fibre, although fibre is the only solution that will guarantee the ability to manage future bandwidth requirements. In some deployments a second fibre is provided for RF video overlay systems; in other cases multiple fibres (2 to 4 per home) are installed to guarantee competition and to be prepared for future applications.

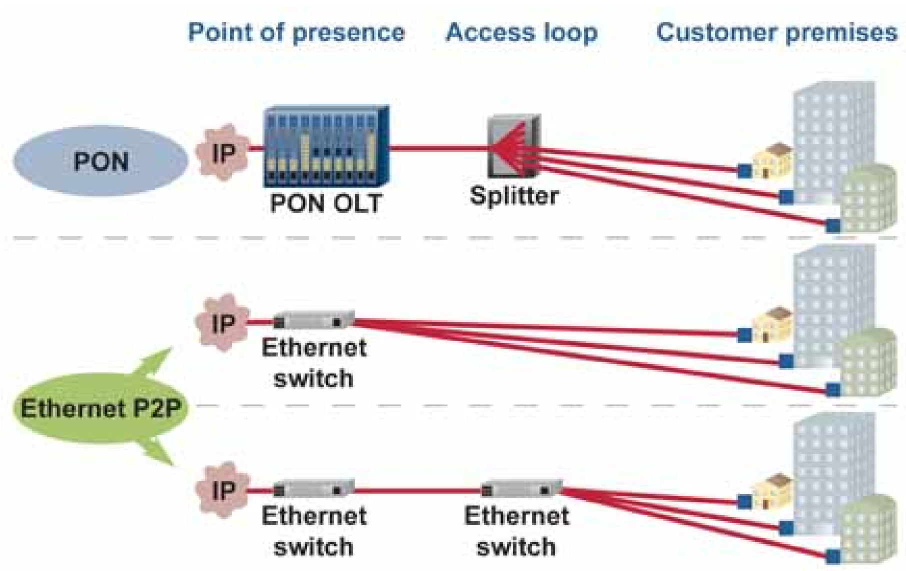


Figure 5: Different FTTH network architectures.

3.1 Passive optical network

The PON equipment comprises an optical line terminal (OLT) in the point of presence (POP) or central office, one fibre to the passive optical splitter and a fan-out towards a maximum of 64 end-users, each having an optical network unit (ONU), where the fibre is terminated.

The ONU exists in several versions, including an MDU version that handles many customers for in-building applications, reusing existing in-building cabling (CAT5/Ethernet).

Advantages of PON include reduced fibre usage (between POP and splitters), the absence of active equipment between the OLT and ONU, dynamic bandwidth allocation capabilities and the possibility of high bandwidth bursts, which could lead to capital and operational cost savings.

It is important to note that the last part of the network – between the last splitter and the end-user – is the same for a point-to-point or a PON solution: every home passed will be connected with one (or more) fibres up to the point where the last splitter will be installed, also known as a fibre concentration point (FCP) or fibre flexibility point (FFP). One of the differentiators of PON will be that the number of fibres between the FFPs and the POP can be reduced significantly (splitting ratio in combination with the subscriber take rate can result in a 1:100 fibre need reduction). Especially in Brownfield areas where some (scarce) resources are already available – either dark fibre and/or duct space – this could translate in considerable cost and roll-out time savings.

3.1.1 PON solutions

There have been several generations of PON technology to date.

The Full Services Access Network (FSAN) Group develops technical specifications, which are then ratified as standards by the International Telecommunications Union (ITU). These standards include APON, BPON, GPON and XG-PON. GPON provides 2.5Gbps of bandwidth downstream and 1.25Gbps upstream shared by a maximum of 64 users. XG-PON offers 10 Gbps downstream and 2.5 Gbps upstream for up to 128 users.

In 2004 the Institute of Electrical and Electronic Engineers (IEEE) introduced an alternative standard called EPON with a capability of 1Gbps in both directions. Proprietary EPON products are also available with 2Gbit/s downstream bit rate. In September 2009 the IEEE ratified a new standard, 10G-EPON, offering 10 Gbps symmetric bit rate.

Trends for access technology over the next ten years will be towards more symmetrical bandwidth. Multimedia file sharing, peer-to-peer applications and the more data-intensive applications used by home-workers will drive subscriber upstream bandwidth. Still, it is difficult to envision complete symmetry in residential applications due to the enormous amount of bandwidth required for HDTV and entertainment services in general – although small businesses could benefit from symmetric, broadband connectivity. Nonetheless, it is the high upstream bit rate of the PON that gives FTTH operators their key competitive advantage over DSL or cable providers.

GPON provides a 20 km reach with a 28dB optical budget using class B+ optics with a split ratio of 1:32. Reach can be extended to 30 km by limiting the splitting factor to a maximum of 1:16, or by introducing C+ optics, which add up to 4 dB to the optical link budget and can increase the optical reach to 60 km. 10G-EPON can also provide a 20 km reach with a 29dB optical budget.

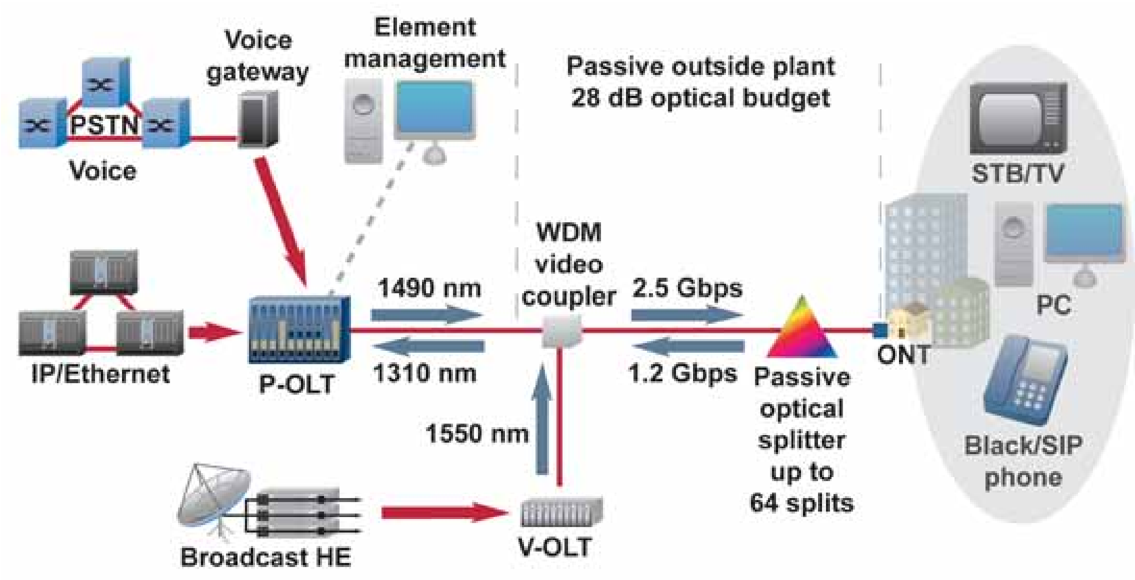


Figure 6: Schematic diagram of a GPON network.

Optionally, an RF video overlay can be added by yet another wavelength (1550 nm); this can be useful in stepwise build-up and time-to-market critical situations for digital TV offerings.

The standards have been defined in such a way that both GPON and XG-PON can coexist on the same fibre through the use of different wavelengths for both solutions.

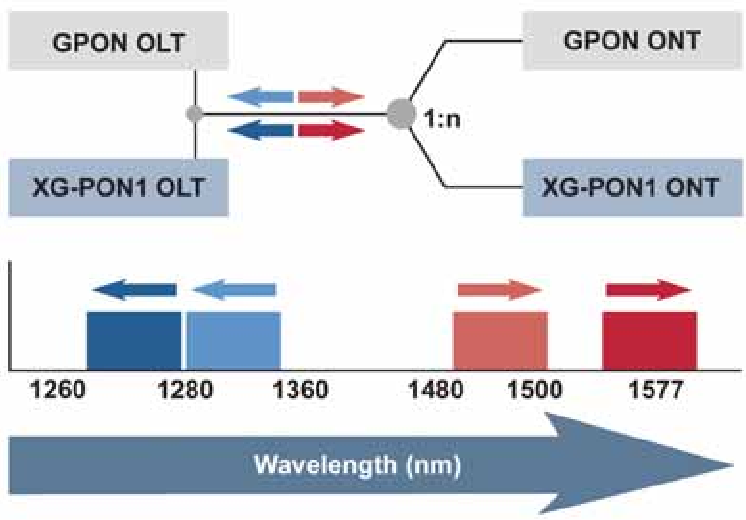
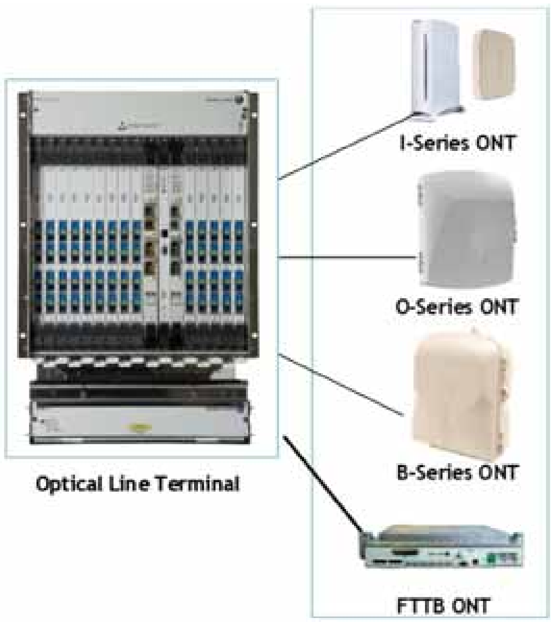


Figure 7: FSAN approach to XG-PON

3.1.2 PON active equipment

Standard PON equipment consists of an optical line terminal (OLT) and the optical network unit (ONU).

The OLT is usually situated at the point-of-presence (POP) or concentration point.



The OLT boards can handle up to approximately 8200 subscribers (based on 64 users per GPON connection) per shelf.

There are different types of ONU available to suit the location:

- indoor application (I-series)
- outdoor application (O-series)
- business application (B-series)
- FTTB application

Figure 8: Different types of ONT

Depending on the application, the ONU can offer analogue phone connections (POTS), Ethernet connections, RF connections for video overlay and, in the case of FTTB, a number of VDSL2 or Ethernet connections.

In the IEEE world the subscriber equipment is always referred to as the ONU. However, in the context of GPON and X-GPON it was agreed that the term ONU should be used in general; ONT was kept only for particular use to mean an ONU supporting a single subscriber. Therefore, the term ONU is more general and always appropriate.

However this definition is not followed by everyone and in other (non-PON) cases any device that terminates the optical network is also referred to as optical network termination (ONT). In this document no preference is expressed and both terminologies are used and as such should be interpreted in their broadest sense.

3.1.3 Bandwidth management

GPON, EPON, XG-PON and 10G-EPON bandwidth is allocated by TDM (time division multiplexing) based schemes. Downstream, all data is transmitted to all ONUs; incoming data is than filtered based on port ID. In the upstream direction, the OLT controls the upstream channel by assigning a different time slot to each ONU. The OLT provides dynamic bandwidth allocation and prioritisation between services using a MAC (Media Access Control) protocol.

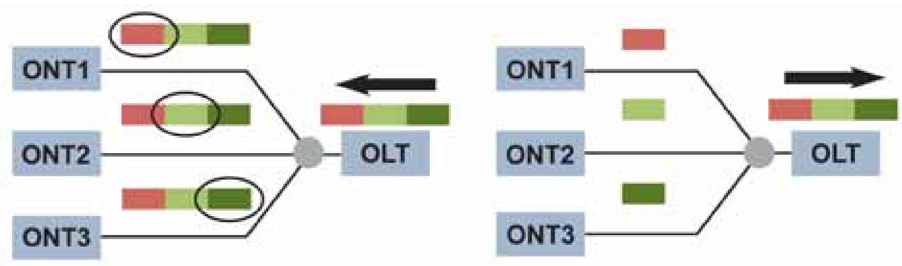


Figure 9: Bandwidth management in PON systems.

3.2 PON deployment optimisation

When deploying PON networks, active and passive infrastructure go hand in hand. It is clear that the timely investment in active equipment (mainly at network side) can be optimised once the correct passive splitting arrangement has been chosen.

Several considerations need to be taken into account when designing the network:

- optimal use of active equipment – assuring an (average) usage rate per PON port well above 50%
- flexible outside plant that can adapt easily to today's and future's customer distribution
- regulatory needs for unbundling the next-generation access (NGA) networks
- optimizing operational cost due to field interventions

These considerations will result in a number of design rules.

To make use of the inherent fibre usage advantage of PON, the location of the splitters should be optimised. In typical European city areas the optimal node size will be somewhere between 500 and 2000 homes passed.

Let's first assume that single-level splitting is employed, also known as centralized splitting. In that case the node size should be defined, i.e. the number of homes passed, where the splitters will be installed. There is a trade-off between the cost of the cabinets and the extra fibre length if cabinets are moved higher in the network (closer to the POP). One of the driving factors in this optimization process is the area density; typically cost will vary with node size as follows:

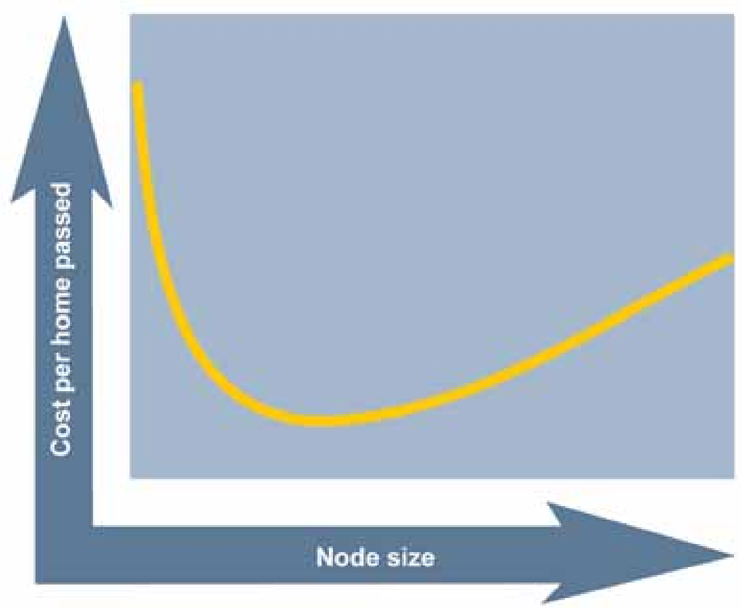


Figure 10: Optimisation of node side in a PON with single-level splitting

Most city areas have a lot of high-rise buildings with several tens or even hundreds of apartments (MDUs). This also is an important input for the design of the network, and we can decide to put splitter(s) in the basement of such buildings. Some networks employ a two-level splitting strategy, also known as distributed splitting where, for instance, 1:8 splitters are put in the buildings and a second 1:8 splitter is put at the node level. In mixed areas containing a combination of MDUs and stand-alone houses, the optimal node size may increase (one fibre coming from a building now represents up to eight homes passed). In some cases even higher levels of splitting, also known as multi-level splitting, can be deployed.

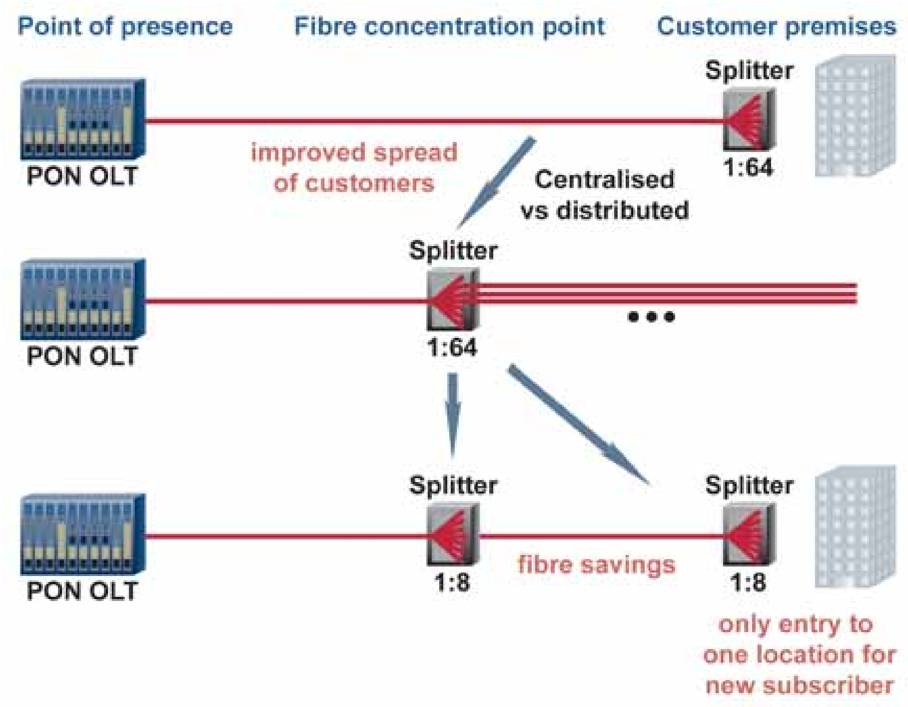


Figure 11: Centralized and distributed splitting in a PON

To enable infrastructure sharing in a technology agnostic way through fibre unbundling means that the splitter sites closest to the end-users must be a fibre flexibility point (FFP) where every service provider will get the possibility to access the customer's fibre.

In case of a multi-fibre per home deployment, some of the fibres may be dedicated to a service provider and will not be available for unbundling (the dedicated fibres may be spliced/hard-wired rather than connectorized).

When a point-to-point outside plant is deployed up to the POP level, a PON service provider will install all his splitters in the POP, but he will lose one of the advantages of a PON network, namely the fact that the feeder fibre usage in the outside plant can be reduced. Another drawback might be that the POP location might be closer to the end-user (fewer homes passed) since every home will have one (or more) fibres into the POP. The PON service provider might even decide to aggregate a number of the point-to-point POP and only install his active equipment (OLTs) in one of these POPs and convert the others to passive (splitter) POPs.

3.3 Ethernet point-to-point

For Ethernet architectures, there are two possibilities, one dedicated fibre per customer between the Ethernet switch located at the POP and the home, or one fibre to an aggregation point and dedicated fibre from there onwards. The first option is easy and straightforward to implement, the second limits the fibre usage in the access loop and is often used in FTTB solutions.

3.3.1 Ethernet point-to-point solutions

From a civil engineering perspective the topologies of the cable plant for point-to-point fibre deployments can look identical to those for PON. However the number of fibres/cables between the POP and the FFP will be significantly lower for a PON deployment.

From the POP, individual feeder fibres for each subscriber are laid down towards some distribution point in the field – typically a fibre flexibility point – either in an underground enclosure or a street cabinet. From this distribution point, fibres are laid towards each individual home.

The higher number of feeder fibres does not pose any major obstacle for from a civil engineering perspective. However, since the fibre densities in the feeder and drop part are very different, it is likely that different cabling techniques will be employed in the two parts of the network.

Deployment can be facilitated by existing conventional ducts, and by other rights of way like sewers or tunnels.

Fibres arriving in the POP are terminated on an optical distribution frame (ODF) – this is a flexible fibre management solution that makes it possible to connect any customer to any port on the switches in the POP.

Due to the large number of fibres handled in a POP, the density of the fibre management solution has to be very high in order to reduce space required. This figure shows an example of a high-density ODF that can terminate and connect more than 2300 fibres in a single rack. For illustration purposes it is positioned next to a rack with active equipment that can terminate 1152 fibres on individual ports.

Figure 12: High density fibre management.

Take rates in FTTH projects typically take some time to ramp up and usually stay below 100%. Fibre management allows a ramp up of the number of active ports in synchrony with the activation of customers. This minimizes the number of unused active network elements in the POP.

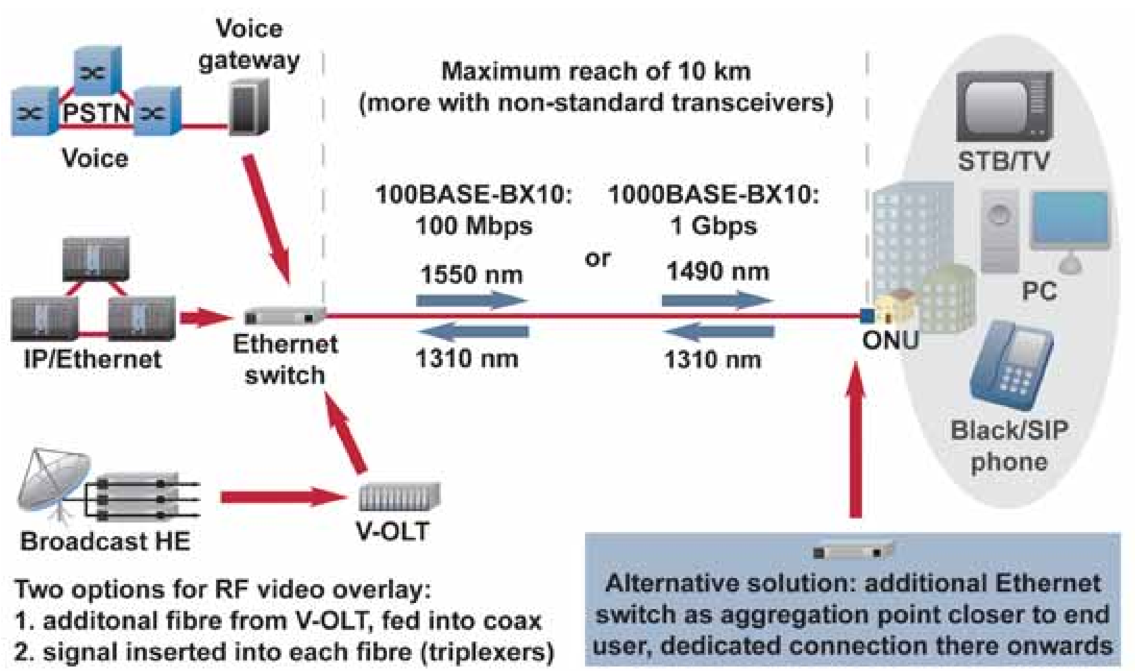


Figure 13: Ethernet network diagram.

3.3.2 Transmission technologies

Recognizing the need for Ethernet in access networks, IEEE established the IEEE 802.3ah Ethernet in the First Mile (EFM) Working Group in 2001. As well as developing standards for

Ethernet over copper and EPON, the group created two standards for Fast Ethernet and Gigabit Ethernet over singlemode fibre.

The EFM standard was approved and published in 2004, and was included into the base IEEE 802.3 standard in 2005.

The specifications for transmission over singlemode fibre are called 100Base-BX10 for Fast Ethernet and 1000Base-BX10 for Gigabit Ethernet. Both specifications are defined for a nominal maximum reach of 10km.

To separate the directions on the same fibre, wavelength-division duplexing is employed. For each of the bit-rate classes two specifications for transceivers are defined, one for upstream (from the customer towards the POP) and one for downstream (from the POP towards the customer). The table provides the fundamental optical parameters of these specifications:

	100Base-BX10-D	100Base-BX10-U	1000Base-BX10-D	1000Base-BX10-U
Transmit direction	Downstream	Upstream	Downstream	Upstream
Nominal transmit wavelength	1550nm	1310nm	1490nm	1310nm
Minimum range	0.5m to 10km			
Minimum channel insertion loss	5.5dB	6.0dB	5.5dB	6.0dB

In order to cope with requirements not considered in the standard, the market offers optical transceivers with non-standard characteristics. Some types can bridge significantly longer distances to suit deployment in rural areas.

Since the nominal transmit wavelength of 100BASE-BX-D (1550nm) is the same as the standard wavelength for video overlays in PON systems, transceivers exist which can transmit at 1490nm. This makes it possible to use off-the-shelf video transmission equipment to insert an additional signal at 1550nm in order to carry the RF video overlay signal on the same fibre.

3.3.3 RF-based video solutions

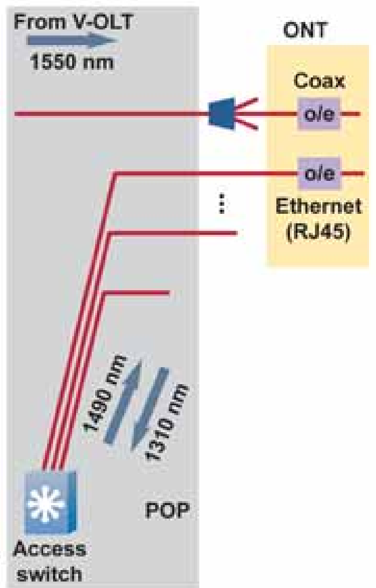


Figure 14: RF video overlay using a

IP-based video solutions provide superior features over simple broadcast solutions and have, therefore, become an indispensable part of any triple-play offering. Quite frequently, however, there is a need to provide RF video broadcast overlays in order to support existing TV sets in the subscribers' households. In PON architectures this is typically accomplished by providing an RF video signal, compatible with cable TV solutions, over an additional wavelength at 1550nm. In point-to-point fibre installations this can be achieved by two different approaches, depending on the possibilities for fibre installation.

In the first approach an additional fibre per customer is deployed in a tree structure, which carries only an RF video signal that can be fed into the in-house coaxial distribution network. In this case the split factors (e.g. ≥ 128) exceed those typically used for PONs so that the number of additional feeder fibres is minimized.

In the second approach a video signal is inserted into every point-to-point fibre at 1550nm. The RF video signal carried by a dedicated wavelength from a video-OLT is first split into multiple identical streams by an optical splitter and then fed into each point-to-point fibre by means of triplexers. On the customer side the wavelengths are separated, the 1550nm signal converted into an RF signal for coax distribution, and the 1490nm signal made available on an Ethernet port.

second fibre per subscriber, deployed in a tree structure.

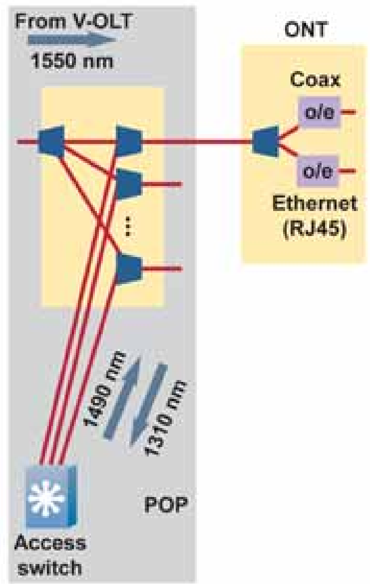


Figure 15: Insertion of RF video signal into point-to-point fibres.

In both cases the CPE/ONU devices comprise two distinct parts:

- a media converter that takes the RF signal on 1550nm and converts it into an electrical signal that drives a coax interface
- an optical Ethernet interface into an Ethernet switch or router

In the single-fibre case the signals are separated by a triplexer built into the CPE, while in the dual fibre case there are individual optical interfaces for each fibre.

4 Customer Equipment

In the early days of broadband, home internet connectivity was delivered by simple, low-cost data modems for PCs, followed by routers and wireless connectivity (Wi-Fi). Today, the proliferation of digital devices inside the home – including but not limited to computers, digital cameras, DVD players, game consoles and PDAs – is placing higher demands on customer equipment. The "digital home" has arrived.

There are two distinct functions in the home environment: the optical network termination (ONT), where the fibre is terminated, and the customer premise equipment (CPE), which provides the necessary networking and service support. These functions may be integrated or separate, depending on the demarcation point between service provider and end-user.

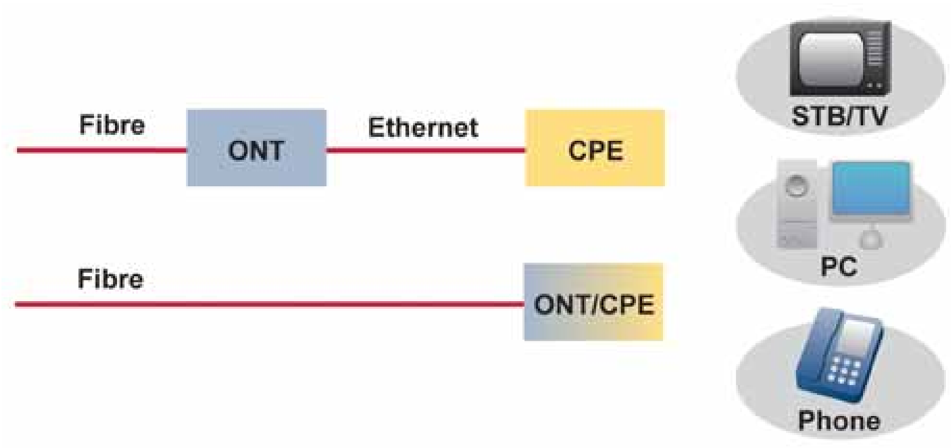


Figure 16: Possible configurations of the ONT and CPE.

