FTTH Handbook

Edition 6

D&O Committee

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Fibre to the Home Council Europe

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First to Fifth editions

These editions were a joint work of all members of the Deployment & Operations Committee of the FTTH Council Europe.

Sixth edition

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The FTTH Handbook is an initiative of the Deployment & Operations Committee of the FTTH Council Europe. The project was coordinated by **Rong Zhao** and **Michaela Fischer**, FTTH Council Europe.

Foreword

The mission of the FTTH Council Europe is to support the rollout of fibre access networks to homes and businesses. This is achieved in a variety of ways but education, and in particular through our best-practice publications, forms a key part of our work to accelerate the adoption of this critical technology.

The environment for operators, investors and utilities is more challenging than ever and ensuring that the best technology choices and investments are made is essential.

Our Guides are intended as a forum where experiences and approaches can be shared throughout the world where they are accessible by new entrants and alternative operators whose aim is to drive real fibre networks across Europe.

The FTTH Handbook was first published in 2007 and since then has been reworked to update the content and bring clarity to the increasingly complicated choices now available to operators. This sixth edition covers every aspect of the network: from central office through to customer equipment; from passive to active equipment choices.

This Handbook is a resource for you; we welcome feedback and suggestions on how we can further improve the content. Extensive additional resources, case studies, reports and opinion pieces are all available on our website.

The FTTH Council Europe represents fibre, cable, equipment and installation companies throughout Europe and it is the experiences from its 160+ members that ensures this Handbook delivers vendor-neutral information based on best-practice and real-world lessons from the industry.

I would like to extend our gratitude to all those that have contributed to the creation and evolution of this Handbook, and to the Deployment and Operations Committee that has compiled and written this comprehensive and useful document.

Karin Ahl

Karin Ahl, President of the FTTH Council Europe

Contents

1 Introduction

FTTH has been proven to be the shining star of the NGA (Next Generation Access) family, and provides an excellent platform for high or ultra-high speed access technologies. Not only do fixed access networks benefit from FTTH solutions, but advanced wireless networks do as well especially in regard to increased backhaul capacity. In contrast to copper-based solutions, FTTH projects are facing multifarious challenges, involving everything from strategic planning to final operations.

The FTTH Council Europe issues a number of publications focusing on different aspects. The FTTH Handbook introduces FTTH basics, such as architecture, topology and technologies, provides in-depth views into various technical issues, as well as providing much-appreciated technical solutions focusing on planning, deployment and operations.

This is the 6th edition of the Handbook. Every edition grows in complexity and detail as knowledge, experience and successful implementation of deployment by the contributors and members of the Council increase. Collating this knowledge and experiences and detailing the success achieved within the covers of this Handbook, while preserving the impartiality of the Council, is a recurring challenge and requires the dedication of the Deployment and Operations Committee members.

The members of the Deployment and Operations Committee have made significant improvements to almost all the chapters of this edition. These changes are the result of broad and professional experience and provide a clearer structure, more precise definitions, updated methodologies and advanced technical solutions. Furthermore, this edition also contains an additional chapter which addresses one of the most important issues: standardisation. In addition, this Handbook also provides an overview of FTTH standards in different areas and for the first time describes the workflow from Fibre in the Home to support, solving the FTTH deployment bottleneck at the customer-end.

One of the objectives of the Council is to create a professional arena which promotes FTTH based on internationally-accepted standards and which have been adopted and become the common value of the members.

This Handbook can only be used as a reference by our readers if they are willing to submit their views and opinions which the Committee will consider whether to implement into future releases.

This Handbook is the property of all professionals within the FTTH field. The main objective, which the editors are committed to maintaining, is its capacity to develop year after year to the benefit of all parties.

Rong Zhao, Chair Deployment & 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 contains the necessary electronic transmission (active) equipment to provide the applications and services, using optical fibre to the subscriber. Each access node, within a large municipality or region, is connected to a larger metropolitan or urban fibre network.

Access networks may connect some of the following:

- fixed wireless network antenna, for example, wireless LAN or WiMAX
- mobile network base stations
- subscribers in SFUs (single family units) or MDUs (multi-dwelling units)
- larger buildings such as schools, hospitals and businesses
- key security and monitoring structures such as surveillance cameras, security alarms and control devices

The FTTH network may form part of a wider area or access network.

2.1. The FTTH network environment

The deployment of fibre closer to the subscriber may require the fibre infrastructure to be located on public and/or private land and within public and/or private properties.

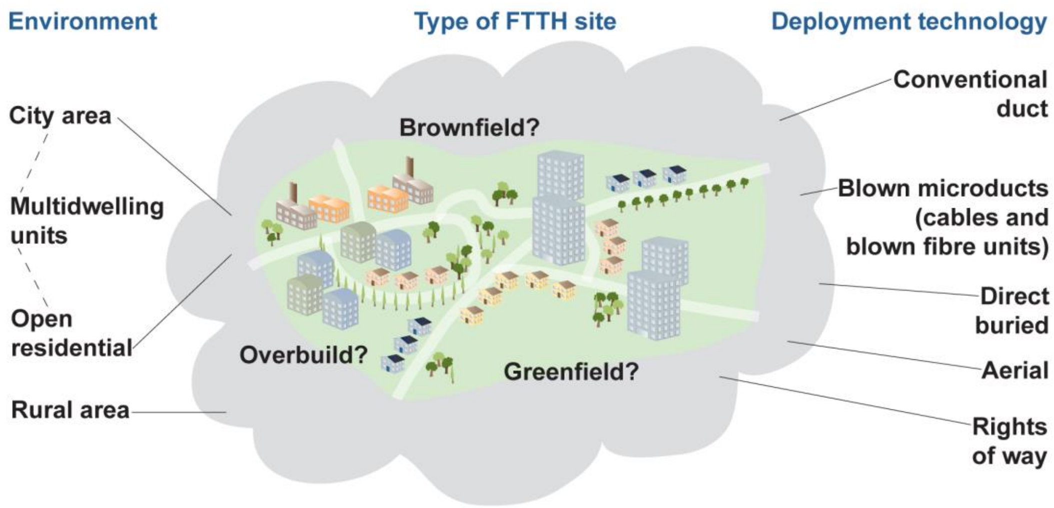


Figure 1: Type of FTTH site

The physical environment can be broadly split into:

- city
- open residential
- rural
- building type and density – single homes or MDUs

Not only does each physical environment constitute different subscriber dwelling densities (per sq km), but country conditions must also be taken into account.

The nature of the 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 installed at the same time as the buildings
- Brownfield – buildings are already in place but the existing infrastructure is of a low standard
- Overbuild – adding to the existing infrastructure

The main influences on the method of infrastructure deployment are:

- type of FTTH site
- size of the FTTH network
- initial cost of the infrastructure deployment (CAPEX)
- running costs for the 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 method and 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 later, include:

- conventional underground duct and cable
- blown micro-ducts and cable
- direct buried cable
- aerial cable
- “other right of way” solutions

Key functional requirements for a FTTH network include:

- provision of high-bandwidth services and content to each subscriber
- a flexible network architecture design with capacity to meet future needs
- direct fibre connection of each end subscriber directly to the active equipment, ensuring maximum available capacity for future service demands
- support for future network upgrades and expansion
- minimal disruption during network deployment, to promote fibre networks gain acceptance by network owners and to provide benefit to FTTH subscribers

When designing and building FTTH networks, it is helpful to understand the challenges and trade-offs facing potential network owners and operators. Some challenges may result in conflicts between functionality and economic demands.

The FTTH network builder must present a profitable business case, balancing capital expenses with operating costs while ensuring revenue generation. A more detailed analysis of the main influences on the business case for FTTH networks is available in the *FTTH Business Guide* from the FTTH Council Europe.

2.2. FTTx Networks Architecture

Variations of the above mentioned basic network architectures are possible depending on the number of fibres, position of splitters (branching points) and aggregation points. Choosing the right network architecture often generates considerable debate especially as there is often no clear winner in today's market as different architectures suit different operator requirements, business and technical priorities.

Fibre to the home (FTTH) – Each subscriber 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 and 100BASE-BX10 or 1000BASE-BX10 transmission for Ethernet technology or GPON (EPON) technology in case of point-to-multipoint topology.

Fibre to the building (FTTB) – each optical termination box in the building (often located in the basement) is connected by a dedicated fibre to a port in the equipment in the POP, or to an optical splitter which uses shared feeder fibre to the POP. The connections between subscribers and the building switch are not fibre but can be copper based and involve 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. This also saves fibres and ports in the POP. The concept of routing fibre directly into the home from the POP or through the use of optical splitters, without involving switches in the building, brings us back to the FTTH scenario.

Fibre to the curb (FTTC) – each switch/or DSL access multiplexer (DSLAM), often found 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 connection. The switches in the street cabinet are not fibre but can be copper based using VDSL2 or VDSL2 Vectoring. This architecture is sometimes called "Active Ethernet" as it requires active network elements in the field.

Fibre to the Distribution Point (FTTDp) – this solution has been proposed in the last two years. Connecting the POP to the Distribution Point via the optical cable and then from the Distribution Point to the customer's premises via existing copper infrastructure. The Distribution Points could be a hand-hole, a drop box on the pole or located in the basement of a building. This architecture could support VDSL or G.Fast technology for a short last mile, normally less than 250m.

This Handbook will, however, concentrate on FTTH/B deployments as in the long term these are considered the target architecture due to their virtually unlimited scalability.

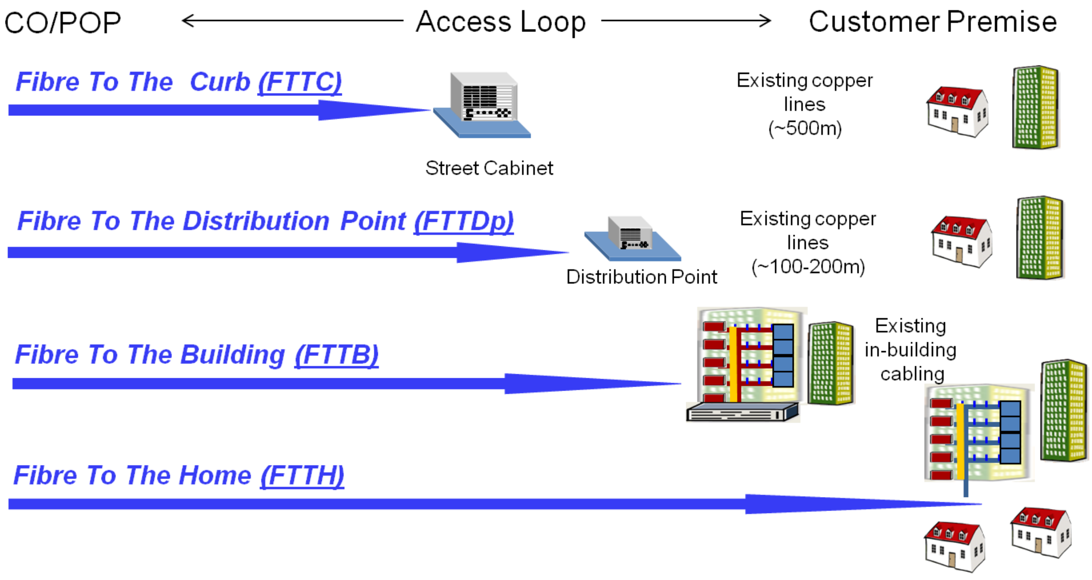


Figure 2: Different types of FTTx networks.

2.3. FTTH Topology and Technology

The network architecture refers to the design of a communication network and provides a framework for the specification of the network from physical components to services. The access network is the piece of the communications network that directly connects to end users.

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) technology, and point-to-point, which typically uses Ethernet transmission technologies.

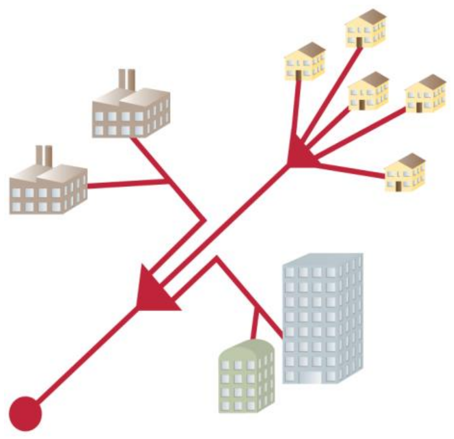


Figure 3: Point to Multi-Point (P2MP)

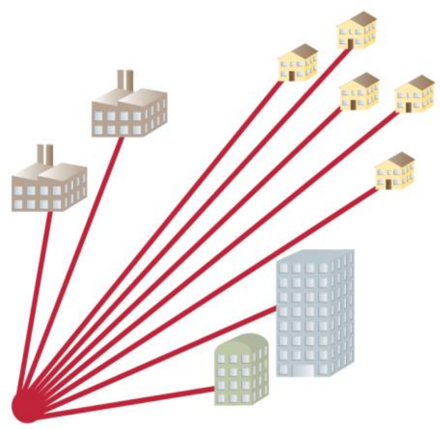


Figure 4: Point to Point (P2P)

Point-to-multipoint topologies (P2MP) provide a single “feeder” fibre from the central office (or POP) to a branching point and from there one individual, dedicated fibre is deployed to the subscriber. A passive optical network technology such as GPON uses passive optical splitters at the branching point(s) and the Data is encoded so that users only receive data intended for them.

Active Ethernet technology can also be used to control subscriber access in a point-to-multipoint topology requiring the placement of Ethernet switches in the field. Each customer has a logical point-to-point connection and the end-user sends and receives only the data intended for them.

Point-to-point topologies (P2P) provide dedicated fibres between the Access Node (or POP) and the subscriber. Each subscriber has a direct connection with a dedicated fibre. The route from the central office (CO) to the customer will probably consist of several sections of fibres joined with splices or connectors, but provides a continuous optical path from the Access Node to the home. Most existing point-to-point FTTH deployments use Ethernet, which 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.

Whatever the network architecture, it is important to consider how the design may affect the evolution of the network in the future. An FTTH network is a long-term investment and the anticipated lifetime of the cable in the ground is at least 25 years, however, the working lifetime will probably be much longer. With the active equipment likely to be upgraded several times in this timeframe, it should be possible to reuse the infrastructure. So decisions made at the start of an FTTH project will have long term consequences.

2.4 Network layers

An FTTH network can comprise of a number of different layers: the passive infrastructure involving ducts, fibres, enclosures and other outside plants; the active network using electrical equipment; the retail services providing internet connectivity and managed services, such as IPTV; and not least, the end users. An additional layer can also be included: the content layer, located above the retail services layer and the end users. This can be exploited commercially by so-called “over the top” content providers.

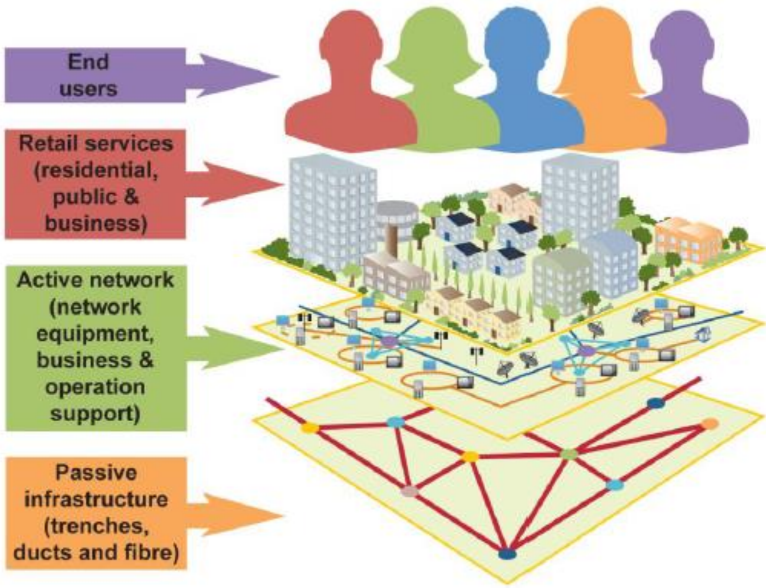


Figure 5: FTTH network layers (source: Alcatel-Lucent).

This technological structure has implications in the way an FTTH network is organised and operated. For example:

Passive infrastructure involving physical elements that are required to build the fibre network. This includes the optical fibre, trenches, ducts and poles on which it is deployed, fibre enclosures, optical distribution frames, patch panels, splicing shelves and so on. The organisation responsible for this layer would also normally be responsible for network route planning, right-of-way negotiations as well as civil works used to install the fibre.

Active network refers to the electronic network equipment needed to bring the passive infrastructure alive, as well as the operational support systems required to commercialize the fibre connectivity. The party in charge of this layer will design, build and operate the active equipment part of the network.

Retail services become involved once the passive and active layers are in place. This layer is where basic internet connectivity and other managed services, such as IPTV, are packaged and presented to consumers and businesses. Besides providing technical support, the company responsible for this layer is also in charge of customer acquisition, go-to-market strategies, and customer service.

Each network layer has a corresponding function. The network owner is in charge of the first layer, although they may outsource its construction to a third party. The network operator owns the active equipment, while the retail services are provided by the internet service provider (ISP).

See also FTTH Business Guide, Chapter 2

2.5 Open Access Networks

The term "open access" implies a resource that is made available to clients, other than the owner, on fair and non-discriminatory terms; in other words, the price for access is the same for all clients and is hopefully less than the cost of building a separate infrastructure.

In the context of telecommunications networks, "open access" typically means the access granted to multiple service providers to wholesale services in the local access network enabling them to reach the subscriber without the need to deploy a new fibre access network. The wholesale pricing structure is transparent and the same for all service providers. Wholesale products are offered at different levels throughout the infrastructure based on the type of open access model:

Passive open access infrastructure like ducts, sewers, poles, dark fibre, and wave-lengths offer telecommunications operators the opportunity to share a passive infrastructure and deploy their own infrastructures on top of delivering services.

Active open access infrastructure such as Ethernet layer-2 and IP layer-3 make it possible for service providers offering residential, business and public services to share a common active infrastructure that is built by a passive infrastructure player and operated by an active infrastructure player.

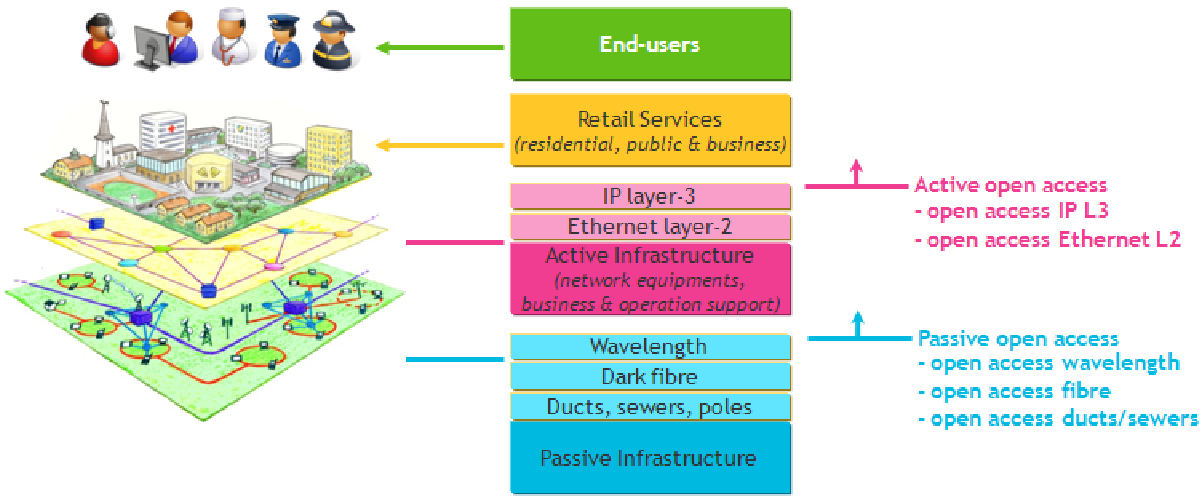


Figure 6: Open access models (source: Alcatel-Lucent)

See also FTTH Business Guide, Chapter 2

3 Network Planning and Inventory

Large investments require careful planning to minimize financial risk. A well-planned network is also the key to minimize investment and improve the average profit per connected user. In other words, careful planning can also enhance the business case. The term 'Planning' often conveys different meanings depending on where in the end to end process of commissioning a network you are. Therefore, this chapter attempts to break out planning into several distinct phases providing some help and guidance about the key activities and goals of each section. Careful planning leads to a cost efficient, flexible network that can be effectively realised and managed during the design phases and through to carrying customer traffic or wholesale services.

3.1 Network Planning

Planning refers to the complete process of preparing to deploy the FTTH network. There are three distinct phases, starting with **strategic network planning**, followed by **high-level network planning**, and ending with **detailed network planning**. These steps are briefly characterized as follows:

- **Strategic network planning** has two main outputs. First, the general business case decision whether and, if positive, to what extent FTTH should be rolled out. Second, the major strategic decisions are made, for instance, what architecture will be implemented,and which cable and duct technologies will be used.
- **High-level network planning** is the phase where structural decisions for a particular geographical planning area are made. These include the placement of network functions (distribution points, branch points etc and connectivity decisions (which location serves which area) and a preliminary bill of materials, including the installation lengths of cables and ducts as well as quantities for the various types of hardware. The aim is to generate the lowest cost network plan within the boundaries of the strategic decisions made in the previous planning phase.
- **Detailed network planning** is, as the final planning step, when the "to build" plan is generated. This includes the network documentation that can be passed to engineering departments or 3rd party construction companies. Further results of this planning phase include detailed connection information such as a splicing plan, the labelling scheme and micro-duct connections.

In general, the three phases of the planning process follow each other sequentially over time. Some early decisions, however, may need to be reviewed in light of new information. For example, the assumed location for a POP may have to change after the detailed plans have been generated. In such cases, it is important to be able to go back to earlier steps in the process and review earlier decisions – ideally with software tools which provide a high degree of automation and optimization. Interplay between the planning levels is thus important by enabling a smooth and constant feed-back loop between high-level and detailed network planning.

3.2 The fuel of network planning: data

To generate a good network plan, every decision should be based on solid information. Therefore, it is crucial to have accurate input data, particularly geo-referenced data about the project's target area.

Software tools can then use this information to model different network topologies under different assumptions, so as to compare scenarios and select the best one. There are also software tools to support the efficient construction and documentation of a detailed "to build" plan.

The type and the accuracy of the required data will vary according to the planning stage. The most important types of planning data can be subdivided into three categories:

- geo-referenced data
- design rules and material specifications
- unit cost

3.2.1 Geo-referenced data

In all planning phases the features of the geographic area must be taken into account. Two main types of geo-referenced input data are required for a planning exercise:

- Demand Point information: this means geographical points representing the customer end-points of the network (can be building entry points, but can also include cabinets, antennas or any other point requiring a fibre connection in the area).
    - The type of customer can also be an important attribute: to consider designing for a mixed network (for example combining a PON architecture for residential users with a P2P connection for business users)
    - The number of fibres required to be terminated in each point is an important aspect when correctly planning the network, for example foreseeing the right amount of fibres to a multi-dwelling unit
- Route information: relates to the geographical lines that give an indication where cables can be deployed. A variety of possible routes can be considered:
    - New underground routes (requiring trenching). Can cover almost all areas where permission is granted. In general this can be sourced from general street topology information as most trenches will be located under pavements and traversing streets
    - Existing pipes extracted from geographical infrastructure documentation systems can be used to indicate where ducts, sewers or other existing pipe infrastructure is available for installation of new fibre cables without the need for additional trenching. The available space in these pipes will need to be verified in order to ensure new cables can be added
    - Pole interconnections are lines between two poles, indicating where an aerial cable could be installed

Regarding route information, a minimal input is the street topology information. This data is available for most areas. Typical data providers for street topologies are the providers of large geographical information systems (GIS) databases that are also used for car navigation systems. This data is often what is displayed on mapping and route planning websites such as http://maps.google.com. Alternative local data providers may exist. For some regions, the open source data from OpenStreetMap, www.openstreetmap.org may be a good starting point.

Figure 7: Sample image from OpenStreetMap. © OpenStreetMap contributors, CC-BY-SA.

Regarding demand points for FTTH or FTTB networks, the location of each building in the area is vital. Purchasing address information from a government agency can be a valid option to consider as this will generally ensure the correct syntax and the most detailed and up to date information. Later, these addresses can form the main address database for all related departments, including customer care, billing and marketing. Other sources of information for this type of information can include own customer databases (in case of existing service providers), commercial GIS databases (including a broad range of detailed data: however some may only contain house-number ranges per street segment or conversely may include additional detailed geo-marketing data on an individual address level). In a growing number of regions open source data, such as OpenStreetMap can also be used to extract building locations in a region (as illustrated in the figure above). In many cases, it is also possible to identify buildings based on satellite pictures and create address points manually using the appropriate GIS tools. This method is also commonly used as a validation method for data obtained from any other source. Missing buildings can easily be added to improve the data quality.

Probably the most difficult data to obtain is information about the type of building and the number of housing units or homes within each building. In early stage planning, this can sometimes be accessed from higher-level information, such as house number ranges or population densities. For more detailed information it may be possible to get this information from the local energy or utilit supplier (for example reporting number of registered electricity meters per building). If a suitable information source is not available, the only remaining options to visit every building and count the number of dwellings.

The accuracy of the planning results can be increased by using additional data, such as:

- the surface type of a street can help provide a better estimate of the cost of digging; this information can also be used to determine whether one- or two-side digging should be used for a particular street segment.
- availability of existing and reusable infrastructure such as poles (for aerial deployments), or existing ducts with spare capacity, are helpful to decrease the respective deployment cost.
- information about the existing gas, electricity, copper infrastructure in the streets can be used to determine potential routes where it is likely that permission for digging will be granted.
- suitable locations for a point of presence (POP) or fibre concentration point (FCP).

This additional data may be harder to obtain and consideration should be given to assessing the effort needed to obtain such data, taking into account the objectives of the planning task.

Some detailed information may be left out at the early stage and will have to be approximated. Nevertheless, since more accurate data will be required in later planning stages, it is generally recommended, for the sake of better strategic and high-level decisions, to gather high-quality data in the early stages as well.

For detailed network planning, as much information as possible is needed, and it can be worthwhile spending time checking and "cleaning" the data, for example using satellite images or field surveys.