As more advanced devices and technologies are adopted, the concept of the residential gateway (RG) has emerged. This device is a CPE that combines a broad set of networking and service capabilities, including optical network termination, routing, wireless LAN (Wi-Fi), Network Address Translation (NAT), security and firewall, as well as capabilities required for the support of VoIP and IPTV service, and quality of service capabilities.

For the deployment of the CPEs the service providers have the choice of different scenarios:

- CPE as demarcation towards the customer. The CPE is an integral part of the service provider's offering, terminating the incoming line and delivering services to the end customer. By owning and maintaining the CPE the service provider controls the end-to-end service delivery, including line termination (ONT) and integrity of the transmission as well as service delivery. The subscriber then connects his home network and devices directly to the subscriber-facing interfaces of the CPE.
- Network Interface as demarcation line towards the customer. The ONT is provided by the service provider and the ONT's Ethernet port(s) is the demarcation line towards the customer. The customer then connects his home network or service-specific devices (voice adapter, video set-top box, etc.) to the ONT.

A common situation where this scenario is utilized is the open access network, where connectivity and services are provided by different service providers. The connectivity provider is responsible for the access and optical line termination, but not for service delivery/termination like voice (telephony) or video. The service-specific CPE are provided by the respective service providers. Devices can either be drop-shipped to the subscribers for self-installation or distributed through retail channels.

To help address concerns related to home and device management, the Broadband Forum (previously the DSL Forum) created the TR-069 management interface standard, which is now available on most modern residential gateways.

A standardized, open home connectivity enables a new competitive landscape in which network operators, internet service providers, IT-vendors, and consumer electronics vendors compete to capture the greatest customer share.

5 Future Technology Development

5.1 Residential bandwidth trends

Access and backbone bandwidth requirements are expected to continue growing exponentially. By that we mean that global peak and average bandwidth will inexorably increase and access bit-rate requirements will soon exceed 100Mbps.

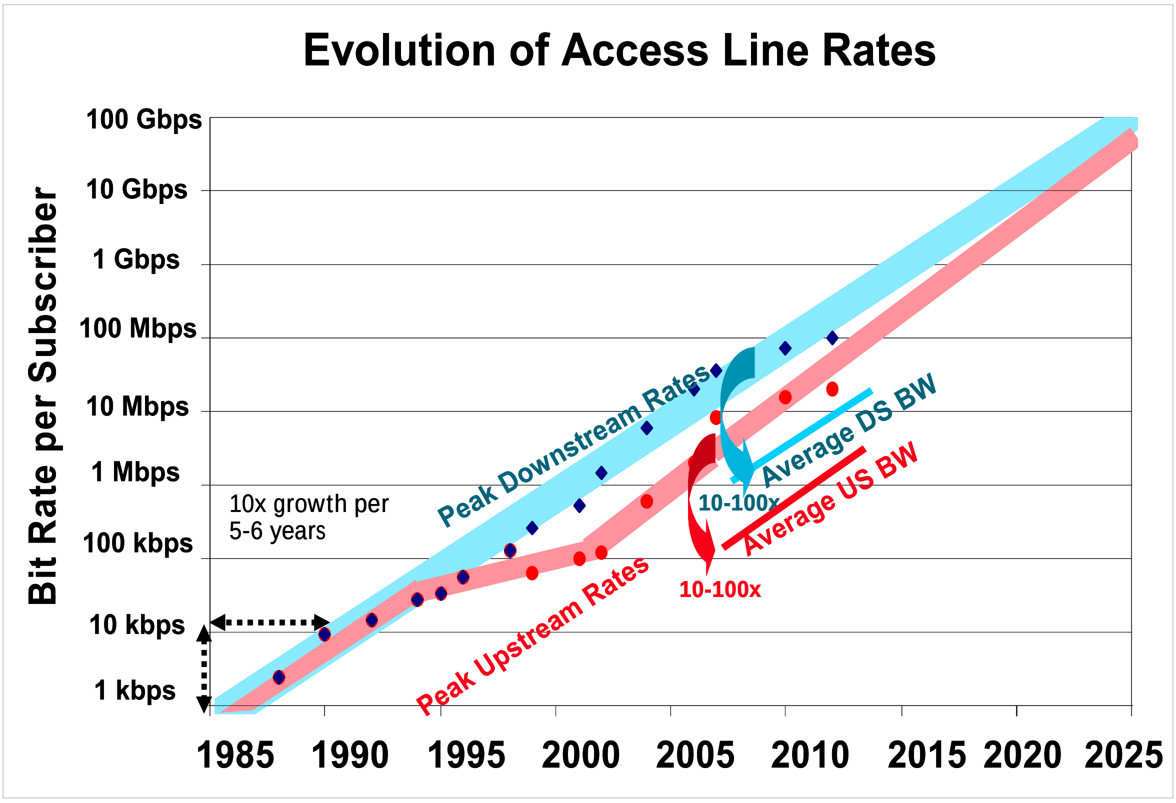


Figure 17: Evolution of access line rates

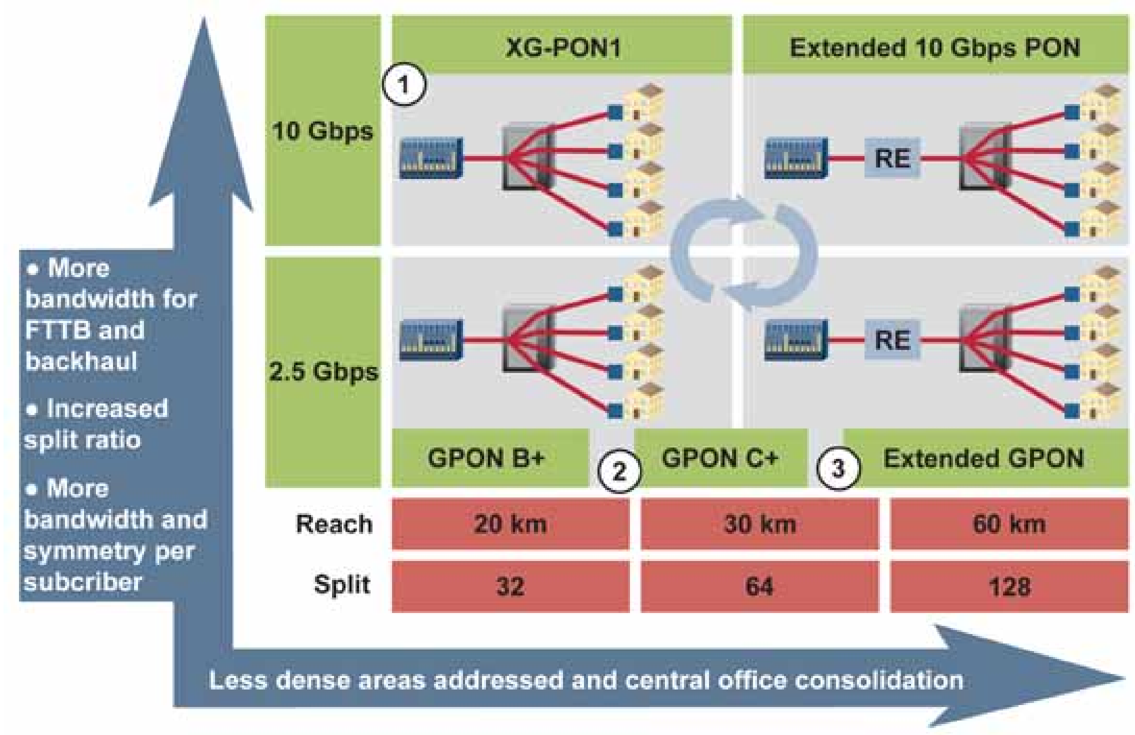
5.2 Evolution of passive optical networks

5.2.1 Evolution of ITU standards

The optical budget of 28dB with GPON technology using class B+ optics enables a reach of 30km when the splitting factor is limited to 1:16. New class C+ optics add another 4dB of link budget, and thus either more distributed splitting capabilities or more reach. GPON extenders increase capabilities further to either 60km reach or 128 end-users.

Although GPON is perceived to possess sufficient bandwidth for the next few years, XG-PON is already standardized and this is not the limit; PON parameters will be pushed to higher values.

XG-PON is a natural continuation in the evolution of PON technologies, increasing bandwidth four times to 10Gbps, reach from 20 to 60 km, and split from 64 to 128 – although reach and split maxima are not obtainable simultaneously. Most importantly, these evolutionary technologies will



avoid the need for significant upgrades to the installed outside plant.

Figure 18: Evolution of ITU PON standards.

5.2.2 Evolution of IEEE standards

The 10G-EPON (10-Gigabit Ethernet PON) standard was ratified in September 2009 under the name 802.3av. This latest standard offers a symmetric 10Gbps, and is backward compatible with 802.3ah EPON. 10G-EPON uses separate wavelengths for 10Gbps and 1Gbps downstream, and will continue to use a single wavelength for both 10Gbps and 1Gbps upstream with TDMA separation of customer data. The 802.3av Task Force has concluded its work, with the 802.3av now being included in the IEEE 802.3 set of standards.

5.3 WDM-PON and beyond

The next step could be to further increase the line speed on the fibre to 40 or even 100 Gbps.

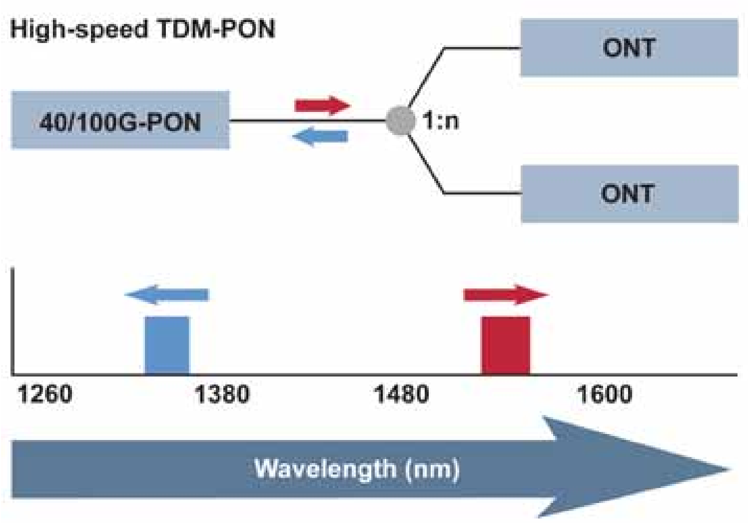


Figure 19: Wavelength plan for TDM-PON

An alternative, which has already seen early deployments, is the use of wavelength-division multiplexing (WDM) techniques to send multiple wavelengths over the same fibre. WDM-PONs promises to combine the best of both worlds – a physical PON network (sharing feeder fibres) with logical point-to-point connectivity (one wavelength per user).

This architecture provides dedicated, transparent connectivity on a wavelength per subscriber basis, and thus allows very-high, uncontended bit rates for each connected subscriber, with the same inherent security as dedicated fibre. Wavelength filters (instead of splitters) in the field map each wavelength from the feeder fibre onto a dedicated drop fibre. As a result, there is a logical upgrade path from current TDM-PON deployments to WDM-PON at the infrastructure level.

The key challenge for WDM-PON is to provide diverse upstream wavelengths while having a single ONU type. Communications providers consider it unmanageable to have a different ONU per wavelength, and tunable lasers are so far not affordable. The technologies required for WDM-PON are available today, but they have to undergo some cost reduction in order to be considered suitable for mass deployment.

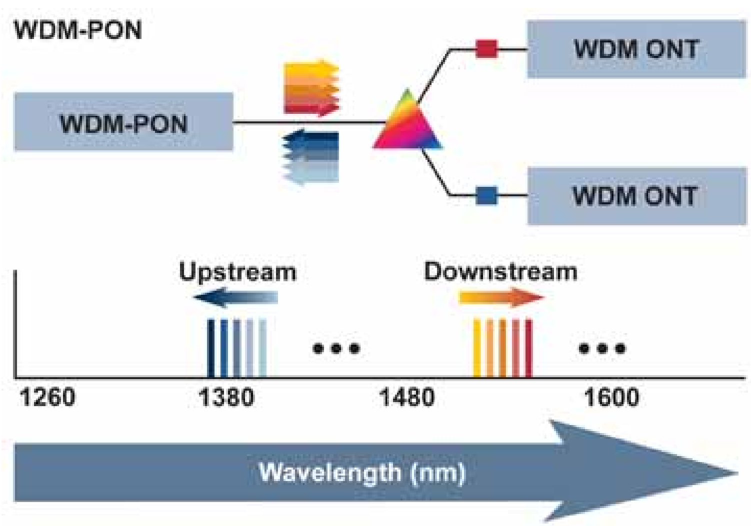


Figure 20: Wavelength plan for WDM-PON

A third possibility is to stack several TDM-PON signals on one fibre, typically a combination of four XG-PON systems running at 10 Gbps each. This is called hybrid TDM-WDM-PON.

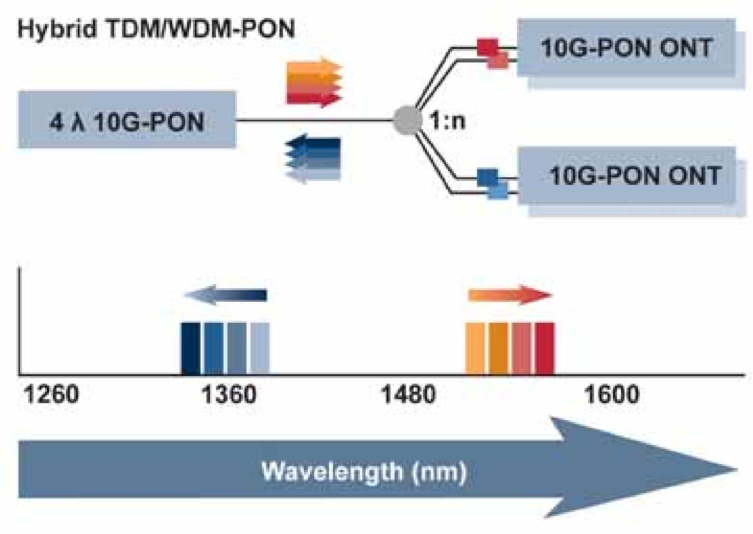
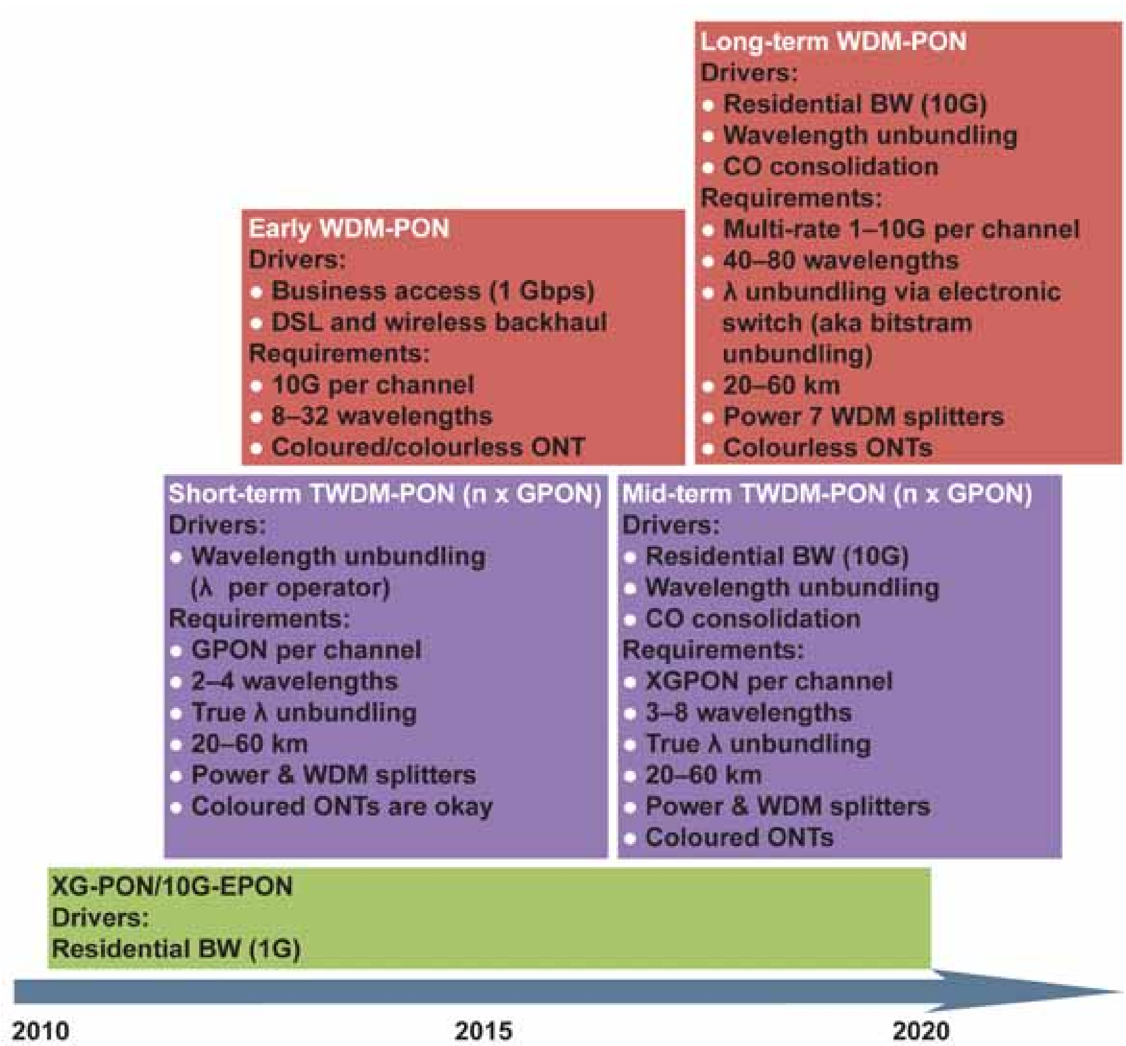


Figure 21: Wavelength plan for hybrid TDM-WDM-PON

A possible evolution scenario could look like this:



6 Cost Considerations

Deployment costs must be considered as part of the build decision criteria. For more information of the main influences on FTTH deployment cost, please read the *FTTH Business Guide*, available from the FTTH Council Europe website.

6.1 Capital costs

FTTH deployment involves a number of different cost components that can be individually optimized. However, it is important to understand the relative contribution of each component, and thus the relative saving potential. The following graph shows a typical cost distribution for Greenfield FTTH deployments.

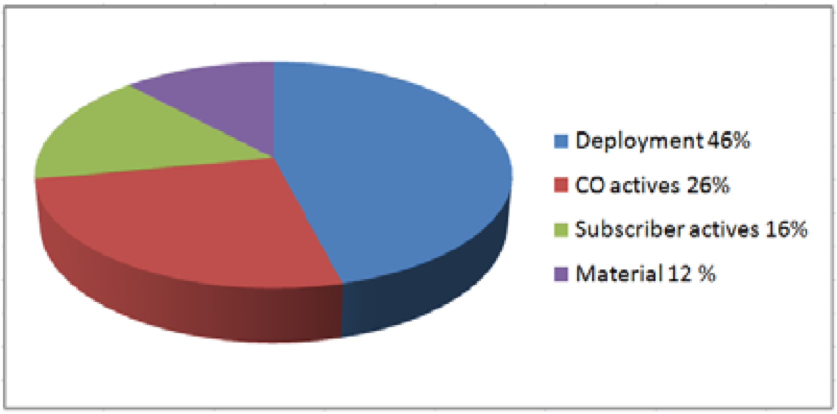


Figure 22: Typical initial CAPEX distribution for Greenfield FTTH deployments.

The graph confirms what could be expected intuitively: civil works comprise over almost half the total initial costs. Obviously, this is the cost component where saving efforts have the largest effect. Therefore, every alternative solution should be considered in order to reduce the start-up costs, including sewers, tunnels, etc.

Active network elements are the second largest component at 26% contribution. Independent of the particular technology employed, this is a component where technological progress will continue to drive costs down on a per-port basis.

6.2 Operation costs

Operation costs are a multi-faceted subject. Although many of these cost items – marketing, subscriber acquisition, and subscriber management to name but a few – are not specific to any particular access technology, the correct installation and, in particular the reliability, of the passive infrastructure will greatly affect the ongoing costs. Therefore network design, simplicity, ease of trouble-shooting and speed to repair are of critical importance.

7 Infrastructure Sharing

Owing to the high costs of FTTH deployment, access to fibre and infrastructure sharing has been a hot topic amongst network builders and owners. Further to that regulatory bodies, looking at creating a competitive environment and trying to avoid monopolies, are keeping a close eye on what is happening in this perspective.

There are various “layered” FTTH business models operating in the market today, which has opened up the market to organisations other than traditional telecom players. New entrants are emerging – utility companies, municipalities, real estate companies, governments – all of them are stepping in and seeking the best approach to bring fibre connectivity to homes.

Please read the *FTTH Business Guide*, available from the FTTH Council Europe website, for more information about the different FTTH operator models.

7.1 Business models

Four business models can be identified in the market today:

1. **Vertically integrated** – one major player covering passive, active and service layers, who offers services directly to their customers, conveys traffic on their networking equipment and uses their own passive infrastructure (exclusively or with wholesale to other communications providers).
2. **Passive sharing** – in this model, the infrastructure owner deploys the passive infrastructure and provides passive access to other players, who concentrate on the active and service layers.
3. **Active sharing** – the vertical infrastructure provider deploys both active and passive infrastructure, and opens it up to service providers, with each service provider taking care of its base of subscribers.
4. **Fully separated** – in some countries the fully separated model has emerged, featuring an infrastructure owner, a network operator and a series of service providers.

7.2 Infrastructure sharing

For each of these models, infrastructure must be shared. There are four methods of infrastructure sharing, ranging from passive to active components of the network:

1. **Duct** - multiple retail or wholesale service providers may share the use of a duct network covering a substantial region by drawing or blowing their fibre cables through the shared ducts, and compete to offer their services.
2. **Fibre** - multiple retail or wholesale service providers may use the FTTH network by connecting at the physical layer (“dark” fibre) interface, and compete to offer their services.
3. **Wavelength** - multiple retail or wholesale service providers may use the FTTH network by connecting at a wavelength layer interface, and compete to offer their services.
4. **Packet** - multiple retail service providers may use the FTTH network by connecting at a packet layer interface, and compete to offer their services to end users.

7.3 Fibre Sharing

Access to fibre can be granted at various points in the network:

- at the central office or POP
- at some place between the building and the central office – typically a street cabinet or a underground enclosure
- at the basement of a multi-tenant building

This point will be called the fibre flexibility point (FFP). It is the location where the different service providers will get access to the customers.

In all these cases, access to the customer will be provided by one or more dedicated fibres in a point-to-point topology.

A PON service provider will install splitter(s) at these FFPs and backhaul the traffic over a reduced number of feeder fibres to the POP.

A P2P service provider will either install Ethernet switch(es) at these FFPs and backhaul the traffic over a reduced number of fibres to the POP or install a cross-connect and connect his customers to the POP using a number of fibres equal to the number of subscribers.

8 Infrastructure Network Elements

Expanding outwards from the access node towards the subscriber, the key FTTH infrastructure elements are:

Infrastructure Elements	Typical physical form
Access node or POP (point of presence)	Building communications room or separate building.
Feeder cable	Large size optical cables and supporting infrastructure e.g. ducting or poles
Primary fibre concentration point (FCP)	Easy access underground or pole-mounted cable closure or external fibre cabinet (passive, no active equipment) with large fibre distribution capacity.
Distribution cabling	Medium size optical cables and supporting infrastructure, e.g. ducting or poles.
Secondary fibre concentration point (FCP)	Small easy access underground or pole cable joint closure or external pedestal cabinet (passive, no active equipment) with medium/low fibre capacity and large drop cable capacity.
Drop cabling	Low fibre-count cables or blown fibre units/ ducting or tubing to connect subscriber premises.
Internal cabling	Includes external building fibre entry devices, internal fibre cabling and final termination unit, which may be part of the ONU.

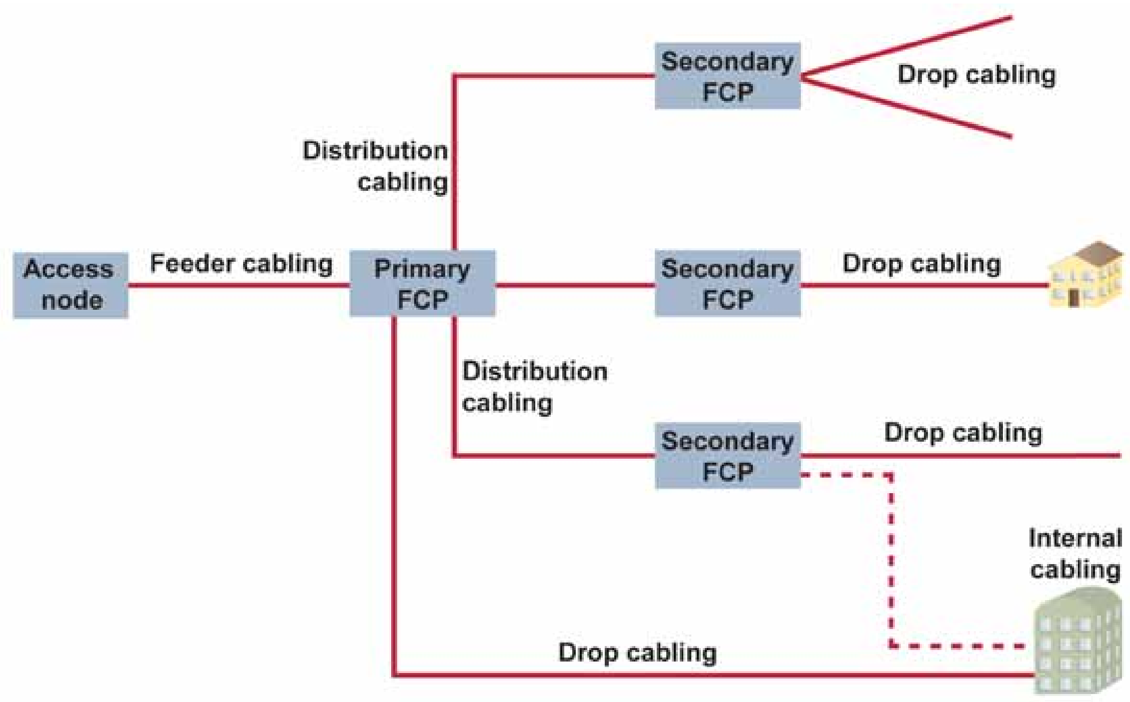
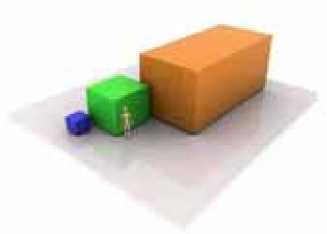


Figure 23: Main elements in a FTTH network infrastructure.

8.1 Access node

The access node, often referred to as the point of presence (POP), acts as the starting point for the optical fibre path to the subscribing customer. The function of the access node is to house all active transmission equipment; manage all fibre terminations and facilitate the interconnection between optical fibres and active equipment. The physical size of the access node is determined by the size and capacity of the FTTH area in terms of subscribers and future upgrades.



Homes connected	Type of access structure	
2-400	in-house	street
400-2000	in-house	concrete
2000 or more	building	

Figure 24: Size indication for P2P access node.

The access node may form part of an existing or new building structure. The main network cables entering the node will terminate and run to the active equipment. The feeder cables will also connect to the active equipment and run out of the building and onto the FTTH network area. All other physical items are used to manage the optical fibres within the node.

Separate cabinets and termination shelves may be considered for equipment and individual fibre management to simplify fibre circuit maintenance as well as avoid accidental interference to sensitive fibre circuits.

The access node should be classed as a secure area. Provision for fire and intrusion alarm, managed entry/access and mechanical protection against vandal attack must be considered.

8.2 Feeder cabling

The feeder cabling runs from the access node to the primary fibre concentration point (FCP). The feeder cabling may cover a distance up to several kilometres before termination. The number of fibres in the cable will depend on the build type.

For point-to-point deployments, high fibre-count cables containing hundreds of fibres are necessary to provide the necessary fibre capacity to serve the FTTH area.

For PON deployments, the use of passive optical splitters positioned further into the external network may enable smaller fibre counts cables to be used in the feeder portion of the network.

It is advisable to select a passive infrastructure that is capable of handling different network architectures should the need arise in future, and to factor modularity into the fibre count in the

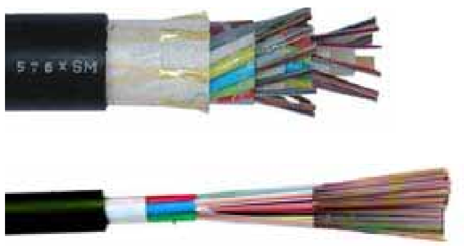


Figure 25: High-count fibre cable.

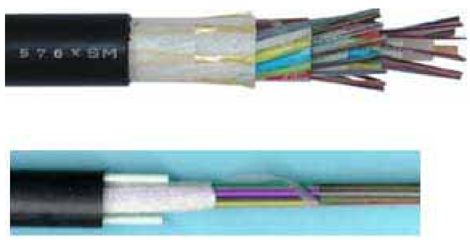


Figure 26: Modular cable in duct system.

feeder cables.

For underground networks, suitably sized ducts will be required to match the cable design, and additional ducts should be considered for network growth and maintenance. If smaller ducts or rigid sub-ducts are used then the feeder capacity is provided by using several smaller cables, for example, 48-72 fibres (Ø 6.0 mm) or up to 216 fibres (Ø 8.4 mm) cables. If flexible textile sub ducts are used, there is no need to use smaller cables. A flexible sub duct (see also Chapter 9 under 9.1.2) only takes up the space of the cables hence bigger and/or more cables be installed which maximizes the fill ratio or capacity of the duct. For example in a typical 40 mm ID HDPE duct flexible sub duct allows you to install 3 x 16 mm cables/ 5 x 12 mm cables/10 x 8.4 mm cables, 18 x 6 mm cables

For aerial cable deployment, pole structures with sufficient cabling capacity will be required. Existing infrastructures may be available to help balance costs.

8.3 Primary fibre concentration point

The feeder cabling will eventually need to convert to smaller distribution cables. This is achieved at the first point of flexibility within the FTTH network, which is generally termed the primary fibre concentration point (FCP). Here the feeder cable fibres are separated and spliced into smaller groups for further routing via the outgoing distribution cables.

Note: all fibre termination points within the FTTH network should be treated as points of flexibility in terms of providing fibre routing options. The term FCP is used throughout the Handbook as a generic name for all of these points, and classified as “primary” or “secondary” depending on its position within the network.

Ideally, the primary FCP should be positioned as close to subscribers as possible, shortening subsequent distribution cable lengths and hence minimising further construction costs. In principle, the location of the primary FCP may be determined by other factors such as the position of ducts and access points.

The FCP unit may take the form of an underground or pole-mounted cable joint closure designed to handle a relatively high number of fibres and connecting splices. Alternatively, a street cabinet structure may be used. In either case, entry and further re-entry into a FCP will be required to configure or reconfigure fibres or to carry out maintenance and fibre testing. Where possible this activity should be achieved without disturbing existing fibre circuits. Although it is not possible to guarantee this, newer pre-connectorised plug-and-play solutions are now available that eliminate the need to access closures, which helps to reduce faults and build errors.

Underground and pole-mounted cable joint closures are relatively secure and out of sight, but immediate access may be hindered because special equipment is required for access. Security and protection from vandal attack should be considered for street cabinet based FCPs.

8.4 Distribution cabling

Distribution cabling connects the FCP to the subscriber connection over distances usually less than 1km. Cables will have medium-sized fibre counts targeted to serve a specific number of buildings within the FTTH area.

Cables may be ducted, direct buried or grouped within a common microduct bundle. Microduct bundles allow other cables to be added on a ‘grow as you go’ basis.

For larger MDUs, the distribution cabling may form the last drop to the building and convert to internal cabling to complete the fibre link.

or aerial networks the arrangement will be similar to that of feeder cables.

Distribution cables are smaller in size than the feeder cables. Total fibre counts will generally be between 48 and 216.

Loose tube cables can be installed by blowing or pulling into conventional ducts and subducts, direct burial and by suspension from poles.

Ducting can vary. In a green field application (new ducts to be installed) ducts can vary from standard 40 mm internal diameter HDPE ducts to microducts. When an existing duct infrastructure is available, all types of ducts can be used (PVC, HDPE, concrete) subducted with rigid or flexible subducts.

Cables installed in microducts may be blown to distances in excess of 1km. Micro ducts, like flexible subducts, offer a means of deferred cable deployment.

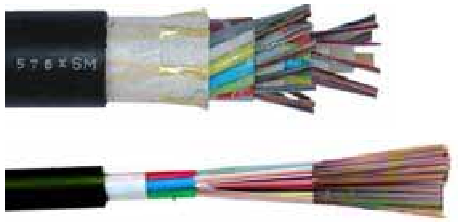


Figure 27: High fibre count cable.

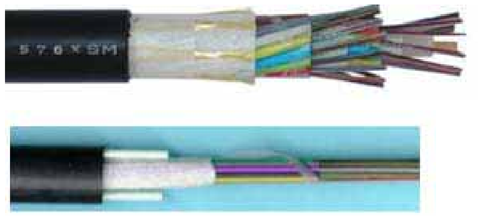


Figure 28: Modular cable in duct system.

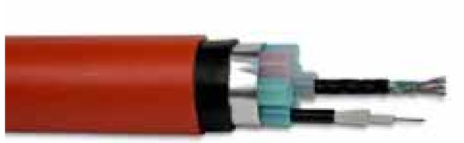


Figure 29: Direct buried tubes with micro cables.

8.5 Secondary fibre concentration point

In certain cases, the fibres may need to be separated at a second FCP within the network before final connection to the subscriber. Like the primary FCP, this second point also needs to be a point of flexibility, allowing fast connection and reconfiguration of the fibre circuits. This is termed the secondary FCP.

At the secondary FCP, distribution cables are spliced to the individual fibres or fibre pairs (circuits) of the drop cables. The secondary FCP is positioned at an optimum or strategic point within the network, enabling the drop cabling to be split out as close as possible to the majority of subscribers. The location of the secondary FCP will be determined by factors such as position of ducts, tubing and access points and, in the case of PON, the location for splitters.

The secondary FCP is typically an underground or pole-mounted cable joint closure designed to handle a relatively small number of fibres and splices. Alternatively, a small street pedestal structure may be used. In either case, entry and further re-entry into the secondary FCP will be required to configure or reconfigure fibres and to carry out maintenance and fibre testing.

In the case of air-blown fibre, the secondary FCP may take the form of a tubing breakout device designed to allow microduct cable or fibre units to be blown directly to the subscriber premises. This reduces the number of splicing operations.

While pole-mounted secondary FCP cable joint closures are relatively secure and out of sight, access may be hindered and special equipment is required for access.Underground secondary FCP joint closures are also relatively secure and out of sight, and will require a small “handhole” for access. Secondary FCPs based on street cabinets may require security and protection from vandal attack; however, immediate access to fibre circuits should be relatively simple.

8.6 Drop cabling

The drop cabling forms the final external link to the subscriber and runs from the last FCP to the subscriber building with a distance restricted to less than 500m, and often much less in high-density areas. Drop cables typically contain up to four fibres for the customer connection, and possibly additional fibres for backup or for other reasons. The drop cable normally provides the only link to the subscriber, with no network diversity.

For underground networks the drop cabling may be deployed within small ducts, within microducts or by direct burial to achieve a single dig and install solution. Overhead drop cables will feed from a nearby pole and terminate on part of the building for routing to the subscriber fibre termination unit. In either case, the cable assembly may be pre-terminated or pre-connectorised for rapid deployment and connection, and to minimize disruption during installation.

Air blown cables and fibre units can enter through the fabric of the building using suitable microduct products and route internally within the building. This will form part of the internal cabling network with the building entry device acting as the transition point for the microduct (external to internal material grade).

Drop cables come in four main types: direct install, direct buried, facade and aerial.

8.7 Direct install cables

Direct install cables are installed into ducts, usually pulled, pushed or blown.

The structure can be non-metallic with external/internal sheath, or a double sheath: one internal low-smoke zero-halogen (LSZH) and one external PE.

Cables are available from 1 to 36 fibres (typically 12 fibres). The fibre elements can be loose tubes, micro sheath, or blown fibre units.

8.8 Direct buried cables

Cables are available in two constructions: non-metal, or with metal protection (corrugated steel).

The advantages of metal-protected cables are their very high crush resistance and high-tension loading.

New non-metal strain-relief and protective sheets have been developed to give non-metal direct buried cables similar performance to metal protected cables. On average, non-metal cables are lower in cost.

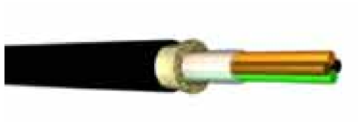


Figure 30: Metal protected direct buried cable.

Figure 31: Direct-buried drop cable without metal protection.

Direct buried drop cables are available in fibre counts from 1 to 12 (typically 2—4).

8.9 Aerial cables

Cables are available as follows:

- continuation of feeder or distribution networks, e.g. optical ground wire (OPGW) or all-dielectric self-supporting (ADSS)
- short-span drop cables, e.g. Figure 8, flat or circular

Aerial cables are designed to a specific tensile load, which is determined by span length and environmental conditions.

The Figure-8 cable consists of a central tube fixed to a steel wire. Typical fibre counts are 2—48 and cable tensile loading will be ~6000 N.

OPGW cables are mainly used in power line connections.

All the above cables can be pre-connectorised which gives an advantage on installation – less installation time in the home and better planning.

The fibre elements can be loose tubes, micro sheath or blown fibre units.

Figure 32: Example of ADSS cable.

Figure 33: Example of Figure-8 cable.

8.10 Facade cables

Façade installation is a suitable installation method for buildings that are connected, such as large blocks of flats or terraced properties. It is useful in Brownfield deployments where the building structure prevents the running of cables. The cables are stapled along the outside of the building with closures, branches or ruggedized connection points providing the drop to customers. There may, however, be appearance issues with owners and authorities, particularly in conservation areas.

Façade cables have a similar structure to direct install cables and also require UV resistance. Because façade drop cables usually feed small buildings, the fibre count is usually low, between 1 to 12 fibres (typically just 1—2 or 4 fibres). The fibre elements can be loose tubes, micro sheath, or blown fibre units.

8.11 Internal cabling

For residential properties, the drop cable can be terminated on the outside structure of the house, or pass through the wall and terminate inside the house.

If termination unit is inside of the building, this will require the fibres to be routed through the building wall fabric via a suitable cable lead-in, and subsequently routed within the building to the ONU. If the ONU is sited externally within a box, the drop cable is simply terminated in a similar manner to a utility feed.

In both case there will be little or no internal optical cabling required, unless the house owner or subscribed decides to add it.

The topic of MDU internal cabling has attracted considerable attention because a large number of FTTH network have been MDU builds. Many suppliers have special riser (vertical) and drop (horizontal) cable solutions. Where installation is challenging, new bend-insensitive fibres can be used, even by non-specialist trades' people.

For larger MDUs, the internal cabling forms a major part of the infrastructure. Cables may be installed in existing service ducts, or surface mounted. To reduce costs and protect the décor, existing infrastructure should be used when possible.

The following diagram identifies ways in which an MDU can be cabled:

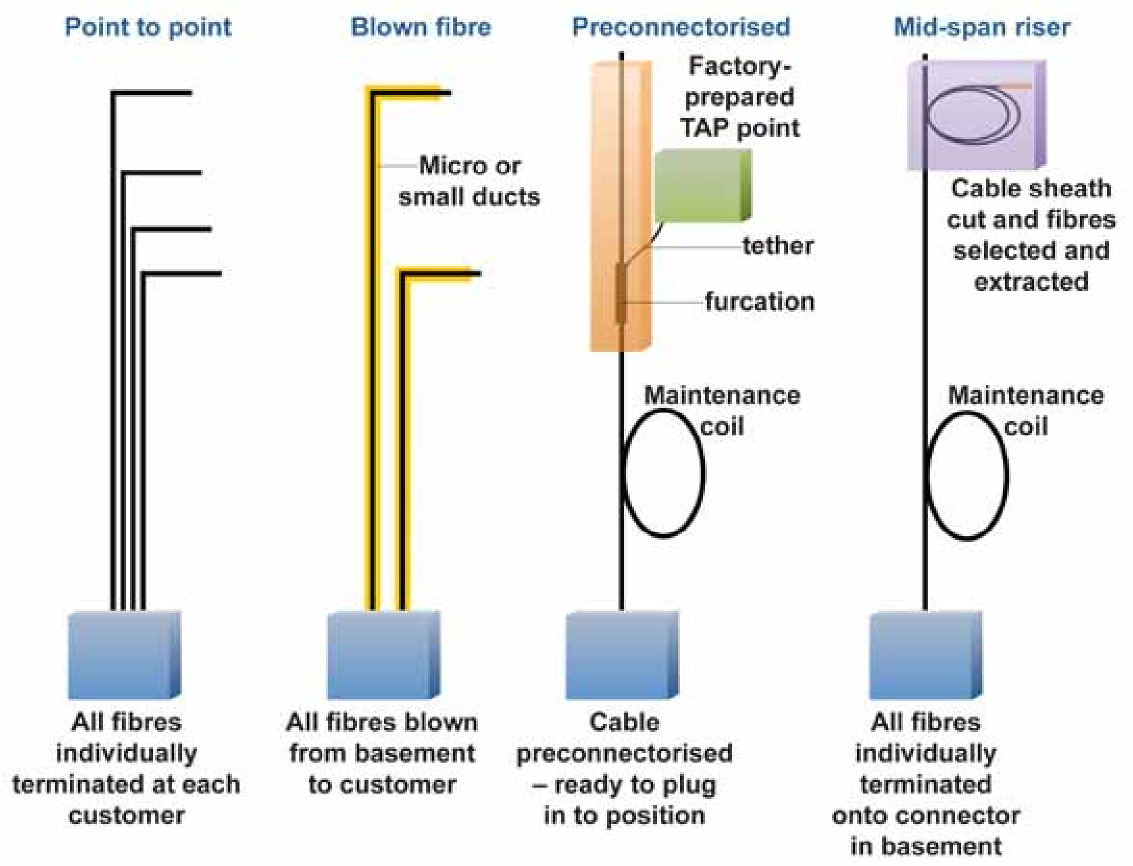


Figure 34: Different schemes for MDU cabling.

The schematic drawing on the right provides a review of some options for internal cabling of a building.

The drop cables or microducts are run up riser shafts to each floor or branched to a riser cable from an entry basement room where is located a building demarcation box.

Cables or ducts are routed horizontally to each apartment or room using breakout devices or riser boxes as necessary.

Note: internal cables or microducts are graded for internal deployment, i.e. low smoke/zero halogen (LSZH). The cables or microducts are anchored at regular intervals in the horizontal and the vertical position.

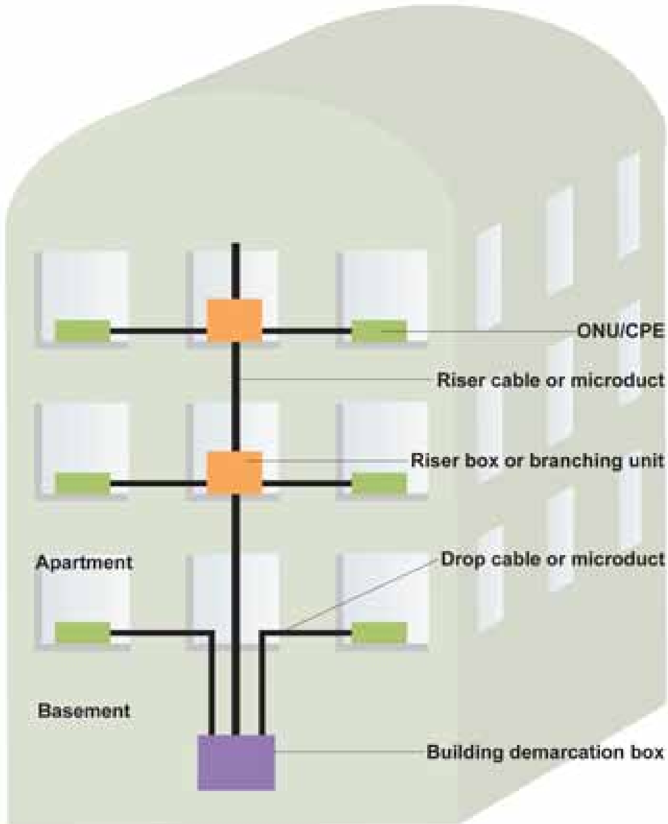


Figure 35: Options for internal cabling of a building.

8.11.1 Building entry point

Most MDUs are fed from the basement with an outside network cable entering the building and terminating at the building entry point. The outside network cable can come from a closure, a street cabinet or from an adjacent building. Once the cable has entered the building either the same cable will feed the apartments in the building (rare unless there are only a few apartments), or a demarcation box installed in the basement acts a flexibility point between the external network and the in-building network.

8.11.2 Flexibility point

A flexibility point provides the ability to incorporate PON splitters and patching for point-to-point networks, and to share the internal cabling when more than one operator has cables feeding the building. This provides local flexibility and reduces the cost of the most expensive part of an MDU build – the internal cabling.

Figure 36: Flexibility point in an MDU.

Most of the boxes used for multi-operator activity are modular. Additional boxes can be added depending on the number of operators in the building.

These points can be configured for fibre management with a splice and patch solution, with mechanical optical connectors or only with splices.

8.11.3 Vertical riser

For the vertical cabling section, often also called riser, it is preferable to install cables inside existing structures such as a riser shaft or duct. It is usual to limit MDU builds to a single installation of vertical cabling, and this is not repeated by each operator.

Depending on the number of apartments in the building, the riser cables can have various structures: mono fibre, bundles of mono fibre, or bundles of multiple fibres.

Figure 37: Riser cable containing bundles of mono fibre.

Riser cables can be installed from the basement or the top floor of the building. For high buildings several riser cables may have to be installed to feed all the premises, e.g. one cable for the first 10 floors, then a second cable for the next 10 floors.

Riser cables can be pre-connectorised to save time during installation.

In additional to pre-connectorised solutions, risers are available with extractable fibre elements. This technology allows the installer to extract some fibre elements from the cable sheath to prepare, at the floor level, the horizontal drop to the premises.

Using the latest solutions available on the market enables the use of less skilled labour to deploy the networks, helping to reduce labour costs.

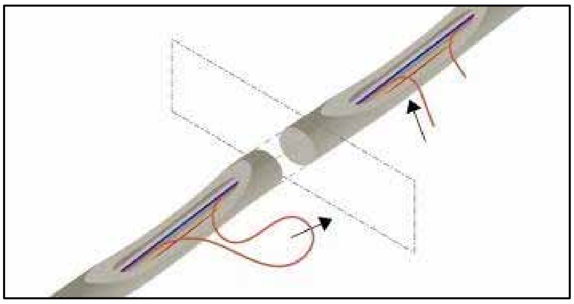


Figure 38: Extractable fibre elements.

8.11.4 Horizontal drop

The horizontal drop is the portion of the network linking the riser cable to the premises with the required number of fibres. The riser and horizontal drop may be one cable. In other designs the riser cable joins to a separate horizontal cable at each floor.

A tube or a cable can be used for the horizontal drop. The cables can be spliced at the riser and floor levels, or can be pre-connectorised at one or both ends of the drop.

Typical issues found with cabling are that there is no existing duct or space available. Since these cables are installed in difficult conditions the use of the new bend-insensitive fibres should be considered – refer to fibre section for details.

Figure 39: Typical floor box, cables spliced or connectorised.

Figure 40: Branching unit without splicing.

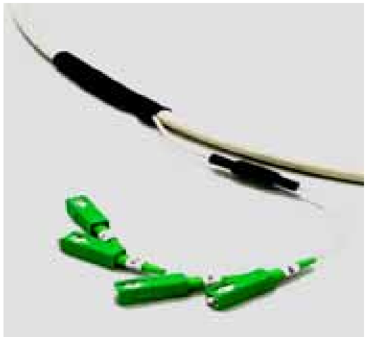


Figure 41: Factory pre-assembled and tested cable interface.

Above are some examples of riser to horizontal solutions; there is also the option of a direct cable or blown fibre from basement direct to each apartment.

8.11.5 Optical network unit

Inside the customer premises, the optical fibre(s) are usually terminated with a connector inside a customer interface box and then a patch cord used to link to the ONU. These boxes can be integrated, or separate.

Figure 42: Typical ONU.

9 Deployment Techniques

This section provides a description of available infrastructure deployment techniques. More than one technique may be used in the same network, depending on the specific circumstances of the network build.

9.1 Conventional duct infrastructure

This is the most conventional method of underground cable installation and involves creating a duct network to enable subsequent installation of cables by pulling, blowing or floatation techniques. This may comprise a large main duct that contains smaller rigid or flexible textile subducts (for individual cable installation), a large main duct into which cables are progressively pulled, one over the other as the network grows, or a small "main" duct for the installation of a single cable. Duct installation enables further access and reconfiguration.

Figure 43: Deploying duct infrastructure.

As with any civil works, consideration needs to be given to other buried services. Efficiency of cable installation in ducts relies heavily on the quality of the duct placement; this applies to all installation methods.

9.1.1 Product map

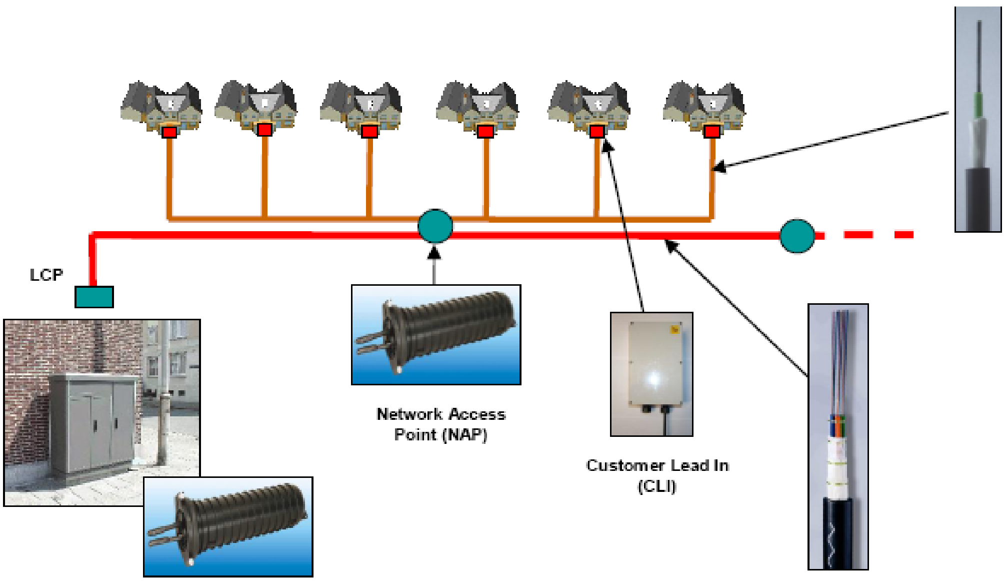


Figure 44: Product map for conventional duct infrastructure.

9.1.2 Duct network

The use of a single duct maximizes the amount of space inside the duct, but in practice can limit the number of cables that can be installed. Entanglement of the cables and high friction between cable jackets can make it difficult to extract older cables from full ducts to create room for new cables – older cables typically end up at the bottom of the duct.

Using rigid subduct reduces the total number of cables that can be installed, but at least older cables can be removed. This method also allows the use of cable blowing as well as cable pulling, since it is easier to create an airtight connection to the subduct. Using flexible textile subduct maximizes the total number of cables which can be installed in a duct and allows older cables to be removed easily. In general using flexible subduct triples the amount of cables which can be installed in a main duct .

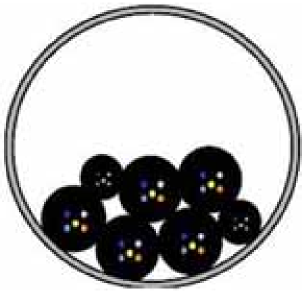


Figure 45: 110mm main duct.

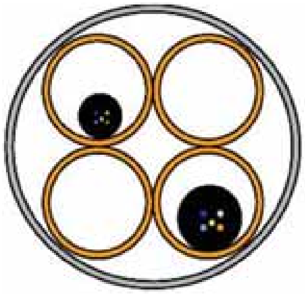


Figure 46: 110mm main duct with four rigid subducts.

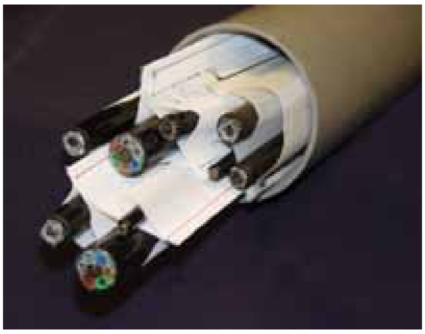


Figure 47: 110mm main duct with nine flexible subducts

Main duct sizes which can be subducted with rigid sub ducts vary from about 60 mm up to 110 mm. Main duct sizes for single cable use are smaller, typical internal diameter is between 20 and 40 mm. Smaller main ducts can be subducted with flexible inner subducts or microducts (see below).

Cables can be installed into the ducts by pulling, blowing or floating. If they are to be pulled, then the duct either needs to contain a pre-installed draw rope or must have one installed by rodding and roping. If cables are to be blown in or floated, then the duct and any connections between sections of duct need to be airtight.

The inner wall of the duct or rigid subduct is manufactured to ensure low friction with the cable sheath. This is typically achieved with a low friction coating. Alternatively, the duct or rigid subduct may have a low-friction extruded profile or special duct lubricants are used. Flexible subducts are prelubricated during manufacturing to achieve low friction.

A number of factors govern the continuous length that can be pulled or blown, including coefficient of friction, bends in the duct route (vertical as well as horizontal), the strength and weight of the cables, and the installation equipment used. Fill ratios should be calculated as part of the planning process. The cable diameter should not be too large compared to the inner diameter of the duct. For existing networks the condition of the ducts should be checked for any potential damage and suitable space and capacity for future cabling.

9.1.3 Type of ducts

Main ducts – underground systems

The feeder ducts run from the access node to the FCP. The number of ducts required will be dictated by the size and amount of feeder cables used. Extra space may be allowed, so that more than one cable can be installed in a single duct to save vital duct capacity (e.g. using blowing or pulling techniques). Maximum amount of extra cables can be installed when using flexible inner duct. Smal main duct sizes will range from 25mm to 50mm outer diameter. Larger main ducts of up to 110mm may be used and these may contain smaller rigid subducts between 20mm and 40mm outer diameter or flexible textile subducts. The duct material of main ducts is HDPE or PVC, and of rigid subducts HDPE. Flexible subducts consist of nylon/polyester.

9.1.4 Types of duct cables

There are a wide variety of cables for use in a duct network.

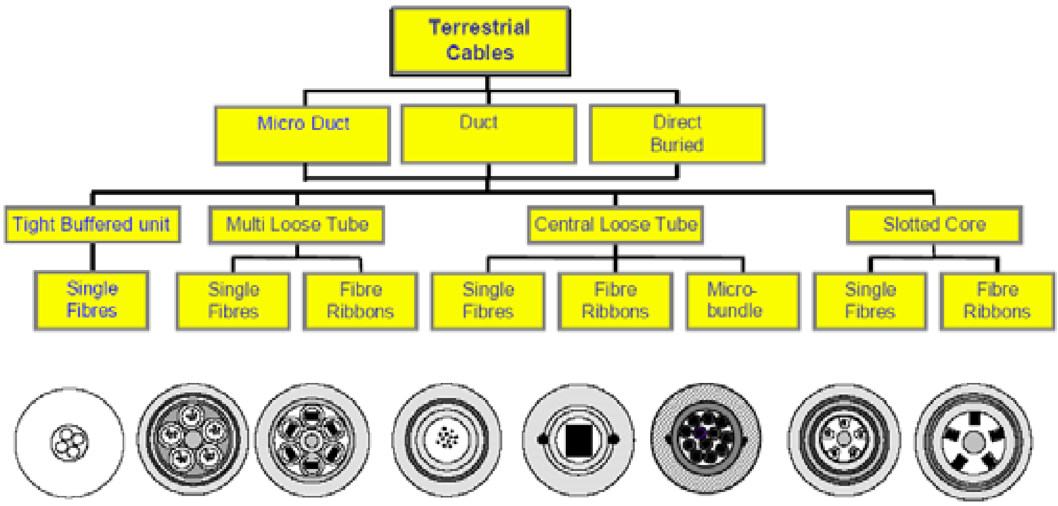


Figure 48: Duct cable selection.