One special type of geo-referenced information, relevant only in the strategic modelling stage, is so-called geo-marketing data. Geo-marketing data refers to any information that allows the planner to have an indication of the different market potential within the various sub-areas. Relevant information can include:

- survey results showing willingness of families to sign up for FTTH offering
- certain types of customers in different regions (for example young families with children, elderly people etc)
- historical adoption of new (broadband) services in certain regions (for example DSL or digital TV)

All this information can be used to adapt the model to assess the best adoption potential and revenues in each region. When combined with cost information for deploying the network per region, this data supports an optimized cherry-picking strategy.

3.2.2 Design rules and Material specifications

The material used in an FTTH network deployment is described in other chapters of this Handbook. This will be taken into account and dimensioned during all phases of the planning process. It is important to take a detailed view of the material, even in the early stages of the planning process, since the details can have a significant impact on the optimal network topology– and therefore on strategic planning.

The material includes but is not limited to active equipment (for example Ethernet switches, OLTs and PON optical terminals) and passive components (for example optical distribution frames, fibre joint enclosures, PON splitters, conventional duct or micro-duct systems, cables and fibres, and fibre termination units).

Starting from the equipment specifications, a set of design rules need to be defined as a planning decision, describing how the material can be used and in what network configuration. This includes:

- assessing the number of fibres that may be needed for each demand point
- the cable sizes and ducts to be installed in the feeder, distribution and drop areas;
- which (inner) cables and ducts fit into which outer ducts (depending on the outer and inner diameter of the associated link components or on design rules);
- what equipment, e.g. splitters, can be installed in buildings, distribution points and/or POPs;
- what capacity of fibres and/or cables can be terminated within a certain cabinet or closure

3.2.3 Unit Costs

One of the main planning objectives is cost control within a given set of constraints and requirements. To do this properly, it is necessary to have a clear view on the various costs of deploying and maintaining the FTTH network. These include:

- labour cost for civil works
- material cost per equipment type
- installation, test and measurement service costs
- network maintenance costs
- the energy cost for active equipment
- costs related to creating and maintaining POPs, FCPs
- costs related to rights of way

The cost areas are often distinguished according to whether they are capital expenditure (CAPEX) or operational expenditure (OPEX). Other important categorizations are: active equipment and passive components; outside plant and in-building cabling; homes passed and homes connected.

3.3 The engine of network planning: tools

In the early days, network plans were generated manually by drawing objects on top of maps, first on paper, and later within traditional CAD (Computer Aided Design) software packages. However, the planning itself was fully manual and therefore both time-consuming and prone to errors. As a result, early stages of the planning process were often ignored or only treated in a theoretical or statistical way, and the planner would focus directly on the detailed planning phase.

Another drawback of this approach was that the plan contained little or no intelligent data about the components of the network because there was no database behind it, which made it difficult to use these plans efficiently during later stages of the network lifetime, for example, for maintenance.

Nowadays many of these issues are solved by using true geospatially aware (GIS) software to design, document and manage the network. The software links the objects on the map with database objects, thus keeping track of all kinds of data about the network components.

FTTH planning tools make the network planning process much more efficient, not only in terms of time (through automation) and the quality of network plans (through dedicated data models), but also in terms of the associated deployment cost of the plans (through intelligent cost optimization algorithms).

Each of the three stages in the network planning process has particular requirements in terms of speed versus complexity that are supported by available software tools.

In the first phase of network planning, the focus is on accurate cost estimations: what is the cost for this whole area, what is the cost for these subareas, etc. The network design tools need to run fast to allow the comparison of different design rules for large areas. Due to the considerable impact of strategic decisions on the business case, the quality of the computations need to be accurate enough to draw valid conclusions.

During high-level network planning, the level of detail increases as does the level of cost-optimization. The result of this phase is a network plan and an associated detailed costing of material on which all structural decisions are made. In addition it also provides a plan of how the network should be built. The generated network design needs to be cost optimized. The process of high-level network planning is typically interactive: the user adds restrictions based on field survey information and the software then calculates a new optimal network design based on these restrictions.

Detailed network planning has fewer requirements around automation. At this stage the planner must produce the to-build plan. Therefore the tools must support the handling of very accurate and detailed network specifications and cable layouts.

3.4 Strategic network planning

Major business decisions are made in this first planning stage. The key question is whether to make the investment in the FTTH network.

To answer this question, the planner needs accurate costs, not only for deploying the network, but also for activating customers and maintaining the network during its lifetime, and some realistic predictions for customer adoption of services and related revenues.

It is important to base the cost analysis on real local data as there can be big differences between different geographical areas – even those with similar population densities. Extrapolations and benchmarking should be avoided where possible.

If the decision is made to proceed with the project, there will be additional questions such as:

- Where will the network be deployed? (Define the geographical scope of the project.)
- Which order to deploy the sub-areas of the network? (Define the geographical order.)
- What methods and technologies will be used? (Identify design rules, components, technologies.)

3.4.1 Where will the FTTH network be deployed?

By comparing different regions in terms of expenditure and revenues, a decision can be made on where to deploy the FTTH network. In reality, investors in FTTH have different profiles. Private investors will put more emphasis on financial performance while public investors have to serve all potential customers equally, sometimes over huge areas, with nationwide deployment being considered. Ideally, both commercial interests and service availability should be considered.

When concentrating solely on cost, it is generally agreed that there is a clear influence regarding population density on average cost per home passed. Nevertheless using only (average) population density to compare various areas based on their attractiveness to deploy an FTTH network can be costly. The differences in density on certain streets or areas with large MDUs can still cause variations in cost of more than 40% between two areas of similar density. Therefore it is strongly recommended to evaluate all candidate areas in detail rather than working with representative areas and extrapolations.

Compiling a detailed analysis of the variations in cost per home for deploying an FTTH network within a large area, results in a cost/coverage statistic for a region. As illustrated in the figure below, the average cost per home passed increases if the most expensive X% of homes are excluded from the deployment. This is very useful information when analysing the need for public funding in certain areas, for example by classifying sub-areas into white, grey and black areas.

The example below illustrates the situation for a specific region which includes more than 100,000 homes comprising of a mix of rural and urban areas. In this case the influence of excluding the more rural parts from the deployment can drastically lower the cost per home passed. Note that this curve can be very different for different regions.

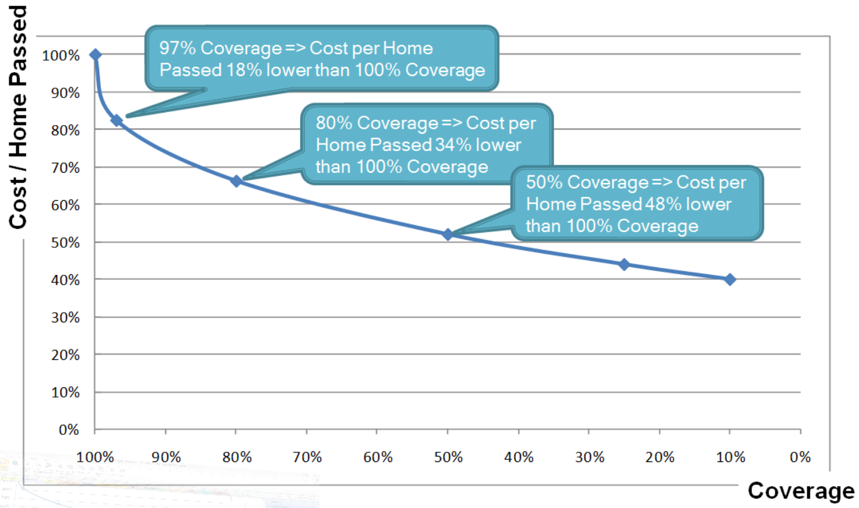


Figure 8: Example of cost/coverage curve: cost per home in function of the percentage of homes passed.

By incorporating geo-marketing data and comparing different areas in their trade-off between required investments (cost per home passed) and expected revenues (linked to expected percentage of homes passed that will be connected), will further improve the prioritization of areas. In addition, when using this combined evaluation, several cases have identified improvements of between 10% and 20% on Return on Investment.

3.4.2 Which order will the sub-areas of the network be deployed?

When an FTTH project covers a large geographical area, the construction process can easily take several years. The longer the deployment timeframe, the more important it becomes to determine the optimal order for rolling out the network in a series of sub-areas. The selection of this order is usually based on a combination of cost and revenue estimates. By selecting the right order, one can maximize the take-rate of the initial deployments, not only increasing the initial revenues, but also maximizing the positive message that can be spread when convincing other potential customers and investors in later phases by showing high take-rates.

3.4.3 What methods, components and technologies will be used to build the network?

There are many possible technologies and component choices for building FTTH networks. The most cost-effective option can only be determined by applying the different engineering rules and constraints for each approach to the actual geography of the region and then comparing the bottom-line results. Each project will have a different optimal selection of technologies, depending on the local situation, including local geography, regulatory obligations, the market situation, and other factors.

In many cases, cost is not the only consideration. To make the right decisions at this early stage, it is important to perform an in-depth evaluation of the different scenarios. The impact of a particular choice on overall deployment costs is crucial, of course, but other aspects such as quality, bandwidth and reliability should also be considered. The choices to be made are often framed along the lines: “Is it worthwhile investing this extra amount for the extra quality/bandwidth/reliability… it will deliver?”

Possible options that can be considered:

- Different architectures (“x” in FTTx, see Chapter 2),
- Different active technologies (PON vs. P2P Ethernet vs. hybrid, see Chapter 4),
- Different levels of fibre concentration (see Chapter 6),
- Different cable deployment methods (micro-cables vs. conventional cabling, see Chapter 8),
- Different splitter architectures (see Chapter 6),
- Different in-house cabling methods (see Chapter 7),
- Different infrastructure sharing strategies (see Chapter 5)

3.5 High-level network planning

Having decided the extent of the project area, attention now turns to making detailed decisions about the structure of the network. The main outputs of this planning stage are a reliable estimate of the anticipated investment, decisions about the location for POPs and FCPs, connectivity decisions about which location serves which area, and a bill of materials.

High-level network planning starts with the following input which are based on the results of the strategic network planning phase:

- defined planning area
- design rules and materials
    - an architecture (P2P, PON, or hybrid)
    - a type of cabling
    - a building connection strategy (number of fibres per building, etc.)

Questions to be answered in the high-level planning phase are:

3.5.1 Where will the POPs be located?

For complex planning areas the planner must decide how many POP locations should be used, where the ODFs and active equipment will be placed. If several POPs are used, the planners must also decide which customers should be served by which POP location.

There is no rule of thumb for how many customers can be served by a single POP. Generally, the more customers served by the POP, the greater the economies of scale in terms of energy, maintenance and aggregation capacity, however, feeder cables will become longer and thus more expensive.

For smaller planning areas, where only one single POP is necessary, its location is typically chosen from a pre-defined limited set of options. These are usually dependent on the availability, to the operator, of the buildings in that specific area. Nevertheless, it is always interesting to know the difference in deployment costs between an available location and the ideal location for a POP.

3.5.2 Where to install the fibre concentration points?

Among the core tasks of high-level network planning is to decide where to place fibre concentration points (FCPs). The planner must also decide which customer locations will be connected to which FCP, and the fibre-optic management solution in each FCP.

These decisions will be subject to constraints imposed by the technical specifications of the available solutions to manage the fibres, and the fibre counts of the cables and duct systems. Nevertheless, the optimal location from a cost perspective may not always be practically possible. Nevertheless it is recommended to start from optimal locations and then to find the nearest practical locations for an FCP because this can result in serious savings in total deployment cost.

3.5.3 Which cable routes serve which distribution and feeder areas?

Cable routes, which provide connectivity between POPs, distribution points, and customer premises, must be decided. Digging and laying out cables and ducts is still very expensive, and so the selection of the routes (sometimes called trails) is one of the most business-critical decisions. It is important to maximise the use of existing infrastructure such as empty ducts, to avoid the necessity of digging and the associated costs. Consideration should also be given to mixed scenarios: laying cables in existing ducts where available and combining newly installed ducts and aerial cables where no ducts exist. In such a scenario the distance between various deployment routes must be calculated in.

3.5.4 What is the expected bill of materials?

Having made decisions about connectivity, it must also be decided which cable and duct installations should be used on which routes. Together with the equipment requirements (such as closures, splitters, active switches, etc.), this information can be used to generate a high-level bill of materials, and used to provide quantity indication to the hardware suppliers. The final bill of materials – which includes all items in details – is generated during the detailed planning phase.

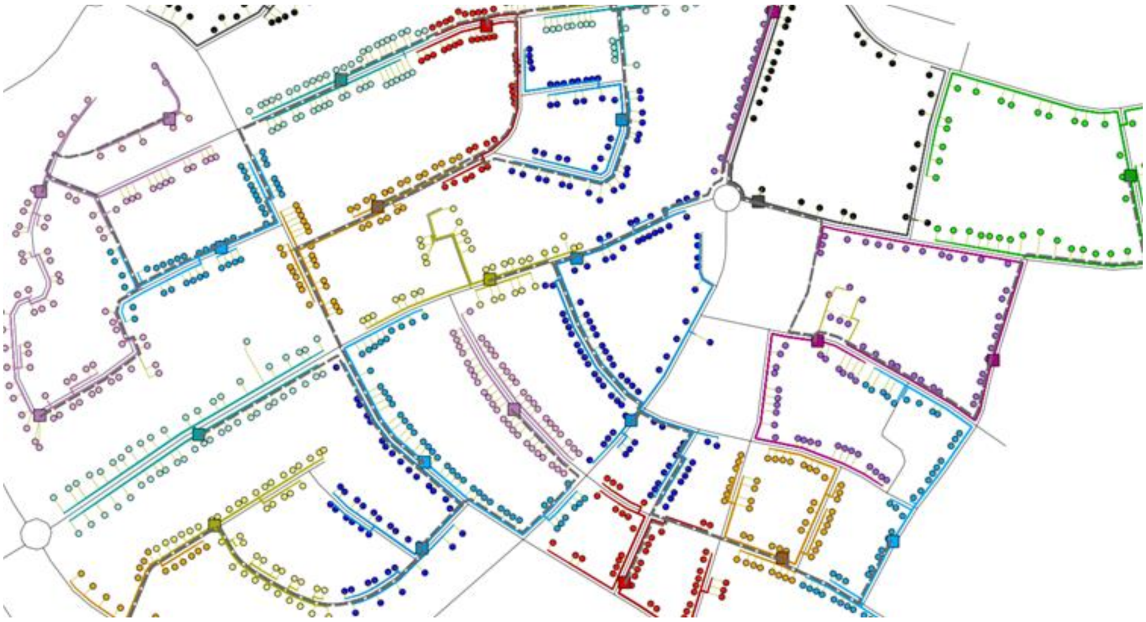


Figure 9: Result of high-level planning – colour-coded distribution locations and areas

The decisions above have been described as if they are individual decisions, but in practice there is a high degree of interdependency. For instance, deciding which customers are served by a POP has a direct impact on the number of cables installed in a particular route, and consequently on the question of whether existing ducts have enough capacity to accommodate them or whether digging is required.

Use of an automatic high-level planning tool is highly recommended because it can handle all decisions in a single integrated planning and optimization step. In such an environment, the planner is the master making decisions about planning parameters and constraints. The automatic high-level planning tool supports the planner in designing a low-cost network that fulfils all technical constraints and which makes optimal use of the existing infrastructure.

3.6 Detailed network planning

In this stage of the planning process results from high-level planning are converted into "to-build" plans. This involves drawing up a network plan that is accurate and detailed enough to ensure that all official permissions can be granted and that working instructions can be generated. Additional specification of aspects such as network connectivity (on individual fibre level, duct level, etc.) and labelling should also be included.

3.6.1 Detailed Data

All data that has been used in the previous planning stages should be reused in the detailed network planning, e.g. geo-referenced data about streets, buildings, addresses with living units, and other major geographical features, as well as database tables of installable components, purchase and installation costs. Also the structural decisions made in the high-level planning should be used as starting points, including:

- the number and the geographical location of the POPs and FCPs
- the serving areas of each POPs and FCP (as colour-coded in Figure)
- the used routes including cable and duct installations

Ideally, the software tools should offer appropriate export and import functionality to ease the reuse of the results from high-level network planning. Although much progress has been made in recent years in the area of spatial data interoperability, any process that involves data import and export can lead to a loss of data fidelity. In order to avoid this, some detailed design clients provide pre-integrated interfaces to high level network planning solutions to aid this important step in the process thus avoiding unnecessary data duplication or corruption.

Additionally, it is important to know the exact specification of ducts, cables, fibres and fibre connectors to avoid incompatibility between different components during planning. This includes, for example:

- colour coding of duct and/or micro-ducting systems
- minimum bending radius for ducting and cables
- Network Policy considerations, e.g. maximum blowing distance or minimum cable specification.
- compatibility constraints for connectors, e.g. APC connector cannot mate with a PC connector
- mode-field diameter compatibility for fibre splicing and commissioning; note that this can be fully granted by properly specifying the fibre according to the latest ITU-T G.657 recommendation (edition 3, October 2012), which tackled such compatibility for all categories, including Category B, by restricting the allowed mode-field diameter range.

In addition to the Outside Plant (OSP) detailed data, the plan must also include information necessary to complete the build out or configuration of the Inside Plant (ISP). Some operators will split these into two separate 'jobs' since the resource types and lead times are often very different between OSP and ISP designs - although the use of a single job across both Inside and Outside Plant also occurs. ISP designs tend to focus on the equipment required to provide the service, but consideration is also given to the supporting infrastructure. In the case of Fibre to the Home, the ISP aspects would include the number and physical location of Optical Line Cards, Layer 2 switches and Optical Distribution Frames as well as the physical rack space, power and cooling required in the Central Office building to support any new equipment.

3.6.2 Surveys

During the planning phase, it is useful if the proposed network information can be correctly geo-referenced and linked to tools such as Google Street View (Figure 10) to perform a "Desktop

Survey”. This makes it easier to check important details: road surface conditions, tree locations, street types, etc. However, as this online map data is not always completely up to date, a decision to perform a physical site visit may still be taken.

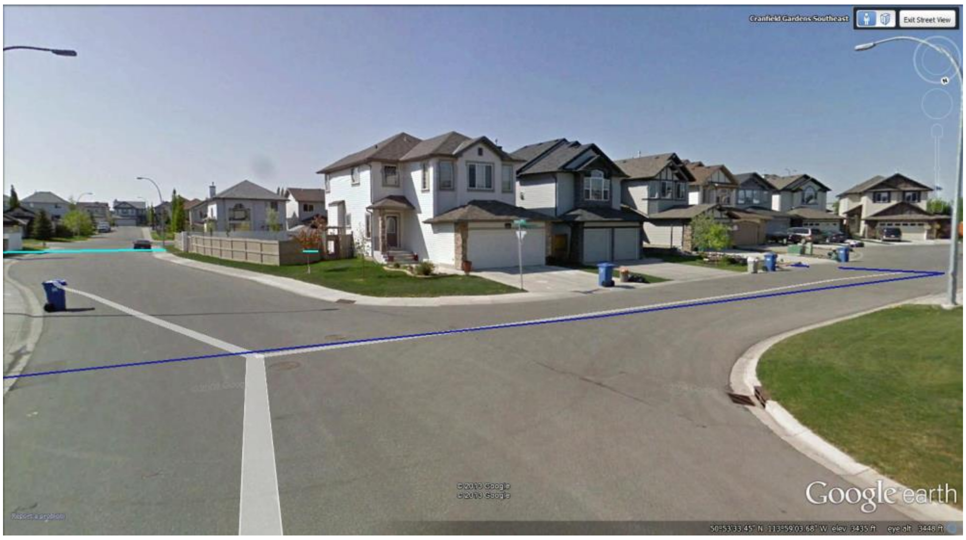


Figure 10: Desktop Survey using Google Street View

Some operators will always perform a physical site visit to verify a proposed detailed design prior to installation, whilst others rely on a desktop survey and visit the site if really necessary. Essentially this decision is a cost/benefit call, and the decision to perform an upfront survey will be determined to some degree by:

- the accuracy of existing infrastructure records
- the amount and type of 3rd party infrastructure in the area
- local considerations, e.g. conservation areas, traffic or planning regulations
- installation cost considerations, e.g. road surface variations
- the cost of corrective action in the case of a failed design or installation
- whether a site survey was conducted as part of a high level design

To avoid potential issues with existing infrastructure buried underground, software tools typically support the import or display of 3rd party utility information alongside the proposed design. In some countries, the amount of shared 3rd party information is limited by legislation and often relates only to the presence of the underground network housing, not the type or quantity of cabling in the area.

3.6.3 Generating the 'to-build' plans

The detailed network planning phase generates “to-build” plans and must add details and accuracy to the high-level network planning result. It comprises the following tasks:

- detailed drop connection: each drop connection (from the last branching point in the street to a building connection point) must be exactly positioned and traced.
- cable/duct-in-duct configuration: for each non-direct-buried cable and each inner duct it must be specified into which outer duct it is blown or pulled, e.g. by specifying the colour and label of a micro-duct system.
- connector placement: for each duct system it must be specified at which geographical position one or more of its ducts (in particular for micro-duct systems) are connected, with what type of connector and to which duct of another duct-system.

- labelling: each component installation receives a unique label according to a consistent, user-defined scheme which enables easy reference and identification for the component in the plan.
- fibre and splicing planning: at ODFs, fibre concentration points and, if conventional cabling is used, at any other cable connection points, it is necessary to define precisely which pairs of fibres are spliced together and what tray the splice will be located.

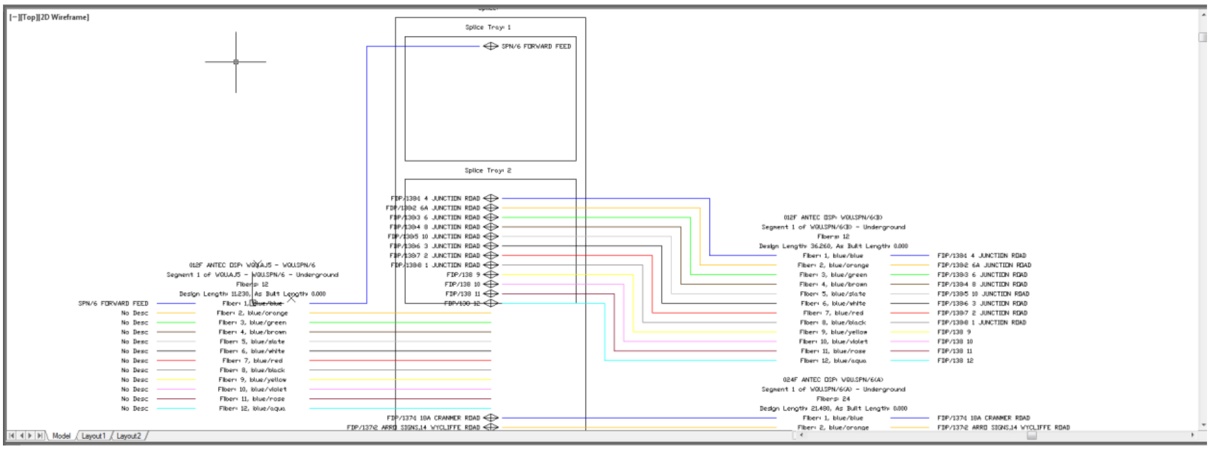


Figure 11: Fibre splicing schematic recording fibre colours, allocations and terminations.

The resulting documentation of the “to-build” network comprises accurate and complete information for upgrading, troubleshooting or restoring a network:

- documentation of the “to-build” network
- documentation of POPs including rack space and placement of active and passive equipment
- generation of work instruction plans for complex objects such as an ODF and Optical Splitters
- reporting of overall summaries, material lists, cost lists and fibre blow lists
- generation of the tender list

3.6.4 Job Management

In contrast to many operations that take place in a modern telecommunications network, network construction can take a long time; perhaps months or several years to complete. Usually large network changes are broken down into smaller projects (or jobs) and consequently many PNI vendors have adopted a ‘long transaction’ or job-based approach to detailed design production. Think about a ‘job’ being a collection of all the changes required to realise a network modification. Jobs can be small, such as connecting a new building to an existing fibre network or large, for example the construction of a new FTTH serving area.

In the detailed planning phase it is particularly important that detailed planning tools support both manual changes for individual configurations and automation of mass data operations which should be consistent over the complete plan (e.g. equipment naming and labelling). Having this flexibility will increase the quality of the output whilst reducing the labour costs associated with creating the detailed design.

3.7 Network Inventory

3.7.1 Software support

The conceptual change from a plan that documents how to build the network to a plan that represents the real network as it has been built, also impacts on the demands placed upon the data and the software being used to manipulate it.

This usually means:

- an increased emphasis on the quality of the geospatial data to create the official record of the position of the ducts/cable.
- the need for a software tool for graphical manipulation and consistency checking of the planned network.
- the requirement for database technology for documentation, network operation, change management, troubleshooting, customer care, marketing and network registration.

For most modern telecom network operators this information will either be created in, or transferred from a specialised Physical Network Inventory (PNI) application. A PNI will almost always be spatially aware and also provide comprehensive support for attribute collection, reporting and visualisation of the network through the use of a modern database framework. Some databases, such as Oracle and Microsoft SQL provide spatial data types as standard, whilst other 3rd party add-ons (e.g. ESRI ArcGIS Server) can be used to extend non-spatial data stores with geographical support. A PNI differs from a pure (often called 'Vanilla') GIS or CAD based system in that it offers sophisticated pre-configured telecoms data models and behaviour that can be used to standardise and validate detailed network documentation.

3.7.2 Workflow management

As we have seen in an earlier section of this chapter, the process of High Level Planning feeds the subsequent processes in Detailed Planning/Design. However, detailed planning phases are not the end of the workflow – far from it since the network is not even built at this stage. Once all detailed planning phases are complete, the process for construction and handover of the network into 'business as usual' is typically as follows:

- Financial Approval
  - authorisation to proceed with construction of the proposed design
- Interaction with Supply Chain
  - the logistics for ordering and delivering the required materials to site
- Interaction with Workforce Management, i.e. arranging the appropriate technicians
- Civil engineering phase
  - construction of manholes, poles, underground ducting, etc.
- Cable installation phase
  - blowing/floating or pulling the cables
- Fibre connection phase
  - fibre splicing
  - fibre patching at flexibility points
- Departure from design feedback cycle
  - can changes to the design be authorised in the field or does it trigger a new detailed design?
- Test and measurement
- Device activation
- Confirm "As Built" network and update records
- Hand over network to operations for accepting orders

These steps need to be integrated with the documentation of the “to-build” and “as-built” networks.

In many cases an operator will want to document this process and identify key inputs and outputs with the aim of bringing transparency to the entire end to end planning process and facilitating the option of generating metrics to support internal business cases. Ideally, the planning software system interfaces with an order management or task/workflow solution showing all the steps in the workflow.

Often the provision of a new FTTH network is as much a logistic challenge as one of network design. It is therefore important that management of costs, comparison of technical design options, scheduling, assignment of technicians, supply chain management and reporting of departures from design are all considered as part of the project.

Additional capabilities from a digital workflow solution may also include project dashboards, jeopardy management, critical path determination and risk mitigation plans. Such a workflow system may be accessible over mobile data connections in the field, allowing the engineer to report the status of the work in near real-time.

3.7.3 ‘As-Built’ Documentation

The final constructed network is rarely identical to the proposed network design. If any changes are made during construction, it is important that the original "to-build" plan is updated. Ideally the updated plan, often called the ‘as-built’ plan, should be used as the basis for the complete documentation of the network. Most adjustments are caused by the civil works and situations arising in the field such as a blocked duct or discovery of 3rd party infrastructure. It is important to record all adjustments from the to-build plan, and update the PNI software so that accurate information is held for future interventions.

The documentation of the “as-built” network contains information for each section and cable:

- Civil Infrastructure
    - name and address of the construction company
    - construction approval details (clerk of works or supervisor details)
    - accurate locational data (perhaps including GPS coordinates or 3 point measurements from fixed locations)
    - accurate As Built trench lengths
    - manufacturer and model of any item not in accordance with the to build plan, e.g. larger man holes or additional ducts
    - Duct Space Records (DSR’s)
    - Aerial Pole support information (guys, anchors, etc.)
- Cables
    - manufacturer and date of the used cable

4 Active Equipment

Passive optical network (PON) P2MP and Ethernet P2P solutions have been deployed worldwide. The choice of equipment depends on many variables including demographics and geographical segmentation, specific deployment parameters, financial calculations etc. In particular, the solution chosen is very much dependent on the ease with which passive infrastructure is deployed. It is clear that in today's market both solutions are acceptable.

In a multi-dwelling unit (MDU), the connections between end-users and the building switch can comprise of either copper or fibre, however, fibre is the only alternative that will guarantee to support 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 competitiveness as well as future applications.

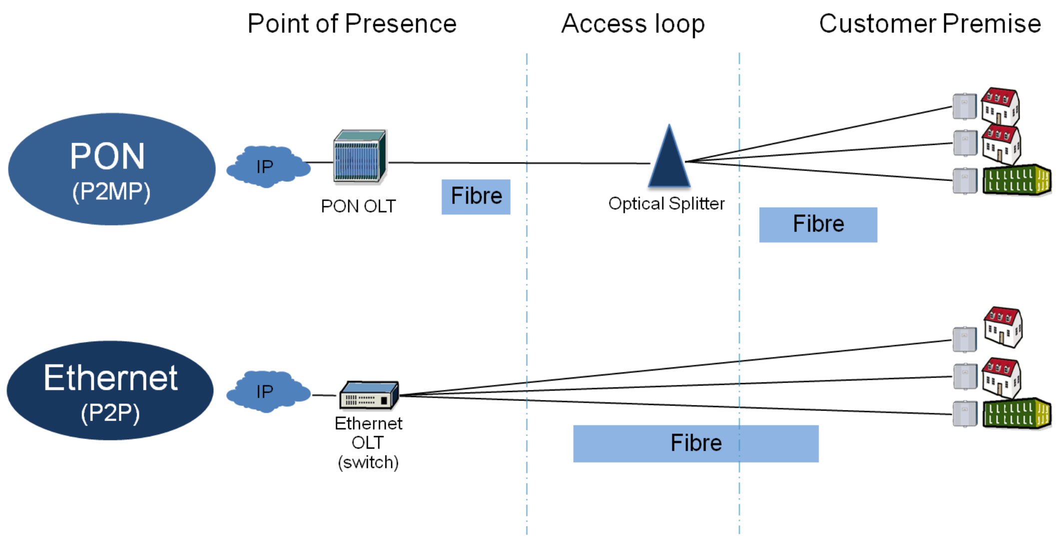


Figure 12: Different FTTH network architectures

4.1 Passive optical network

The PON equipment comprises of an optical line terminal (OLT) in the point of presence (POP) or central office. One fibre runs to the passive optical splitter and a fan-out connects a maximum of 64 end-users with each having an optical network unit (ONU) at the point where the fibre terminates.

The ONU is available in several versions, including an MDU version suitable for multiple subscribers for in-building applications and incorporates existing in-building cabling (CAT5/Ethernet or xDSL)

Advantages of PON includes reduced fibre usage (between POP and splitters), 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 is to be installed, this is also known as a fibre concentration point (FCP) or fibre flexibility point (FFP). One of the differentiators of PON is that the number of fibres between the FFPs and the POP can be reduced significantly (splitting ratio in combination with the subscriber acceptance rate can result in a 1:100 fibre need reduction). This is especially so in Brownfield areas where some (limited) resources are already available, either dark fibre and/or duct space, which could translate in considerable cost and roll-out time savings.

4.1.1 PON solutions

There have been several generations of PON technology to date.

The Full Services Access Network (FSAN) Group develops use cases and technical requirements, which are then specified and 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 1:128. XG-PON offers 10Gbps downstream and 2.5Gbps upstream for up to 128 users.

As envisioned by FSAN, the new approach, NG-PON2 will, by 2015, increase PON capacity to at least 40 Gbps downstream and at least 10 Gb/s in the upstream, reaching a minimum of 20Kms with a minimum of 1:64 split ration. Enhancements to add more wavelengths, reach 60 kms and a split ratio of 1:256 are also being addressed by the specification. 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 10Gbps 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 more data-intensive applications used by home-workers will drive subscribers towards upstream bandwidth. Besides these, the main drivers behind the intensive usage of PON technologies will be Business Service, Mobile and Wi-Fi / Small cells backhaul networks that operators need to support beyond the residential services. Business services or mobile backhaul will require sustained and symmetric 1 Gb/s data rates. However, 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 offers FTTH operators key competitive advantages over DSL or cable providers. GPON provides a 20 km reach with a 28dB optical budget using class B+ optics with a split ratio of1:128. The 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, by using reach extenders. 10G-EPON can also provide a 20 km reach with a 29dB optical budget.

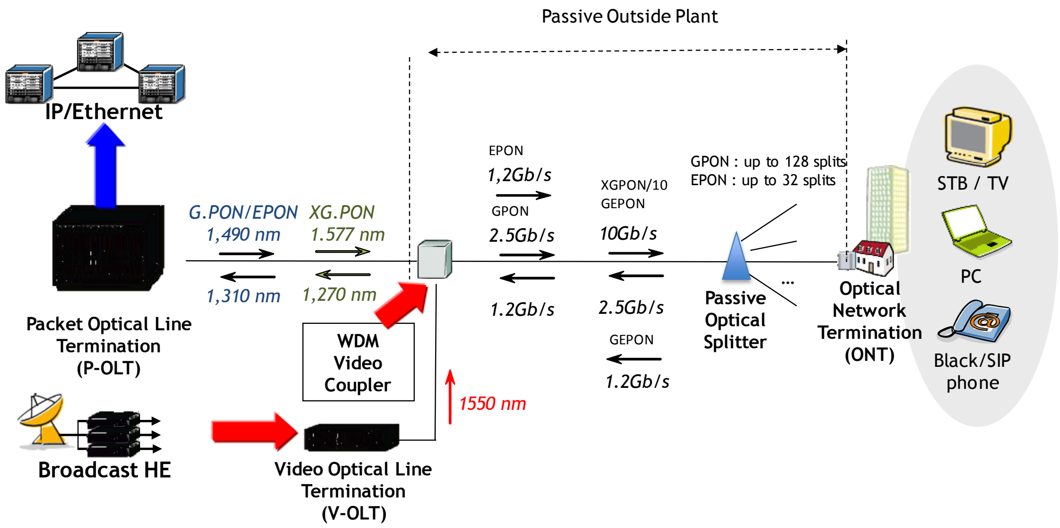


Figure 13: Schematic diagram of a GPON network

As an option, an RF video overlay can be added through the use of an additional wavelength (1550 nm) which is compatible with a step-by-step build-up or time-to-market critical situations for digital TV applications.

The standards have been defined to allow both GPON and XG-PON to coexist on the same fibre by using different wavelengths for both solutions. This is acceptable as long as requirements such as the G.984.5 recommendation, which refined the spectrum plan for GPON and defined the blocking filters in the GPON optical network units (ONUs), prevents crosstalk from non-GPON wavelengths.

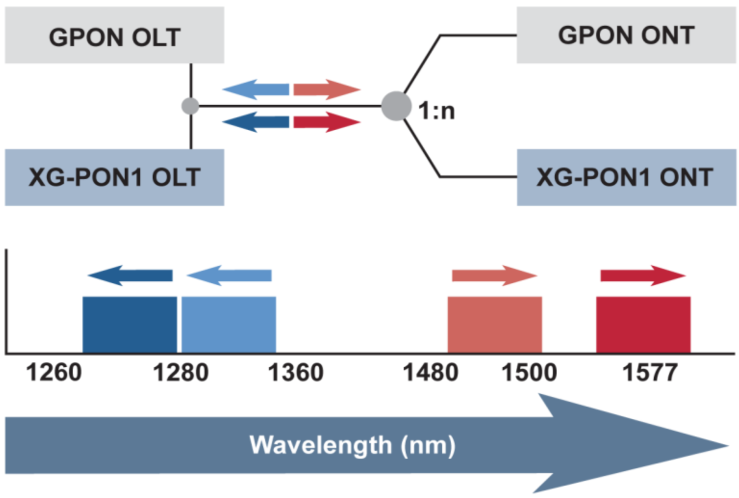


Figure 14: FSAN approach to XG-PON

NG-PON2, the new approach by ITU and FSAN will address the evolution according to the following topologies:

Basic:
40 Gbps downstream and 10 Gbps upstream capacity, using 4 wavelengths

Extended:
80 Gbps downstream and 20 Gbps upstream capacity, using 8 wavelengths

Business:
Symmetrical services, 40/40 Gbps to 80/80 Gbps

Mobile Fronthaul:
Point to Point WDM (CPRI)

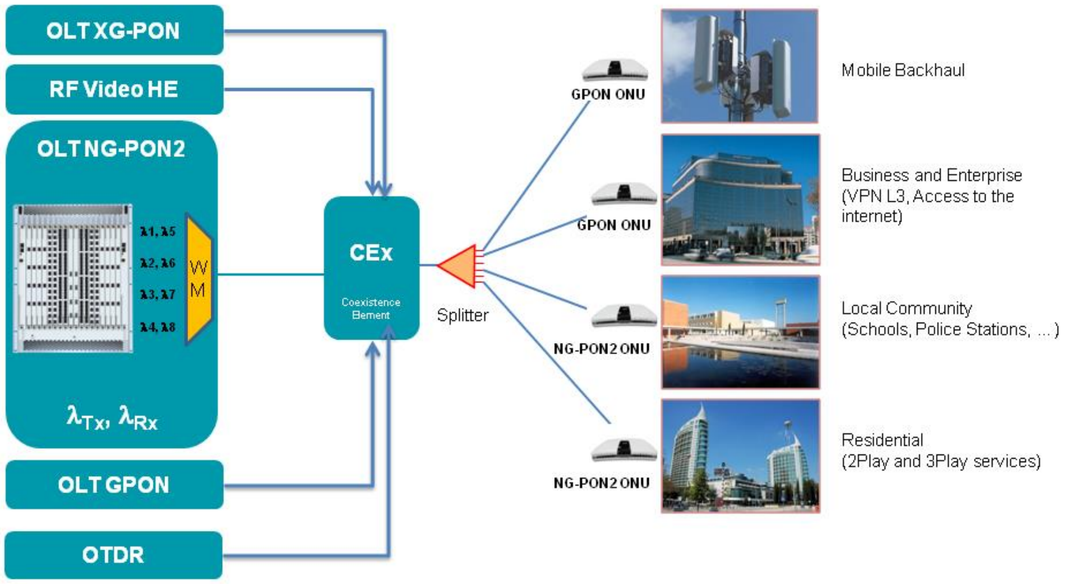


Figure 15: Coexistence of different FTTH technologies

Coexistence is ensured by a passive element known as ***Coexistence Element (CE).*** This combines/splits wavelengths associated to each service and PON technology.

It is also expected that NG-PON2 devices will support Mobile Backhaul (MBH) timing applications (1588 BC and TC clocks to support accurate frequency and phase time requirements)

4.1.2 PON active equipment

Standard PON active equipment consists of an optical line terminal (OLT) and an 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 16,384 subscribers (based on 64 users per GPON connection) per shelf. OLT boards can also provide up to 768 point-to-point connections (Active Ethernet) for applications or clients that require this dedicated channel.

OLTs provide redundancy at the aggregated switch, power unit and uplink ports for improved reliability.

Some OLTs can also offer ring protection mechanisms for their uplink ports with ERPS (ITU-T G.8032 Ethernet Ring Protection Switching) functionalities as well as capacity to MUX the RF

Overlay internally (and incorporate the EDFA amplifiers) making it an integrated solution for operators.

OLTs can be installed with GPON, XG-PON or NG-PON2 cards making them the perfect choice for a ***pay-as-you-grow*** scenario, meaning that the investment in the chassis will last as the new PON technologies and line cards become available. A Coexistence Element (CE) can also be integrated in the chassis to ease the upgrade towards NG-PON2.

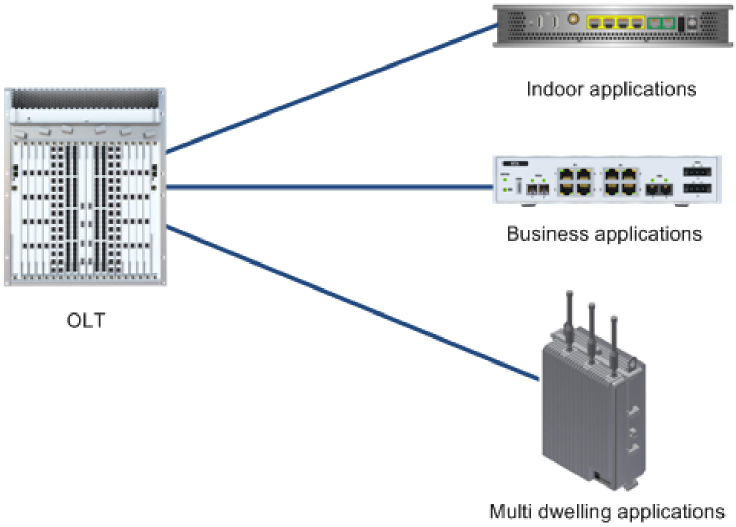


Figure 16: Different types of ONT

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

- indoor applications
- outdoor applications
- business applications
- MDU applications

Depending on the application, the ONU can provide analogue phone connections (POTS), Ethernet connections, RF connections for video overlay and, in the case of FTTB, a number ofVDSL2 or Ethernet connections, Wi-Fi 2.4/5 GHz and G.hn (G.9960).

MDU (Multi dwelling ONUs) can be an intermediate solution for the full end to end fibre architecture, for buildings with existing copper networks. As VDSL2 links can now achieve 100Mbps full-duplex (Annex 30a), this provides the opportunity to access more customers without actually having to take the fibre inside their homes. Furthermore, this type of ONU can be used to replace legacy exchange telephone systems, namely in remote areas. As fibre becomes available in those areas, it makes sense to migrate all old telephone lines into ONUs (with a high number of POT ports) thus converting them to VOIP and thereby reducing OPEX and CAPEX. Enhancements such as vectoring, bonding and G.fast (G.9970) can further improve the offered bandwidth.

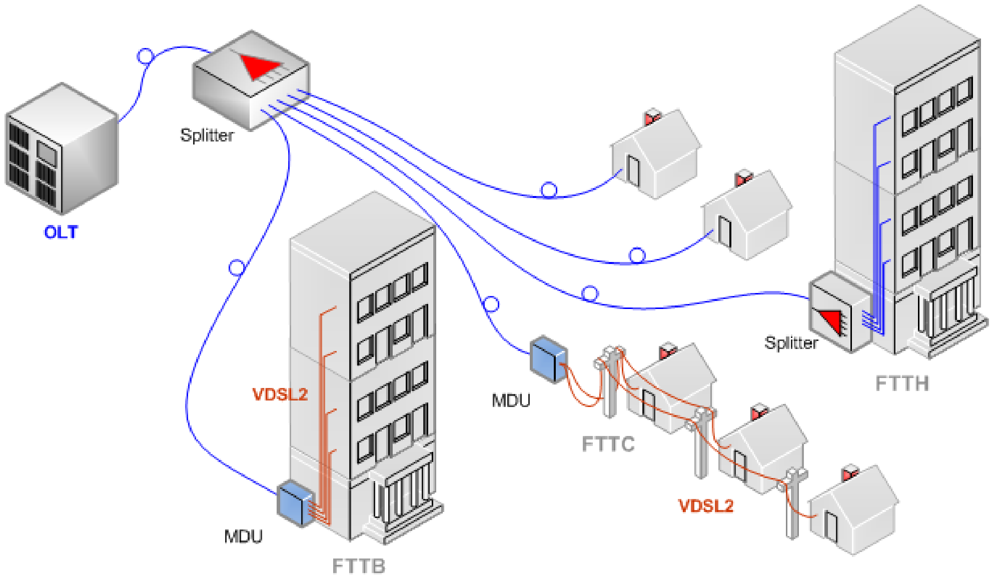


Figure 17: FTTH Applications

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

This definition is not always adhered to by all and in other (non-PON) cases; any device that terminates the optical network is also referred to as an 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.

4.1.3 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 then 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.

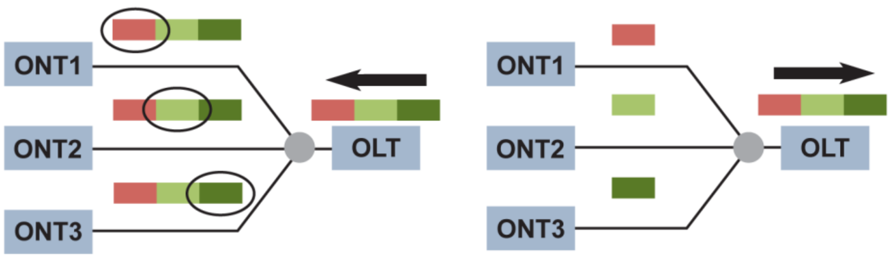


Figure 18: Bandwidth management in PON systems

4.1.4 Wavelength management

A set of wavelengths has been defined by ITU-T to ensure the co-existence of different PON technologies over the same fibre, via WDM.

These specifications also define the wavelength-blocking characteristics for filters that protect the GPON downstream signal in the ONU from interference from new bands.

However, there is a need for some additional aspects to be defined concerning management and control methods of the multiple wavelengths in the system. These aspects are being developed in an ITU-T Recommendation G.multi.

4.2 PON deployment optimisation

When deploying PON networks, active and passive infrastructures work together. It is clear that timely investment in active equipment (mainly associated with the 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 exceeding 50%
- flexible outside plant that easily adapts to present and future subscriber distributions
- regulatory requirements for unbundled next-generation access (NGA) networks
- optimizing operational costs 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 2,000 homes passed.

Assuming that single-level splitting, also known as centralized splitting, is employed, the size of the node should be defined, meaning the number of homes passed, where the splitters will be installed. There is a trade-off between the cost of the cabinets and the need for extra fibre if cabinets are moved higher in the network and closer to the POP. One of the critical factors in this optimization process involves the area density; typically cost will vary with node size as follows:

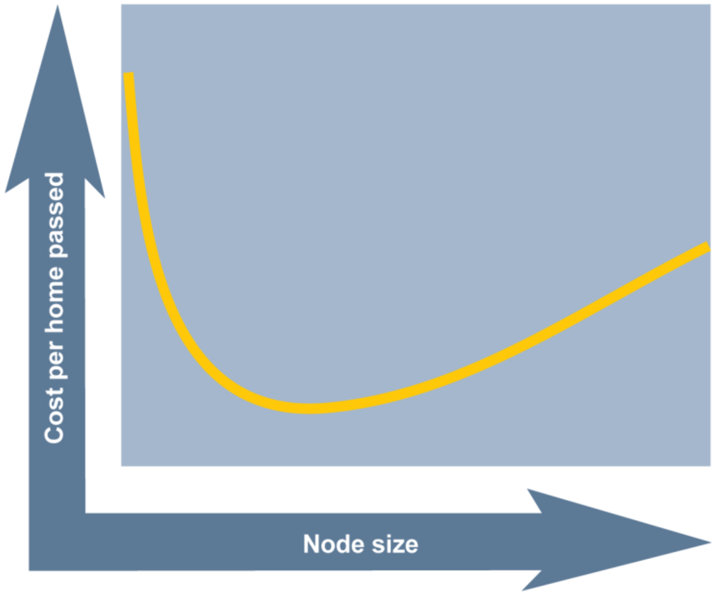


Figure 19: Optimisation of node side in a PON with single-level splitting

Cities comprise of many MDU's, some contain a few apartments and others many hundreds. This is also an important factor when designing a network, such as how many splitters need to be installed in the basement of the buildings. Some networks employ a two-level splitting strategy, also known as distributed splitting where, for instance, 1:8 splitters are located in the buildings and a second 1:8 splitter is installed at node level. In areas where there is a combination of MDUs and SFU's (single family dwellings), 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.

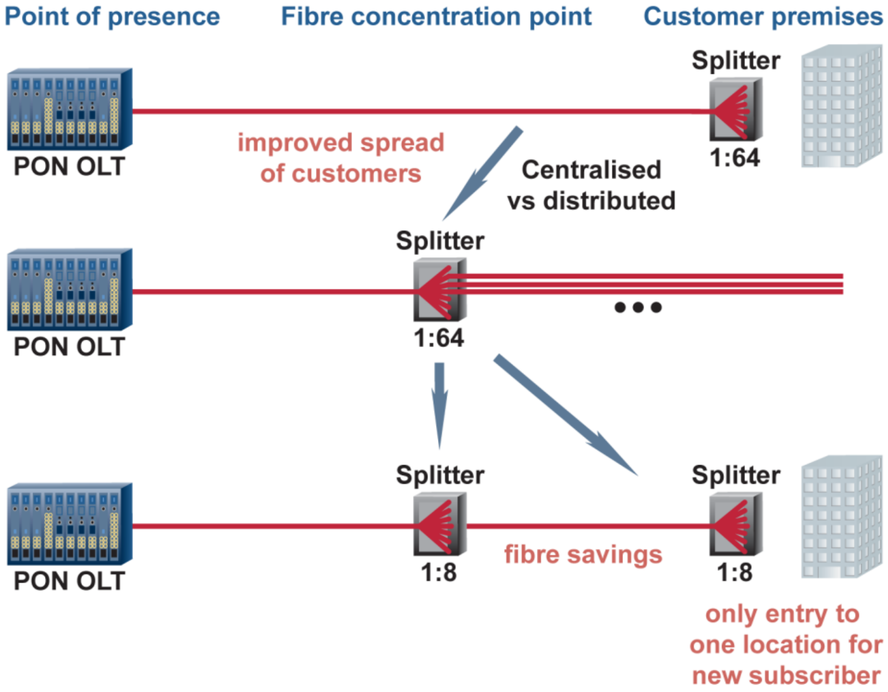


Figure 20: Centralized and distributed splitting in a PON

To enable infrastructure sharing in a technology agnostic way through fibre unbundling the splitter sites closest to the end-users must be a fibre flexibility point (FFP) thus ensuring that every service provider will have the best possible access to each subscribers fibre.

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

When a point-to-point outside plant is deployed at the POP level, a PON service provider will install all his splitters in the POP. This will result in a reduction in feeder fibre usage in the outside plant. An additional drawback could be the location of the POP which might be closer to the end-user (fewer homes passed) since every home will have one (or more) fibres connected 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.

4.3 Ethernet point-to-point

For Ethernet architectures, there are two options available, one involving a dedicated fibre per subscriber between the Ethernet switch located at the POP and the home; or one fibre to an aggregation point and a dedicated fibre from there onwards. Implementing the first option is simple and straightforward whilst the second limits the fibre usage in the access loop and, more often than not is used in FTTB solutions.

4.3.1 Ethernet point-to-point solutions

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

From the POP, individual subscriber feeder fibres are connected to a distribution point in the field. This is often a fibre flexibility point which is either located in an underground enclosure or in a street cabinet. From this distribution point, fibres are then connected to the homes.

Large numbers of feeder fibres do not pose any major obstacle from a civil engineering perspective. However, since the fibre densities in the feeder and drop are very different, it is likely that a variety of cabling techniques will be employed in the two parts of the network.

Deployment can be facilitated by existing ducts, as well as through other right of way systems such as sewers or tunnels.

Fibres entering the POP are terminated on an optical distribution frame (ODF) which is a flexible fibre management solution allowing subscribers to be connected to any port on the switches in the POP.

To cope with the large number of fibres in the POP and the reduced space, the density of the fibres need to be very high. There are already examples of a high-density ODF on the market that can terminate and connect more than 2,300 fibres in a single rack. Acceptance rates in FTTH projects need 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 subscribers. This minimizes the number of unused active network elements in the POP.