Although cable designs can vary, they are based on a small number of elements. The first and most common building block is a loose tube, comprising a plastic tube containing the required number of fibres (typically 12) together with a tube filling compound that both buffers the fibres and helps them to move within the tube as the cable expands and contracts at environmental and mechanical extremes. Other building blocks include multiple fibres in a ribbon form or in a thin easy-strip tube coating. Fibres may also be laid in narrow slots grooved out of a central cable element.

Tubes containing individual fibres or multiple ribbons are laid around a central cable element that comprises a strength member with plastic jacketing. Water blocking materials such as water-swellable tapes or grease can be included to prevent moisture permeating radially or longitudinally through the cable, which is over-sheathed with polyethylene (or alternative materials) to protect it from the external environment. Fibres, ribbons or bundles (protected by a coloured micro-sheath or identified by a coloured binder) may also be housed within a large central tube. This is then over sheathed with strength elements included.

If cables are pulled in using a winch, then they may need to be stronger than blown versions, because the tensile force applied may be much higher. Blown cables need to be suitably lightweight with a degree of rigidity to aid the blowing process. The presence of the duct affords a high degree of crush protection, except where the cable emerges into the footway box. Duct cables are normally jacketed and non-metallic – to remove the need for earthing, for lightning protection and for environmental reasons. However, they may contain metallic elements for higher strength (steel central strength members), for remote surface detection (copper elements) or for added moisture protection (longitudinal aluminium tape). Duct environments tend be benign, but the cables are designed to withstand potential long-term flooding and occasional freezing.

9.1.5 Cable installation by pulling

The information below is an outline of the required installation and equipment considerations. Reference should also be made to IEC specification 60794-1-1 Annex C, Guide to the installation of optical fibre cables.

When cables are pulled into a duct, there needs to be either a pre-existing draw-rope or one must be installed prior to cable winching. The cable should be fitted with a swivel, which allows the cable to freely twist as it is installed, and a fuse rated at or below the cable's tensile strength. Long cable section lengths can be installed if the cable is rated to take the additional tensile pulling load, or by "fleeting" the cable at suitable section mid-points to allow a secondary pull operation, or by using intermediate assist pullers (capstans or cable pushers). Fleeting involves laying loops of fibre on the surface during a pull using figure of eight loops to prevent twisting in the cable. If spare ducts or subducts are installed, then subsequent cables can be installed as the need arises ("just in time").

When installing cables, due account should be taken of their mechanical and environmental performances as indicated on the supplier's datasheets, which should not be exceeded. The tensile load represents the maximum tension that should be applied to a cable during the installation process and ensures that any strain imparted to the fibres is within safe working limits. The use of a swivel and mechanical fuse will protect the cable if the pulling force is exceeded.

Figure 49: Pulling cable swivel.

Figure 50: Cable guide pulley.

Cable lubricants can be used to reduce the friction between the cable and the sub-duct, hence reducing the tensile load. The minimum bend diameter represents the smallest coil for cable storage within a cable chamber. Suitable pulleys and guidance devices should be used to ensure that the minimum dynamic bend radius is maintained during installation. If the cable outer diameter exceeds 75% of the duct inner diameter the pulling length may be reduced.

9.1.6 Cable installation by air blowing

Traditionally, cables were pulled into ducts. More recently, particularly with the growth of lightweight non-metallic designs, a considerable proportion of cables are now installed by blowing (if the duct infrastructure was designed for it). This can be quicker than pulling, and may allow longer continuous lengths to be installed, thus reducing the amount of cable jointing. If spare ducts or subducts are installed, then subsequent cables can be installed as the need arises.

When cables are blown into a duct, it is important that the duct network is airtight along its length. This should be the case for new-build, but may need to be checked for existing ducts, particularly if they belong to a legacy network.

A balance must be struck between the inner diameter of the duct and the outer diameter of the cable. If the cable's outer diameter exceeds 75% of the duct's inner diameter, air pressures higher than those provided by conventional compressors are required or the blow length may be reduced. Nevertheless, good results have also been obtained for between 40–-85% fill ratios. If the cable is too small then this can lead to installation difficulties, particularly if the cable is too flexible. In such cases, a semi-open shuttle attached to the cable end can resolve this difficulty.

A cable blowing head is required to both blow and push the cable into the duct. The pushing overcomes the friction between the cable and duct in the first few hundred metres, and hauls the cable from the drum. A suitable air compressor is connected to the blowing head. The ducts and connections must be sufficiently air tight to ensure an appropriate flow of air through the duct. Hydraulic pressure at the blowing head must be strictly controlled to ensure no damage to the cable.

9.1.7 Cable installation by floating

Considering that most outside plant underground cables are exposed to water over a major part of their life, floating is an alternative method to blowing. Floating can be done with machinery originally designed for blowing: air is simply replaced by water. Compared to blowing, floating makes it possible to place considerably longer cables in ducts without an intermediate access point.

Floating can prove very efficient for over-laying cable in many situations. The performance of the process decreases when placing cables with an outer diameter exceeding 75% of the duct inner diameter. Nevertheless good results have also been obtained for higher fill factors; for example, a 38mm cable was floated over 1.9km in a duct with inner diameter of 41 mm (fill factor 93%).

Floating is also a safe method for removing cables from the duct, thus making possible the re-use of such cable. Blowing out cable is, by comparison, a hazardous operation.

9.1.8 Cable de-coring

New techniques have been developed to successfully de-core cables. With this method, the core of copper cables can be replaced cost-effectively and speedily with fibre-optics.

Instead of digging up the entire cable length, the cable is now only accessed at two points 50 to 400 metres apart. A special fluid is pumped under pressure into the space between cable sheath and cable core wrapping, detaching the core from the sheath.

Next, the old cable core is extracted mechanically and treated for clean, environmentally friendly disposal or recycling. Simultaneously, an empty, accurately fitted sheathing for the new fibre-optic cable is drawn into the old cable sheath.

Afterwards these so-called "microducts" are connected, the pits are closed and, finally, the empty cable sheath is refilled with fibre optics.

Apart from the positive environmental aspects – old cables can be recycled homogenously, and the fluid is biodegradable – this technique can be 40 to 90% cheaper than installing a new cable, especially due to the much faster completion time and the reduction in planning and building costs.

Figure 51: Cable de-coring.

9.1.9 Access and jointing chambers

Suitable sized access chambers should be positioned at regular intervals along the duct route. These can be located to provide the best position for connection to the customer drop cables. The duct chambers must be large enough to enable all duct cable installation operations, storage of slack cable loops for jointing and maintenance, cable hangers and bearers, and the storage of the cable splice closure.

The chambers may be constructed on site or be provided as pre-fabricated units to minimise construction costs and site disruption. On site constructed modular chamber units are also available. Where existing legacy access chambers are insufficient due to size or over population of cables/closures then an 'off-track or spur' chamber should be considered.

9.1.10 Cable joint closures

Cable joint closures may act as a track or straight-through joint, to join sequential cable and fibre lengths together, or provide a function for distribution of smaller drop cables. Closures will usually be sited in the manhole or underground chambers. Occasionally the cable joint may take place within an off-track chamber or above ground cabinet.

Closures may be placed as regularly as every 500m in medium-density areas and as frequently as every 250m in high-density areas. Certain networks may require the use of mid-span joints, which enable fibres to be continued through the joint un-spliced; only the required fibres are intercepted for splicing.

The closure must be resistant to long term flooding and any future need to re-open for adding or changing customer fibre circuits.

9.2 Blown microducts and microcable

This option utilises compressed air to blow fibre unit and small diameter cables quickly through a network of tubes to the customer/ premises. Fibre deployment can be deferred until the customer requirement has been confirmed, hence deferring costs compared to speculative up-front build programmes. Also, the number of splices can be minimised by blowing long lengths of fibre through the network of tubes (which themselves are easily joined via push-fit connectors). Blown microducts may be used in combination with duct, direct buried and aerial infrastructure and the tubes may be housed in constructions designed for any of these three methods.

9.2.1 Product Map

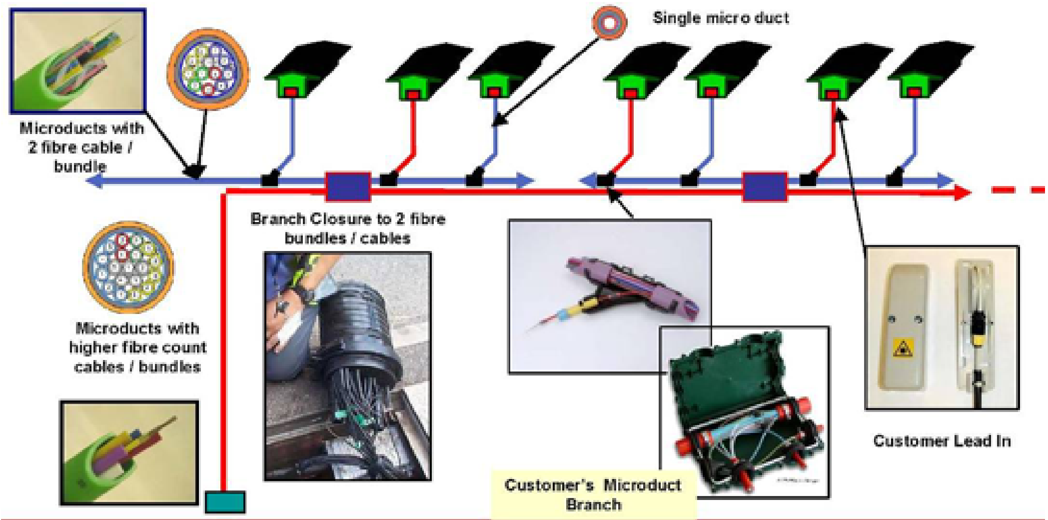


Figure 52: Product map for blown microducts and microcable.

9.2.2 Microduct solutions

Microducts are small, flexible, lightweight tubes typically less than 16mm in diameter. They could be smaller versions of conventional duct (e.g. 10 mm outer diameter, 8 mm inner diameter) that are pre-installed or blown into a larger subduct. Microduct can be used to further segment a subduct (for example using five 10mm microducts). The microducts may be blown directly into the subducts. They could also be small tubes (e.g. 5mm outer diameter, 3.5 mm inner diameter) manufactured as a single or multi-tube cable assembly, known as a “protected microduct”. Protected microduct assemblies (typically containing from one to twenty-four microducts) may be constructed in a similar fashion to the aerial, direct buried or duct cables described previously, and would be installed in a similar fashion.

Figure 53: Sub-divided subduct.

Figure 54: Post-installed microduct.

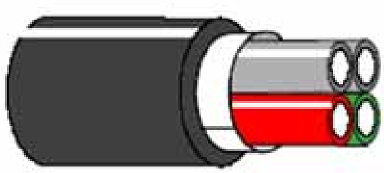


Figure 55: Protected microduct.

Thick-walled microducts do not need to be placed or blown inside another duct or tube. Bundles of thick-walled microducts offer the most user-friendly connector solution. From a technical perspective, this is the best solution for near-surface needs where temperatures may vary significantly. These products can be direct buried over long distances in bundles of 2, 4, 6, 7, 12, or 24, or they can be buried individually over shorter distances. In addition, microducts offer the easiest solution for branching – just cut the thin outer coating and snap on a connector.

Figure 56: Thick walled microduct bundle

Figure 57: Branching of thick walled microduct.

Tight-bundled microducts offer a larger number of microducts pre-installed in a standard duct. They consist of a standard HDPE duct pre-sheathed around a bundle of microducts. Both the main duct and the microducts come in a variety of sizes to accommodate different types of fibre cables. Tight-bundled microducts are sheathed in a manner that they do not have space to buckle, which makes them less susceptible to temperature changes.

Loose bundled microducts are notable for their high crush resistance and record-breaking distances over which fibre can be blown. Loose bundled microducts are installed in two ways:

- Pre-installed in various size HDPE ducts and so ready to be laid in trenches and branched where necessary.
- Blown in after the HDPE ducts have been buried, for the ultimate in network expansion flexibility.

9.2.3 Microduct tube connectors and closures

Sections of microduct can be joined with specialist connectors, which are available in water and gas-sealed versions.

Thick-walled microduct connectors have a simple design that allows the installer to snap together the ends of two microducts – there is no need for a closure, Y-branch, or tube management box. Gas-tight connectors or terminations must be used at network access points to protect the integrity and safety of the design.

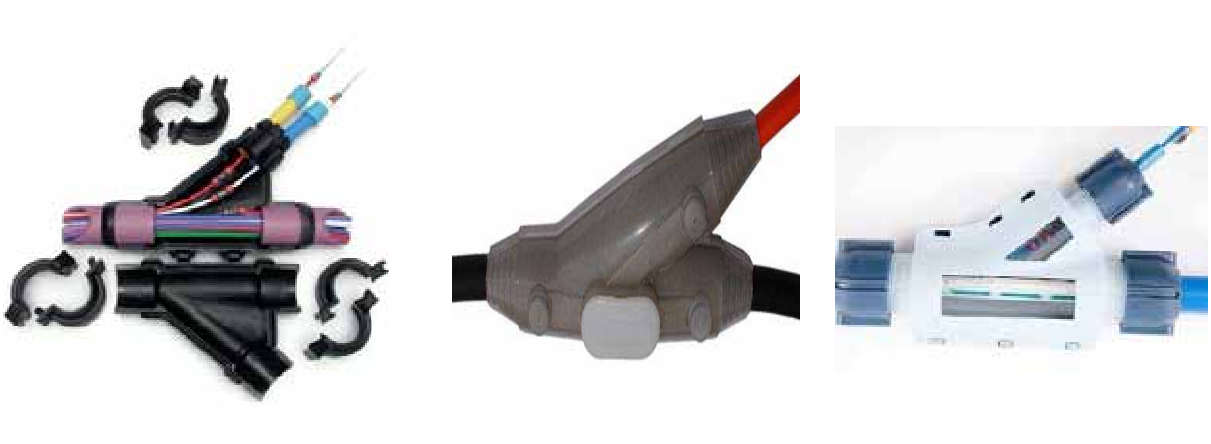


Figure 58: Branching components.

Tight-bundled microducts need a watertight closure for branching. Watertight Y-branch and wraparound connector products make it possible to access and branch microducts at any point in a network. Tube management boxes can also be used when several microducts branch in different directions. Straight connectors, reducers, and branching components for connecting and branching the ducting layout are widely used. Gas-tight connectors or terminations must be used at network access points to ensure the integrity and safety of the design.

Figure 59: Push-fittings (left to right): gasblock tube connectors, straight tube connectors, and end-tube connectors.

9.2.4 Microduct cable and fibre units

Microducts tubes house microduct cables (e.g. 96 fibre 6.4mm diameter for use in a 10mm/8mm microduct) or very small blown-fibre unit cables 1 to 3 mm in diameter containing up to 12 fibres (e.g. 4 fibres in a 1 mm cable for use in 5 mm/3.5 mm tubes). The cables used in these tubes are small lightweight designs that require the tube for protection. In other words, the tube and cable act together as a system. The cables are installed by blowing, and may have special outer coatings to assist with blowing.

Figure 60 Microduct cables.

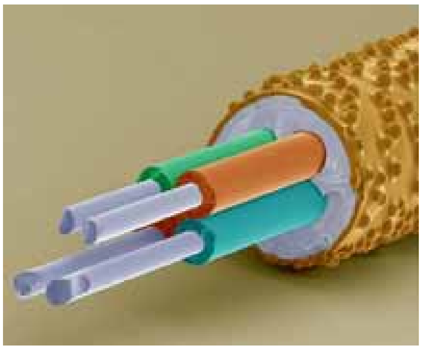


Figure 61: Microduct cable with 4 fibres.

The microduct size must be chosen to suit the cable and required fibre count. Typical combinations of cable and duct size are given in the table following. Other sizes and combinations can be used.

Microduct outer diameter (mm)	Microduct inner diameter (mm)	Typical fibre counts	Typical cable diameter (mm)
16	12	24–216	9.2
12	10	96–216	6.5–8.4
10	8	72–96	6–6.5
7	5.5	48–72	2.5
5	3.5	6–24	1.8–2
4	3	22–12	1–1.6

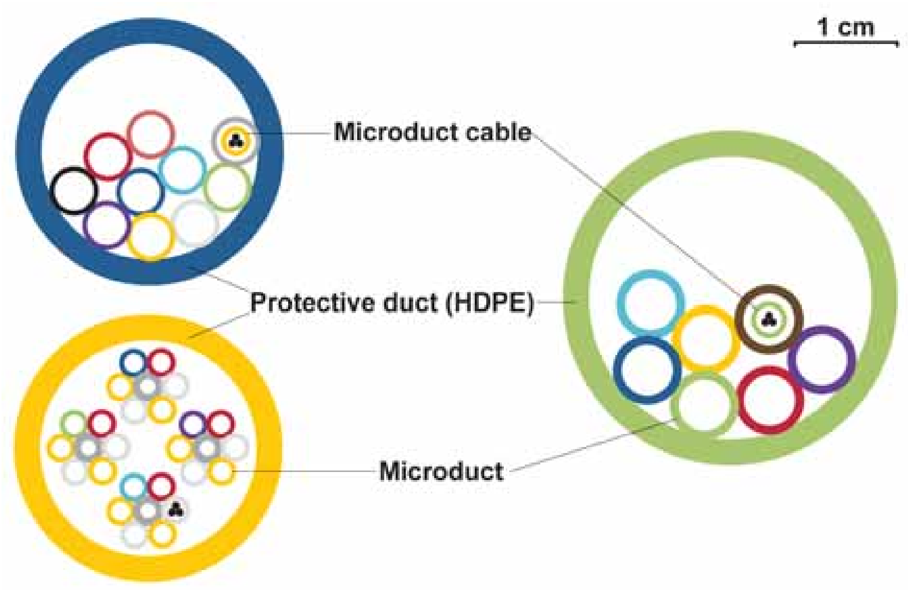


Figure 62: Protected microducts with loose package.

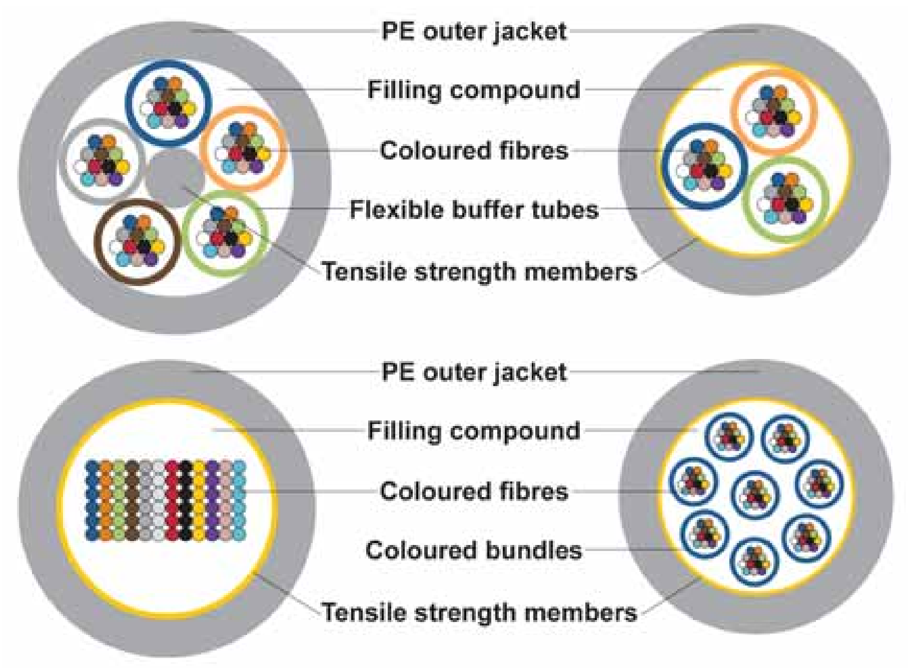


Figure 63: Microduct optical fibre cables (not to scale).

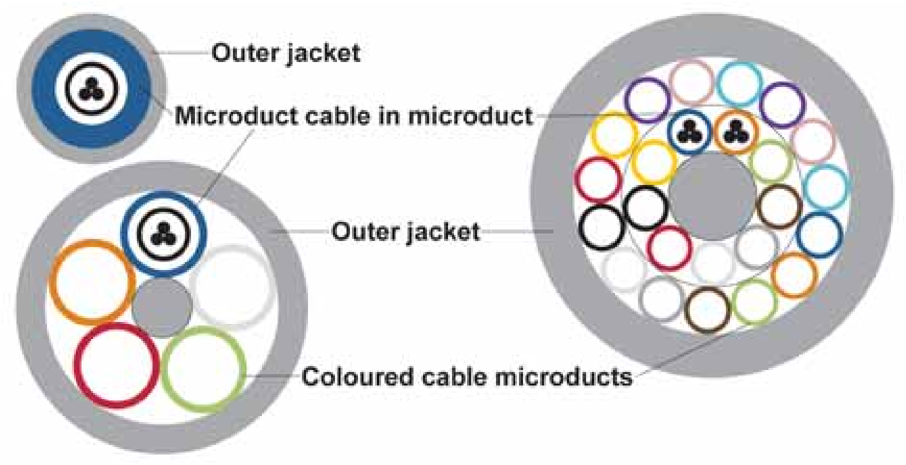


Figure 64: Protected cable microduct with tight integral outer duct (not to scale).

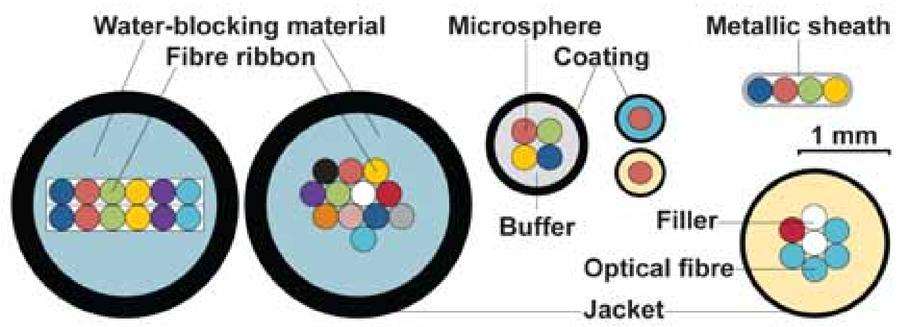


Figure 65: Examples of Fibre units.

The distance achieved by blowing will depend on the microduct, cable and installation equipment used plus route difficulty, particularly turns in the route and vertical deviations. As the fibre reaches its final drop to the home, it may be possible to use even smaller tubes (e.g. 4mm/3mm or 3mm/2.1mm), since the blowing distance will be quite short.

9.2.5 Microcable/blown fibre unit installation

The installation method will be very similar to the equipment for full-size cables, but with smaller blowing equipment and using smaller, lighter and more flexible cabling payoff devices – reels instead of drums and cages and pans. Under certain conditions, microcables can be floated using smaller floating equipment

9.2.6 Access and jointing chambers

The same principles apply as for microduct cable normal cable. Additionally, it is possible to branch microduct tubes at hand-hole locations using a suitable swept branch closure, rather than requiring a full-size chamber.

9.2.7 Microcable joint closures

Microcable joint closures have the same basic features as duct joint closures. There are different types, depending on whether the joint is being used to join or branch fibres, or whether it is the tubes themselves that are to be branched or jointed. These closures allow considerable flexibility with the routing of the ducts whilst minimising the number of installation steps, because the cables or fibres may be blown through the whole route once the tubes are connected, and may be facilitated using simple joints rather than full-scale joint closures.

External tubing can be joined directly to suitable indoor tubing, hence avoiding the need for a joint splice at the building entry point. Additional safety features may be required, particularly with respect to pressure relief. If a fully jointed airtight closure is required, then dangers may occur when fibre is blown through a joint if there happens to be an air-leak within the tubes housed in the joint. To prevent pressure build-up in the joint that could cause it to blow apart, the fitting of a reliable safety valve or other pressure relief mechanism is strongly recommended.

9.3 Direct buried cable

Direct burial offers a safe, protected and hidden environment for cables, but requires careful survey to avoid damaging other buried services. A narrow trench must be excavated in order to effectively bury and protect the cable. Excavation techniques include mole ploughing, open trenching, slotting and directional boring. A combination of these options can be used in a deployment area.

9.3.1 Product map

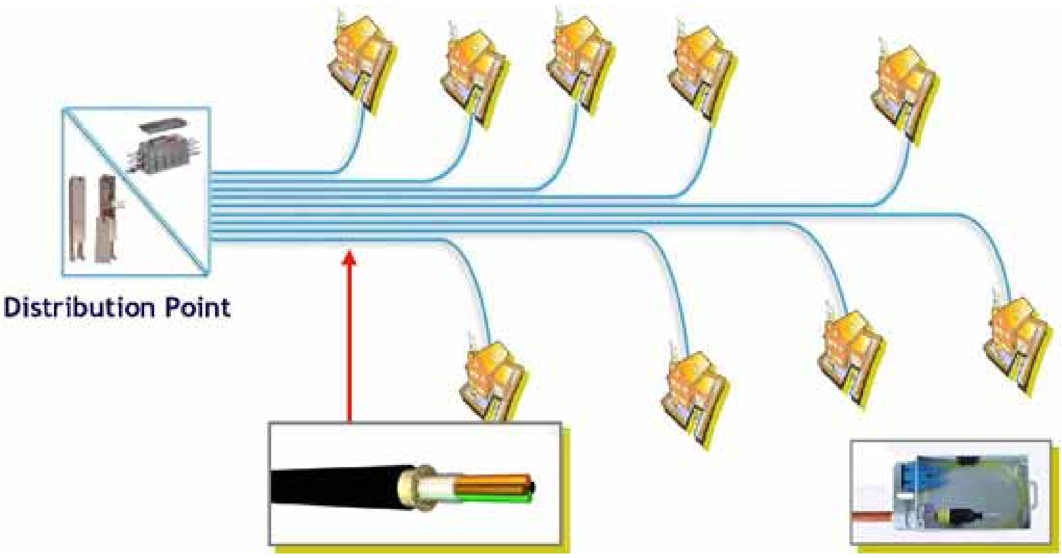


Figure 66: Product map for direct buried cable.

9.3.2 Installation options

A number of excavation techniques are possible including open trenching, mole ploughing, slotting and directional boring – more than one method may be used.

9.3.3 Types of direct buried cable

Direct buried cables are designed in a similar fashion to duct cables, employing similar elements, such as filled loose tubes. The cables may have additional armouring to protect them, although this depends on the burial technique. Pre-trenching and surrounding the buried cable with a layer of sand can permit the use of quite lightweight designs, whereas direct mole-ploughing or backfilling with stone-filled soil may require a more robust design. Crush protection is a major feature and could consist of a corrugated steel tape or the application of a thick sheath of suitably hard polyethylene.

Figure 67: cable with corrugated steel protection.

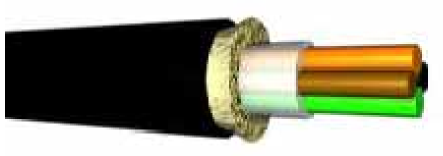


Figure 68: non-metal direct buried cable.

9.3.4 Lightning protection

Non-metallic designs may be favoured in areas of high lightning activity, but have less crush protection than a cable with a corrugated steel tape. The steel tape can survive being struck by lightning, particularly if the cable contains no other metallic components, since it can absorb a direct strike, and offers excellent crush protection.

9.3.5 Rodent protection

Corrugated steel tape has proven to be one of the best protections against rodent damage or other burrowing animals. If the cable needs to be non-metallic, then a complete covering of glass yarns may deter rodents to some degree.

9.3.6 Termite protection

Nylon sheaths, though expensive, offer excellent protection against termites. Nylon resists bite damage, and is chemically resistant to the substances excreted by termites.

9.3.7 Access and jointing chambers

Depending on the actual application, buried joints are typically used in lieu of the access and jointing chambers used in duct installation.

9.3.8 Direct buried cable joint closures

Basic joint closures for direct buried cable are similar to those used for duct cables, but may require additional mechanical protection. The closure may also need to facilitate the distribution of smaller drop cables.

9.4 Aerial cable

Aerial cables are supported on poles or other tower infrastructure, and represent one of the more cost-effective methods of deploying drop cables in the final link to customer. The main benefits are the use of existing pole infrastructure to link customers, avoiding the need to dig roads to bury cables or new ducts. Aerial cables are relatively quick and easy to install, using hardware and practices already familiar to local installers.