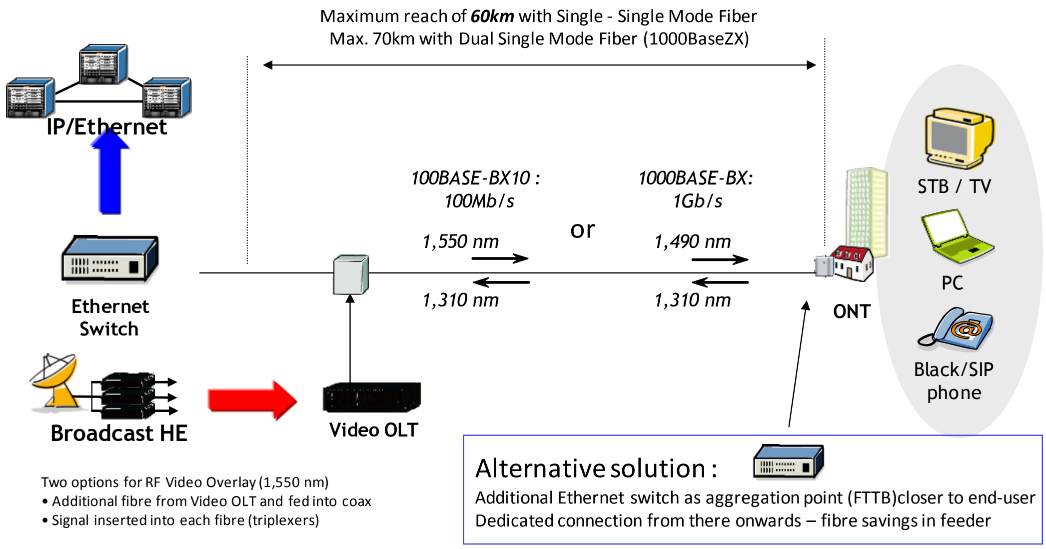


Figure 21: Ethernet network diagram

4.3.2 Transmission technologies

Recognizing the need for Ethernet in access networks, an IEEE 802.3ah Ethernet in the First Mile (EFM) Working Group was established 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 single mode fibre.

The EFM standard was approved and published in 2004 and included in the basic IEEE 802.3 standard in 2005.

The specifications for transmission over single mode 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 subscriber towards the POP) and one for downstream (from the POP towards the subscriber). The table provides the fundamental optical parameters for 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

To cope with unusual situations, the market offers optical transceivers with non-standard characteristics and for example some are capable of bridging significantly longer distances making them suitable for deployment in rural areas.

As 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.

For highest reach and power 1000-BX20, -BX40 or –BX60 are already available on the market. 10GE interfaces are also becoming available.

When taking these P2MP and P2P access network approaches, it makes sense to allow for the insertion, on the same OLT chassis line cards, of GPON, XG-PON and NG-PON2, as well as Ethernet P2P and 10G Ethernet P2P. This will provide Service Providers with all the flexibility to address their customers' needs while consolidating the Central Office.

4.3.3 RF-based video solutions

The features of IP-based video solutions are superior to that of simple broadcast solutions and have, therefore, become an indispensable part of any triple-play offering. Frequently, RF video broadcast overlays are needed to support existing TV receivers in subscriber households. PON architectures usually achieve this by providing an RF video signal, compatible with cable TV solutions, over an additional wavelength at 1550nm. Point-to-point fibre installations offer two different approaches, depending on the individual fibre installation.

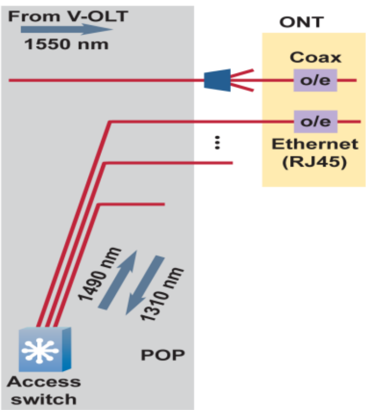


Figure 22: RF video overlay using a second fibre per subscriber, deployed in a tree structure.

The first approach involves an additional fibre per subscriber which is deployed in a tree structure and carries an RF video signal which is fed into the in-house coaxial distribution network. With this option, the split factors (e.g. ≥ 128) exceed those typically used for PONs thus minimizing the number of additional feeder fibres.

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. The wavelengths are separated at the subscriber end and the 1550nm signal converted into an RF signal for coax distribution, with the 1490nm signal being operational on an Ethernet port.

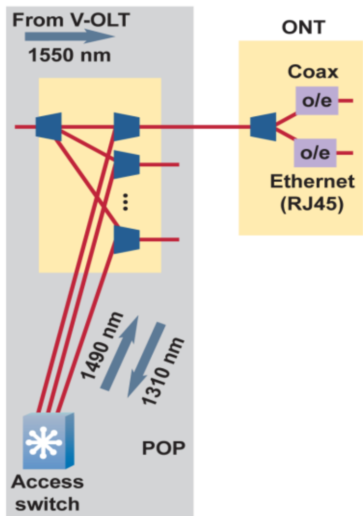


Figure 23: Insertion of RF video signal into point-to-point fibres.

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

New technological approaches are becoming available to improve the reach and quality of the RF Overlay signal. These include incorporating the RF Overaly amplifiers and wdm muxes inside the OLT chassis, thus reducing power losses and CAPEX with the result that the whole system can be integrated under the same Network Management System.

4.4 Subscriber equipment

In the early days of broadband, home internet connectivity was delivered to PCs through simple, low cost data modems. This was 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 PDA, places higher demands on home-user equipment. The “digital home” has arrived.

There are two distinct options available in the home environment: the optical network termination (ONT), where the fibre is terminated; and the subscriber premise equipment (CPE) providing the necessary networking and service support. These options may be integrated or separated, depending on the demarcation point between service provider and end-user.

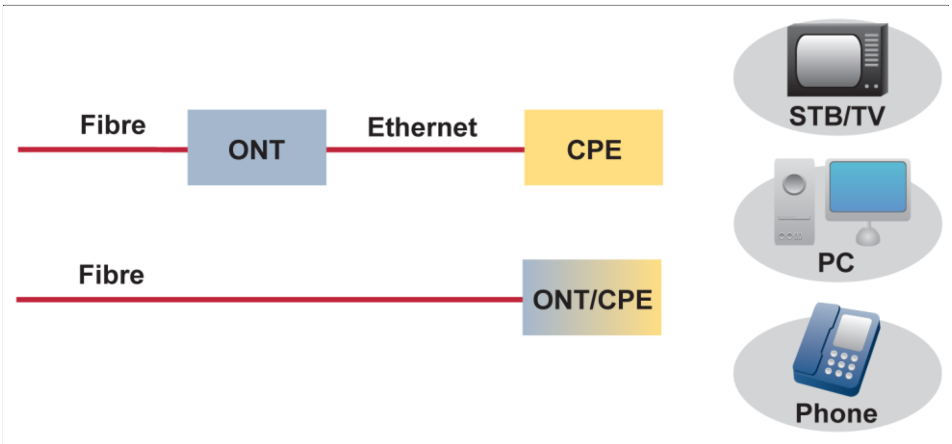


Figure 24: Possible configurations of the ONT and CPE

With the creation of more advanced technologies and devices, the concept of the residential gateway (RG) has emerged. CPE combines a broad range of networking capabilities including options and services, such as optical network termination, routing, wireless LAN (Wi-Fi), Network Address Translation (NAT) as well as security and firewall. These technologies are also capable of incorporating the necessary capabilities needed to support VoIP and IPTV services, USB connectivity for shared printers, telemetry dongles, storage media centres and quality of service requirements. Some ONTs also provide interfaces suitable for home networking over power lines, phone lines and coaxial cables.

For deployment of the CPEs the service providers can choose from two scenarios:

- **CPE as demarcation with the subscriber.** CPE becomes an integral part of the service provider’s product range, terminating at the incoming line and delivering services to the subscriber. The service provider owns and maintains the CPE thus controlling the end-to-end service delivery, which includes the termination (ONT), and integrity of the transmission as well as delivery of service. The subscriber connects his home network and devices directly to the subscriber-facing interfaces of the CPE.

- **Network Interface as a demarcation line between the subscriber and the service provider.** The ONT is provided by the service provider and the ONT's Ethernet port(s) is the demarcation line with the subscriber connecting 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 involving different service providers for connectivity and services. 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 CPEs 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 subscriber share.

4.5 Future technology development

4.5.1 Residential bandwidth trends

Access and backbone bandwidth requirements are expected to continue to grow exponentially which means that global peaks and average bandwidths will inexorably increase and access bit-rate requirements will soon exceed 100Mbps.

Convergence to mobile is also expected. As more and more data is now being exchanged between mobile users (smart phones, tablets, etc), residential accesses might become part of the backhaul network, thus offloading the mobile backhaul network. EAP authentication mechanisms will allow the user to seamlessly switch from both networks.

4.5.2 Business and Mobile bandwidth trends

4G and future mobile technologies will require more resources from the network in terms of coverage, bandwidth availability and symmetry, jitter and latency. These issues can only be addressed in an *all fibre* topology.

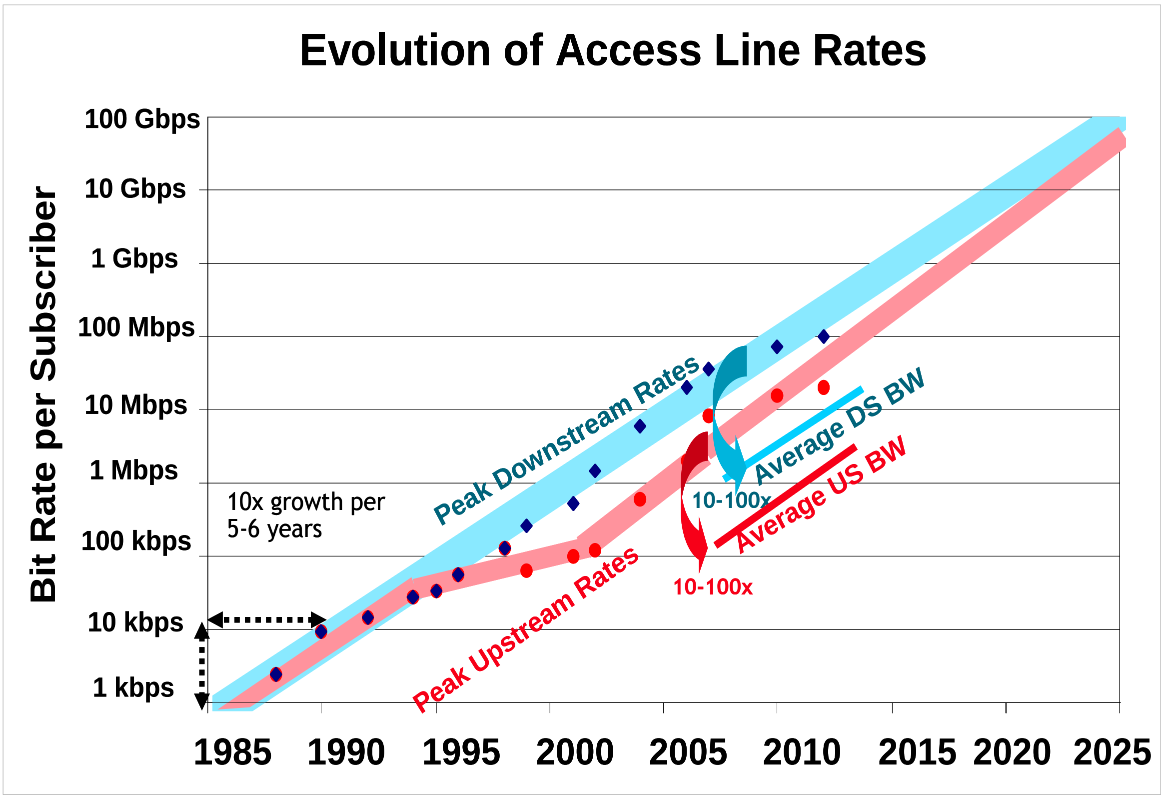


Figure 25: Evolution of access line rates

4.5.3 Passive optical networks

About the 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. The new class C+ optics add a further 4dB of link budget providing the option of additional distribution splitting capabilities or more reach. GPON extenders increase capabilities further to 60km reach or 128 end-users.

Although GPON is perceived to possess sufficient bandwidth for the coming years, XG-PON is already standardized.

XG-PON is a natural continuation in the evolution of PON technologies, increasing bandwidth four-fold to 10Gbps, with a reach extending from 20 to 60 km and split from 64 to 128. It should be noted that the split and reach maxima are not obtainable simultaneously. Most importantly, these evolutionary technologies will avoid the need for significant upgrades to the existing outside plant.

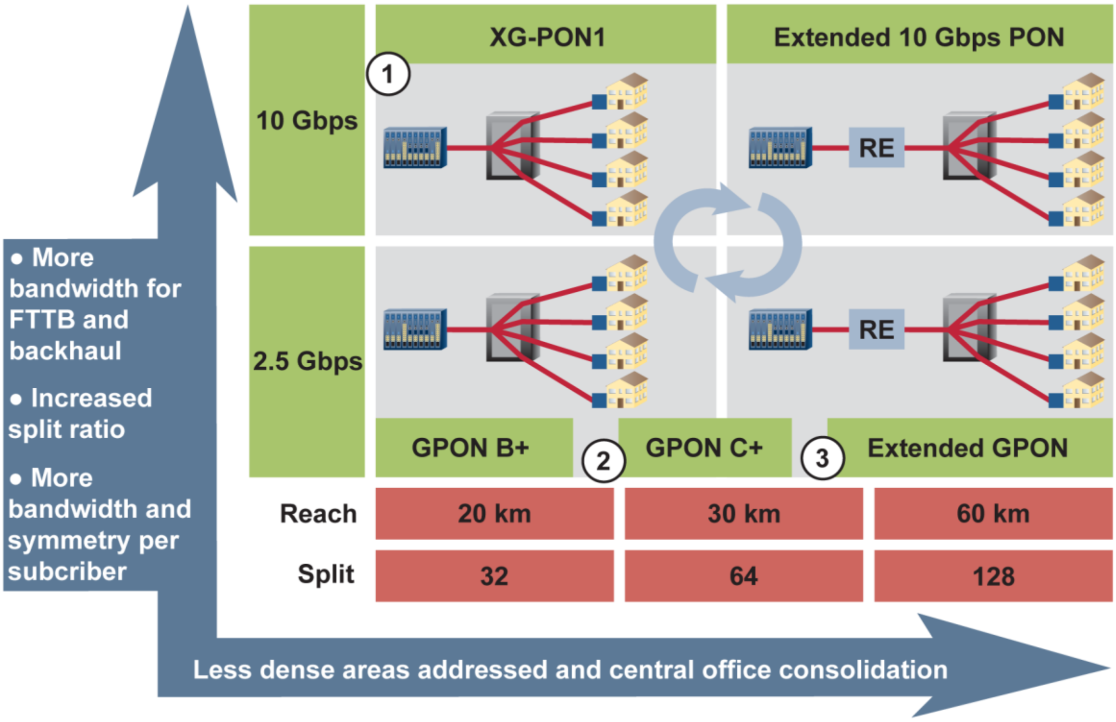


Figure 26: Evolution of ITU PON standards

About the IEEE standards

The 10G-EPON (10-Gigabit Ethernet PON) standard was ratified in September 2009 under the title of 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 subscriber data. The 802.3av Task Force has concluded its work, with the 802.3av and will be included in the IEEE 802.3 set of standards.

4.5.4 Next-generation PON technologies

The next step after XG-PON could involve increasing the line speed of the fibre to 40 or even 100Gbps.

As previously mentioned, before 2015 ITU/FSAN will have the new standard for NG-PON2 ready. This will provide long term technological support for the new challenges posed to operators: bandwidth growth for business services and mobile backhaul.

This new standard will leave room for the coexistence of different wavelengths as well as improved reach and split-ratio. Several technologies are being considered for this standard, though TDWDM seems to be the most feasible.

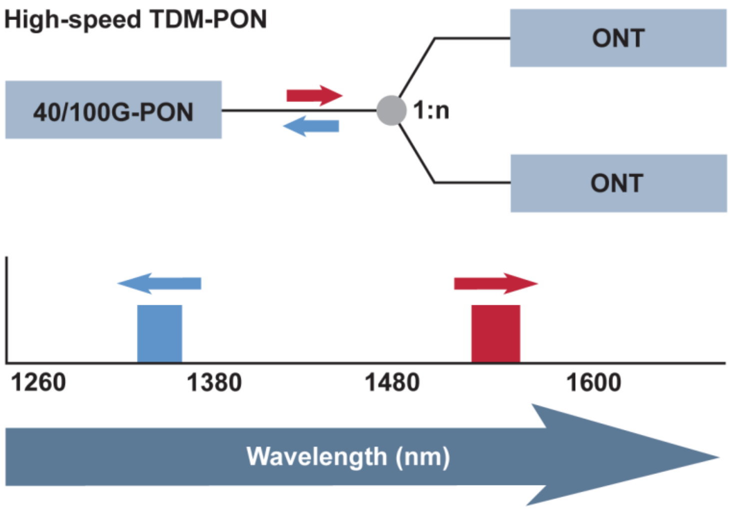


Figure 27: Wavelength plan for TDM-PON

An alternative already seen in 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. The result is the provision of very-high, uncontended bit rates for each connected subscriber offering the same inherent security as dedicated fibre. These architectures use wavelength filters instead of splitters in the field to 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 level of physical infrastructure.

The key challenge for WDM-PON is to provide diverse upstream wavelengths while having a single ONU type – concept of colourless ONUS. Communications providers consider it unmanageable to have a different ONU per wavelength, and tuneable lasers are, as yet, too expensive. The technologies required for WDM-PON are available today, however, a reduction in costs is necessary if they are to be considered suitable for mass deployment. To ensure that the evolution process has minimal impact on the services for end users and on current O&M systems, provisioning and inventory are vital for the success of the acceptance of this new technology.

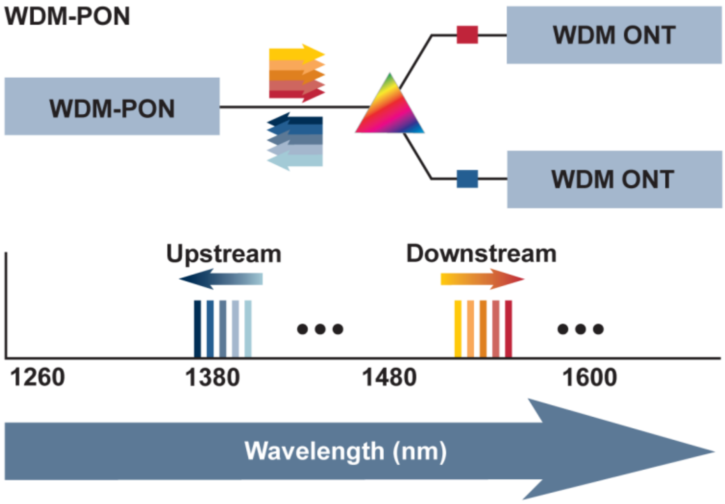


Figure 28: Wavelength plan for WDM-PON

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

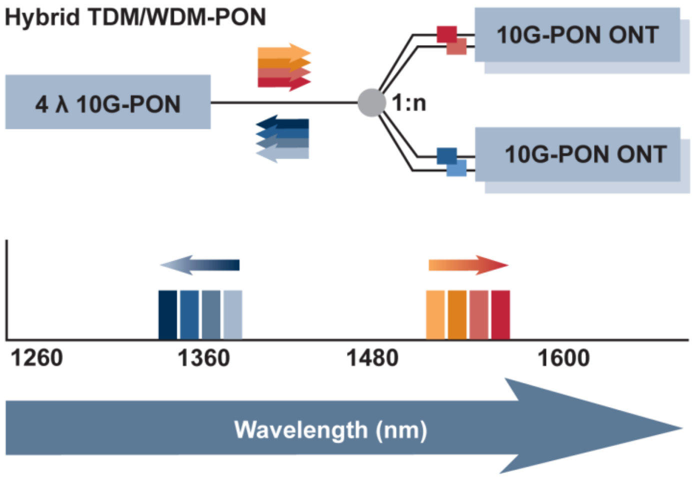
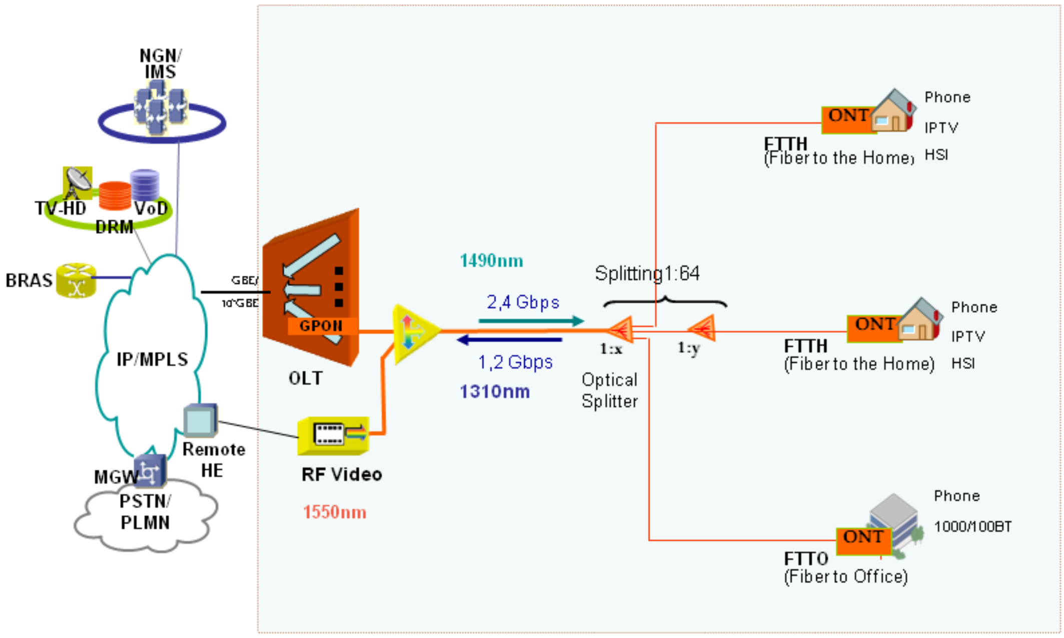


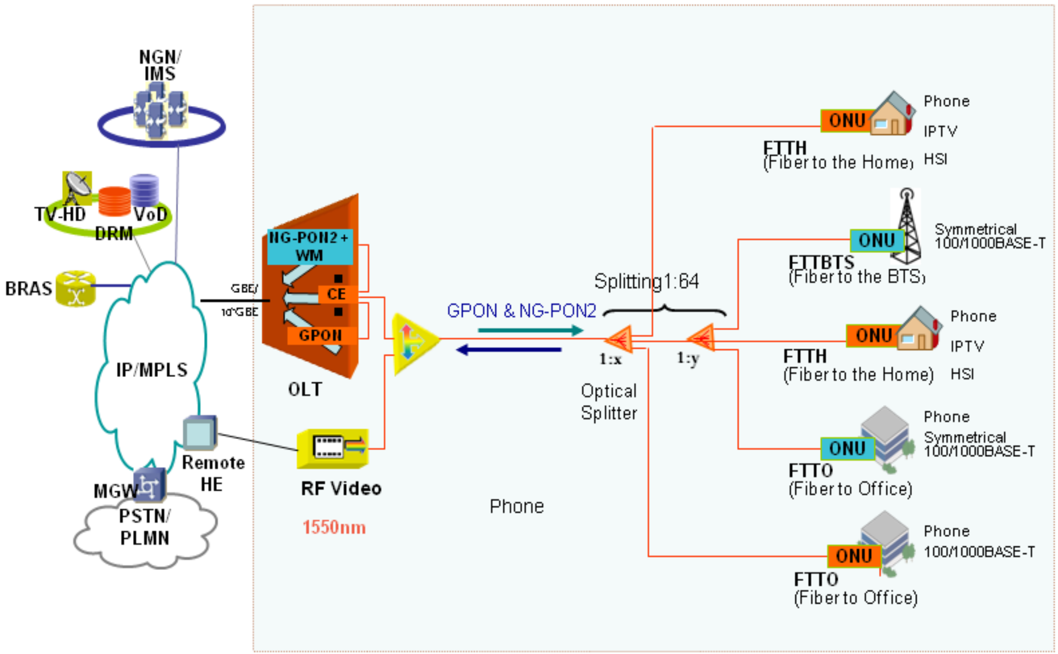
Figure 29: Wavelength plan for hybrid TDM-WDM-PON

After 2015 increased growth of installed transmission capacity using a higher number of wavelengths is expected. This will also allow for wavelength unbundling and an increase in reach as well as cheaper ONUs.

The following diagram is the typical arrangement of a current GPON network:



Evolving from this GPON network requires the proper placement of coexistence elements (CE) as well as ensuring that the current GPON ONUs are equiped with the WDM filters as described in ITU-T G.984.5. To ascertain this, simply insert a NG-PON2 blade at the OLT and route the fibres to the Coexistence Element (CE). It is now possible to provide the next generation of bandwidth services to the end users.



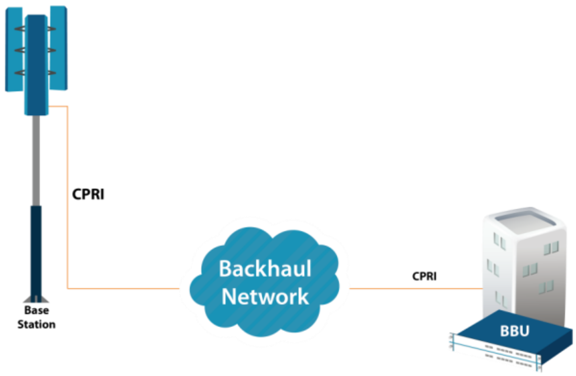
NG-PON2, with the availability of more wavelengths, will make it feasible to deploy logical point to point connection. These are currently considered to be WDM-PON.

Beyond NG-PON2, technology is expected to address a converged WDM/TDM GPON running at 100 Gbps and reaching more than 100 Kms with a split ratio of 1:1024.

4.5.5 Applications of Next Generation FTTH technologies

4.5.5.1 CPRI backhaul

As new FTTH technologies allow for the concept of dedicated wavelengths on top (logical P2P connections), CPRI backhauling, all the way from the CO to the antenna using a dedicated wavelength per cell site, can be used. This allows for very low (<1us) and reduced jitter and packet loss.



In addition, the common public radio interface (CPRI) specifications are standardized to provide a cost effective solution for service providers thus supporting emerging broadband wireless topologies. OPEX & CAPEX will be reduced due to:

- fewer cell site visits (upgrades can be performed centralized)
- reduced site costs (site rental) and civil work for new sites
- elimination of heating and cooling of enclosure
- improved security (no cabinets to break into)
- improved X2 performance

4.5.5.2 Small cells

Mobile-network bandwidth demands continue to increase, driven by the proliferation of newer mobile devices such as smartphones and tablets. Emerging machine-to-machine requirements, including sensor networks and connected car platforms, will further add traffic loads to today's mobile networks.
Small cells introduce additional end points and are deeper in the network and closer to subscribers. This necessitates the need for activating, monitoring, optimizing and assurance of backhaul networks. A small-cell backhaul introduces additional layers of aggregation in the backhaul network, creating hub-and-spoke topologies.

The evolution towards small cell architecture configurations will redefine the backhaul need for mobile networks (capillarity of small cells). The upgrade of backhaul capacity might provide the operators with the golden opportunity to share fixed and mobile investments: in particular expanding FTTH coverage while meeting backhaul needs. NG-PON2, with all the value added technological benefits is the obvious choice to address the new elements of this network.

4.5.6 Conclusion

All in all, shared platforms and networks, symmetric high bandwidth pipes, large capacities and unified network management are the future trends. Though XG-PON is the natural evolution for GPON networks, the need for larger bandwidths will lead operators to migrate directly to NG-PON2. However, much work still remains to be done regarding cost and performance of components, especially to tuneable receivers and tuneable transmitters at the ONU. Also, ensuring that the evolution process has minimal impact on the services for end users and on current O&M systems is key to the success of the move towards NG-PON2.

5 Infrastructure Sharing

Due to the high costs of FTTH deployment, cooperation of fibre and infrastructure networks has been hotly discussed by interested parties. In addition, regulatory bodies are closely observing activities in this field with the aim of encouraging a competitive environment thus avoiding monopoly situations.

There are various “layered” FTTH business models operating in the market today; this has paved the way for non-traditional telecom operators to become involved in this sector. These include utility providers, municipalities, real estate developers, and governments etc. all of which are looking to find the optimal way of bringing fibre access to the home.

More detailed information about this subject is available in the *FTTH Business Guide*, accessible on the FTTH Council Europe website.

5.1 Business models

Listed below are four business models operating on the market today:

1. **Vertically integrated** – one major operator, such as infrastructure owner, network operator, service provider as well as the content provider with passive active and service layers, provides services directly to the subscriber. Traffic is conveyed on their own network and other communication providers can operate on the passive infrastructure (exclusively or wholesale).

2. **Passive sharing** – allows the infrastructure owner to deploy passive access to the passive infrastructure allowing each to provide active and service layers to the subscriber.

3. **Active sharing** – allows access to other service providers, who are responsible for maintaining the subscriber base.

4. **Fully separated** – some countries operate a fully separated model involving an infrastructure owner, network operator and a number of service providers.

5.2 Infrastructure sharing

For each of these models, infrastructure has to 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 within a substantial region by drawing or blowing their fibre cables. They then compete with one another on available 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 with one another on available services.

   Access to fibre can be granted at various points in the network: at the central office or POP or at some place between the building and the central office or in the basement of an MDU.
   This point is known as the fibre flexibility point (FFP) and is the location point where the various service providers gain access to the subscribers.

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

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

3. **Wavelength** - multiple retail or wholesale service providers may use the FTTH network by connecting at a wavelength layer interface, and compete with one another on available services.

4. **Packet** - multiple retail service providers may use the FTTH network by connecting at a packet layer interface, and compete with one another on available services.

6 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 Fibre in the Home	Includes fibre entry devices, internal fibre cabling and final termination unit. (Fibre in the Home has a dedicated section, see Chapter 7 of this Handbook).

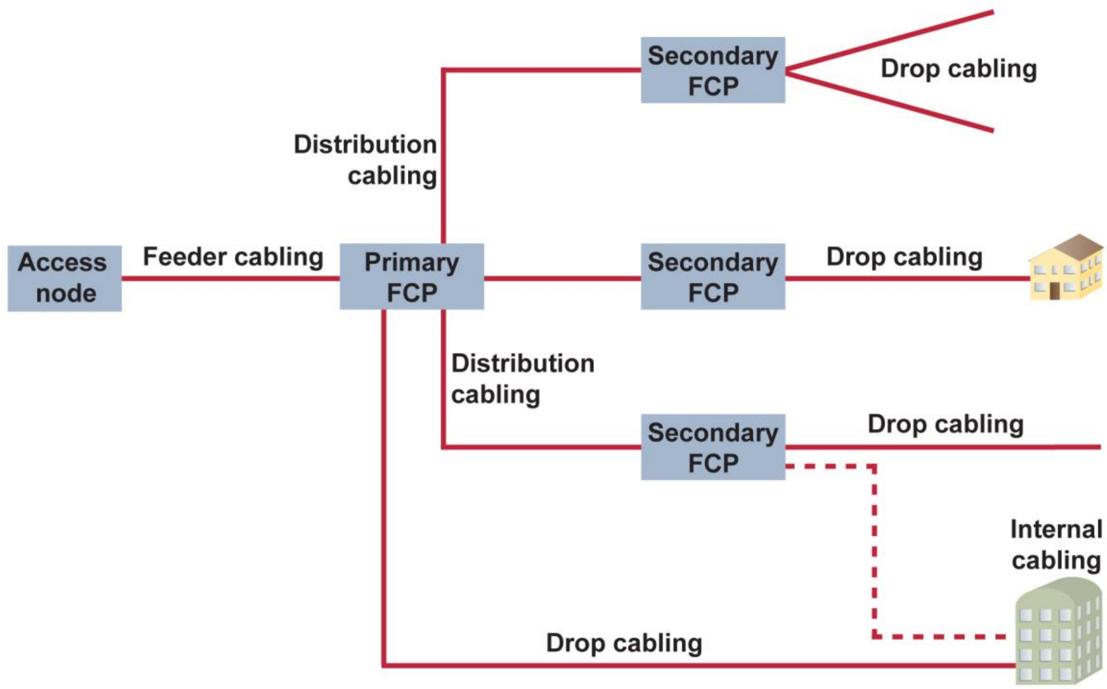
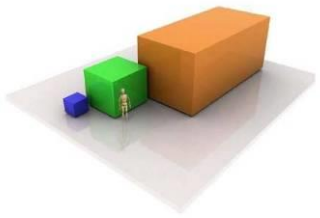


Figure 30: Main elements in a FTTH network infrastructure.

6.1 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 subscriber. The function of the access node is to house all active transmission equipment from the telecom provider, 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
400-2,000	in-house	concrete
2,000 or more	building	

Figure 31: 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 be connected to the active equipment and run out of the building into the FTTH network area. All other physical items such as Optical Distribution Racks (ODR's) and fibre guiding systems are used to manage the optical fibres within the node.

Fibres are connected either as cross-connect or inter-connect. Typically for an FTTH Access Node an inter-connect method is used due to cost as fewer fibre termination building blocks are required. To maintain maximum flexibility in an open access network, for example, a cross-connect method might be the alternative.

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 vandalism must be considered. In addition an uninterrupted power supply (UPS) and climate control are necessary infrastructure elements within an Access Node Building.

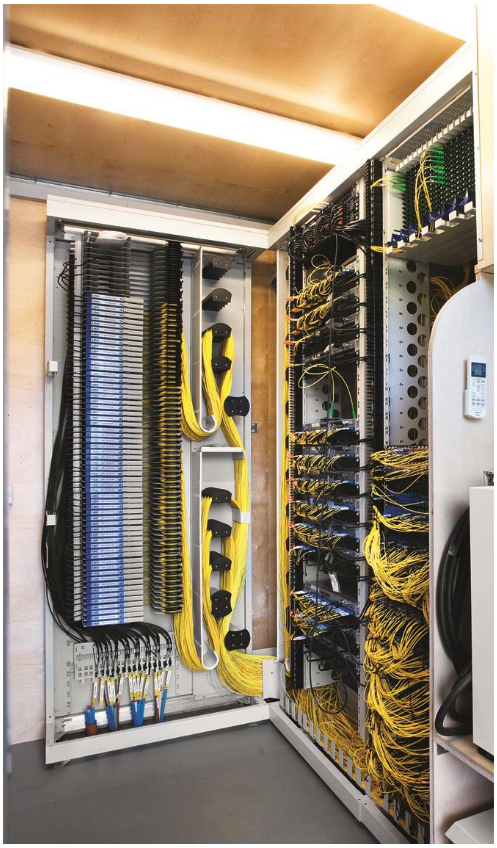


Figure 32: view into a POP equipped with an ODR, Ethernet switches, climate control and UPS.

6.2 Feeder cabling

The feeder cables run from the Access Node to the primary fibre concentration point (FCP) and 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 (up to 729/864) are needed to provide the necessary fibre capacity in order to serve the FTTH area.

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

It is advisable to select a passive infrastructure capable of handling a number of different network architectures should the need arise in future. In addition, considering modularity into the fibre count in the feeder cables is necessary.

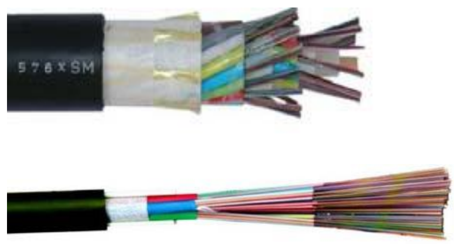


Figure 33: High-count fibre cable.

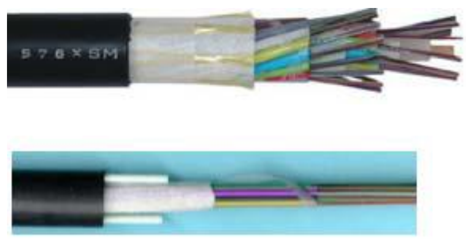


Figure 34: Modular cable in duct system

In regard to 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 through the use of several smaller cables, for example, 48-72 fibres (Ø 6.0 mm) or up to 288 fibres (Ø 9.4 mm) cables. If flexible textile sub-ducts are used, smaller cables are not needed. A flexible sub-duct (see also Chapter 8) only takes up the space of the cables hence bigger and/or more cables can be installed which maximizes the fill ratio or capacity of the duct. For example in a typical 40 mm ID HDPE duct flexible sub-ducts allow for the installation of 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 incorporated to help balance costs.

6.3 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 and is generally known as the first concentration point (FCP). At this stage 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, reducing subsequent distribution cable lengths thus minimising additional construction costs. In principle, the location of the primary FCP may be determined by other factors such as the location 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 an FCP will be required to configure or reconfigure fibres or to carry out maintenance and conduct fibre testing. Where possible this activity should be conducted without interference to existing fibre circuits. Although guaranteeing this is not possible, newer pre-connectorized plug-and-play solutions are available that eliminate the need to access closures, which helps to reduce faults and building errors.

Underground and pole-mounted cable joint closures are relatively secure and not visible, however immediate access may be difficult as special equipment is necessary. Security and protection from vandalism should be considered for street cabinet based FCPs.

6.4 Distribution cabling

Distribution cabling that connects the FCP to the subscriber does not usually exceed distances of 1km. Cables will have medium-sized fibre counts targeted to serve a specific number of buildings or a defined area.

Cables may be ducted, direct buried or grouped within a common micro-duct bundle. The latter allows 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.

For aerial networks the arrangement is similar to that of feeder cables.

Distribution cables are smaller in size than the feeder cables and have a total fibre count in the region of 48-216.

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

Ducting can vary. In a Greenfield application (installation of new ducts) ducts can vary from a standard 40 mm internal diameter HDPE to micro-ducts. With existing duct infrastructures, all types of ducts can be used (PVC, HDPE, concrete) sub-ducted with rigid or flexible sub-ducts.

Cables installed in micro-ducts may be blown to distances in excess of 1km. Micro-ducts, such as flexible sub-ducts, offer a means of deferring cable deployment.

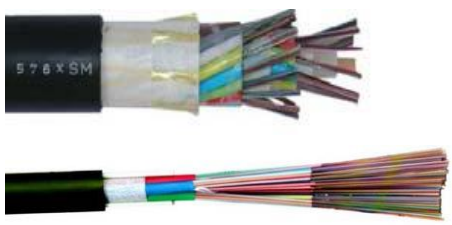


Figure 35: High fibre count cable

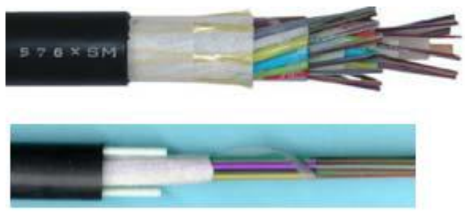


Figure 36: Modular cable in duct system

Figure 37: Direct buried tubes with micro-cables

6.5 Secondary fibre concentration point

In some instances, the fibres may need to be separated within the network before being connected to the subscriber. As in the case of the primary FCP, this second point requires flexibility to allow for speedy connection and reconfiguration of the fibre circuits. This is called the secondary FCP point.

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 additional 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 micro-duct 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 “hand-hole” for access. Secondary FCPs based on street cabinets may require security and protection from vandalism; however, immediate access to fibre circuits should be relatively simple.

6.6 Drop cabling

Drop cabling forms the final external link to the subscriber and runs from the last FCP to the subscriber building for a distance not exceeding 500m which is reduced considerably in high-density areas. Drop cables used for subscriber connections, usually contain a number of fibres but may include additional fibres for backup or for other reasons. Drop cable normally the only link to the subscriber lacking network diversity.

For underground networks the drop cabling may be deployed within small ducts, within micro-ducts or by direct burial to achieve a single dig and install solution. Overhead drop cables will feed from a nearby pole and terminate at a chosen point on the building for onward routing to the termination unit. In either case, the cable assembly may be pre-terminated or pre-connectorized for rapid deployment and connection, as well as to minimize disruption during installation.

Air blown cables and fibre units can enter through the fabric of the building using suitable micro-duct 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 micro-duct (external to internal material grade).

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

6.6.1 Direct install cables

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

The structure can be non-metallic with an 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.

6.6.2 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 extremely 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 capabilities to that of metal protected cables. On average, non-metal cables are lower in cost.

Figure 38: Metal protected direct buried cable

Figure 39: Direct-buried drop cable without metal protection

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

6.6.3 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 an optical cable with a steel wire embedded in the same jacket. 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-connectorized. This is an advantage during installation as time spent in the home is reduced and also aid planning.

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

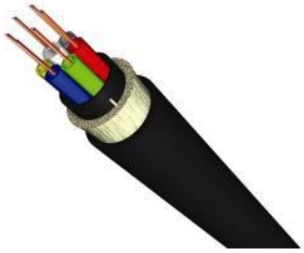


Figure 40: Example of ADSS cable

Figure 41: Example of Figure-8 cable

6.6.4 Façade cables

Façade installation is suitable for buildings such as large MDU's or terraced properties. This method can also be employed in Brownfield deployments where running cables are not suitable. The cables are stapled along the outside of the building with closures, branches or ruggedized connection points providing the drop to subscriber. However, appearance may be an issue with owners and authorities, particularly in conservation areas.

Façade cables have a similar structure to direct install cables and also require UV resistance and as these cables are normally used in 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.

7 In-house Cabling-Fibre in the Home

Homes today are expected to become intelligent environments – Smart Homes. A Smart Home is a house that has advanced, automatic or remotely operated control systems to manage the living environment; these include temperature gauges, lighting, multimedia, security, window and door operations as well as numerous other functions.

The expression “Smart Homes” is becoming increasingly trendy but there is much more to be said about this concept than first meets the eye. The FTTH Council Europe is interested in promoting this area and to this end decided to form a new committee: The Smart Cities Committee. The work carried out by this Committee has resulted in the FTTH Smart Guide which can be downloaded from the FTTH Council resources area.

In-house installation or Fibre in the Home extends from an entrance facility normally located in the basement of a building to an optical telecommunications outlet (socket) in the subscriber’s premises. This is a typical model for the majority of European MDUs. In the case of Single Dwelling Units an “OTO” can also be integrated into the Building Entry Point. In both scenarios an optical telecommunication socket can form an integral part of the centralised multimedia distribution cabinet.

Unfortunately the residential wiring solution is rarely considered when building a network but is probably the weakest link in the delivery of service. Why are wired networks necessary in the home, when wireless solutions fulfil all the needs? Some arguments for this on-going debate are:

- wired networks are more stable and dependable than wireless and channel interference in wired network from other devices is non-existent (or other access points operating in the same channel).
- wired networks are faster than their wireless counterparts with, multi-media, voice, video, network games and other real time applications performing better in a wired network.
- wired networks are more secure despite the existence of encryption in wireless networks. It is still possible for a determined hacker to access the network with the right tools or awareness of vulnerabilities in the network but wired networks can only be connected from within the home thus making it difficult for the hacker to access.

The aim of this section is to provide the best practices from available technical guidelines as well as from the workflow point of view for the physical media of layer 1 of the Fibre in the Home installation. Generally the goals of the technical guidelines are to ensure that the in-house installation can be shared by two or more service providers serving the same location. In addition these guidelines will also highlight the benefit that in-house installation to any given building is a one-time activity.

While the technical guidelines describe a number of important aspects of the in-house installation, it does not represent a complete solution. Each FTTH developer plans and implements an FTTH network according to its own business case, plans and deployments methods.

7.1 Fibre in the Home cabling reference model

The in-house installation (FITH) extends from a building entrance facility placed typically in the basement of an MDU building to an optical telecommunications outlet (socket) in the subscriber's premises.

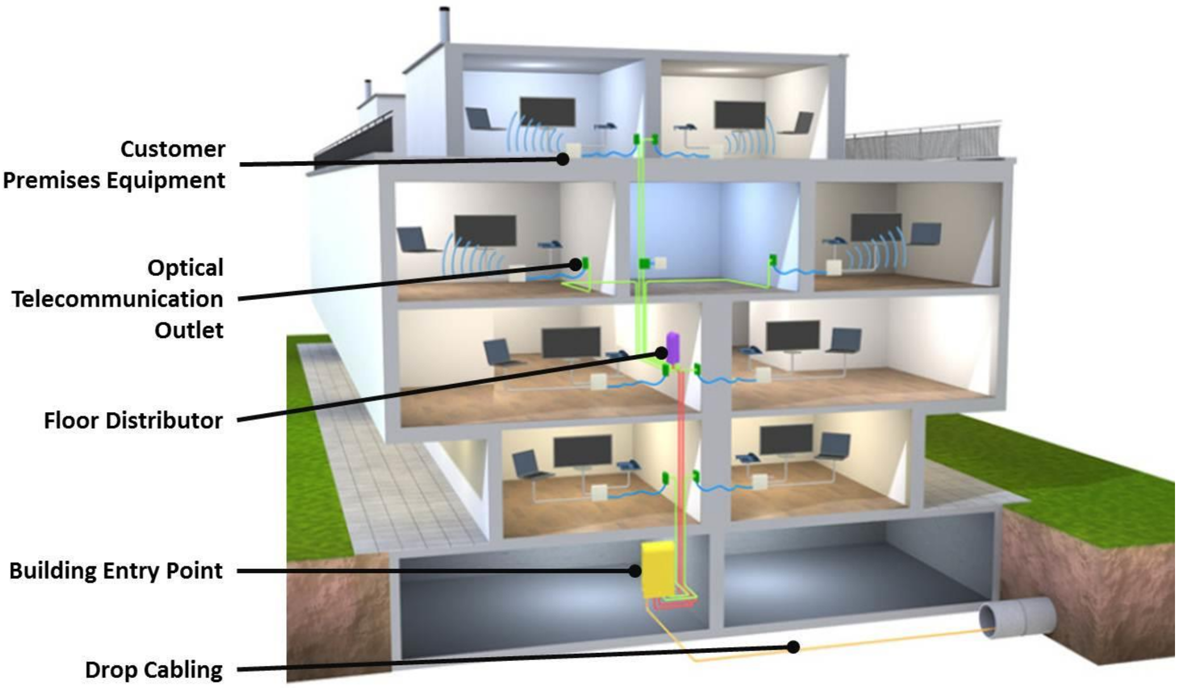
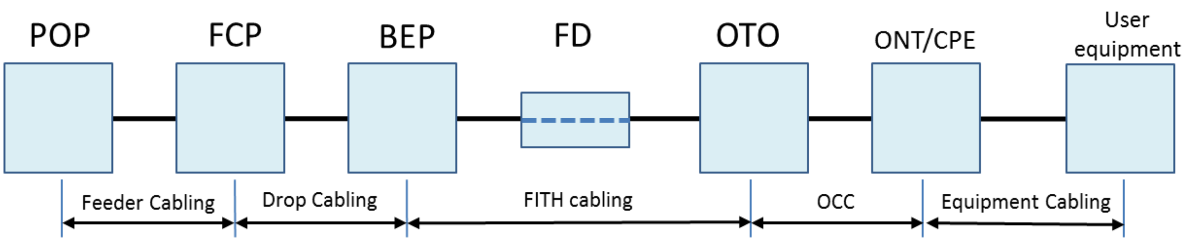


Figure 42: Art design of basic Fibre in the Home network elements

A reference model is used, based on international standards, to specify physical infrastructure elements and described processes.



Infrastructure elements of the reference model

POP	Point of Presence	Act as the starting point for the optical fibre path to the subscriber
	Feeder Cabling	Feeder cables run from the POP to the Fibre Concentration Point
FCP	Fibre Concentration Point	In the Fibre Concentration Point a feeder cable will eventually be converted to smaller drop cables. At this stage the feeder cable fibres are separated and spliced into smaller groups for further routing via drop cables
	Drop Cabling	Connects the FCP to the subscriber and may form the last drop to the building

BEP	Building Entry Point	Is the interface between the drop cabling (optical access network) and the internal "in-the-home" network. The BEP allows the transition from outdoor to indoor cable. The type of transition may be a splice or a removable connection
FD	Floor distributor	Is an optional, sub-dividing element between the BEP and the OTO located in the riser zone which allows the transition from the vertical to the horizontal indoor cable
FITH cabling	Fibre in the Home cabling	The FITH cabling links the BEP to the OTO. The main components are an optical indoor cable or similar, blowing-based, installation of fibre elements
OTO	Optical Telecommunications Outlet	The OTO is a fixed connecting device where the fibre-optic indoor cable terminates. The optical telecommunications outlet provides an optical interface to the equipment cord of the ONT/CPE
ONT	Optical Network Termination	The ONT terminates the FTTH optical network at the subscriber premises and includes an electro-optical converter. The ONT and CPE may be integrated
CPE SPE	Customer Premise Equipment Subscriber Premise Equipment	The subscriber or customer premises equipment (SPE/CPE) is any active device, e.g. set-top box, which provides the subscriber with FTTH services (high-speed data, TV, telephony, etc.). The ONT and SPE/CPE may be integrated
OCC	Optical Connection Cable	The connection cable between the optical telecommunication outlet (OTO) and the customer premises equipment (CPE)
	Equipment cabling	The equipment cabling supports the distribution of a wide range of applications such as TV, telephone, internet access etc. within the premises. Application-specific hardware is not part of the equipment cabling
	User equipment	The user equipment such as TV, phone, or personal computer, allows the subscriber to access services

7.2 Riser Cabling

For larger multi dwelling properties, the internal cabling forms a major part of the Fibre in the Home infrastructure. Typical architectures using above mentioned basic network elements are based on these two network structures:

- direct drop architecture (Point to Point)
- riser architecture with or without floor distribution boxes

The interconnection between the BEP and the Floor Distributor and/or the Optical Termination Outlet is known as the riser cabling using conventional cable, Micro-duct deployment or installation time efficient pre-connectorised solutions.

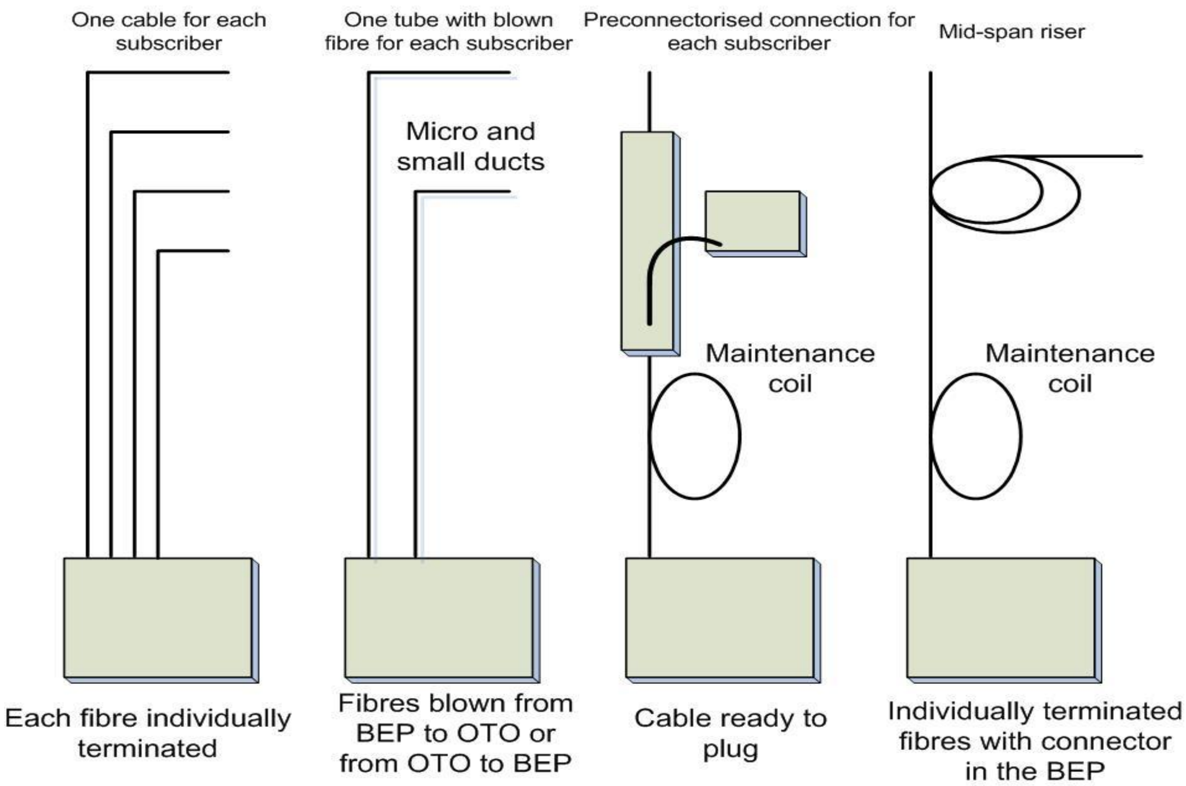


Figure 43: Example of riser architecture

Riser fibre cables or ducts fed with fibres are normally installed in existing cable conduits e.g. electrical installations or individually installed cable conduits for the FITH network. It is common to install a vertical riser from the basement or the top floor of the building. The vertical riser represents the most time consuming installation part of in-house cabling, especially in the section where local fire regulations need to be taken into account as they often pass stairways used as escape routes.

Depending on the architecture, the number of fibres per subscriber and 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.