9.4.1 Product map

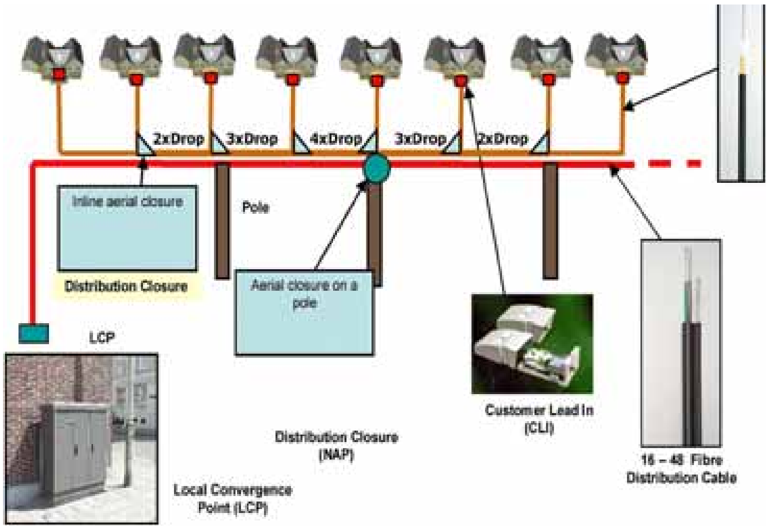


Figure 69: Product map for aerial cable.

9.4.2 Condition of the pole infrastructure

The poles to which the optical cable is going to be attached may already exist and have other cables already attached to them. Indeed, the pre-existence of the pole route could be a key reason for the choice of this type of infrastructure. Adding cables will add to the loading on the poles, so it is important to check the condition of the poles and their total load capacity. In some countries, such as the UK, the cable design for aerial cables has to be designed to break if it comes into contact with high vehicles to prevent damage to poles.

9.4.3 Types of aerial cable

Types of aerial cable include circular self-supporting (ADSS or similar), Figure 8, wrapped or lashed.

ADSS is useful where electrical isolation is important, for example, on a pole shared with power or data cables, and when a high degree of mechanical protection is required. ADSS cable may be favoured by companies used to handling copper cables, since similar hardware and installation techniques can be used.

Figure 70: Wrapped aerial cable.

The Figure-8 design allows easy separation of the optical package away from the strength member, while in the ADSS cable the strength member bracket is part of the cable.

ADSS cables have the advantage of being independent of the power conductors. ADSS and phase-wrap cables use special anti-tracking sheath materials when used in high electrical fields.

Lashed or wrapped cable is created by attaching conventional cable to a separate catenary member using specialist equipment; this can simplify the choice of cable. Wrap cables use specialised wrapping machines to deploy cables around the earth or phase conductors.

If fibre is deployed directly on a power line, then this may involve OPGW (optical ground wire), earth. OPGW protects the fibres within a single or double layer of steel armour wires. The grade of armour wire and the cable diameters are normally selected to be compatible with the existing power line infrastructure. OPGW offers excellent reliability but is normally only an option when the ground wires also need to be installed or refurbished.

Aerial cables can have similar cable elements and construction to those of duct and buried optical fibre cables described previously. Circular designs, whether self-supporting, wrapped or lashed, may include additional peripheral strength members plus a sheath of polyethylene or special anti-tracking material (when used in high electrical fields). Figure-8 designs combine a circular cable with a high modulus catenary strength member.

If the feeder cable is fed by an aerial route then the cable fibre counts will be similar to the underground version.

It should be noted that all of the above considerations are valid for blown fibre systems deployed on poles or other overhead infrastructure.

Extra consideration needs to be taken for the environmental extremes that aerial cables may experience, such as ice and wind loading. Cable sheath material should also be suitably stabilised against solar radiation. Installation medium also need to be properly considered (e.g. poles, power lines, short or long spans, loading capabilities).

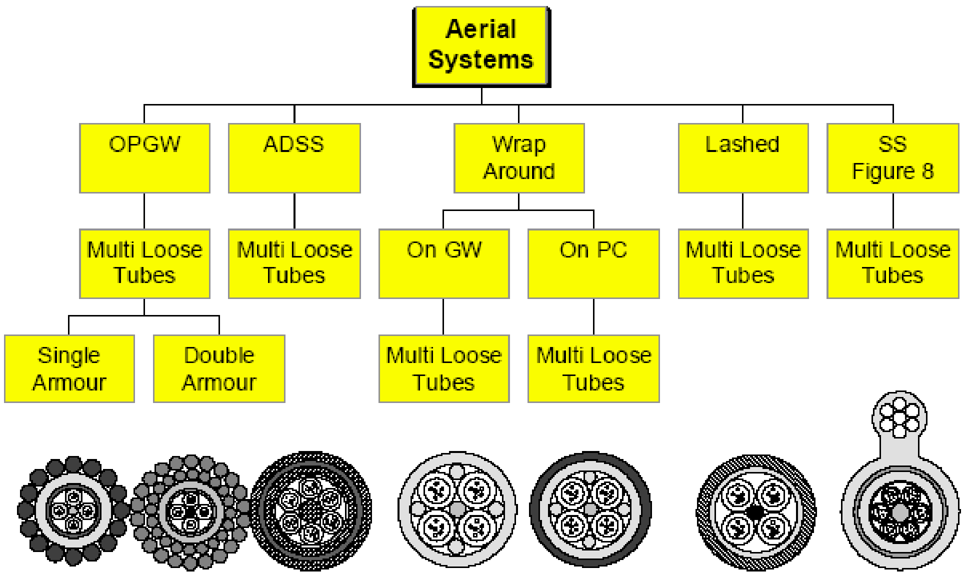


Figure 71: Aerial cable selection.

In addition cables are also available with a “unitube” structure.

9.4.4 Cable pole support hardware

Support hardware can include tension clamps to anchor a span of cable to a pole or to control a change of pole direction, and intermediate suspension clamps to support the cable between the tensioning points. The cable may be anchored with bolts or with preformed helical accessories, which provide a radial and uniform gripping force. Both types of solutions should be carefully selected for the particular diameter and construction of the cable. The cable may need protection if it is routed down the pole, e.g. by covering with a narrow metal plate.

Where there are very long spans or when snow or ice accretion has modified the conductor profile, right angle winds of moderate or high speed may cause aerodynamic lift conditions which can lead to low frequency oscillation of several metres amplitude known as "galloping". Vibration dampers fitted to the line, either close to the supporting structure or incorporated in the bundle spacers are used to reduce the threat of metal fatigue at suspension and tension fittings.

9.4.5 Cable tensioning

Aerial cables are installed by pulling them over pre-attached pulleys, and then securing them with tension and suspension clamps or preformed helical dead-ends and suspension sets to the poles. The installation is usually carried out in reasonably benign weather conditions and the installation loading is often referred to as the everyday stress (EDS). As the weather changes, temperature extremes, ice and wind can all affect the stress on the cable. The cable needs to be strong enough to withstand the extra loading.

Figure 72: Aerial cable installation.

Care also needs to be taken that the installation sag and subsequent additional sagging, due to ice loading for example, does not compromise the cable’s ground clearance (local authority regulations on road clearance need to be taken into account) or lead to interference with other pole-mounted cables with different coefficients of thermal expansion.

9.4.6 Aerial cable joint closures

Closures may be mounted on the pole or tower, or located in a footway box at the base. In addition to duct closure practice, consideration should be given to UV and possible shotgun protection, particular for closures mounted on the pole. The closure may require a function for the distribution of smaller drop cables.

9.4.7 Other deployment considerations

Aerial products may be more accessible to vandalism than ducted or buried products. Cables could, for example, be subject to shotgun damage. This is more likely to be low energy impact, due to the large distance from gun to target. If this is a concern, however, then corrugated steel tape armouring within a Figure-8 construction has been shown to be very effective. For non-metallic designs, thick coverings of aramid yarn, preferably in tape form, can also be effective. OPGW cable probably has the best protection, given that it has steel armour.

9.5 Pre-terminated network builds

Both cables and hardware can be terminated with fibre-optic connectors in the factory. This enables factory testing and hence improved reliability, while reducing the time and the skills needed in the field.

Pre-terminated products are typically used from the primary fibre concentration point in cabinets through to the final customer drop. In this way the network can be built out quickly, passing homes, but when a customer requests service the final drop is made with a simple plug-and-play cable assembly.

There are several pre-connectorised solution methods that allow termination either inside or outside the product closures, some examples are shown below.





Figure 73: First row: fully ruggedized, environmentally sealed connectors. Second row: cable assembly with rugged covers, conventional connector with rugged cover, standard connectors in thin closure. Third row: Rugged closures that take conventional connectors.

9.6 Street cabinets

A buried FTTH network contains communication equipment that can either reside below or above ground level. Street cabinets can be provided both above and below ground although the recognised convention is above ground.

With the different sizes, lower profiles and smaller above-ground footprint, modern street cabinets are less of an eyesore than the larger cabinets required for a copper or VDSL network. Although visibility is an important consideration, it is not the only one. Other considerations include:

- **Cost** – In FTTH deployments the labour costs of installation often dwarf the material cost of the network components. Cabinets can be a cost-effective method of providing a network access point, if the build specification and methodology allows. A scalable or modular cabinet solution can help to control project costs because the size of the cabinet can easily be extended if the need arises.
- **Network accessibility** – Depending on the geographical location, the cleanliness of the splice closure installed will normally be better in an above ground installation. Wet conditions can turn a traditional hand and manholes into miniature mud pools, increasing the installation time. In cold winters, underground access can sometimes be impossible due to ice.

When the advantages of a cabinet are required but there are issues with location, an underground solution is also available that allows the cabinet can be raised out of the ground for access; when stored no more than a manhole cover is seen.

The biggest concern in terms of above ground installation is the relative vulnerability of cabinets to uncontrolled damage, for example car accidents and vandalism. Distances from sidewalks and positioning on streets with heavy traffic must be taken into consideration. Positioning may also be restricted by local authority rules, for example, in historic city centres or secure public places.

A typical street cabinet has three functions:

1. **Duct management** is made in the root compartment to connect, separate and store ducts and cables. The same area can be used as point of access to facilitate blowing in (also midpoint blowing) of fibre units, ducts or cables.
2. **Base management** is where ducts, modular cables and fibre-optic cables can be fixed and managed, usually on a mounting rail.
3. **Fibre management** is where the fibres of the different cable types can be spliced. This construction facilitates easy and fault-free connection of different fibre types.


Figure 74: Duct management.


Figure 76: Base management.


Figure 75: Fibre management.

When protecting active components which are sensitive to extremes of temperature and/or humidity, a controlled environment is required and this can be provided by climate-controlled outdoor cabinets.


Figure 77: Examples of street cabinets in a range of sizes.

Street cabinets can also be provided pre-stubbed and terminated. These cabinets are assembled in the factory and tested prior to delivery. The cabinets have a cable stub that is run back to the next closure and offer a patch panel for simple plug-and-play connectivity. This provides faster installation, and greatly reduces the incidence of installation faults on site.

Compact pedestals and cabinets that are designed to be the last premises distribution/termination point can be placed directly in front of residents' property or along the street. These cabinets are also used as an easy repair and access point in the fibre optical network

9.7 Other deployments options using rights of way

In addition to the traditional cabling routes, it can also be advantageous to exploit other rights of way (RoW) that already exist within towns and cities. Deployment costs and time may be reduced by deploying cables within water and sewer networks (sanitary and stormy), gas pipe systems, canals and waterways, and other transport tunnels.

Cable installations in existing pipe-networks must not impair their original function. Restrictions during repair and maintenance work have to be reduced to a minimum and coordinated with the network operators.

9.7.1 Fibre-optic cables in sewer systems

Sewers may be used for access networks, since they reach almost every corner of the city and pass all potential customers. Utilising sewers avoids the need to gain digging approvals and reduces the cost of installation.

Tunnel sizes in the public sewer range from 200mm in diameter to those that can be entered by boat. The majority of public sewer tunnels are between 200mm and 350mm in diameter – sufficient cross-section for installation of one or more microduct cables.

Various installation schemes are possible, depending on the sewer cross-section. One scheme uses steel bracings to fix corrugated steel tubes (that will carry the cable) to the inner wall of the smaller sewer tube without drilling, milling or cutting. This is done by a special robot based on a module used for sewer repairs.

9.7.2 Fibre-optic cables in gas pipes

Gas pipelines can also be used for deploying optical fibre networks without major disruption and destruction of the streets and sidewalks normally caused by conventional cut and fill techniques. The fibre network is deployed using a specially developed I/O port, which guides the cable into and out of the gas pipe, bypassing the gas valves.

The cable is blown into the gas pipes by means of a stabilized parachute either by using the natural gas flow itself or by using compressed air, depending on the local requirements.

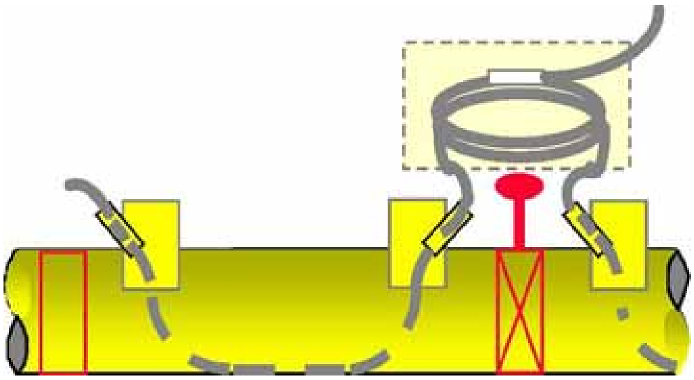


Figure 78: Gas pipeline section, including I/O ports and the bypassing of a valve defining one point-of-presence for the fibre optic cable.

The gas pipeline system provides good protection for the optical fibre cable, being situated well below the street surface and other infrastructure.

9.7.3 Fibre-optic cables in drinking water pipes

Drinking water pipes can be used for the deployment of fibre optical cables in a similar manner as in the case of gas pipes.

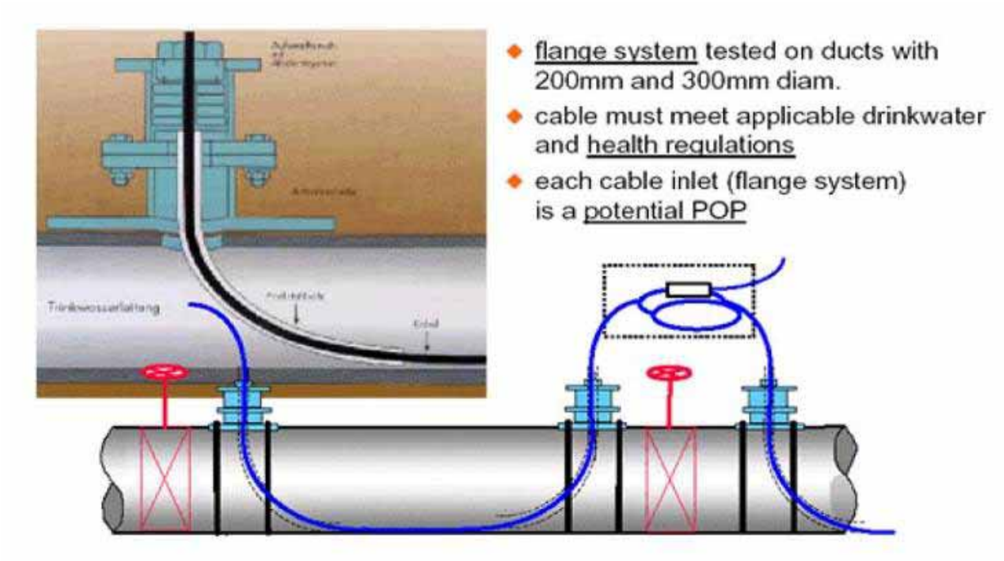


Figure 79: Cross-section showing fibre installed in a drinking water system.

9.7.4 Canals and waterways

To cross waterways and canals, hardened fibre optic cables can be deployed without any risk as fibre is insensitive to moisture.

9.7.5 Underground and transport tunnels

Underground tunnels can be used to install fibre-optic cable, often alongside power and other data cabling. Typically, they are installed on hangers fixed to the wall of the tunnel. They may be fixed in a similar manner to cables used in sewers.

Two key issues to consider are fire performance and rodent protection.

Should a fire occur in a transport tunnel, then the need to evacuate personnel is critical. IEC TR62222 gives guidance on “Fire performance of communication cables in buildings”, which may also be applied to transport tunnels if the fire scenarios are similar. This lists potential hazards such as smoke emission, fire propagation, toxic gas and fumes, which can all be detrimental to evacuation.

Figure 80: Cable installation in a train tunnel.

Potential users of underground and transport tunnels should ensure that all local regulations for fire safety are considered prior to installation. This would include fixings, connectivity and any other equipment used.

Cables in tunnels can also be subject to rodent attack which could require the cable to have extra protection, such as a corrugated steel tape.

9.8 Internal cabling

9.8.1 Indoor cables

Indoor cables start may extend for short runs within a house or long runs through a building. The cable designs may from single fibre cables, possibly pre-connectorised, through to multi-fibre designs using tight-buffered or loose tube cable. There is also blown fibre and microduct for indoor application.

Whilst the designs may vary, they are all used in customer premises, therefore they should all typically offer some form of fire protection. This would typically include the use of a low smoke zero halogen (LSZH) sheath. The cable would be constructed in such a way as to afford some degree of protection from flame propagation (for example IEC60332-1 and IEC 60332-3-24 category C) and smoke emission (IEC61034). The materials may be characterized for halogen content in line with IEC60754-1 and for conductivity and pH in accordance with IEC60754-2.

Other criteria may apply, depending on the user's exact requirements, but attention to public safety is paramount. Typical cable performance requirements are given in the IEC60794-2 series of specifications (see Appendix A).

Figure 81: Single fibre.

The simplest cable type is the patch cord or pigtail. This comprises a single 250µm diameter, acrylate-coated fibre jacketed with nylon with an outer diameter of 0.8-1mm. The jacket improves the handling properties of the fibre and the robustness of the connector. It may be applied as a tight buffer for optimum robustness, or as a semi-tight layer to enable easy-strip (for example where 1m or more is stripped for ease of tray storage). Strength is given by a layer of aramid yarns. The cable is covered with a low-smoke sheath material.

Figure 82: Multi-tight design.

For distribution of fibres through a building, one popular construction is the 'multi-tight' design. This is similar to the cable above, except that it would typically house up to 24 fibres.

Fibres may be housed within loose tubes, either central loose tube (for up to 24 fibres) or multi-loose tube for up to 144 fibres; or bundles inside a central tube for all fibre-counts up to 144 fibres. These types of cable are typically used for connection to racks in exchange buildings.

Figure 83: Loose tube design.

Microduct cables are also constructed with low smoke zero halogen (LSZH) materials for indoor application.

There are a number of tubing distribution and breakout devices available that connect and distribute the in-building tubes.

From small (slim) boxes up to large distribution boxes for high-count tubes, these boxes are available in watertight, open and vandal proof construction.

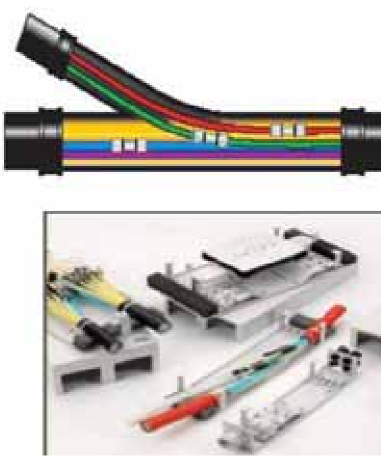
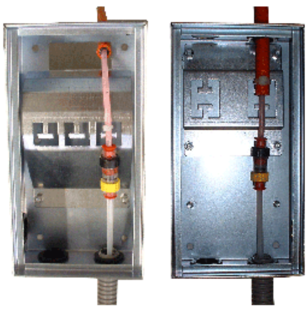


Figure 84: Examples of tubing distribution and breakout devices.

9.8.2 Building entry point

There are many ways to enter the customer building and this depends on factors such as local rules, aesthetics and how the network changes at the interface.



The above examples show typical solutions for:

- where the internal and external ducts are joined and the cable continues into the building
- where the duct stops a gas block is provided and only the cable continues into the building
- where the cable simply passes through the wall
- where a ruggedized optical connection is made at the interface to an internal cable in this case a plug and play connection point

9.8.3 Customer premises equipment

This is the point where the passive network ends and the active equipment is installed. The fibre is terminated inside the CPE with connectors, usually SC/APC or LC/APC.

The position of the CPE depends on the operator. Some networks have the CPE mounted outside to the premise to aid access and maintenance. Other operators choose to position the equipment inside the premises, to ensure the active equipment is retained close to the equipment it will feed. For MDUs the CPE may be positioned in a basement or at a floor level.

In this example of an external fibre termination unit, the fibre network terminates in a wall unit that also contains the CPE equipment. From this position the feed will be with a copper cable.

One downside with an external CPE is the need to get power to the unit; also it is exposed to potential vandalism.

Figure 85: External fibre termination box.

10 Fibre and Fibre Management

10.1 Choice of optical fibre for FTTH

Several types of optical fibre are available. FTTH schemes are usually based on singlemode fibre, but multimode fibre may also be used in specific situations. The choice of fibre will depend on a number of considerations. Those listed below are not exhaustive; other factors may need to be considered on a case-by-case basis.

- **Network architecture** – The choice of network architecture will affects the data rate that must be delivered by the fibre, and the available optical power budget of the network. Both factors affect the choice of fibre.
- **Size of the network** – Network size can refer to the numbers of properties served by the network. However, in this context we mean the physical distance across the network. The available power budget will determine how far away the POP can be from the customer. Power budgets are affected by all components in the optical path including the fibre.
- **The existing network fibre type** – If linking into an existing network, then the optical fibre in the new network must be compatible with the fibre in the existing network.
- **Expected lifetime** – FTTH networks are designed with a lifetime of at least 30 years. Therefore, it is imperative that any investment made in the FTTH infrastructure is able to serve future needs as well as those of today. Changing the fibre type halfway through the expected lifetime of the FTTH network is not a desirable option.

10.1.1 Optical fibre basics

Optical fibre is effectively a "light pipe" carrying pulses of light generated by lasers or other optical sources to a receiving sensor (detector). Transmission of light in an optical fibre can be achieved over considerable distances, supporting high-speed applications unsustainable by today's copper-based networks. Conceived in the 1960s, optical fibre has been highly developed and standardised to form a reliable, proven backbone of today's modern telecommunication transmission systems.

Fibre is manufactured from high purity silica, starting from glass-like rods, which are drawn into fine hair-like strands and covered with a thin protective plastic coating.

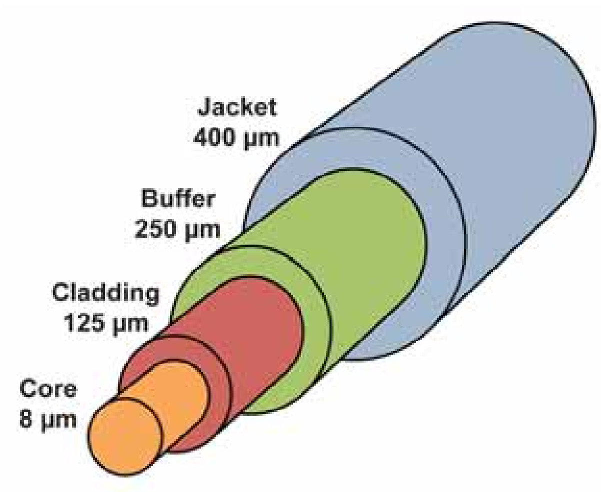


Figure 86: Optical fibre construction.

Fibre is made up of a core, cladding and outer coating. Light pulses are launched into the core region. The surrounding cladding keeps the light travelling down the core and prevents it from leaking out. An outer coating, usually made of a polymer, is applied during the drawing process.

Fibres are subsequently packaged in various cable configurations before installation. Whilst there are many different fibre types, this document concentrates on fibre for FTTH applications.

The fibre core can be designed in varying geometrical sizes. These impact how the light pulse travels, thus producing differing optical performance.

A number of parameters determine how efficiently light pulses are transmitted down the fibre. The two main parameters are attenuation and dispersion.

Attenuation is the reduction of optical power over distance. Even with the highly pure materials used to manufacture the fibre core and cladding, power is lost over distance by scattering and absorption within the fibre. Fibre attenuation limits the distance light pulses can travel and still remain detectable. Attenuation is expressed in decibels per kilometre (dB/km) at a given wavelength or range of wavelengths.

Dispersion can be broadly described as the amount of distortion or spreading of a pulse during transmission. If pulses spread out too far, the detector at the other end of the fibre is not able to distinguish one pulse from the next, causing loss of information. Chromatic dispersion occurs in all fibres and is caused by the various colours of light (components of a light pulse) travelling at slightly different speeds along the fibre. Dispersion is inversely related to bandwidth, which is the information carrying capacity.

There are many other parameters, which affect fibre transmission performance. Further information can be found in IEC 60793 series of specifications.

10.1.2 Singlemode fibre

Singlemode fibre has a small core size (<10μm) which supports only one mode (ray pattern) of light. Most of the world's fibre systems are based on this type of fibre.

Single-mode fibre provides the lowest optical attenuation loss and highest bandwidth transmission carrying capacity of all the fibre types. Singlemode fibre incurs higher equipment cost than multimode fibre systems.

For FTTH applications, the ITUT G.652 recommendations for singlemode fibre should adequately cover most users' needs.

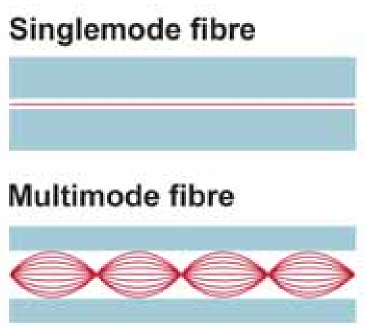


Figure 87: Light paths inside fibre.

More recently, a newer type of singlemode fibre was introduced to the market that has reduced optical losses at tight fibre bends. This fibre is standardized in the ITU-T G.657 recommendation.

10.1.3 Graded-index multimode fibres

Multimode fibres have a larger core size (50 or 62.5 μm), which supports many modes (different light paths through the core). Depending on the launch characteristics, the input pulse power is divided over all or some of the modes. The different propagation speed of individual modes (modal dispersion) can be minimised by adequate fibre design.

Multimode fibre can operate with cheaper light sources and connectors, but the fibre itself is more expensive than singlemode. Multimode fibre is used extensively in data centres and sometimes used in campus networks and for in-building applications. It has lower bandwidth capability and restricted transmission distance.

The ISO/IEC11801 specification describes the data rate and reach of multimode fibre grades, referred to as OM1, OM2, OM3 and OM4.

10.1.4 Bend insensitive fibre

When cabling inside buildings there are many areas that would provide difficulties for conventional fibres resulting in poor optical performance or the need for very careful and skilled installation practice or special fibre protection with ducts and cable designs. However, new fibre types described by the ITU-T G.657 standard are now available, which enable fibre-optic cables to be installed just as easily as conventional copper cables. The fibres inside these cables, which are termed “bend-insensitive”, are capable of operating at a bend radius down to 7.5mm, with some fibres fully compliant down to 5mm.

The recommendation G657 defines two sub-categories of fibres that satisfy the objectives of this recommendation:

Category A contains the recommended attributes and values needed to support optimized access network installation with respect to macrobending loss, while the recommended values for the other attributes still remain within the range recommended in G.652.D. This category has two sub-categories with different macrobending requirements: G.657.A1 fibre (previously G.657(12/2006).A) and G.657.A2 fibre.

Category B contains the recommended attributes and values needed to support optimized access network installation with very short bending radii applied in fibre management systems and particularly for in- and outdoor installation restricted distance installations. For the mode-field diameter and chromatic dispersion coefficients, the recommended range of value might be outside of the range of values recommended in ITU-T G.652. This category has two sub-categories with different macrobending requirements: G.657.B2 (previously G.657(12/2006).B) fibre and G.657.B3 fibre.

10.2 Optical distribution frames

An optical distribution frame (ODF) is the interface between the outside plant cables and the active transmission equipment. ODFs are usually situated in the POP, bringing together several hundred to several thousand fibres. A single ODF cabinet can connect up to 1400 fibres; large POPs will use multiple ODF cabinets.

The POP is an access node and should be classified as a secure area. Therefore provision for fire, intrusion alarm, managed entry/access and mechanical protection against vandal attacked must be considered.


Figure 88: Active pop.


Figure 89: Ducts near POP.


Figure 90: Small POP.

Outdoor cables are terminated within an ODF using an optical connector. To terminate the cable, a connectorised fibre pigtail is spliced to each individual fibre.

In most cases, the ODF offers flexible patching between active equipment ports and the field fibre connectors. Fibres are identified and stored in physically separated housings or shelves to simplify fibre circuit maintenance and prevent accidental interference to.


Figure 91: Combined POP/ODF with climate control.

For a compact ODF system, climate controlled street cabinets can provide a flexible solution. The cabinets can be equipped with the same security measures and un-interrupted power supply as in large scale access nodes.

Internal optical cables are run between the ODFs and active equipment. A fibre-guiding platform is built between the active equipment and the ODF cabinets. This provides a protected path for the internal cables to run between the two locations.

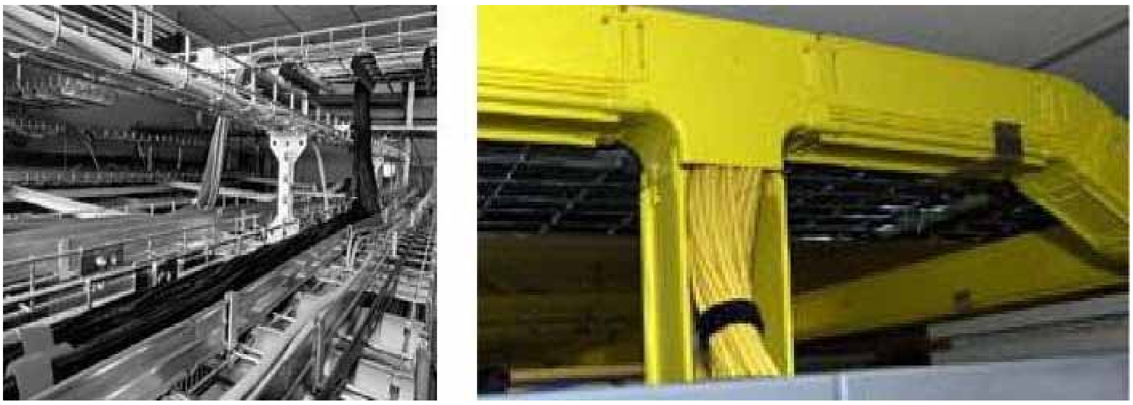


Figure 92: Examples of overhead cable guiding systems.

An uninterruptible power supply (UPS) provides emergency power back up in case of external power supply failure. The access node may also require a second diverse external power supply, which may form part of local & statutory requirement (provision of emergency services). Available UPS modules vary in size and depend upon the power requirement to be backed up.

Suitable air conditioning equipment is required to keep the active equipment within environmental operation limits. The size and capacity of the unit will depend on the size of the equipment room to be served.

Figure 93: Uninterruptible power supply.

Figure 94: Air-conditioning unit.

10.3 Patchcords and pigtails

Patchcords are fibre-optic cables fitted with a connector at one end (pigtail) or both ends (jumper). The cables are generally available in two different constructions:

- 900 µm (typical) tube or buffer without any strength member
- 1.7—3.0 mm ruggedized cable with construction based on 900 µm tubing with aramid yarns as strength members and a plastic jacket over the sheath

The optical loss of a connector is the measured loss of two mated connectors fitted within the adapter housing. The typical loss of a connector is 0.5dB when randomly mated, and 0.2dB when mated with a reference connector (an “ideal connector”).

Some connector types are also available in low loss versions with typical insertion loss of 0.15dB when randomly mated.

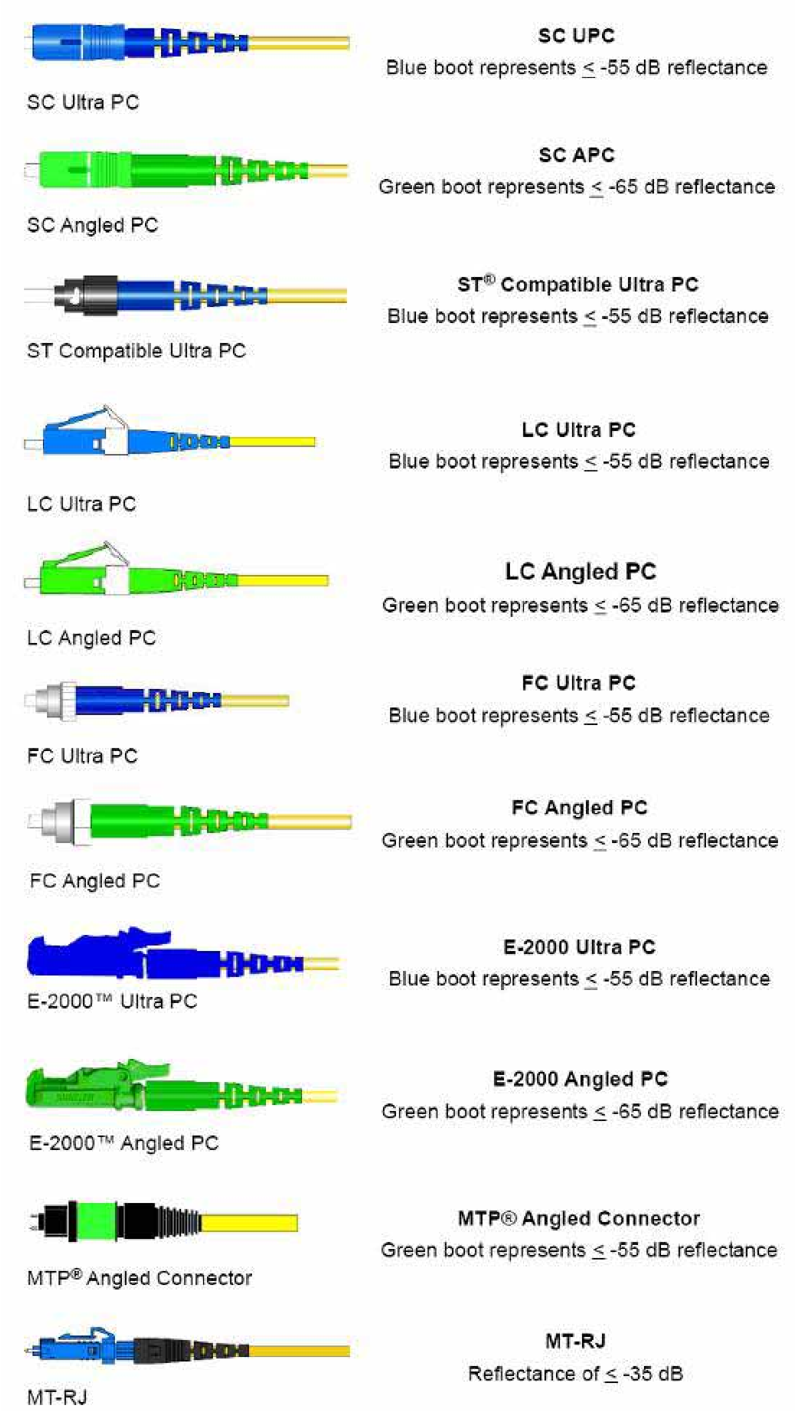
Power budget considerations will determine the class of connector to be used. Where low loss connector performance is required, many vendors are able, through design, to achieve lower loss by tuning connectors to minimise the lateral fibre offset between a mated pair.

Connectors are also characterised with a return loss value. When light is transmitted into a connector, a portion of the light is reflected back from the fibre end face. For PC connectors this gives rise to attenuation of 45dB; for UPC types this value is 50dB; and for APC it is 60dB (non-mated versions). It is desirable for this figure to be as high as possible to avoid problems with transmission lasers.

Pigtails can be deployed in OSP conditions in temperatures ranging from –40 to +70°C. Connectors should be protected from high amounts of dust and humidity.

Cable regulation in Europe usually requires that polymers for indoor wiring are LSZH-rated (low smoke, zero halogen) to minimise toxic gases when burned.

There is a mix of connector styles in use in today's networks. The complete range is shown in the following diagram:



More common standards are the SC and LC.

Standard size connector styles include: SC, FC, E2000, ST, and DIN.

Small form factor connector styles (half size) include: LC, MU, and F3000.

Connectors are supplied either without angle polishing (PC or UPC) or with angle polishing (APC).

10.4 Quality grades for fibre-optic connectors

Approved in March 2007, the standard IEC 61753 describes application-oriented grades for connection elements in fibre-optic networks (see table 1). The clear identification according to grades and the test method required by the IEC helps planners and those responsible for networks during the selection of plug-in connectors, patch cables, and pigtails. Data centre operators and telecommunications companies can determine the fibre-optic assortment according to usage and make faster and more targeted purchasing decisions. They also avoid the purchase of over-specified products which in service potentially do not deliver the expected loss values.

The current requirements catalogue is based in part on IEC 61753. This standard defines loss values. Additionally, the standards IEC 61755-3-1 and IEC 61755-3-2 play a role. They define geometric parameters for fibre-optic plug-in connectors. The interaction of these three standards creates the basis for the compatibility of fibre-optic plug-in connectors from different manufacturers and for the determination of manufacturer-neutral loss values.

Attenuation Grade	**Attenuation random mated IEC 61300-3-34**	
Grade A*	≤ 0.07 dB mean	≤ 0.15 dB max. for >97% of samples
Grade B	≤ 0.12 dB mean	≤ 0.25 dB max. for >97% of samples
Grade C	≤ 0.25 dB mean	≤ 0.50 dB max. for >97% of samples
Grade D	≤ 0.50 dB mean	≤ 1.00 dB max. for >97% of samples
Return Loss Grade	**Return Loss Random mated IEC 61300-3-6**	
Grade 1	≥ 60 dB (mated) and ≥ 55 dB (unmated)	
Grade 2	≥ 45 dB	
Grade 3	≥ 35 dB	
Grade 4	≥ 26 dB	

Table 1: Overview of performance criteria of the new performances grades for data transmission in fibre-optic connections according to IEC 61753. The definition of Grade A* has not yet been finalised. Criteria for multi-mode fibres are still under discussion.

Theoretically, the attenuation grades (A* to D) can be mixed at will with return loss grades. However, a Grade A*/4 would not make sense, and for this reason the following common combinations have been established:

	Grade A*	**Grade B**	**Grade C**	**Grade D**
Grade 1	✓	✓	✓	✗
Grade 2	✓	✓	✓	(✓)

Grade 3	✖	✖	✖	✓
Grade 4	✖	✖	✖	(✓)

Each-to-each values

The loss values specified in IEC 61753 are also referred to as each-to-each (or random mate) values. Each-to-each means that the loss of a connector to a reference connector is not measured, but rather that for testing purposes, every connector of a lot is connected to every other connector once and the loss of the combination connector/sleeve/connector measured.

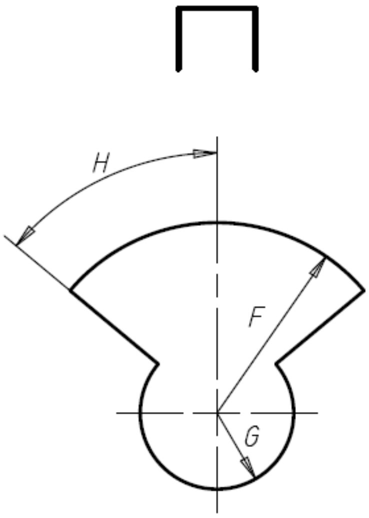
The rational for this model: loss values generated according to the IEC specification for random connector pairs is much closer to actual operating conditions than manufacturer-specified loss values that, in many cases, are based upon a best-case measurement under laboratory conditions. In best-case measurements, the connector is measured against a reference cable. Here, the reference cable is selected so the measurement in the factory results in the lowest possible value (lower than can be achieved later in practice)

Mean values

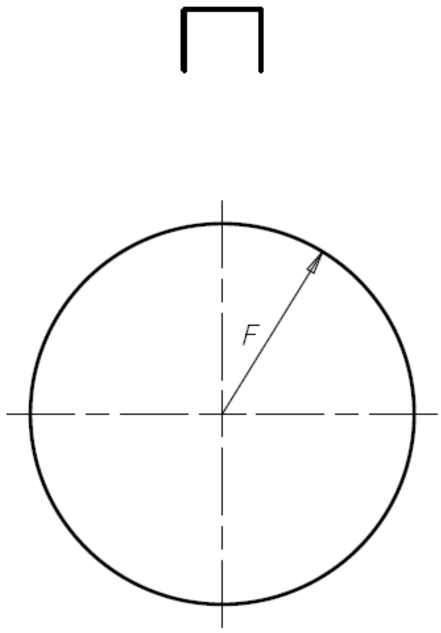
One new development resulting from grades is the call for mean values. This is an optimal basis for the calculation of link attenuation. Particularly in large networks, it was previously necessary to calculate attenuation using the maximum value, which as already noted had low reliability for each-to-each connections. Now the stated mean values can be used for calculation. In this way, every planner can use the proper class to meet existing needs – which guarantees an optimal cost/benefit ratio. Example:

Specification	Each-to-each values	Budget for 10 connections
0.1 dB connector	approx. 0.2 dB (possibly higher if different manufacturers are combined or unadjusted connectors are used)	approx. 2 dB, unclear range of tolerance
Grade C	Mean ≤0.25 dB, Max ≤0.50 dB	≤2.5 dB
Grade B	Mean ≤0.12 dB, Max ≤0.25 dB	≤1.2 dB
Grade A*	Mean ≤0.07 dB, Max ≤0.12 dB	≤0.70 dB

The causes of loss are known to the IEC standardisation committees. For this reason they defined the parameters H, F, and G presented below:



Grades B and C



Grade D

IEC 61755-3-1 (PC connector, 2.5 mm ferrule)							
	Grade B		Grade C		Grade D		
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Remarks
H:	0	50	0	50	0 (⇒NA)	0 (⇒NA)	Degrees
F:	0	0.0012	0	0.0015	0	0.0016	Radius, mm
G:	0	0.0003	0	0.0003	0 (⇒NA)	0 (⇒NA)	Radius, mm
IEC 61755-3-2 (APC connector, 2.5 mm ferrule)							
	Grade B		Grade C		Grade D		
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Remarks
H:	0	50	0	50	NA	NA	Degrees
F:	0	0.0010	0	0.0014	0	0.0015	Radius, mm
G:	0	0.0003	0	0.0003	NA	NA	Radius, mm

Geometric parameters for fibre-optic connectors according to IEC 61755-3-1 and 61755-3-2.

Manufacturer specifications and real usage conditions

An example from real life demonstrates why the use of grades is so important: A network operator uses patch cable with an insertion loss specified by the manufacturer of 0.1 dB. During measurements on the ground, the patch cables "suddenly" exhibit values between 0.2 and 0.3 dB. Where do these serious discrepancies originate that often occur in practice?

The manufacturer had determined the value found in the product specification in a best-case environment. For this, particularly low-loss reference or master cables are used to achieve the lowest possible value during insertion loss measurement. However, if the patch cables are connected each-to-each, this value can no longer be reproduced; it lies significantly above the best-case measurement result.

This unrealistic – but unfortunately still common – measurement method has consequences: Unaware of the precise measurement conditions for manufacturer's specifications, network planners often purchase expensive and over-specified products only to then discover to their surprise that the calculated insertion loss budget cannot be met. Delays in initial start-up and expensive replacement purchases are unavoidable.

The network operator in the example above would have done better with patch cables according to IEC 61753 Grade A*. Then he could have counted on a maximum insertion loss of 0.15 dB.

It is important to use connectors with the IEC 61753 grades and additionally that manufacturers use an in-factory worst-case quality check.

In this context, it is important to note the following: The installation of fibre-optics and the handling of connectors in daily practice require special expertise and a great deal of training. It is therefore recommended to consider the appropriate certification of the specialist firm or personnel.

10.5 Splicing of fibres

Two technologies are common for splicing fibre to fibre: fusion and mechanical.

10.5.1 Fusion splicing

Fusion splicing requires the creation of an electric arc between two electrodes. The two cleaved fibres are brought together in the arc, so that both ends melt together.

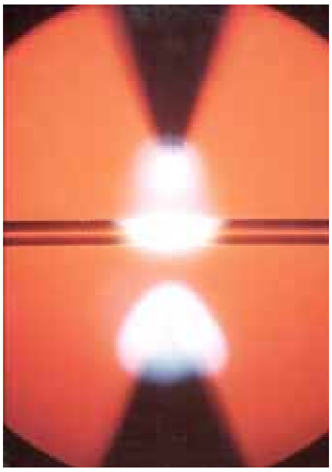


Figure 95: Fusion arc in.

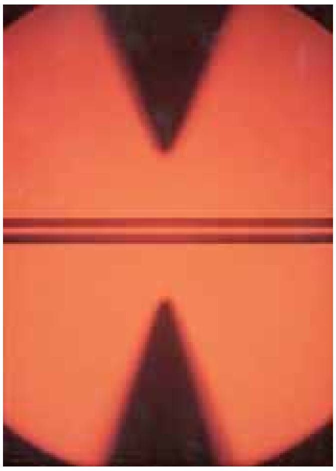


Figure 96: Splice complete.

The optical losses of the splice can vary from splicer to splicer, depending on the alignment mechanism. Splicing machines with core alignment match up the light-guiding channel of the fibre (9µm core) one to the other. These machines produce splices with losses typically <0.05dB.

Figure 97: Fusion splice machines.

Some splice machines (smaller handheld versions for example) align the cladding (125 µm) of a fibre instead of the cores that transport the light. This is a cheaper technology, but can cause more error because of the larger dimensional tolerances of the cladding. Typical insertion loss values for these splice machines are better than 0.1dB.

10.5.2 Mechanical splicing

Mechanical splicing is based on the mechanical alignment of two cleaved fibre ends so that light is coupled from one fibre into the other. This also applies to terminating fibres onto connectors. To facilitate the light coupling between the fibres, an index matching gel is often used. Different manufacturers have various tooling to terminate the fibres in the mechanical splice.

Mechanical splices can be angle cleaved or non angle cleaved, but the angled cleave has higher return loss. The insertion loss of a mechanical splice is typically <0.5 dB.

Figure 98: Mechanical splicers.

10.6 Street cabinets

Street cabinets are metal or plastic enclosures, which serve as a distribution/access point between the distribution fibre and the drop fibre to the subscriber. They are usually placed for relatively easy and rapid access to fibre circuits, and can handle larger capacities than fibre joint closures. Access/distribution points often serve from 24 to 96 subscribers, whilst compact pedestal types of cabinet typically serve from 1 to 24 subscribers.

Cabinets can also be used as above-ground access points for fibre closures. Where these are mounted inside the street cabinet, an easy-to-remove solution is required to allow clean and efficient access when required.

Street cabinets are often used to store PON splitters, which also require flexible connectivity to customer-dedicated fibres. Street cabinets are also used in point-to-point network architectures.

Figure 99: Typical street cabinet.

Figure 100: Pre-stubbed and terminated cabinet.

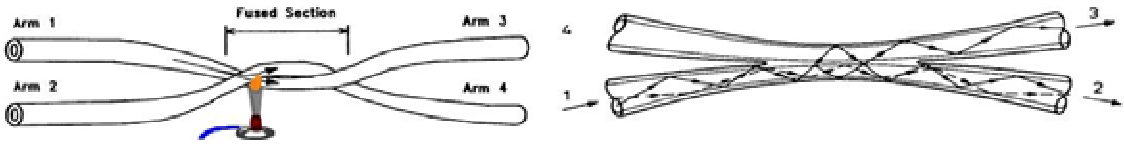
An important factor in the roll-out of new networks is speed. Cabinets are now being provided pre-stubbed and terminated. These cabinets are assembled in the factory and tested prior to delivery. They have a cable stub that is run back to the next closure, and offer a patch panel for simple plug-and-play connectivity. This provides faster installation, and reduces the incidence of installation faults.

Pre-stubbed and terminated cabinets can be combined with plug-and-play PON splitters, which can be installed as and when required without the need for further field splicing.

10.7 Optical splitters

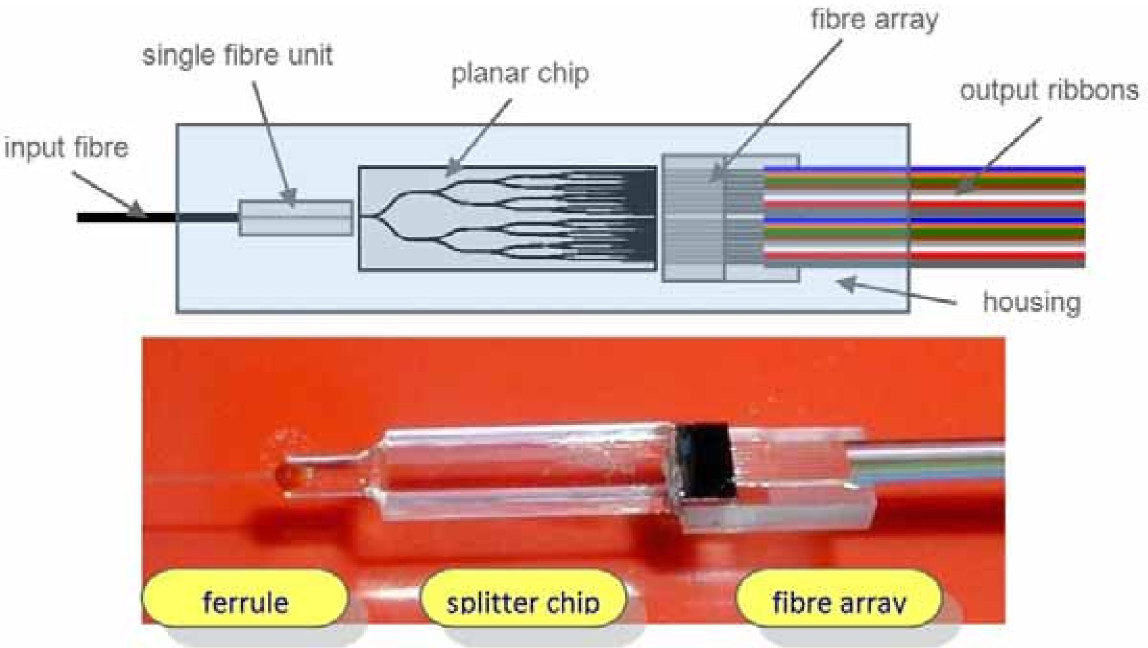
Two technologies are common in the world of passive splitters: fused biconic taper and planar waveguide splitters.

10.7.1 Fused biconic taper



- FBT splitters are made by fusing two wrapped fibres.
- Well known production process.
- Proven technology for OSP environments.
- Monolithic devices are available up to 1x4 split ratio.
- Split ratios greater than 1x4 are built by cascading 1x2, 1x3 or 1x4 splitters.
- Split ratios from 1x2 up to 1x32 and higher (dual input possible as well).
- Higher split ratios have typically higher IL (Insertion Loss) and lower uniformity compared to planar technology.

10.7.2 Planar splitter



- optical paths are buried inside the silica chip
- exist from 1x4 to 1x32 split ratios and higher become available, dual input possible as well
- only symmetrical splitters available as standard devices
- compact compared to FBT at higher split ratios (no cascading)
- better insertion loss and uniformity at higher wavelengths compared to FBT over all bands
- better for longer wavelength, broader spectrum

11 Operations and Maintenance

This section provides a brief overview of the planning, operational and maintenance aspects of an FTTH network infrastructure. While each FTTH network design will differ and operate in different environments and conditions, the planning, operation and maintenance remains a common requirement.

During network construction, the builder will need to ensure minimum disruption to the general public and surrounding environment. This will most likely be a requirement through a contract to ensure that installation and build processes cause little or no disturbance within the FTTH area. This can only be achieved by careful planning and execution. This will also drive the need for efficient build methods to be deployed that will ultimately benefit the FTTH business case. Poor planning will have the opposite effect and potentially lead to poor network performance and a failing build programme.

Whilst fibre is a reliable medium whose reliability has been proven in service over tens of years, it is still vulnerable to unexpected breakdown that will require mobilisation and rapid and efficient repair. During such times immediate access to the networks records by those tasked with repair is essential. It is vital from the onset of the network build that records and documentation are collated and centralised to support all subsequent network analysis.

Maintenance procedures must be planned in advance and contractual arrangement put in place to ensure the appropriate manpower is on hand when needed.

11.1 Network planning guidelines

11.1.1 Site control and installation operation planning

Work with underground duct systems or installations on sideways or poles, will require careful planning and in many cases cause disruption to traffic. Liaison with local authorities will be required and suitable controls must be put in place. The following sections briefly list the main installation considerations that need to be taken into account when embarking upon a duct type installation.

11.1.2 General management considerations

Familiarity and experience working with underground or aerial duct and cable systems, practices and working operations is essential.

Careful planning of the installation will lead to an efficient and safe operation. Liaison with the local authorities prior to installation is recommended, where appropriate.

A full appreciation of nearby utility services must be obtained both from the local authorities and by on site confirmation using suitable detection equipment.

11.1.3 Safety

Proper safety zones using marker cones and traffic signals should be organised.

Disruption of traffic should be coordinated with local officials.

All manholes and cable chambers should be identified and those intended for access should be tested for flammable and toxic gases before entry.

For confined spaces, full air and oxygen tests should be carried out before entry and forced ventilation provided as necessary. Whilst working underground, all personnel must have continuous monitoring gas warning equipment in operation at all times – flammable, toxic, carbon dioxide and oxygen levels.

In cases where flammable gas is detected, the local Fire Service should be contacted immediately.

All existing electrical cables should be inspected for any possibility of damage and exposed conductors.

11.1.4 Construction, equipment and planning

A full survey of the complete underground duct system or aerial plant should be carried out prior to installation.

Manhole and cable chambers with excess levels of water should be pumped out.

Ducts should be checked for damage and potential obstructions. Rodding of the duct sections using a test mandrel or brush is recommended prior to installation.

Manholes should be checked to ensure suitable space for coiling slack cables, provision of cable supports and space for mounting splice joint closures.

A plan should be established to optimally position the cable payoff, mid-point fleeting and cable take-up/ winching equipment. The same also applies if the cables are to be blown into the duct, which will require a blowing head and compressor equipment.

Allowances for elevation changes should be taken into account accordingly.

Fleeting the cable at mid sections using a “figure of 8” technique can greatly increase the pulled installation section distance using long cable lengths. Preparation is needed to make sure these locations are suitable for cable fleeting.

The duct or inner duct manufacturer should be contacted for established cable installation guidelines.

Ribbed, corrugated ducts and ducts with a low-friction liner are designed to reduce cable/duct friction during installation. Smooth non lined ducts may require a suitable compatible cable lubricant.

Pulling grips are used to attach the pulling rope to the end of the cable. These are often mesh/weave based or mechanically attached to the cable end minimising the diameter and thus space of duct used. A fused swivel device should also be applied between the cable-pulling grip and pulling rope.

The swivels are designed to release any pulling generated torque and thus protect the cable. A mechanical fuse protects the cable from excess pulling forces by breaking a sacrificial shear pin. Pins are available in different tensile values.

A pulling winch with a suitable capacity should be used. These should be fitted with a dynamometer to monitor tension during pulling.

Sheaves, capstans and quadrant blocks should be used to guide the cable under tension from the payoff, to and from the duct entry and to the take-up equipment to ensure that the cable's minimum bend diameter is maintained.

Communication radios, mobile phones or similar should be available at all locations in the operation.

Use of midpoint or assist winches may be recommended in cases where the cable tensile load is approaching its limit and could expedite a longer pull section.

Use of a cable payoff device – a reel or drum trailer – is also recommended.

For aerial applications, appropriate equipment such as bucket trucks should be foreseen. Specific safety instructions for working at height need to be respected. Specific hardware is available for cable and closure fixture.

11.1.5 Cabling considerations

Duct and microduct cabling

Duct installation and maintenance is relatively straightforward. Occasionally cables may be dug up inadvertently; hence maintenance lengths should be available at all times.

Duct and buried cables can have similar constructions, with the latter having more protection from the environment in which it is to be installed.

When calculating the route length, make allowance for jointing: typically 3-5m per joint will suffice.

Space cable spare/slack loops at chamber positions of typically 20m. This will allow for mid-span access joints to be added at a later date.

Minimum bend radii (MBR) and maximum tensile load values for the cables must not be exceeded.

MBR is usually expressed as a multiplier of the cable diameter (e.g. 20xD) and is normally defined as a maximum value for static and dynamic situations

Static MBR is the minimum allowable bend value for the cable in operation, i.e. coiled within a manhole or chamber. The dynamic MBR value is the minimum allowable bend value for the cable under installation pulling conditions.

Pulling load (or pulling tension, N; or force, Kgf) values are normally specified for short and long-term conditions. Short-term load values represent the maximum tension that can be applied to the cable during the installation process and long-term values represent the maximum tension that can be applied to the cable for the lifetime of the cable in service.

In cases where cables are to be installed by blowing, the cable and duct must be compatible for a blowing operation. The cable and duct supplier/s must be contacted for installation guidelines.