As these cables are installed in difficult locations (e.g. low bending radius across edges), use of bend-insensitive fibres is a common practise for today’s Fibre in the Home cabling.

7.3 Fibre in the Home cabling – general considerations

7.3.1 Fibre characteristics

At the BEP, fibres from the drop cabling (outdoor cable) and fibres from the in-house cabling (indoor cable) have to be connected. The specifications of these fibres are described in the different standard fibre categories and must fulfil certain requirements as described below. Drop and in-house cabling can be realised by using blowing techniques in micro-ducts. The deployment of G657 fibres (IEC 60793-2-50 B6), especially G.657.A2 grade (IEC 60793-2-50 B6a2) is recommended as they fully secure transmission over the whole 1260-1650nm window and yet are totally compatible with and compliant to G.652.D. This is true even in demanding environments, or when using compact 200µm coating for higher fibre density, or more advanced cable designs.

Cable type	ITU Code	IEC Code
Outdoor cables	G.652.D	IEC 60793-2-50 B1.3
Outdoor cables	G.657.A1/A2 with possible 200µm coating option	IEC 60793-2-50 B6a1/a2 with possible 200µm coating option
Indoor cables	G.657.A2/B2/B3	IEC 60793-2-50 B6a2/b2/b3

Figure 44: Fibre characteristics

7.3.2 Splicing compatibility between different fibre types

The splicing of different fibre types with different mode field diameters and tolerances may result in higher splicing losses. Therefore the splicing machine needs to be set properly in each case. To determine the correct splicing loss a bi-directional OTDR measurement should be performed. In practise the splicing loss limit is set at ≤ 0.1dB.

7.3.3 Bend radius requirements

Bend radius in the BEP and outdoor cable sections for standard single mode fibres G.652D should be 30mm and above. Subcategory G.657.A1 fibres are appropriate for a minimum design radius of 10 mm. For a minimum design radius of 7.5 mm. a subcategory G.657.A2 are the most appropriate.

For Fibre in the Home cabling, especially in the OTO and indoor cable sections, the G.657.A2, G.657.B2 (both appropriate for a minimum design radius of 7.5 mm) or G.657.B3 (appropriate for a radius down to 5mm) can be used to preserve the acceptable attenuation and secure the expected lifetime of typically at least 20 years; mechanical reliability expectation for optical fibres, related to mechanical stresses, is detailed for bend-insensitive fibres in the Appendix I of the ITU-T G.657 recommendation edition 3 ("Lifetime expectation in case of small radius bending of single-mode fibre").

These bending performances are of particular interest for installation and maintenance operations for inside networks (central offices, multi-dwelling units, apartments, individual houses) but also for outdoor deployments (splice enclosures, joints, mid-span access, street cabinets and similar).

Cable type	ITU Code	IEC Code	Bend radius [mm]
Outdoor cables	G.652.D	IEC 60793-2-50 B1.3	R 30
Outdoor cables	G.657.A1/A2 with possible 200µm coating option	IEC 60793-2-50 B6a1/a2 with possible 200µm coating option	R 10 for A1 R 7.5 for A2
Indoor cables	G.657.A2/B2/B3	IEC 60793-2-50 B6a2/b2/b3	R 7.5 for A2/B2 R 5 for B3

Figure 45: Bend radius requirements

7.3.4 Cable type

Optical loose tube fibre cables according to the IEC 60794 series or micro-duct cabling for installation by blowing technique according to the IEC 60794-5 series [6] are typically used for installations at the BEP. The compatibility of other cable constructions to the standard cables at the specified interfaces is to be considered.
Special attention should be given to the recommendations of the cable manufacturer and the specified physical limitations which must not be exceeded. Damage by mechanical overload during installation may not be immediately apparent, but can later lead to failures during operation.

7.3.5 Outdoor cable

A wide variety of outdoor cables exist for use in FTTH networks. If pulled in using a winch, they may need to be stronger than blown versions. Blown cables need to be suitably lightweight with a degree of rigidity to aid the blowing process. Outdoor cables are normally jacketed and non-metallic (to remove the need for earthing and/or lightning protection). However, they may contain metallic elements for higher strength or for added moisture protection.
The fibre count of such cables depends on network structure and size of building.
Outdoor cables are covered by IEC 60794-3-11 [7].
The operating temperature range is between –30°C and +70°C.

Figure 46: Example of a Micro-duct cable systems

Figure 27: Example of a conventional loose tube

7.3.6 Indoor cable

Indoor cables installed between the BEP and OTO may be suitable for short runs within a house or long runs through a building. These may range from single fibre cables, possibly pre-connectorised, through to multi-fibre designs using tight buffered or loose tube designs. The fibre count should be defined according to the network structure and may number between 1 and 4 fibres.
Whilst their design may vary, they are all used in customer premises and therefore should offer some form of proper fire protection. Indoor cables are covered by IEC 60794-2-20 [8].
The operating temperature range is between –20°C and +60°C.

Figure 48: Example of a typical easy to install in-house cable

7.3.7 Colour coding of fibres

Fibres within buffer tubes, as well as buffered fibres, are colour coded to differentiate the fibres within the cable. This colour coding enables installers to easily identify fibres at both ends of the fibre link and also indicates the appropriate position of each fibre in the cable. Colours correspond to standard colours in IEC 60304 [5].
For fibre counts above 12, additional groups of 12 fibres should be identified by combining the above sequence with an added identification (for example, ring marking, dashed mark or tracer).

7.3.8 Micro-duct cabling for installation by blowing

This option utilises compressed air to blow fibre units and small diameter cables through a network of tubes to the customer premises. Micro-duct cabling uses small, lightweight tubes which may be a small conventional duct typically less than 16mm in diameter (e.g. 10mm outer diameter). Alternatively they could also be small tubes (e.g. 5mm outer diameter) that are manufactured as a single or multi-tube cable assembly, known as “protected micro-duct”. It should be possible to install or remove the micro-duct optical fibre cable from the micro-duct or protected micro-duct by blowing during the operational lifetime.
Micro-duct optical fibre cables, fibre units, micro-ducts and protected micro-ducts for installation by blowing are defined in the IEC 60794-5 series [6].

7.3.9 Cables containing flammable materials

Indoor cables must have proper fire protection properties. This would typically include the use of a low smoke, free halogen jacket (LSZH). The cable can be constructed in such a way as to afford some degree of protection from flame propagation (for example IEC60332-1-2 and IEC60332-3 category C) and smoke emission (IEC61034-2). The materials may be characterised 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.

7.4 General requirements at the BEP

For the interface between the optical drop cable and the internal “in-the-home” network a BEP is used for splicing or routing the fibres and therefore generally represents the termination of the optical network from the operators’ perspective. For some network structures multiple operators connect the customer to their network at either the POP or Fibre Concentration Point (Open Access Network). But for some network structures all operators terminate their drop cable at the BEP. Such a structure generally requires Multi-Operator housings for the Building Entry Point. Therefore installation of an optical fibre cable and connecting elements at the BEP can be significantly influenced by careful planning and preparation of an installation specification.

7.4.1 Fusion splice at the BEP

Fusion splicing at the BEP is a common practise. The requirements for fusion splices and splice protectors to be used at the BEP are specified below. Splice protector types are heat shrink or crimp.

Characteristics	Requirement
Max. attenuation of splices	≤0.15 dB @ 1550nm
Return loss	> 60 dB
Operating temperature range	–25°C to 70°C

Figure 49: Fusions splice specifications at the BEP

7.4.2 Connection box at the BEP

The size of the fibre management system at the BEP depends on the size of the building, the overall complexity of the installation as well as the network structure.
Typically fibre management at the BEP uses specially designed boxes allowing the correct number of cables in/out, a required number of splices, fibre reserves and correct fibre management. In addition, fibre identification, a store of unconnected fibres, locking systems and future extension of the BEP boxes are important features to consider. With a PON network the BEP housing may also be used to accommodate passive splitters.
The Ingress Protection is important and depends on the conditions within the space dedicated to the BEP. Typically an in-house installation would be IP20 and IP54 for outdoor.
The excess lengths in the connection box and/or splice tray are normally in lengths of no less than 1.5m.

Figure 50: Example of a IP54 BEP

Figure 51: Example of a IP44 BEP

Figure 52: Example of a IP55 BEP

Figure 53: A modular solution suitable for a large-scale multi-dwelling unit

7.4.3 Splice tray

As the BEP's main objective is to hold the fibre management and the splices between the OSP and the indoor cables, splice trays and additional fixing, splice holders and guiding accessories are needed to support the fibre infrastructure on a high level. Strain reliefs, spaces and rules to store over length fibres are designed mainly for future re-splicing. Bending radius protection must always receive the highest attention.
Various types of splice cassette systems are available, which allow for the handling of individual or groups of fibres or even splitter components, depending on the decisions taken in the design phase. The trays have to fulfil the needs for fixing or stacking.

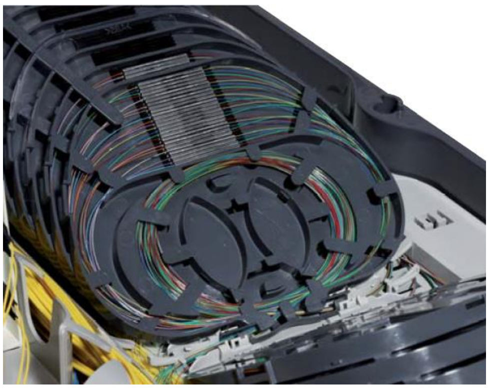


Figure 54: Example of stacked splice trays with individual fibre management

Figure 55: Example of a stack of splice trays

7.4.4 Positioning the BEP

This is always a disputed detail, influenced by the conditions in the field, the building owners and physical conditions which preferably involve low levels of humidity, dust and vibrations. As previously mentioned, the Ingress Protection level has to correspond to these conditions.

It is important that the BEP is positioned close to the vertical cabling path in order to permit optimal transition for the cables.

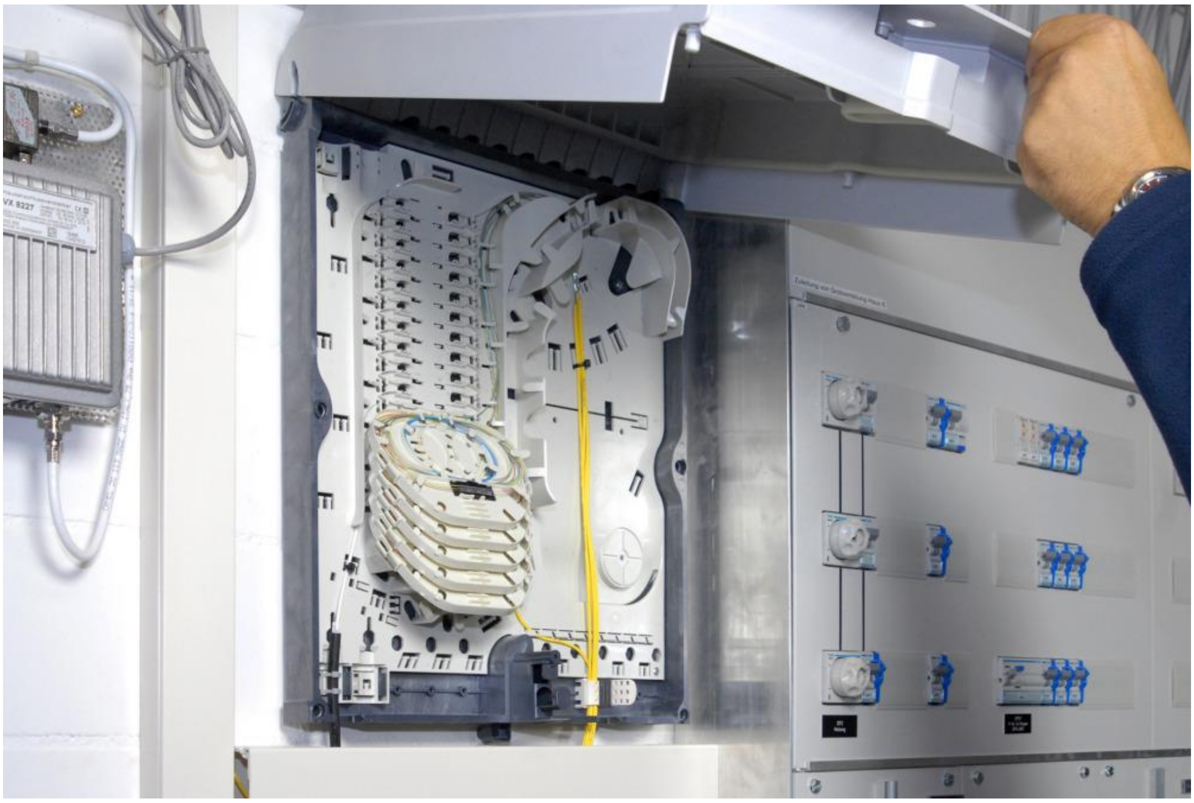


Figure 56: Example of wall mounted BEP installed next to a power distribution

7.5 Floor distributor

The connection to the Optical Termination Outlet for large installations (where for example there is a high density of subscriber premises on one floor in an MDU) can be achieved using a floor distribution point, considered a transition and fibre management point, between the vertical cabling and the horizontal connections.

The floor distributor uses the same box types and has similar functions as the BEP with sizes corresponding to the number of incoming and outgoing fibres. Ingress Protection level is typically IP20. When floor distributors are used, the recommended option to connect the OTO to this point is the single end, pre-connectorised cable solution. In this case the connectorised end of the cable runs to the OTO and the non-connectorised end can be spliced in the floor distribution box.

The link between the floor distributor and the OTO is called horizontal drop. In the network's topology the horizontal drop links the vertical riser cable from the floor distribution to the subscriber interface with the required number of fibres. Typical fibre counts for horizontal drop cable are between one and four fibres depending on local regulations and planned future applications of the network owner.

Connection between the vertical riser and the horizontal drop in the floor box can be achieved by:

- pre-terminated drop cable assemblies – at one or both ends
- splicing
- installation of field mountable connectors

Typical issues found with cabling include lack of available space for ducts or cables to pass through walls. Since these cables are installed in difficult conditions and in areas directly accessible by the end subscribers, who are generally unfamiliar with handling fibre, new types of fibre-optic cables equipped with bend-insensitive fibres should be considered in order to support simplified in-house installations, even by untrained installers.

7.6 Optical telecommunications outlet (OTO)

Optical Telecommunications Outlets are designed to manage different fibre counts – typically up to 4 – with a minimum bending radius protection of 15mm.

The fibre-optic outlets' design should allow the housing of certain fibre over lengths and provide space for the splices. The design of the fibre over length management should guarantee long-term stability for fibres. Fatigue break should not occur, even after 20 years in use. The outlets' front plate should have cut-outs corresponding to the chosen type of adapters to hold the simplex or duplex connectors according to the network design.

It is important that identification details are marked in a visible position on the OTO. Marking is important mainly for network maintenance and troubleshooting as well as in network testing.

Although generally an OTO is likely to be installed in dusty environments an Ingress Protection level 20 (IP20) is sufficient when the physical contact itself is properly dust protected.

Often the first outlet within subscriber premises is called the Optical Telecommunication Outlet (OTO) offering a choice of sockets for the termination depending upon the respective residential cabling:

- sockets with fixed fibre-optic adapters
- sockets with interchangeable fibre-optic adapters
- hybrid sockets with both fibre-optic and copper based adapters

Different sockets have different features. Some have dust and laser protected interfaces, radius protected fibre over length management as well as child proof patch cord locking features. Some of the sockets are designed for surface and some for flush mounting.

7.6.1 Fibre type and connection characteristics in the OTO

The most common fibre type currently being used in the OTO is the G.657, allowing a small bending radius. The fibre connection type to the OTO can be:

- pre-terminated cable assemblies
- spliced pigtails
- field mounted connectors

Within the G.657 bend-insensitive family, most current deployment is based on the G657.A2, which is the recommended choice as the indoor cabling standardization in some countries.

7.6.2 Optical connectors

The type of optical connector used in the OTO is usually defined in the design phase. Ideally such a connector is tailored to residential requirements. Increased protection against soiling of the connector end face, integrated laser protection in connectors and adapters as well as an automatic self-release mechanism, which is activated when the permissible release force on the OTO is exceeded, are the main features required for a residential proven connector.

The main recommendation with regard to the end face of the connectors is for APC with a clear specification for the attenuation and return loss (for example Grade B for IL and Grade 1 for the RL – for further details see Chapter 9).

The mechanical and climatic requirements typically used are as defined in IEC 61753-021-2 [15] for category C (controlled environment) with a temperature range of -10°C to +60°C.

Figure 57: Example of a connection cable featuring laser and dust protection and automatic self-release

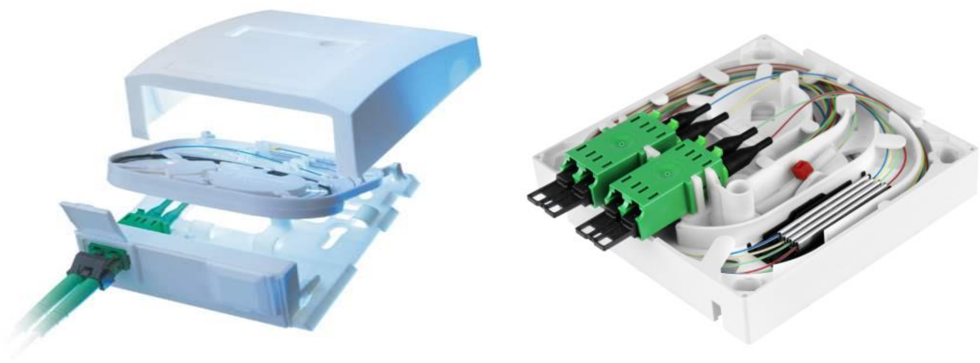


Figure 58: Detailed view of 2 different outlets: splice tray, bend radius guide, front plate with LC type

The fastest, simplest and most reliable way to install such an OTO is to use a pre-assembled solution, i.e. a cable already connectorised in the factory as shown below. Time consuming fusion splicing inside customer premises is not needed with such “plug & play” systems and installers do not require special training or equipment.

Figure 59: Example of pre-assembled Optical Telecommunication Outlet

7.6.3 Splices

The requirements for splices at the OTO are generally in a higher range as it is possible to use both technologies, fusion and mechanical, estimated typically in the design phase at max, 0.25 dB and a RL>60 dB mainly when RF overlay is considered.

7.6.4 Positioning the OTO

House distribution boxes are typically available in newly constructed buildings and, if available, they are often used for the OTO installation. It is important a power socket is available for the ONT/CPE which also requires sufficient space and adequate ventilation.

The connection between the OTO and the (SPE) CPE or ONT/(SPE) CPE respectively, has to be optimized for residential use and should feature the following:

- plug & play system
- integrated dust and laser protection
- sealing against dust
- self-release mechanism in order to protect the OTO in case of unintentional pulling of the connecting cables
- lowest bend-radii to prevent damage to the cable
- easy installation or removal by subscribers

In many cases the OTO is installed in living rooms or other spaces dedicated for work and/or entertainment.

Figure 60: OTO integrated in a home distribution cabinet

An OTO can be installed in the home electrical distribution panel as shown in Figure 61.

Figure 61: OTO integrated in the home electrical distribution panel

7.6.5 Testing the in-house cabling, the BEP-OTO link

The type of tests used and measurements specified are defined in the design phase, see the Network Planning chapter for more details.

However, the installer is responsible for installing the in-house cabling (BEP-OTO) according to the quality defined in the detailed planning phase and comprise of values described earlier in this section.

The measurements can be carried out as follows:

1. Reference test method: bi-directional OTDR measurement between POP and OTO
2. Alternative test method: unidirectional OTDR measurement from the OTO

For more details see Chapter 11, FTTH Test Guidelines.

7.7 CPE (SPE)

Customer premises equipment is the point where the passive network ends and the active equipment is installed. Generally, fibre is terminated inside the CPE using one connector. CPE's predominantly have an SC interface which apparently is difficult to access for end consumers. These devices are either purchased by the subscriber, or provided by the operator or by the service provider.

7.8 General safety requirements

Installations must be performed by certified technicians only. The laser safety requirements are in accordance with IEC 60825 series [19] and other national or local standards.

Designers and installers are responsible for correctly interpreting and implementing the safety requirements described in the referenced documents.

7.8.1 Laser safety

According to the IEC 60825 series the type of subscriber premises is "unrestricted".

As long as FTTH implementations respect hazard level 1 (IEC 60825 series [19]) at the subscriber premises, as well as laser class 1 or 1M (IEC 60825 series [19]) of the laser sources, no special requirements regarding marking or laser safety are necessary at the subscriber premises (from the optical cable entry point into the building through to the optical-electrical converter, including BEP and OTO).

7.9 Fibre in the Home workflow

One of the key factors of a cost efficient FTTH rollout is the in-house cabling from the Building Entry Point (BEP) to the ONT or CPE. FTTH-infrastructure distribution costs are approximately 21% for the active network, 48% for the passive network and 31% for the in-house fibre network. Optimisation of the Fibre in the Home cabling delivery is therefore crucial in maintaining the rollout budget within a certain limited framework. Therefore the resources used for FITH cabling should be carefully planned and dispatched if excessive manpower hours, time and budget are to be avoided. This is especially so when it comes to a mass-roll-out of FTTH including Fibre in the Home cabling, the in-house cabling processes should be highly professional and optimized.

Additional areas that must be considered in the Fibre in the Home cabling processes are the signal-handover from the outside plant installation, legal access to the building, contracts with the building owner, FTTH service contracts with the customer, material logistics, the ONT configuration and the in-house installation.

The parties and necessities involved in successful Fibre in the Home cabling are:

Network department/carrier: responsible for the delivery of the FTTH signal to the BEP or FCP. The BEP is usually the interface between Network department/Network carrier and the Fibre in the Home cabling provider, but the FCP could also be the demarcation point.

Acquisition: arranges the legal access to the building and/or flat

Legal: prepares the legal documents and basics for access to the building/flat

Data base: is a centralized data base for all legal documents, network documents, in-house cabling documentation and customer relationships

Building owner: has to be consulted for access to the building and cabling agreements

Marketing: has to prepare forecast per region and per area

Sales: signs contracts with subscribers

Subscriber: signs contract based on personal requirements or service available

Logistics: responsible for seeing that correct and sufficient material is delivered to requested place

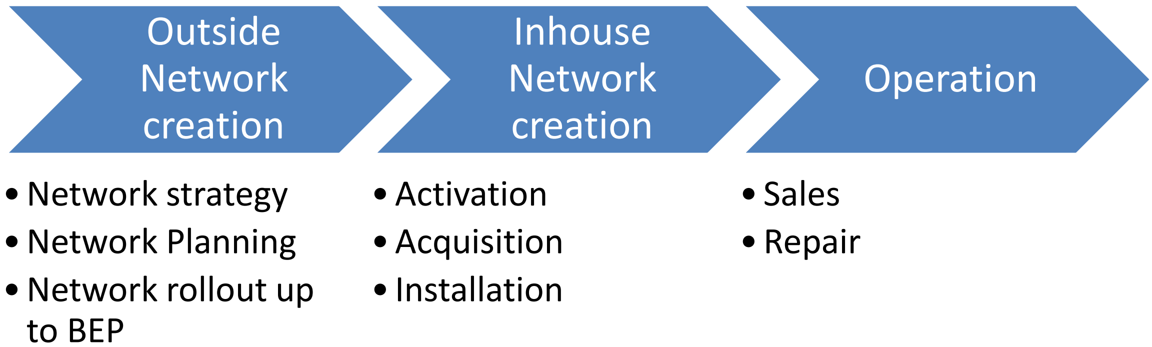
Dispatcher: arranges appointments with subscribers or building owner, dispatches technicians

Installation Technicians: install in-house cabling and the ONT/CPE

Configuration Technician: pre-configure the ONT according to customer data

7.9.1 General Fibre in the Home environment

Fibre in the Home processes are located between the implementation of the outside plant network (including the drop cable between FCP and BEP if necessary) and the operation of the FTTH network. After rollout of the outside plant network up to the demarcation point (BEP), the in-house cabling connects the ONT/CPE with the BEP and once the activation of the ONT is complete the FTTH customers go into operation.



7.9.2 Acquisition

Fibre in the Home can start once the outside plant FTTH network has been installed and the signal is on the line. Handover from outside plant network to in-house cabling can occur on a Building Entry Point (BEP) outside or inside the building. To implement the Fibre in the Home cabling an agreement with the building owner is necessary and ideally should take the form of a legal document. The contents of this document should include all mutual agreements for the in-house cabling, such as the material of the cabling, cabling locations, ownership of the cabling, permitted user of the cabling, access to the building, access to the cabling and maintenance issues. To speed up the process, acquisition could be completed in advance if the network rollout plan is known.

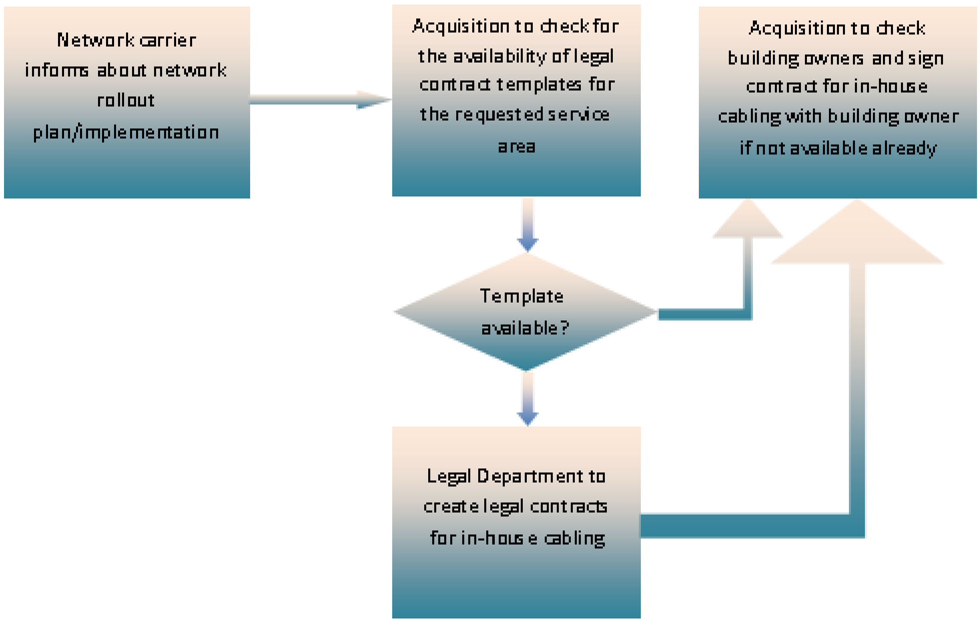


Figure 62: High Level Acquisition Process

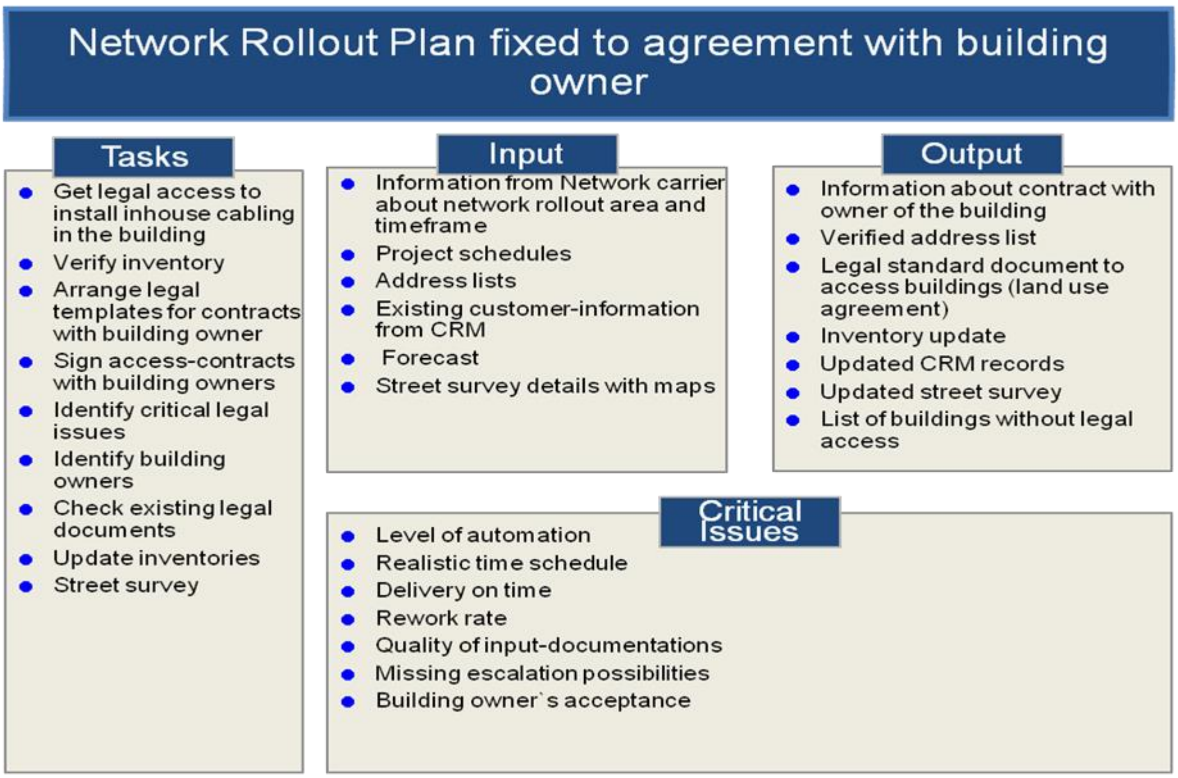


Figure 63: Acquisition Process

7.9.3 Sales

The aim of sales activity targets is to get as many signed service contracts as possible. In a brownfield FTTH rollout, existing service contracts should be upgraded to include additional FTTH services. Greenfield areas involve acquiring signatures on new service contracts by each customer. All sales activities should commence as soon as the network rollout plan and the sales strategy and product/service portfolio are known.

A general FTTH rollout strategy could involve rolling-out FTTH to include only a specific area once customers have signed up for a minimum number of FTTH-services. In such cases, sales activities have to be conducted before the network rollout.

Figure 64: High Level Sales Process

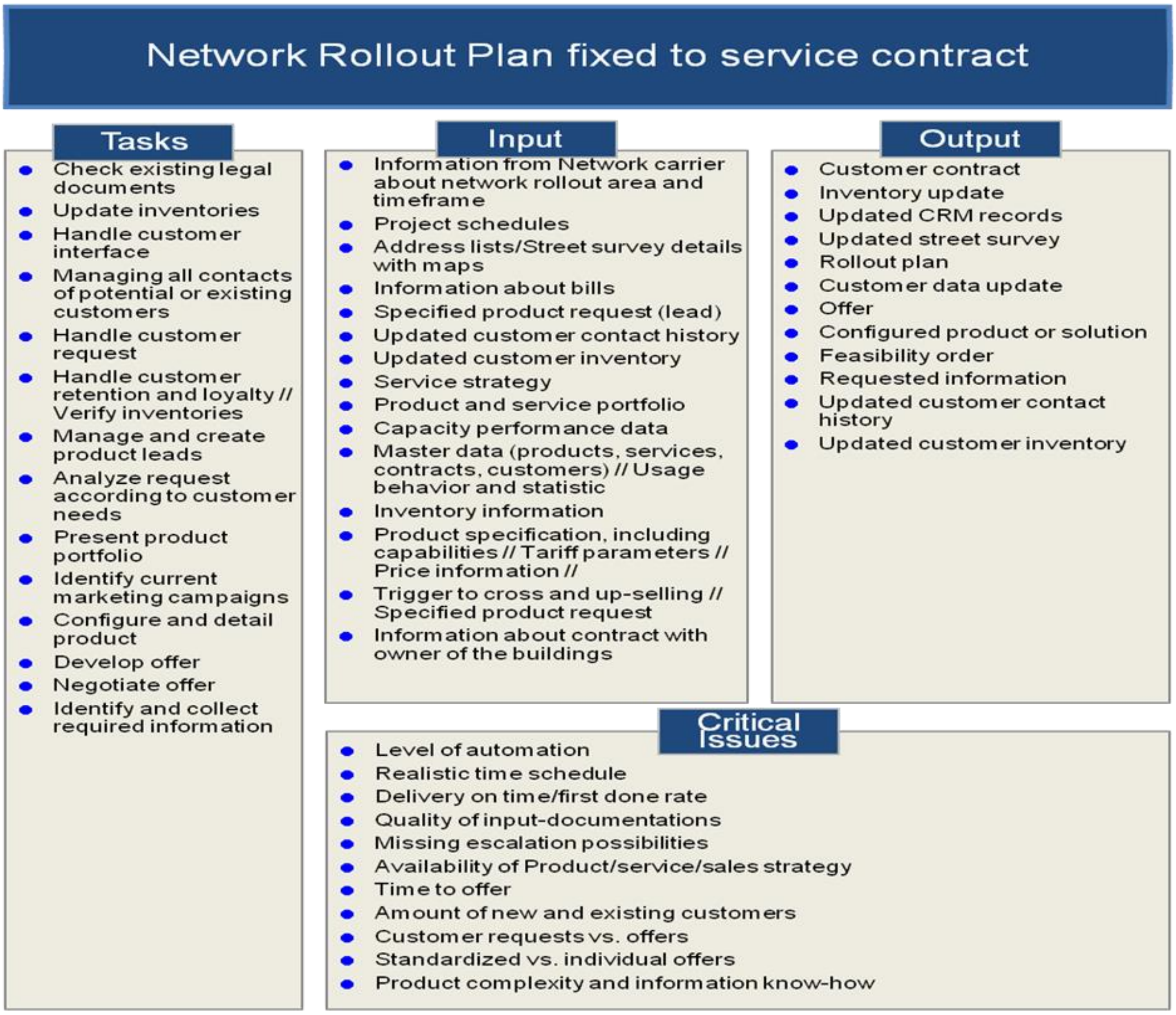


Figure 65: Sales Process Details

7.9.4 Installation Preparation

Installation is dependent upon sales and acquisition activities. The owner of the work order is the dispatcher who coordinates the technicians with the subscriber and/or the building owner as well as with the logistics team and activates the ONT. Additional visits by the technician to the customer/building should be avoided when using proper time-planning and appointments by the dispatcher.

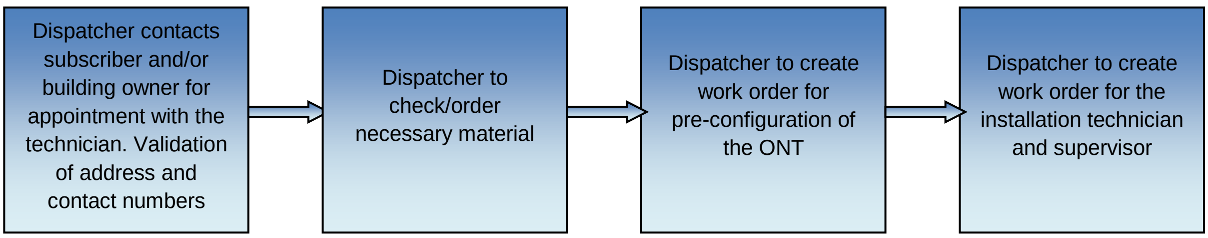


Figure 66: High Level Installation Preparation Process

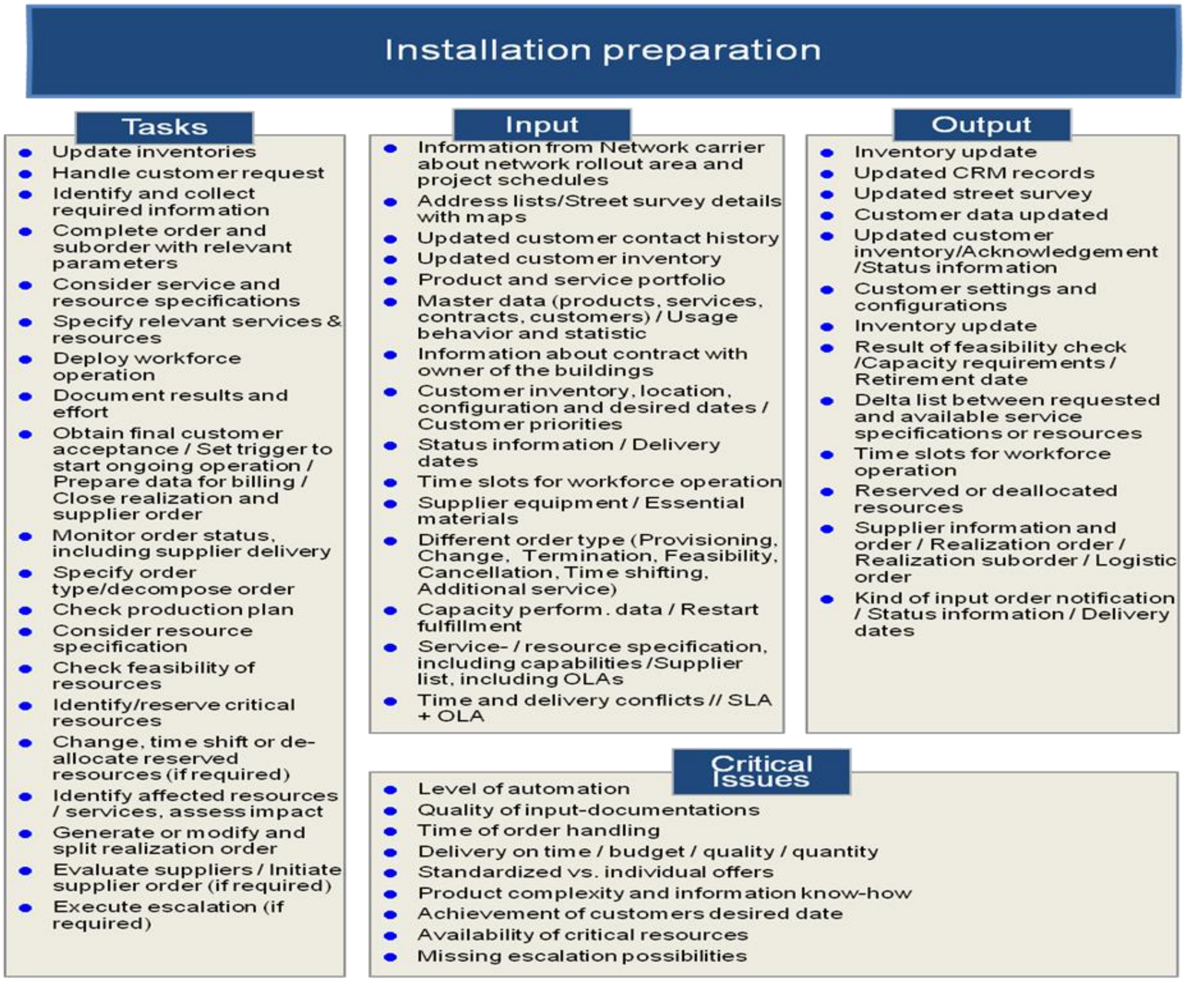


Figure 67: Installation Preparation Process Details

7.9.5 Installation

The installation technician should be able to start and finish the installation work according to the dispatcher´s timeframe and additional information from sales and/or acquisition. He receives the material and the pre-configured ONT. Before he starts with installation work he should check for incoming signal at the BEP. If no signal could be indicated at the BEP, a trouble ticket should be created for the Network carrier.

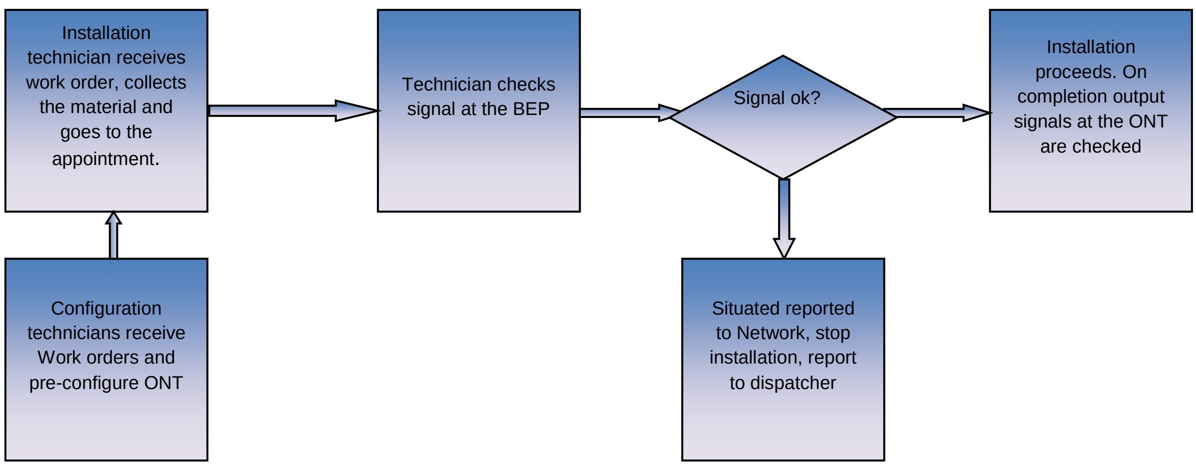


Figure 68: High Level Installation Process

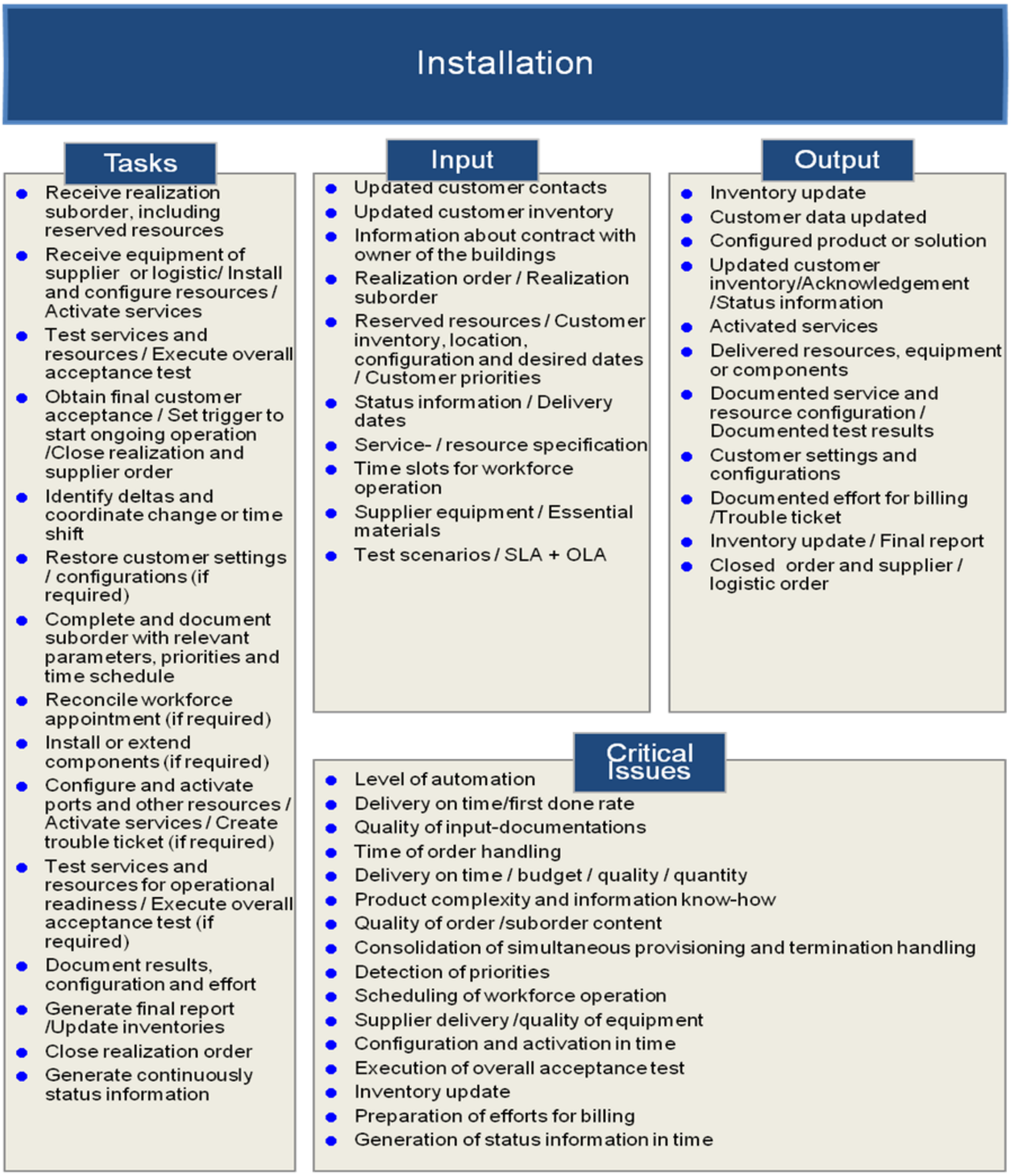


Figure 69: Installation Process Details

7.9.6 IT systems

Appropriate IT-systems should be used as much as possible (if available). Possible IT-systems are:

- NMS/EMS
- Inventory system
- GIS
- WFM
- CRM

All systems, if not using the same database, should synchronize their data periodically.

8 Deployment Techniques

This chapter 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. As roughly 50% of the cost of a ducted network build is related to civil works (trenching) it is recommended that an evaluation be conducted to ascertain whether existing infrastructure (ducts from telecom operators, municipalities, power companies, the public lighting system, sewers, water and gas pipes as wells as for an aerial deployment existing poles) can be utilised.

8.1 Duct infrastructure

This is the most conventional method of underground cable installation and involves creating a duct network to enable subsequent installation of cables using a pulling, blowing or floatation technique. A conventional duct infrastructure can be constructed in several ways:

1. main duct system containing smaller, rigid or flexible sub-ducts for individual cable installations.
2. large diameter ducts allowing cable to be pulled progressively as the network grows (cable over cable installations).
3. small diameter ducts for single cable installation.

Figure 70: Deploying duct infrastructure

A duct infrastructure allows for additional access network development and reconfiguration.

As with all civil works, when installing an FTTH duct infrastructure, consideration must be given to existing buried duct systems as well as inconvenience and disruption to traffic and pedestrians.

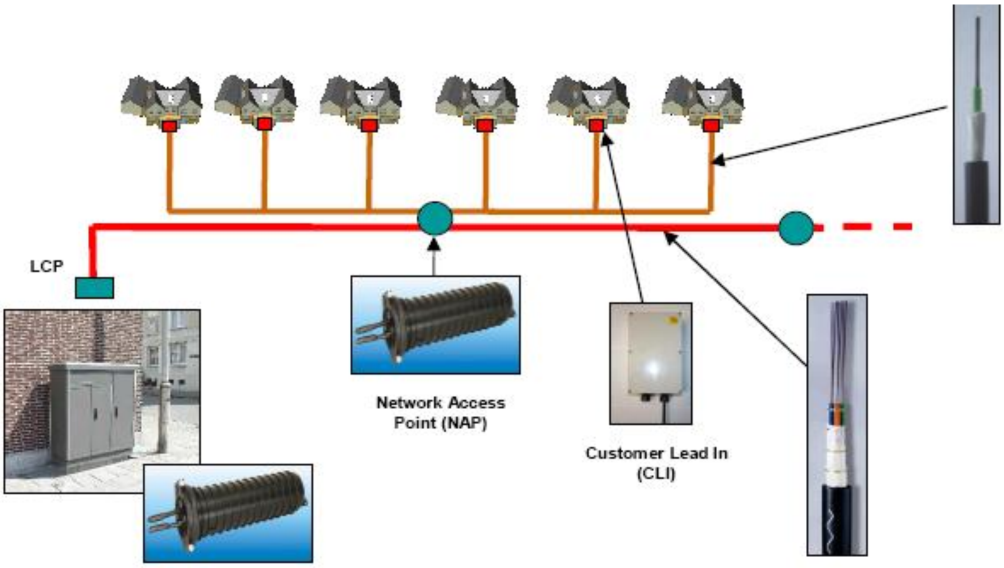


Figure 71: Product map for conventional duct infrastructure

8.1.1 Duct network

Multiple cables can be installed in a single duct but they do need to be put in place simultaneously or incrementally (cable after cable). However, a single duct system does limit the number of cables that can be installed due to entanglement of the cables and high friction between the cables jackets. This can even lead to damaged cable jackets which reduces the lifespan of a cable. Likewise, entanglement may make it difficult to extract older cables from full ducts to allow space for new cables to be installed. It is normal for older cables to be located at the bottom of the duct.

Figure 72: Cable entanglement

Rigid sub-ducts reduce the total number of cables that can be installed but also involve the need to remove the older cables. This method incorporates both cable blowing as well as cable pulling, as it helps to create an airtight connection to the sub-duct. Flexible textile sub-ducts maximize the total number of cables which can be installed in a duct and allows older cables to be easily removed. In general, flexible sub-ducts allow for the installation of 3 times more cables in a duct compared with rigid sub-ducts. If the outer duct is already occupied with cables, a flexible inner duct will maximize the number of cables which still can be added.

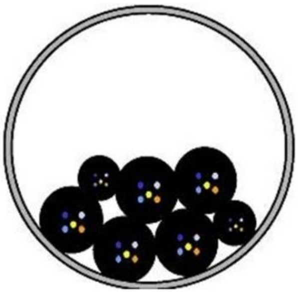


Figure 73: 110mm main duct

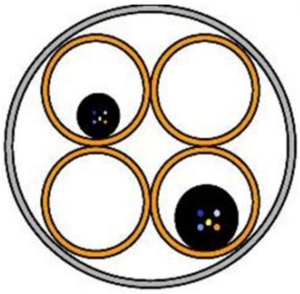


Figure 74: 110mm main duct with four rigid sub-ducts

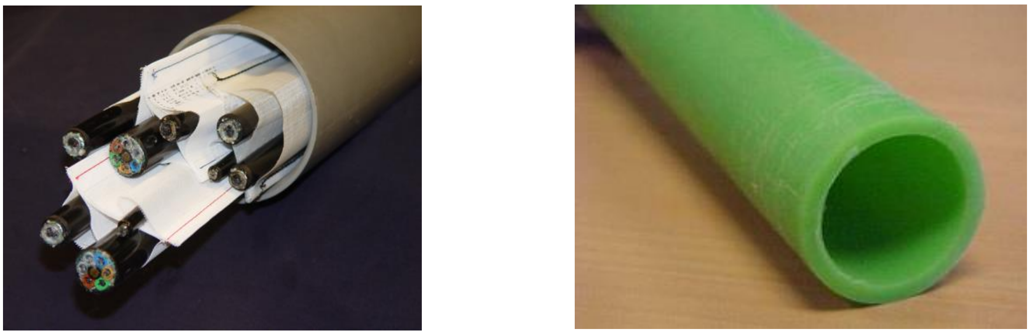


Figure 75: 110mm main duct with nine flexible sub-ducts

Main duct sizes which can contain rigid sub-ducts vary from about 60mm up to 110mm. Main duct sizes for single cable use are smaller, with a typical internal diameter of between 20 and 40mm. Smaller main ducts can also hold flexible inner ducts or micro-ducts (see below).

Cables can be installed into the ducts by pulling, blowing or floating. If they are pulled, then the duct must contain a pre-installed draw rope or if this is not the case then a rope would have to be installed by blowing or by using a rod. If cables are to be blown in or floated through the duct and any other connections between sections of duct, the entire system needs to be airtight.

The inner wall of the duct or rigid sub-duct is manufactured with a low friction coating to ensure low friction with the cable sheath. Alternatively, the duct or rigid sub-duct may have a low friction extruded profile or in some cases, special duct lubricants are used. Flexible sub-ducts are pre-lubricated 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 as well as the installation equipment used. Fill ratios should be calculated as part of the planning process as should the size of cable in relation to duct. In the case of existing networks, the condition of the ducts should be checked for any existing damage and for suitability of space and capacity for future cabling.

8.1.2 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 allocated to allow for more than one cable to be installed in a single duct as this saves vital duct capacity (e.g. using blowing or pulling techniques). Small main duct sizes range from 25mm to 50mm outer diameter. Larger main ducts of up to 110mm may be used and can contain smaller rigid sub-ducts between 20mm and 40mm outer diameter or flexible textile sub-ducts. The duct material used in the manufacture of main ducts is HDPE or PVC with rigid sub-ducts being produced in HDPE. Flexible sub-ducts consist of nylon/polyester.

8.1.3 Types of duct cables

There are a wide variety of cables that can be used in a duct network.