Direct buried cable

Installation techniques for burying cables can include trenching, ploughing, directional drilling and thrust boring. Reference should also be made to IEC specification 60794-1-1 Annex C.3.6 *Installation of buried cables*.

Confirm minimum bend radii of cable and maximum pulling tensions for installation and long-term service conditions.

Ensure cable tension is monitored during burial and cable maximum limits are not exceeded.

A full survey of the buried section will ensure an efficient installation operation.

Cross over points with other services and utilities must be identified.

All buried cables must be identified and marked for any future location.

Backfilling must ensure the cables are suitably protected from damage from large rocks e.g. sand. All back filling must be tamped to prevent future ground movement and settlement.

All surfaces must be restored to local standards.

Aerial cable

Reference should be made to IEC specification 60794-1-1 Annex C.3.5 *Installation of aerial optical cables*.

Cables used in aerial installations are different in design to those for underground applications, and are designed to handle wind and snow/ice loads. Requirements may differ according to geographic area, for example, a hurricane region will experience higher winds.

Cables need a defined amount of slack between poles to reduce the cable loading due to its own weight.

On-pole slack needs to be stored for cable access or closure installation.

Sharing of poles between operators or service providers (CATV, electricity, POTS, etc.) is common practice and will require specific organisation as well.

11.2 Operation and maintenance guidelines

Consideration should be given to:

- measurements
- fibre cable and duct records
- marking of key infrastructure items
- complete documentation
- identification of infrastructure elements subject to maintenance operations
- minor maintenance list
- plan for catastrophic network failure from external factors, such as accidental digging of cable or duct
- spare infrastructure items to be kept on hand in case of accident
- location and availability of network records for the above provision of maintenance agreement(s)

12 FTTH Test Guidelines

12.1 Connector care

12.1.1 Why is it important to clean connectors?

One of the first tasks to perform when designing fibre-optic networks is to evaluate the acceptable budget loss in order to create a product that will meet the design requirements. To adequately characterize the budget loss, the following key parameters are generally considered:

- transmitter – launch power, temperature and aging
- fibre connections – connectors and splices
- cable – fibre loss and temperature effects
- receiver – detector sensitivity
- others – safety margin and repairs

When one of the above variables fails to meet specifications, network performance can be affected; in the worst case, the degradation can lead to network failure. Unfortunately, not all variables can be controlled with ease during the deployment of the network or the maintenance stage; however, there exists one component—the connector— that is too-often overlooked, sometimes overused (test jumpers), but which can be controlled using the proper procedure.

CONNECTOR CONTAMINATION IS THE #1 SOURCE OF TROUBLESHOOTING IN OPTICAL NETWORKS

A single particle mated into the core of a fibre can cause significant back reflection (also known as return loss), insertion loss, and equipment damage. Visual inspection is the only way to determine if fibre connectors are truly clean.

By following a simple practice of proactive visual inspection and cleaning, poor optical performance and potential equipment damage can be avoided.

Since many of the contaminants are too small to be seen with the naked eye, it is important that every fibre connector is inspected with a microscope before a connection is made. These fibre inspection scopes are designed to magnify and display the critical portion of the ferrule where the connection will occur.

12.1.2 What are the possible contaminants?

Connector design and production techniques have eliminated most of the difficulties in achieving core alignment and physical contact. However, maintaining a clean connector interface still remains a challenge.

Dirt is everywhere; a typical dust particle just 2–15µm in diameter can significantly affect signal performance and cause permanent damage to the fibre end face. Most field-test failures can be attributed to dirty connectors; the majority are not inspected until they fail, when permanent damage may have already occurred.

If dirt particles get on the core surface the light becomes blocked, creating unacceptable insertion loss and back reflection (return loss). Furthermore, those particles can permanently damage the glass interface, digging into the glass and leaving pits that create further back reflection if mated. Also, large particles of dirt on the cladding layer and/or the ferrule can introduce a physical barrier that prevents physical contact and creates an air gap between the fibres. To further complicate matters, loose particles have a tendency to migrate into the air gap.

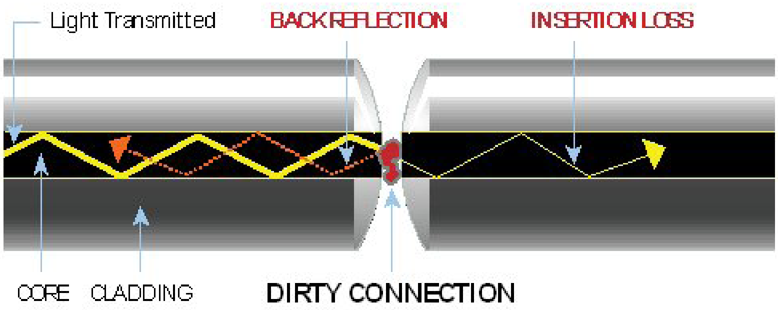


Figure 101: Increased insertion loss and back reflection due to dirty fibre connection.

A 1µm dust particle on a singlemode fibre core can block up to 1% (0.05 dB loss) of the light – imagine what a 9µm dust particle can do. Another important reason for keeping end-faces free of contaminants is the effect of high-intensity light on the connector end-face: some telecommunication components can produce optical signals with a power up to +30dBm (1W), which can have catastrophic results when combined with a dirty or damaged connector end face (e.g. fibre fuse).

Inspection zones are a series of concentric circles that identify areas of interest on the connector end face (see figure). The inner-most zones are more sensitive to contamination than the outer zones.

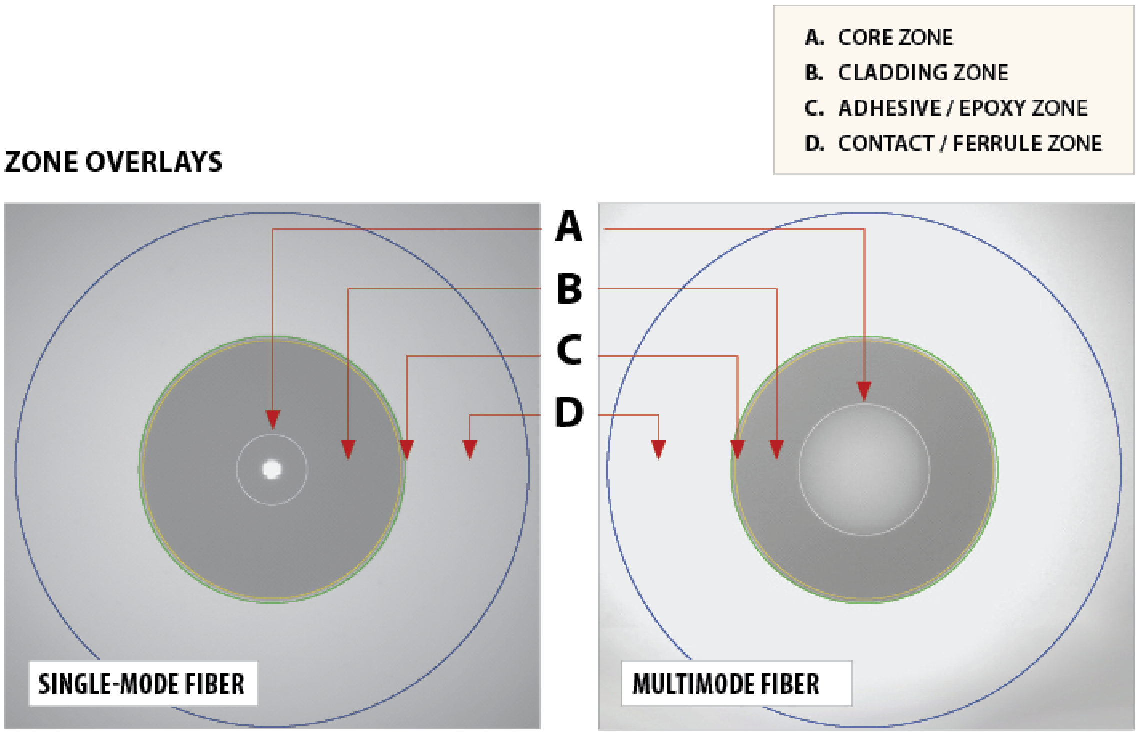


Figure 102: Connector end face inspection zones

Dust, isopropyl alcohol, oil from hands, mineral oils, index matching gel, epoxy resin, oil-based black ink and gypsum are among the contaminants that can affect a connector end-face. These contaminants can occur on their own or in combinations. Note that each contaminant has a different appearance, but regardless of appearance, the most critical areas to inspect are the core and cladding regions—as contamination in these regions can greatly affect the quality of the signal. Figure 3 illustrates the end-face of different connectors that have been inspected with a video-inspection probe.

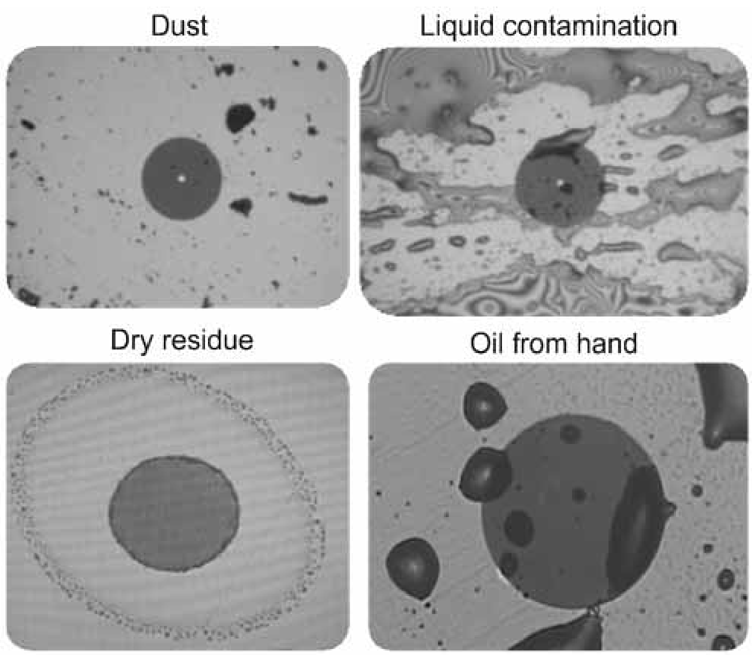


Figure 103: Appearance of various contaminants on a connector end-face.

12.1.3 Where do we need to inspect and clean?

Inspection and cleaning is recommended for the following network components:

- patch panel
- test jumper
- cable connectors

12.1.4 When should a connector be inspected and cleaned?

Connectors should be checked as part of an inspection routine to prevent costly and time consuming fault finding later. These stages include:

- on delivery
- before installation
- before testing

12.1.5 How to check connectors

To inspect the connector end-face properly, the use of a microscope designed for the fibre-optic connector end-face is recommended. There are many types of inspection tools on the market, but they all fall into two main categories: fibre inspection probes (also called video fibrescopes) and optical microscopes. The table below lists the main characteristics of these inspection tools:

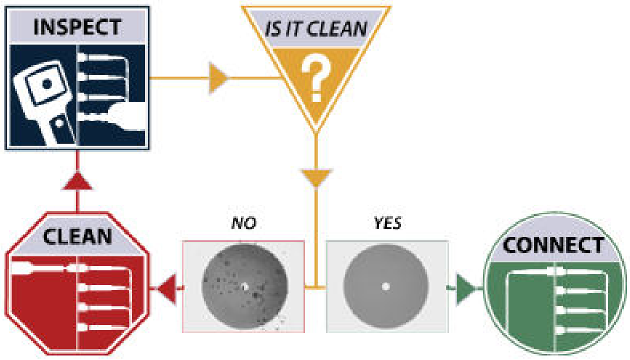
Inspection tool	Main characteristics
Fibre inspection probes/ video fibrescopes	Image display on an external video screen, PC or test instrument. Eye protection from direct contact with a live signal. Image- capture capability for report documentation. Ease of use in crowded patch panels. Ideal for checking patchcords, patch panels, and multi-fibre connectors (e.g. MTP). Different degrees of magnification available (100X/200X/400X). Adapter tips for all connector types available.
Optical microscopes	Safety filter* protects eyes from direct contact with a live fibre. Two different types of microscopes needed: one to inspect patch cords and another to inspect connectors in bulkhead patch panels.

* Never use a direct magnifying device (optical microscope) to inspect live optical fibre.

A fibre inspection probe comes with different tips to match the connector type: angle-polished connectors (APC) or flat-polished connectors (PC, SPC or UPC).

12.1.6 Inspection instructions

Visual Inspection of fibre interconnects is the only way to determine if connectors are clean prior to mating them. A video microscope magnifies an image of a connector end face for viewing on either a laptop or portable display depending on the product used.



INSPECT	• Select the appropriate tip for the connector/adaptor you are inspecting. • Inspect both connector end faces (patchcord/bulkhead/ pluggable interface) using the microscope.

IS IT CLEAN?

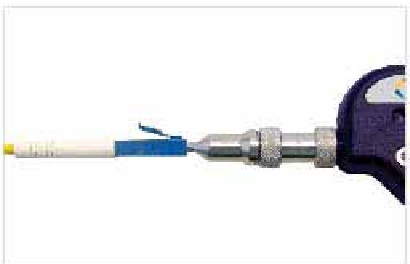
CLEAN	No – upon inspection, if defects are found on the end-face, clean the connector using a designed-for optics cleaning tool.
CONNECT	Yes – if non-removable non-linear features and scratches are within acceptance criteria limits according to operator's thresholds or standards, the fibre interfaces can be connected.

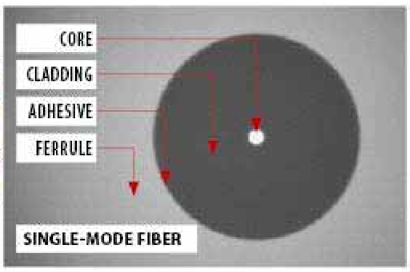
12.1.7 Tools needed for inspection

There are two methods for fibre end-face inspection. If the cable assembly is accessible, you can insert the connector ferrule into the microscope to do an inspection; this is generally known as patchcord inspection. If the connector is within a mating adaptor on the device or patch panel, you can insert a probe microscope into the open end of the adaptor and view the connector inside; this is known as bulkhead or through adaptor connector inspection.

Patchcord inspection

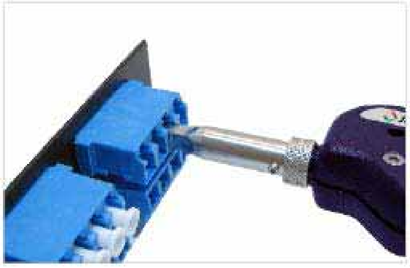
- Select the appropriate tip that corresponds to the connector type under inspection and fit it on to the microscope.
- Insert the connector into the tip and adjust focus to inspect.

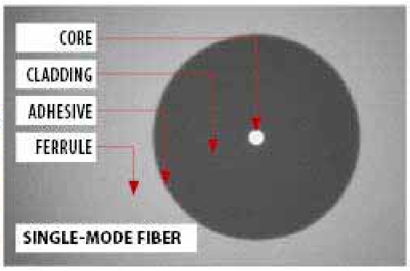




Bulkhead/through adaptor connector inspection

- Select the appropriate tip/probe that corresponds to the connector type under inspection and fit it to the probe microscope.
- Insert the probe into the bulkhead and adjust focus to inspect.





12.1.8 Cleaning wipes and tools

Dry Cleaning

Simple dry cleaning wipes including many types of lint free wipes and other purpose built wipes are available. This category also includes purpose built fibre-optic connector cleaning cassettes and reels, e.g. Cletop cartridges.

WARNING! EXPOSED WIPES CAN EASILY BECOME CONTAMINATED IN THE FIELD.

Cleaning materials must be protected from contamination until just prior to use.

Wipes should be used in the hand or on a soft surface or resilient pad. Use on a hard surface can cause damage to the fibre. Do not use the surface of the wipe that you handled as this can contain finger grease residue.

Figure 104: Examples of dry cleaning wipes and tools for fibre-optic connectors.

Figure 105: Examples of cleaning fluid and wipes.

Damp cleaning

Cleaning fluids or solvents are generally used in combination with wipes to provide a combination of chemical and mechanical action to clean the fibre end-face. Also available are pre-soaked wipes supplied in sealed sachets, e.g. IPA mediswabs. Caution: some cleaning fluids, particularly IPA, can leave a residue that is difficult to remove.

- Cleaning fluid is only effective when used with the mechanical action provided by a wipe.
- The solvent type must be fast drying.
- Do not saturate as this will over-wet the end-face. Lightly moisten the wipe.
- The ferrule must be cleaned immediately with a clean dry wipe.
- Do not to leave solvent on the side walls of the ferrule as this will transfer onto the optical alignment sleeve during connection.
- Wipes must be used in the hand or on a soft surface or resilient pad.
- Use on a hard surface can cause damage to the fibre.

Bulkhead / through adaptor connector cleaning tools

Not all connectors can be readily removed from a bulkhead/through adaptor, and are, therefore, more difficult to access for cleaning. This category includes ferrule interface (or fibre stubs) and physical contact lenses within an optical transceiver, but does not include non-contact lens elements within such devices.

Sticks and bulkhead cleaners are designed to reach into alignment sleeves and other cavities to reach the end face or lens, and aid in removal of debris. These tools make it possible to clean the end face or lens in-situ, within the adaptor or without removing the bulkhead connector. When cleaning transceiver or receptacles care must be taken to identify what is within the port prior to cleaning. Take care when cleaning transceiver flat lenses due to possible damage.

Figure 106: Examples of bulkhead/through adapter cleaning tools.

Recommendations when manipulating fibre-optic cables:

- When testing in a patch panel, only the port corresponding to the fibre under test should be uncapped—protective caps should be replaced immediately after testing.
- Unused caps should be kept in a small plastic bag.
- The life expectancy of a connector is typically rated at 500 matings.
- The test jumpers used in conjunction with the test instruments should be replaced after a maximum of 500 matings (refer to EIA-455-21A).
- If a launch cord is used for OTDR testing, do not use a test jumper in between the OTDR and launch cord or in between the launch cord and the patch panel. Launch cords should be replaced or sent back to manufacturers for re-polishing after 500 matings.
- Unmated connectors should never be allowed to touch any surface, and a connector ferrule should never be touched for any reason other than cleaning.
- Each connector should be cleaned and inspected using a fiberscope or, better yet a videoscope, after cleaning or prior to mating.
- Test equipment connectors should be cleaned and inspected (preferably with a videoscope) every time the instrument is used.

12.2 Qualifying FTTH networks during construction

During network construction, part of testing occurs at the outside-plant level. When laying down fibre, new splices must be made, and therefore splicing qualification is performed using an OTDR. For accurate measurements, bidirectional OTDR measurements should be performed.

For acceptance testing, it is important to test each segment of the construction. There are several methods of testing —some of which are presented here – and each has specific advantages and disadvantages. You should select the most appropriate method, depending on the constraints you are facing: labour costs, loss budget, testing time combined with service activation time, maximum acceptable measurement uncertainty, and so on.

Another factor that needs taking into account when determining how much testing is necessary is the skill level of your technicians. Do not make the mistake of trying to use technicians that lack fibre-optic skills. Mistakes made during construction are extremely expensive to rectify both before and after service is added, resulting in a huge increase of your cost per-customer-passed. When it comes to testing during the construction phase, there should be no shortcuts.

12.2.1 Method #1: Use of optical loss test sets

This first method involves using an optical loss test set (OLTS), comprising two test sets that share data to measure insertion loss (IL) and optical return loss (ORL). First, the two units should be referenced prior to measuring IL.

Figure 107: Test sets should be referenced prior to measurement.

Next, ORL sensitivity is set by calibrating the minimum ORL that the units can measure. The limitation comes from the weakest part of the test setup, which is most likely to be the connector between the units and reference test jumper. Follow the manufacturer's instructions to set the ORL sensitivity on both units, and to reference the source and the power meter.

Now you are ready to perform measurements on the end-to-end network or any individual installed segment, such as the fibres between the FCP and the drop terminal. The purpose of the test is to identify whether there are any transposed fibres, and measure the IL and ORL to make sure that the loss budget has been met.

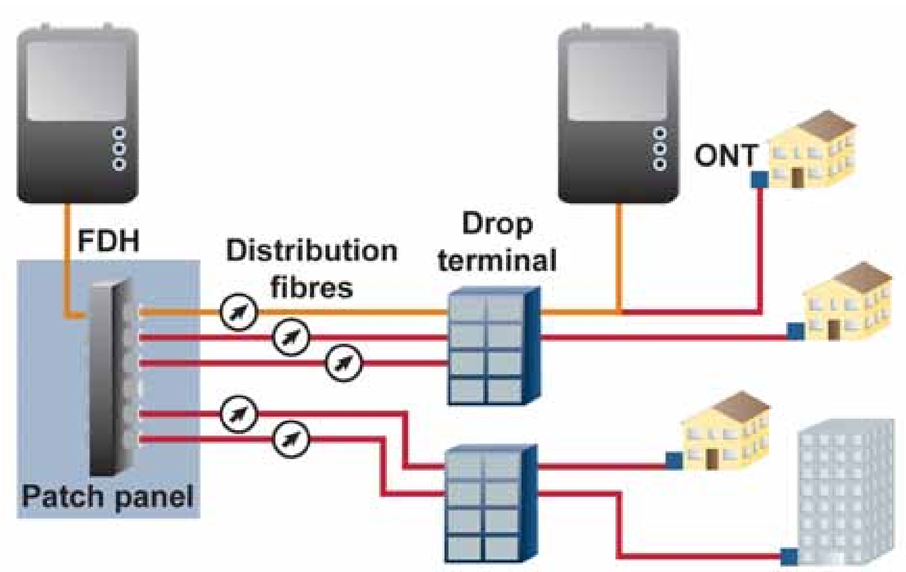


Figure 108: Measuring distribution fibre IL and ORL using a pair of OLTS.

Results table for IL and ORL (Pr = premises, CO = central office):

Fibre	λ (nm)	Loss (Pr→ CO)	Loss (CO → Pr)	Average	ORL (Pr → CO)	ORL (CO → Pr)
001	1310					
	1490					
	1550					
002	1310					
	1490					
	1550					

The following table illustrates the expected ORL values for the network:

Length (metres)	1310nm (dB)	1490nm (dB)	1550nm (dB)
50	53	56	57
300	46	50	50
500	44	47	48
1000	41	45	46

These values only take two connections into account. In FTTH networks there are often multiple connection points and, with reflectance values being very sensitive to dust and scratches, these values can easily be blown away by bad connections. For example a single connector may generate an ORL of 40dB, which would exceed the expected value for the entire network. For point-to-multipoint network, the ORL contribution of each fibre is attenuated by 30 to 32 dB because of the splitter's bidirectional loss.

Advantage of Method #1: OLTS	Disadvantages of Method #1: OLTS
Accurate IL and ORL measurement	Two technicians required (however with point-to-multipoint network, a single OLTS close to the OLT can be used for all customers within the same network)
Bidirectional IL and ORL values	Communication required between technicians (when switching fibres)
Possibility to test every distribution fibre	With point-to-multipoint network, one technician needs to move from drop terminal to drop terminal
Macrobend identification during testing is performed at 1550 and 1310 nm or at another combination of wavelengths involving the 1625 nm wavelength	In case of a cut fibre or macrobend, an OTDR is required to locate the fault
Transposed fibre identification on point-to point networks	Impossible to detect transposed fibre on point-to-multipoint network
Fast testing	

12.2.2 Method #2: Use of an OTDR

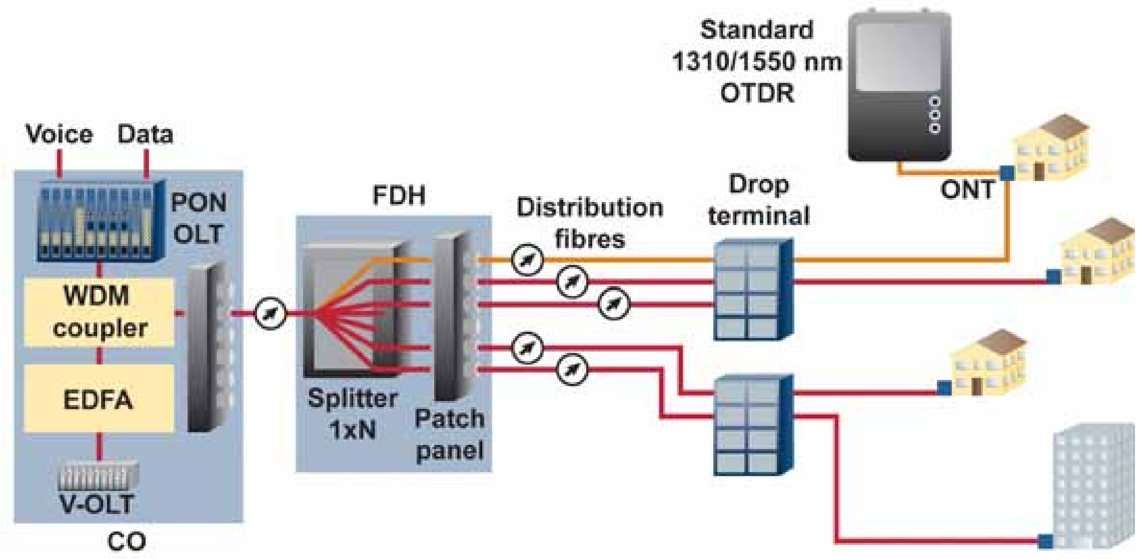


Figure 109: Measurement with an OTDR.

This method uses an optical time-domain reflectometer (OTDR). Unlike an OLTS, the OTDR can identify and locate the position of each component in the network. The OTDR will reveal splice loss, connector loss and reflectance, and the total end-to end loss and ORL.

All fibres between the OLT and before the first splitter (transport side) may be tested to characterize the loss of each splice and find macrobends. The test could be done in both directions. Post-processing of the results will be required to calculate the real loss of each splice (averaged between each direction).

The engineer can measure the loss of the splitter and the cumulative link loss, as well as identifying whether any unexpected physical event has occurred before, or after, the splitter. Construction testing can significantly reduce the number of problems that occur after customer activation by certifying end-to-end link integrity.

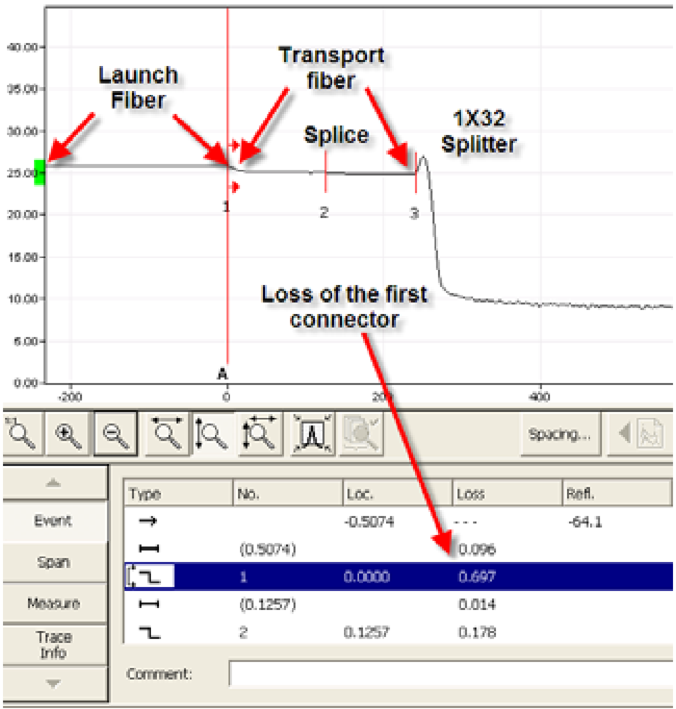


Figure 110: Using a launch fibre makes it possible to characterize the first connector on any segment of your network. A pulse width of 300-500m will be sufficient for this test.

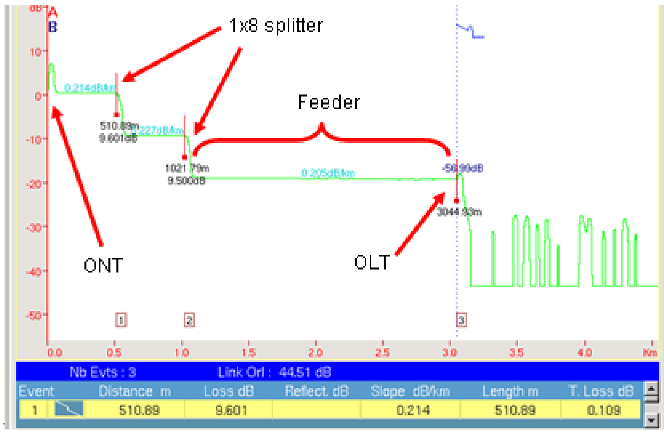


Figure 111: PON optimised OTDR test from the ONT to the OLT.

Advantages of Method #2: OTDR	Disadvantages of Method #2: OTDR
Measures both IL and ORL values.	When testing after the splitter on the ONT side, the ORL is not measured in the right direction (opposite from the video signal).
Possible to test every distribution fibre.	The technician needs to move from drop terminal to drop terminal.
Macrobend identification during testing is performed at 1550 and 1310nm or at another combination of wavelengths involving the 1625nm wavelength.	It requires a skilled technician to interpret the trace.
In case of a cut fibre or macrobend, the fault can be located.	

Only one technician required.	
Fast testing	

Service activation

The service-activation phase may seem very straightforward at first glance, but this task should not be taken lightly because this is the moment at which the customer experience begins. The service-activation scheme can be different, depending on topology of the fibre network. There is also a trend towards pre-engineered plug-and-play components with multiple connection points, rather than an all-spliced approach, particularly for deployments in MDUs.

Another thing to keep in mind is that FTTH networks are point-to-multipoint networks linking one location to multiple end-users, in contrast with legacy fibre networks, where a fibre typically links one location to another.

In terms of data storage, PON service activation brings about two new dimensions:

- Results should be linked to customers or ONUs instead of fibres.
- More than one test location may be required, typically two or three.

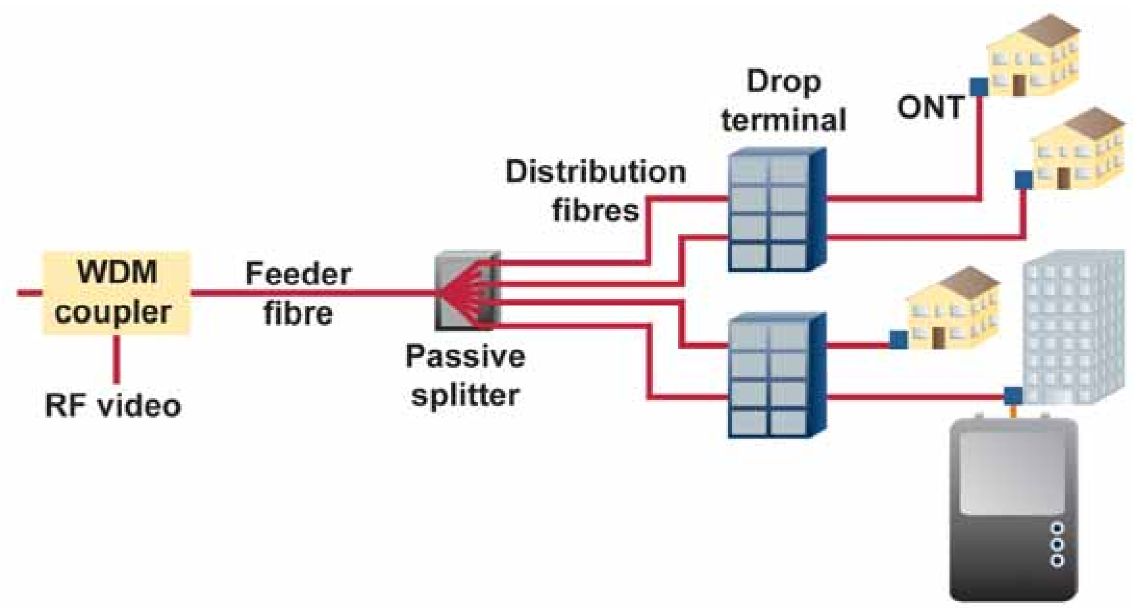
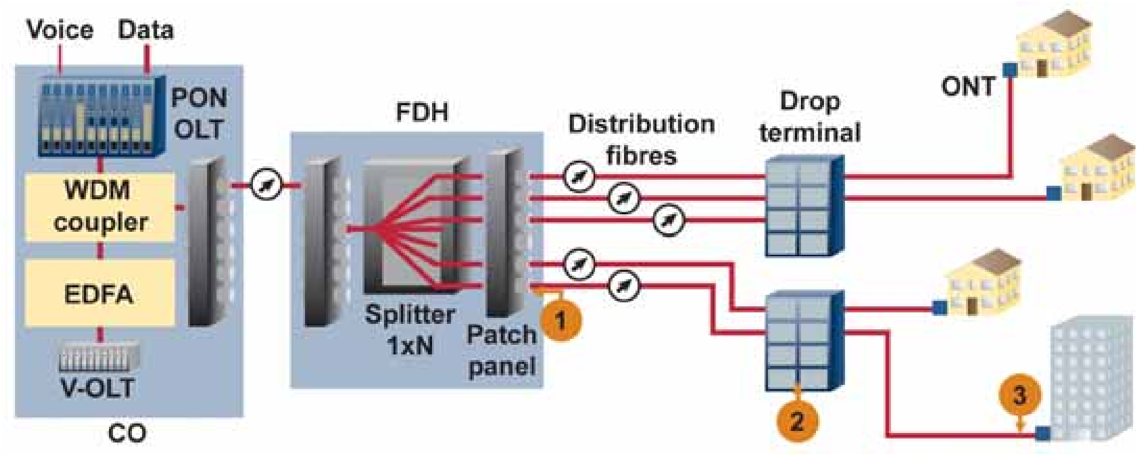


Figure 112: Activation testing using a PON power meter.

Since the service-activation phase is often performed by subcontractors, reporting and data authenticity protection are important, especially in PON deployments where hundreds of results may be generated for a single PON activation. Following the right steps in daily activity ensures a smooth workflow and high productivity.

Multiple testing locations

Verifying optical levels at various locations along the same fibre path helps test engineers pinpoint problems and/or defective components before activating a customer's service. Since FTTH network problems are often caused by dirty or damaged connectors, component inspection greatly reduces the need for troubleshooting, as power levels are verified for each network section. It is also highly recommended to inspect each connection point using a fibre inspection probe before each power measurement.



Testing points

1. By performing a power-level certification at the splitter—more specifically at the output—users can verify if the splitter branch is working properly. This simple assessment makes it possible to confirm that all network components from the CO (including the feeder fibre, F1) to the splitter output are in good condition. Typically, the FDH includes SC/APC or LC/APC connectors but may also include fusion splices.

2. By performing a power-level certification at the drop terminal, engineers can characterize the distribution fibre and the drop terminal ports. Usually, a splice tray is included within the drop terminal, which can cause macrobend problems.

3. The fibre connecting the drop terminal to the customer premises is generally installed during service activation. To ensure reliable services to the customer, the network and the customer ONU must meet their specifications. The best way to guarantee this is to perform a pass-through connection to fully characterize all operating wavelengths (upstream and downstream) in the PON. The only way to achieve this at the service-activation phase is to use a dual-port PON power meter with a pass-through connection; a normal power meter can only certify downstream signals from the CO.

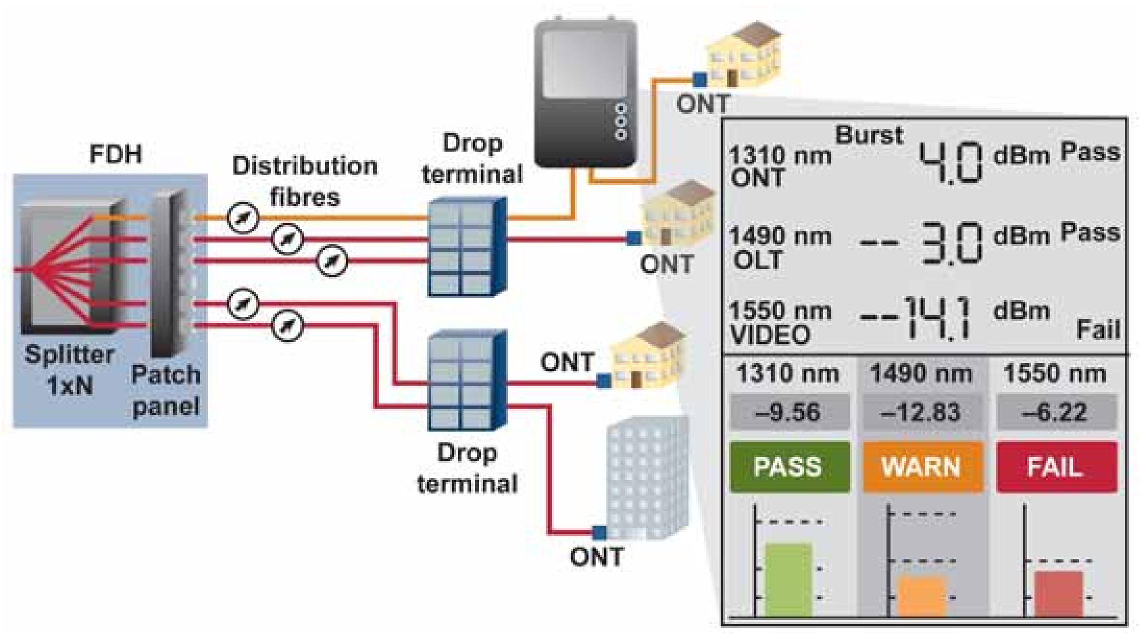


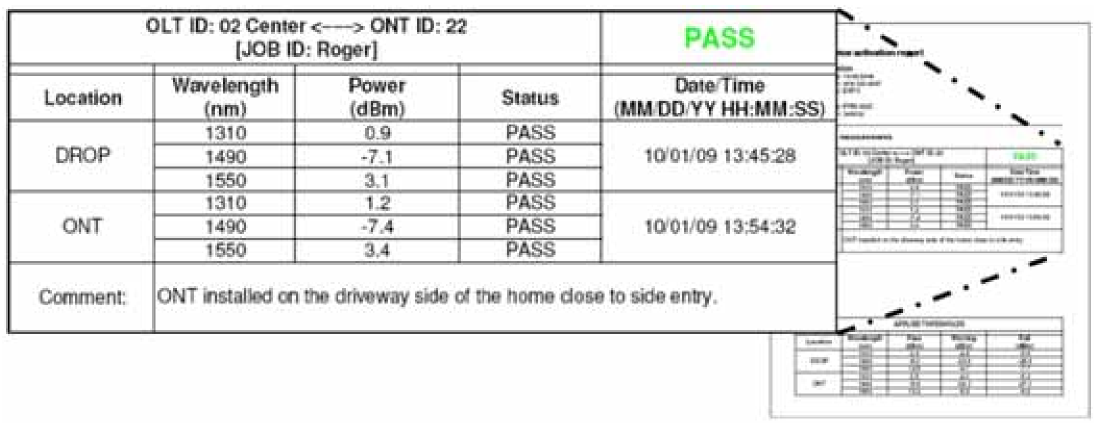
Figure 113: Pass-through testing of all wavelengths.

12.3 Service activation reporting

Back at the office, engineers will have to generate reports to keep track of test results from the service activation phase. These results can be used later to pinpoint problems such as power degradation. Operators dealing with subcontractors may also use this information to keep track of customers being activated.

A service activation report will typically include:

- customer name and/or phone number
- power level for each wavelength and each location
- time stamp for each measurement
- pass/warning/fail status compliant to standards such BPON, GPON or EPON
- thresholds used to perform the pass/warning/fail assessment



OLT ID: 02 Center <---> ONT ID: 22 [JOB ID: Roger]				PASS
Location	Wavelength (nm)	Power (dBm)	Status	Date/Time (MM/DD/YY HH:MM:SS)
DROP	1310	0.9	PASS	10/01/09 13:45:28
	1490	-7.1	PASS	
	1550	3.1	PASS	
ONT	1310	1.2	PASS	10/01/09 13:54:32
	1490	-7.4	PASS	
	1550	3.4	PASS	
Comment:	ONT installed on the driveway side of the home close to side entry.			

Figure 114: Service activation report.

Once the service activation report has been received from the installer, the operator can activate and validate the services.

13 FTTH Network Troubleshooting

Troubleshooting on an out-of-service network (i.e. on a point-to-point network or when the entire PON network is down) can be carried out easily with a power meter or OTDR.

On a live PON network, a PON power meter must be used to investigate when signals are out of tolerance. To pinpoint any fibre breaks, macro-bending, faulty splices or connectors, an OTDR with a live testing port must be used from the customer's location.

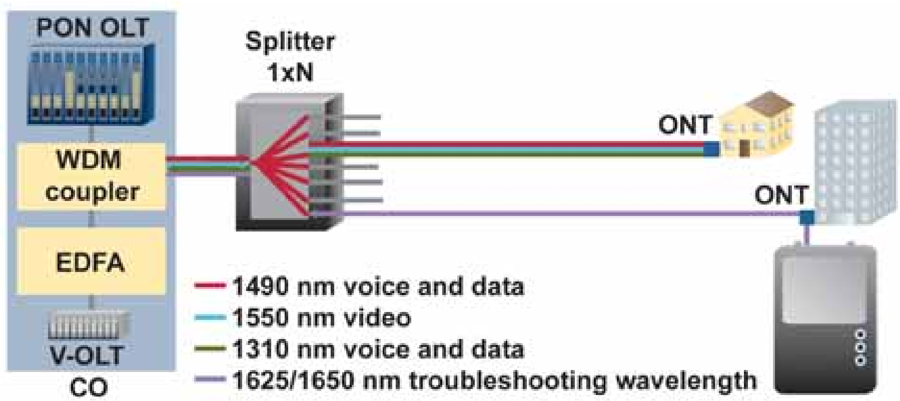


Figure 115: PON network troubleshooting

The test engineer will connect an OTDR at the output of the drop cable and perform an upstream test using a short pulse width (i.e. 3/5ns). Due to the high loss observed at the splitter location and the relatively low measurement dynamic range provided by a short pulse, the end of the fibre link will be identified at the splitter location.

Make sure the fibre length corresponds to the length in between the drop cable output and the splitter location. If not, it indicates that a problem (break or macrobend) is present at this location.

If the length measurement is correct, check that every splice point doesn't exceed the normal splice values. Any point exhibiting an excessive loss value will indicate the presence of a macrobend, kink on the fibre or a bad splice.

The fibre is terminated at the home by an ONU that provides interfaces to serve analogue and digital video over coaxial cable; video, VoIP, or data over Ethernet; and phone service over twisted pair wiring. Service providers may wish to provide digital video through quadrature amplitude modulation (QAM) or IPTV or a combination.

For the premises architecture that uses both QAM for broadcast video and IPTV for on-demand, the IPTV video shares the coaxial cable with the QAM digital video and is typically delivered using the Multimedia over Coax Alliance (MoCA) standard. The HPNAv3 protocol can also be used to deliver IPTV and data since it can run on existing twisted pair telephone lines or coaxial cable.

13.1 In-home wiring issues

In addition to loss, latency, and jitter emanating from the fibre network, a number of in-home issues, including phone line problems, Ethernet wiring mis-configuration or faulty termination, poor coaxial cabling integrity, and noise impairments, can combine to degrade the customers' quality of experience.

Phone line issues

Phone lines (twisted pair) in the premises often carry both voice service and data services using HomePNA (HPNA) standards. The ONU emulates the POTS network by providing all of the battery voltages, ring tones, and dial tones that were provided by the central office in the past. Consequently, troubleshooting VoIP carried over the phone wiring is very similar to troubleshooting POTS.

Common errors affecting in-home wiring installations include:

- opens
- shorts
- crossed wires
- broken wires

Identifying Ethernet wiring issues

Many homes are now pre-wired with twisted-pair wiring suitable for Ethernet data services. Verification of proper termination is very important. Between 75% and 85% of the time in-home technicians spend troubleshooting can be attributed to improper terminations. The most common termination faults can be found by a wiring verifier.

Continuity tests include:

- verification of pin-to-pin connections
- ability of the wire to carry a signal
- shields
- voltage on line

This is a basic connectivity test, not a stress test.

Locating and resolving coax problems

Existing coaxial home networks present a variety of challenges. Constructed by the home builder, the owner, or perhaps a previous service provider, the quality and routing of the network is rarely known. A high-quality coaxial installation should provide at least 30dB of noise isolation to the outside world (noise immunity).

However, these networks often contain:

- splitters
- pinches
- breaks
- bad cables
- un-terminated ends
- bad connections
- amplifiers

Any of these may lead to network problems and quality of service issues. Proper grooming of the network to repair or replace portions of the network to meet the triple-play service provider standards is critical to providing reliable services.

13.2 High-speed data over FTTx

To validate data service over an FTTx network the technician must:

- establish connectivity to the ISP
- provision necessary network elements for increased data flow and class of service treatment

To complete the installation process, field personnel must verify physical layer performance, ISP connectivity and data throughout. Technicians should use a test instrument in IP ping mode to verify the routing connectivity across the network to an IP host or server, while assessing packet-loss rates and packet delay to and from the ping destination.

The instrument should check the IP layer by verifying whether another host device is alive and able to echo back; use a flood mode to gauge network congestion; and determine the minimum, maximum, and average packet delay time of IP packets.

Tracking packet delay and loss helps determine whether delays and slow service are due to service provider error or CPE problems. Since users can only reach the ISP end of the service with the correct username, password and encapsulation, test tools must support the appropriate IP encapsulations and authentication protocols.

FTP throughput testing with selectable file sizes in both upload and download direction can be used to establish the performance of the link in a way that more closely matches actual usage than a simple download test. HTTP testing must also be completed to ensure the end-users' ISP access/connectivity is working properly.

IPTV

Video service quality is ultimately determined by the end-user or subscriber. The quality of experience is a subjective concept with components that are nearly impossible to measure in a practical, operational manner. However, a service provider needs to make objective measurements on a set of parameters that can be used to judge the performance of the network.

A model for mapping objective measurements to quality of experience is the basis for good installation and troubleshooting procedures. Mapping of objective measures of quality for video services— video quality of service parameters—cannot be made in a one-to-one, direct correlation manner, nor can all subjective issues be measured directly. This is true especially of certain video artefacts which may be present in the video payload.

In order to help with this correlation and add structure to measurement approaches, quality in this context can be organized into a logical model:

- content quality – the actual video and audio payload
- video stream quality – the video transport stream packet flows
- transport quality – the IP packet flows
- transactional quality – the interaction between the user and the service

VoIP

Prior to completing service turn-up, field technicians must verify connectivity to signalling gateways, service provisioning, and call quality. Terminal adapters or VoIP phones are installed and applications are tested in this phase. Field technicians rely heavily on handheld testing devices to troubleshoot problems. Terminal adapters or IP phones are set up and plugged in to the LAN and their IP addresses are provisioned. Handheld test sets are normally used because they can assume unique aliases to mimic an end device on the network.

Handheld test sets can also be plugged in at any point in the network to help isolate problems. For instance, a handheld device can be used to determine if a specific end device's alias has been provisioned correctly. It can help identify errors in provisioning network equipment during installation. It can also be used to verify the installation of specific equipment in the VoIP network.

Voice quality issues are resolved at this stage. The technician must place and receive calls through the network to ensure that the link is properly provisioned with the correct signalling protocol. Calls should be placed within the VoIP cloud and from the VoIP cloud to the PSTN. Local and long distance calls should be placed to multiple exchanges. Case-by-case trouble shooting is used to resolve any issues before service turn-over. By confirming that all of the possible calls can be placed, a technician can confidently connect the CPE knowing that any signalling issues will not be within the carrier's cloud.

Another important practice is to capture all test records gathered at this phase for baseline/SLA reference and for use during future troubleshooting calls.

13.3 Summary of optical testing tools

The following is a list of optical testing tools used for FTTH networks:

Test Equipment	Function	Use
Inspection scope	Visual inspection of connectors	Fibre link construction and troubleshooting
VFL (visual fault locator	Continuity check up to 5km, break/bend visual identifier for fibre along patch panel/hub areas	Fibre link construction and troubleshooting at locations where fibres are accessible
Optical talk set	Enables communication between engineers using cable link	When two engineers are required for end to end test
Light source/ power meter or bidirectional loss test set	Measures the fibre link insertion loss, tests continuity	Fibre link construction, acceptance testing and troubleshooting
Power meter only	Measure the power output of equipments	Equipment and fibre link turn up and troubleshooting
Power meter with clip-on device	Estimates the optical power in the link	Equipment and fibre trouble-shooting at any location where fibres are accessible, even when connectors cannot be accessed
Clip-on fibre identifier	Identify traffic and traffic direction on fibre, may also estimate output power along the link	Equipment and fibre trouble-shooting at any location where fibres are accessible, even when connectors cannot be accessed
1310/1490/1550 selective power meter with through mode	Measures the power levels of equipment and fibre link when OLT/ONT connected	Fibre link and equipment (ONT/OLT) turn-up and troubleshooting
ORL meter	Measure the overall optical return loss	Fibre link construction and troubleshooting
OTDR	Measures all the characteristics of the fibre link	Fibre link construction, acceptance, troubleshooting

Appendix A: IEC Standards

Overview of optical fibre and cable-related International Electrotechnical Commission (IEC) international standards for the access network:

IEC 60793-1-1 Ed. 2	Optical fibres - Part 1-1: Measurement methods and test procedures: General and guidance
IEC 60793-2 Ed 5	Optical fibres – Part 2: Product specifications – General
IEC 60794-1-1 Ed2*	Optical fibre cables – Part 1-1: Generic specification – General
IEC 60794-1-2 Ed2*	Optical fibre cables – Part 1-2: Generic specification – Basic optical cable test procedures
IEC 60794-2-10 Ed 3.0	Optical Fibres – Part 2-10: Product specifications – sectional specification for category A1 multimode fibres
IEC 60794-2-50 ED 2.0	Optical Fibres – Part 2-50: Product specifications – sectional specification for class B single-mode fibres
IEC 60794-2 Ed3*	Optical fibre cables – Part 2: Indoor cables – Sectional specification
IEC 60794-2-10 Ed1*	Optical fibre cables – Part 2-10: Indoor cables – Family specification for simplex and duplex cables
IEC 60794-2-11 Ed1	Optical fibre cables – Part 2-11: Indoor cables – Detailed specification for simplex and duplex cables for use in premises cabling
IEC 60794-2-20 Ed1	Optical fibre cables – Part 2-20: Indoor cables – Family specification for multi-fibre optical distribution cables
IEC 60794-2-21 Ed1	Optical fibre cables – Part 2-21: Indoor cables – Detailed specification for multi-fibre optical distribution cables for use in premises cabling
IEC 60794-2-30 Ed1	Optical fibre cables – Part 2-30: Indoor cables – Family specification for optical fibre ribbon cables
IEC 60794-2-31 Ed1	Optical fibre cables – Part 2-31: Indoor cables – Detailed specification for optical fibre ribbon cables for use in premises cabling
IEC 60794-2-40 Ed1*	Optical fibre cables – Part 2-40: Indoor cables – Family specification for simplex and duplex cables with buffered A4 fibre
IEC 60794-2-40 Corr.1 Ed1*	Corrigendum 1 – Optical fibre cables – Part 2-40: Indoor cables – Family specification for simplex and duplex cables with buffered A4 fibres
IEC/PAS 60794-2-50 Ed1*	Optical fibre cables – Part 2-50: Indoor optical fibre cables – Family specification for simplex and duplex optical fibre cables for use in terminated cable assemblies or for termination with optical fibre passive components
IEC 60794-3 Ed3	Optical fibre cables – Part 3: Sectional specification – Outdoor cables
IEC 60794-3-10 Ed 1*	Optical fibre cables – Part 3-10: Outdoor cables – Family specification for duct and directly buried optical telecommunication cables
IEC 60794-3-12 Ed1	Optical fibre cables – Part 3-12: Outdoor cables – Detailed specification for duct and directly buried optical telecommunication cables for use in premises cabling
IEC 60794-3-20 Ed1*	Optical fibre cables – Part 3-20: Outdoor cables – Family specification for optical self-supporting aerial telecommunication cables

IEC 60794-3-21Ed1	Optical fibre cables – Part 3-21: Outdoor cables – Detailed specification for optical self-supporting aerial telecommunication cables for use in premises cabling
IEC 60794-3-30 Ed1*	Optical fibre cables – Part 3-30: Outdoor cables – Family specification for optical telecommunication cables for lake and river crossings
IEC 60794-4 Ed1	Optical fibre cables – Part 4: Sectional specification – Aerial optical cables along electrical power lines
IEC 60794-5	Optical fibre cables – Part 5: Sectional specification for microduct cabling for installation by blowing
IEC 60794-5-10 (not published yet)	Optical fibre cables – Part 5-10: Family specification for outdoor microduct optical fibre cables, microducts and protected microducts for installation by blowing
IEC 60794-5-20 (not published yet)	Optical fibre cables – Part 5-20: Family specification for outdoor microduct optical fibre cable duct optical fibre units, microducts and protected microducts for installation by blowing

Appendix B: European Standards

Overview of optical fibre connectivity products related European Standards for the access network:

EN 50733-1	Connector sets and interconnect components to be used in optical fibre communication systems – Product specifications – Part 1: General and guidance
EN 50377-2-x	Product specification – Part 2 – FC connectors
EN 50377-4-x	Product specification – Part 4 – SC connectors
EN 50377-7-x	Product specification – Part 7 – LC connectors
EN 50377-8-x	Product specification – Part 8 – LSH connectors
EN 50377-10-x	Product specification – Part 10 – MU connectors
EN 50377-14-x	Product specification – Part 14 – Patchcords
EN 50411-1	Fibre organisers and closures to be used in optical fibre communication systems – Product specifications – Part 1: Fibre organisers
EN 50411-2	Fibre organisers and closures to be used in optical fibre communication systems – Product specifications – Part 2: General and guidance for optical fibre cable joint closures, protected microduct closures, and microduct connectors
EN 50411-2-2	Product specification – Part 2-2: Sealed pan fibre splice closures Type 1, for category S & A
EN 50411-2-3	Product specification – Part 2-3: Sealed inline fibre splice closures Type 1, for category S & A
EN 50411-2-4	Product specification – Part 2-4: Sealed dome fibre splice closures Type 1, for category S & A
EN 50411-2-5	Product specification – Part 2-5: Sealed closures for air blown fibre microduct, type 1, for category S & A
EN 50411-2-8	Product specification – Part 2-8: Microduct connectors, for air blown optical fibres, type 1
EN 50411-3-2 (not published yet)	Product specifications – Part 3-2: Singlemode mechanical fibre splice
EN 50411-3-3 (not published yet)	Product specifications – Part 3-3: Singlemode optical fibre fusion splice protectors

Glossary

ADSS	all-dielectric self-supporting
APC	Angle-polished connector
ATM	Asynchronous Transfer Mode
CATV	cable television
CWDM	Coarse Wavelength Division Multiplexing
DWDM	Dense Wavelength Division Multiplexing
FCP	fibre concentration point
FBT	fused biconic tapered
FDH	fibre distribution hub (another term for FCP)
FTTC	fibre to the curb
FTTB	fibre to the building
FTTH	fibre to the home
FTTN	fibre to the node
FTTx	generic term for all of the fibre-to-the-x above
FWA	fixed wireless access
G.650	ITU Rec.G.650 Definition and testing methods for single mode fibres
G.651.1	ITU Rec. G.651.1 Characteristics of a 50/125 µm multimode graded index optical fibre cable for the access network (G.651 is obsolete)
G.652	ITU Rec. G.652 Characteristics of a single-mode optical fibre and cable
G.655	ITU Rec. G.655 Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable
G.657	ITU Rec. G.657 Characteristics of a bending loss insensitive single-mode optical fibre and cable for the access network
Gbps	Gigabits per second
HDPE	high-density polyethylene
IEEE	Institute for Electrical and Electronics Engineers
IL	insertion loss
ISO	International Organisation for Standardisation
IEC	International Electrotechnical Commission
ITU-T	International Telecommunication Unit – Telecommunications Standards
LAN	Local Area Network
LI	local interface
LSZH	low smoke, zero halogen
Mbps	Megabits per second
MMF	multimode fibre
MDU	main distribution unit
MDU	multi-dwelling unit
ODF	optical distribution frame

OLT	optical line termination
OLTS	optical loss test set
ONU	optical network unit
ONT	optical network termination
OPGW	optical power ground wire
OTDR	optical time domain reflectometer
PE	polyethylene
PMD	polarisation mode dispersion
PON	passive optical network
POP	point of presence
PTP	point-to-point
PVC	polyvinylchloride
RL	return loss
ROW	right of way
SMF	singlemode fibre
STP	shielded twisted pair
UPC	ultra polished connector
UPS	uninterruptible power supply
UTP	unshielded twisted pair
WDM	Wavelength Division Multiplexing
WLAN	wireless LAN (Local Area Network)

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