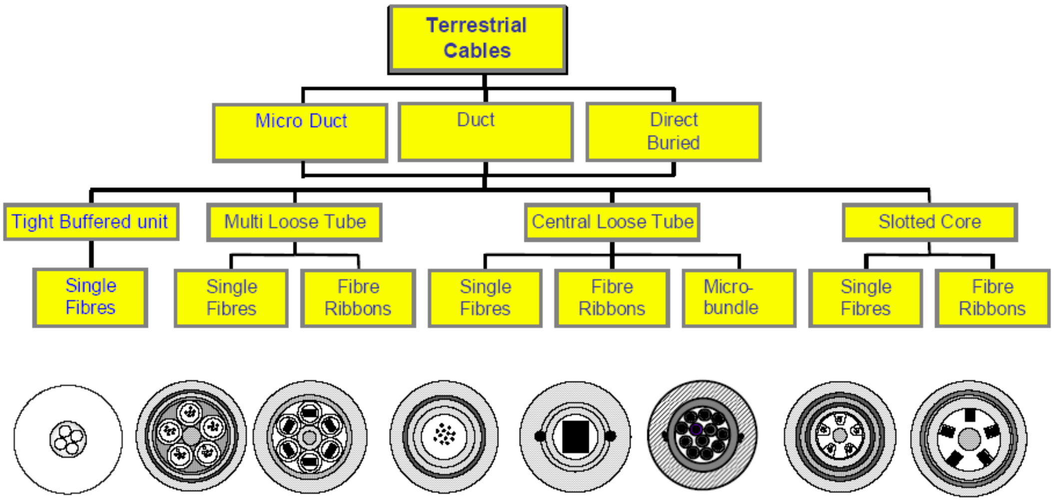


Figure 76: Duct cable selection

Although cable designs can vary, they are, however, based on a small number of elements. The first and most common building block is a loose tube. This is a plastic tube containing the required number of fibres (typically 12). This tube is lined with a tube filling compound that both buffers the fibres and helps them to move within the tube as the cable expands and contracts according to environmental and mechanical extremes. Other building blocks include multiple fibres in a ribbon form or 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 of 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 external environments. 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.

If cables are pulled using a winch, they may need to be stronger than those that are blown as the tensile force applied may be much higher. Blown cables need to be 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 which negates the need for them to be earthed in the event of lightening. 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 to be benign, but the cables are designed to withstand possible long-term flooding and occasional freezing.

8.1.3.1 Cable installation by pulling

The information given 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 Installation of Optical Fibre Cables.

When cables are pulled into a duct, a pre-existing draw-rope must be in place or one installed prior to cable winching. The cable should be fitted with a swivel allowing the cable to freely twist as it is installed; also a fuse is required which is set at or below the cable’s tensile strength. Long cable section lengths can be installed if the cable is capable of taking 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 using figure of eight loops to prevent twisting in the cable. If spare ducts or sub-ducts are installed, then further cables can be installed as the need arises ("just in time").

When installing cables, their mechanical and environmental performances should be considered as indicated on the supplier's datasheets. These 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 77: Pulling cable swivel

Figure 78: Cable guide pulley

Cable lubricants can be used to reduce the friction between the cable and the sub-duct, thus 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.

8.1.3.2 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 this action). This system 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 sub-ducts 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-builds, 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.

8.1.3.3 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 conducted using 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.

8.1.4 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 “micro-ducts” 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 as completion time is much faster and planning and building costs lower.

Figure 79: Cable de-coring

8.1.5 Access and jointing chambers

Suitably-sized access chambers should be positioned at regular intervals along the duct route and located so as to provide a good connection to the subscriber´s drop cables. The duct chambers must be large enough to allow for all duct cable installation operations, storage of slack cable loops for jointing and maintenance, cable hangers and bearers, as well as storage of the cable splice closure.

The chambers may be constructed on site or 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 unsuitable due to size or over population of cables/closures then an ‘off-track or spur’ chamber should be considered.

8.1.6 Cable joint closures

Cable joint closures may take the form of 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 occur within an off-track chamber or above ground cabinet.

There are no specific regulations relating to the spacing of the closures, however they 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 accessible if the need arises for future additions or alterations to subscriber fibre circuits.

8.2 Blown micro-ducts and micro-cable

This option utilises compressed air to blow fibre unit and small diameter cables rapidly through a network of tubes to the subscriber/ premises. Fibre deployment can be deferred until subscriber requirement has been confirmed thus avoiding speculative up-front build programmes. In addition, 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 micro-ducts may be used in combination with ducts, direct buried and aerial infrastructure and the tubes may be housed in constructions designed for any of these three methods.

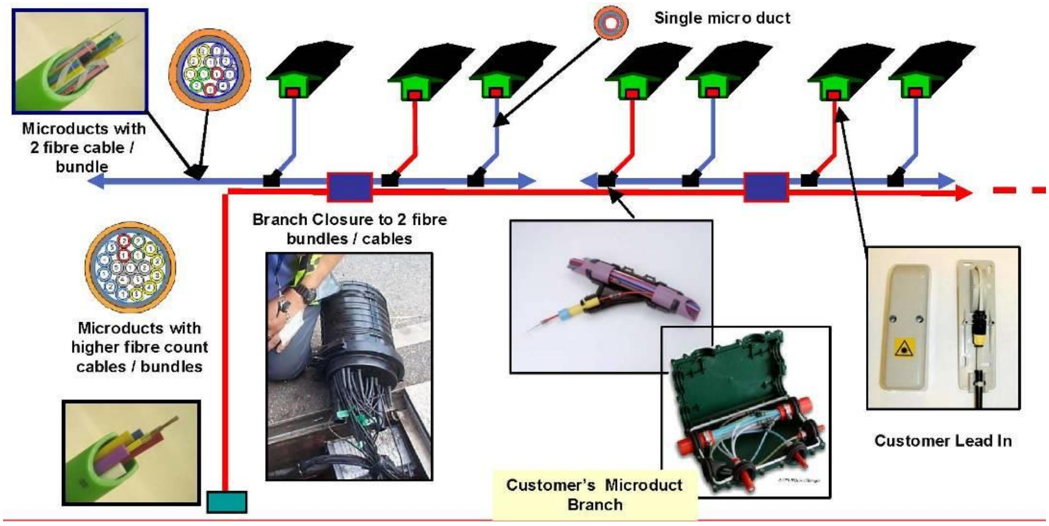


Figure 80: Product map for blown micro-ducts and micro-cable

8.2.1 Micro-duct solutions

Micro-ducts are small, flexible, lightweight tubes usually less than 16mm in diameter and resemble smaller versions of conventional ducts (e.g. 10mm outer diameter, 8mm inner diameter) that are pre-installed or blown into a larger sub-duct. Micro-ducts can be used to further segment a sub-duct (for example using five 10mm micro-ducts). The micro-ducts may be blown directly into the sub-ducts. They could also be small tubes (e.g. 5mm outer diameter, 3.5mm inner diameter) manufactured as a single or multi-tube cable assembly, known as a “protected micro-duct”. Protected micro-duct assemblies (usually contain from one to twenty-four micro-ducts) 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 81: Sub-divided sub-duct

Figure 82: Post-installed micro-duct

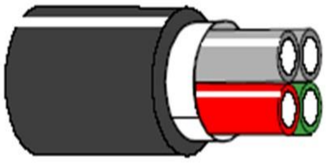


Figure 83: Protected micro-duct

Thick-walled micro-ducts do not need to be placed or blown inside another duct or tube. Bundles of thick-walled micro-ducts offer the most user-friendly connector solution. From a technical perspective, this is the optimal 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 buried individually over shorter distances. In addition, micro-ducts offer the easiest solution for branching, remove the thin outer coating and snap on a connector.

Tight-bundled micro-ducts offer a larger number of micro-ducts pre-installed in a standard duct. They consist of a standard HDPE duct pre-sheathed around a bundle of micro-ducts. Both the main duct and the micro-ducts come in a variety of sizes to accommodate different types of fibre cables. Tight-bundled micro-ducts are sheathed to avoid buckling which makes them less susceptible to temperature changes.

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

- Pre-installed in various size HDPE ducts suitable for laying directly in trenches and branched where necessary.
- Blown in after the HDPE ducts have been buried and an optimal solution for network expansion flexibility.

Figure 84: Thick walled micro-duct bundle

Figure 85: Branching of thick walled micro-duct

8.2.2 Micro-duct tube connectors and closures

Sections of micro-ducts can be joined together using specialist connectors which are available in water and gas-sealed versions.

The design of thick-walled micro-duct connectors allows the installer to snap together the ends of two micro-ducts negating the 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 86: Branching components

Tight-bundled micro-ducts require a watertight closure for branching. Watertight Y-branch and wraparound connector products provide access and allow for micro-ducts to be branched at any point in a network. Tube management boxes can also be used when several micro-ducts 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 87: Push-fittings (left to right): gas block tube connectors, straight tube connectors, end tube connectors

8.2.3 Micro-duct cable and fibre units

Micro-duct tubes house micro-duct cables (e.g. 96 fibre 6.4mm diameter for use in a 10mm/8mm micro-duct) or very small blown-fibre unit cables 1 to 3 mm in diameter which allows for 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 of a small lightweight design that needs a tube for protection. In other words, the tube and cable act together as a system. The cables are installed by blowing and may be coated with a special substance to aid blowing.

Figure 88: Micro-duct cables

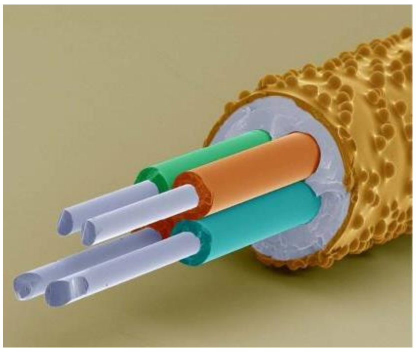


Figure 89: Micro-duct cable with 4 fibres

The micro-duct size must be chosen to suit the cable and required fibre count. Typical combinations of cable and duct sizes are given in the following table, however other sizes and combinations can be used.

Micro-duct outer diameter (mm)	Micro-duct 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

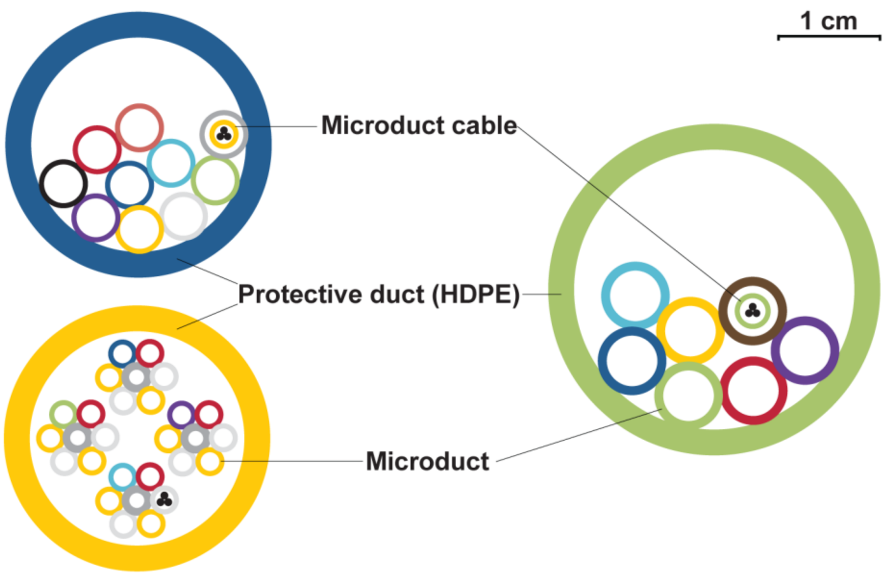


Figure 90: Protected micro-ducts with loose package

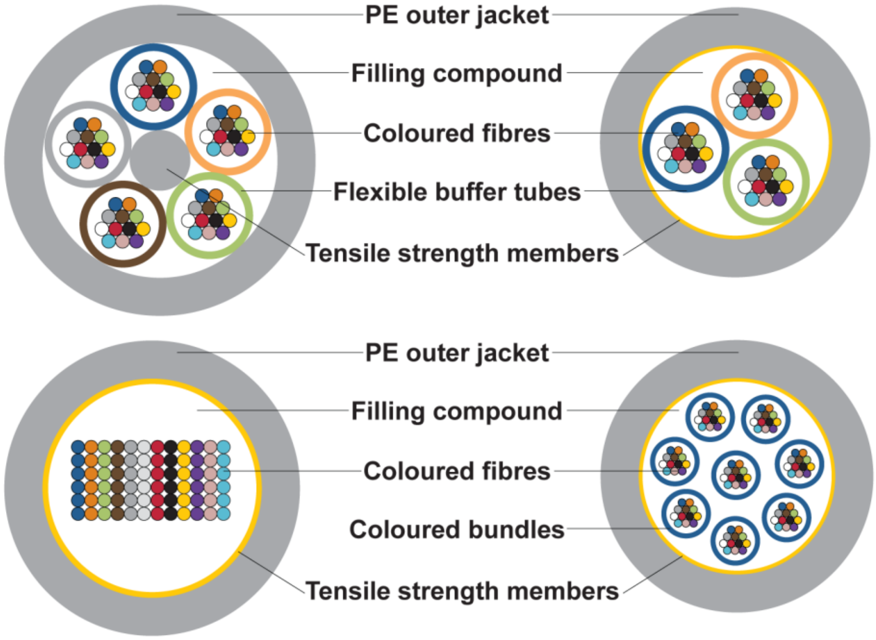


Figure 91: Micro-duct optical fibre cables (not to scale)

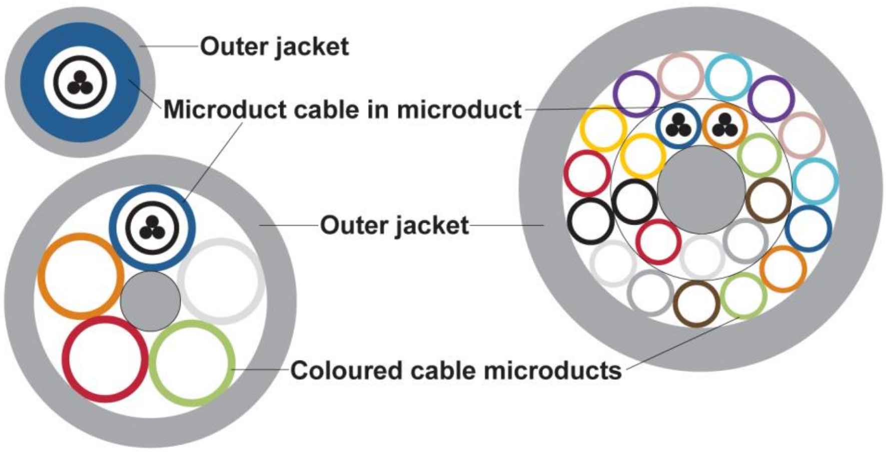


Figure 92: Protected cable micro-duct with tight integral outer duct (not to scale)

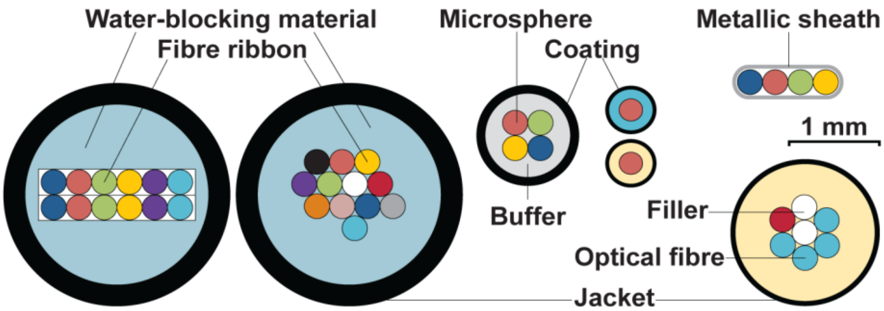


Figure 93: Examples of Fibre units. Micro-duct spelling in diagram

The distance achieved through blowing will depend on the micro-duct, cable and installation equipment used as well as route complexity, 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 remaining blowing distance will be quite short.

8.2.4 Micro-cable/blown fibre unit installation

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

8.2.5 Access and jointing chambers

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

8.2.6 Micro-cable joint closures

Micro-cable joint closures have the same basic features as duct joint closures, however there are a number of different types, depending on whether the joint is being used to join together or branch fibres, or whether the tubes themselves need to be branched or jointed. These closures allow considerable flexibility with routing the ducts whilst minimising the number of installation steps. The cables or fibres may be blown through the entire route once the tubes have been connected facilitating the use of simple joints rather than full-scale joint closures.

External tubing can be joined directly to suitable indoor tubing avoiding the need for joint splicing 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, a serious situation may arise when the fibre is blown through a joint and an air-leak occurs within the tubes housed in the joint. To prevent a build-up of pressure that could result in the joint being blown apart, a reliable safety valve or other pressure relief mechanism needs to be fitted.

8.3 Direct buried cable

Direct burial offers a safe, protected and hidden environment for cables; however, before the cables are laid in a narrow trench, a detailed survey must be conducted to avoid damaging other buried services which may be in the vicinity.

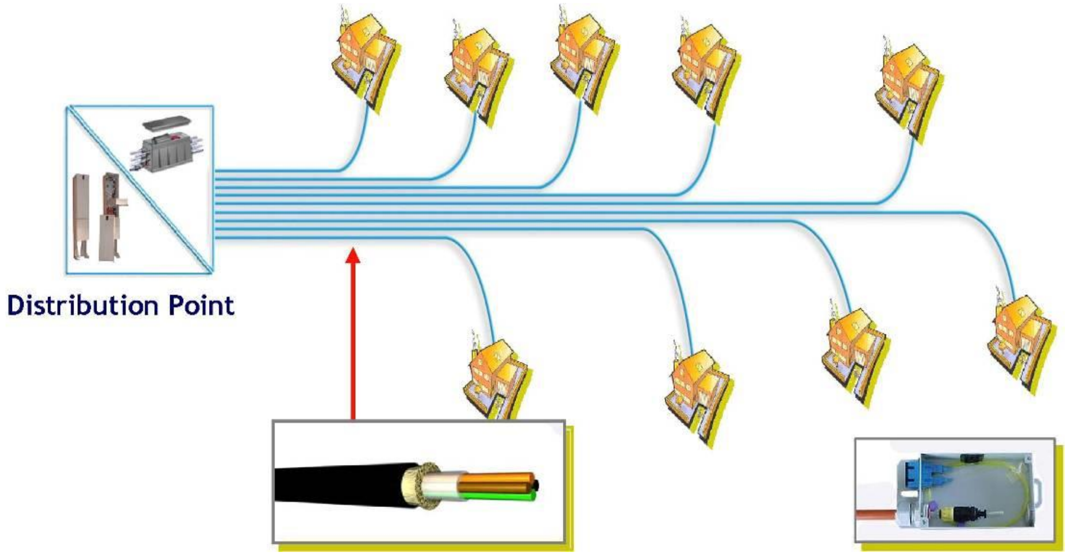


Figure 94: Product map for direct buried cable

8.3.1 Installation options

There are a number of excavation techniques that can be used to dig the trench including mole ploughing, open trenching, slotting and directional drilling. A combination of these options can be used in a deployment area.

8.3.2 Types of direct buried cable

Direct buried cables are similar to duct cables as they also employ 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 be sufficient to allow for lightweight cable designs to be used, 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.

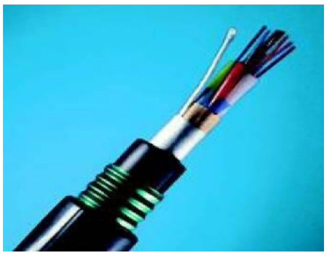


Figure 95: cable with corrugated steel protection

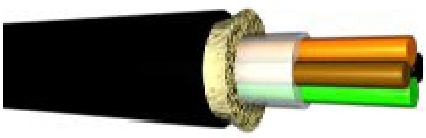


Figure 96: non-metal direct buried cable

8.3.3 Lightning protection

Non-metallic designs may be favoured in areas of high lightning activity. However these have less crush protection than a cable with a corrugated steel tape. The steel tape can cope with a direct lightning strike, particularly if the cable contains no other metallic components and it also offers excellent crush protection.

8.3.4 Rodent protection

Corrugated steel tape has proven to be one of the best protections against rodent damage or other burrowing animals. If the cable has to comprise of non-metallic materials then the best solution is a layer of rigid dielectric members between two jackets. A further option could be a complete covering of glass yarns which may deter rodents to some degree.

8.3.5 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.

8.3.6 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.

8.3.7 Direct buried cable joint closures

Basic joint closures for direct buried cables 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.

8.4 Aerial cable

Aerial cables are supported on poles or other tower infrastructures and represent one of the more cost-effective methods of deploying drop cables in the final link to the subscriber. The main benefits are the use of existing pole infrastructure to link subscribers, avoiding the need to dig in 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.

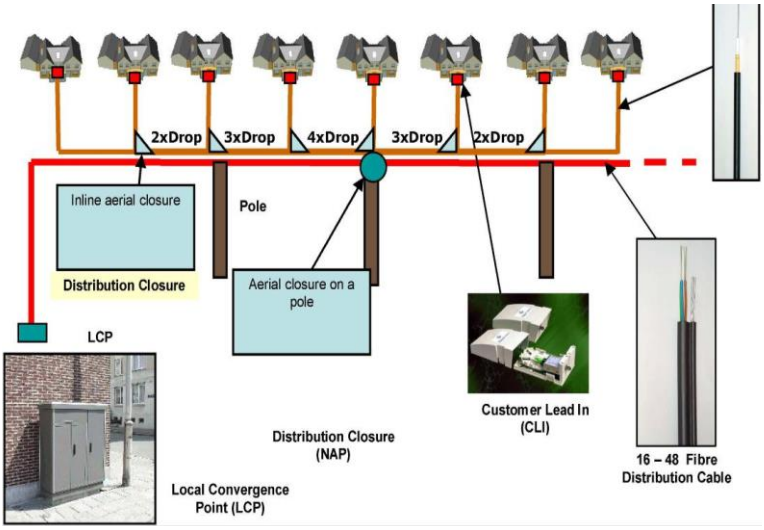


Figure 97: Product map for aerial cable

8.4.1 Load capacity of the pole infrastructure

The poles to which the optical cable is to be attached may already loaded with other cables 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 increase the load borne by the poles, therefore it is important to check the condition of the poles and their total load capacity. In some countries, such as the UK, the cables used in aerial cabling have to be designed to break if they come into contact with high vehicles to avoid damage to the poles.

8.4.2 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 requiring a high degree of mechanical protection. This type of cable is also favoured by companies used to handling copper cables, since similar hardware and installation techniques can be used.

Figure 98: Wrapped aerial cable

The Figure-8 design allows easy separation of the optical package avoiding contact with the strength member.
However, with the ADSS cable design, the strength member bracket is part of the cable.

ADSS cables have the advantage of being independent of the power conductors as together with phase-wrap cables they 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 this may involve OPGW (optical ground wire) in the 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 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 infrastructures.

Extra consideration needs to be taken of environmental extremes that aerial cables can be subjected to including ice and wind loading. Cable sheath material should also be suitably stabilised against solar radiation. Installation mediums also need to be seriously considered (e.g. poles, power lines, short or long spans, loading capabilities).

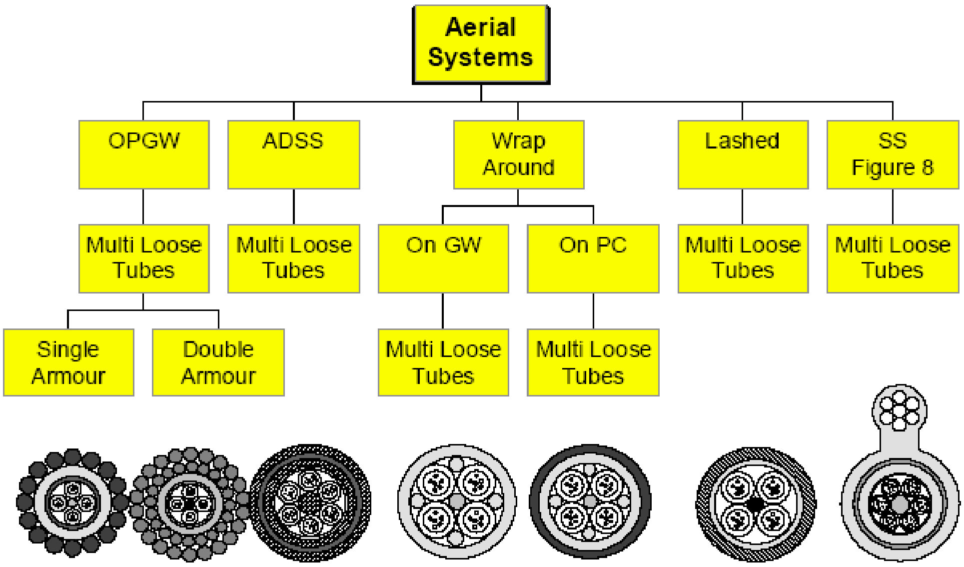


Figure 99: Aerial cable selection

In addition cables are also available with a "unitube" structure.

8.4.3 Cable pole support hardware

Support hardware can include tension clamps to anchor a cable to a pole or to control a change of pole direction. Intermediate suspension clamps are used 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.

8.4.4 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. Installation is usually carried out in reasonably benign weather conditions with installation loading often being 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 100: Aerial cable installation

Care also needs to be taken to see that installation 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.

8.4.5 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 providing protection from UV rays and possible illegal shot gun practice, particularly for closures mounted on the pole. The closure may require a function for the distribution of smaller drop cables.

8.4.6 Other deployment considerations

Aerial products may be more susceptible to vandalism than ducted or buried products. Cables can, for example, be used for illegal shot gun practice. This is more likely to be low energy impact, due to the large distance from gun to target. If this is a concern 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.

8.5 Pre-terminated network builds

Both cables and hardware can be terminated with fibre-optic connectors in the factory. This facilitates factory testing and 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 subscriber drop enabling the network to be built quickly, passing homes. When a subscriber requests service the final drop requires only a simple plug-and-play cable assembly.

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

Figure 101:

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.

8.6 Street cabinets

A buried FTTH network contains communication equipment that can either reside below or above ground level. Street cabinets can be installed above as well as below ground although the recognised placement is above ground.

Modern street cabinets come in a variety of sizes, have lower profiles and smaller above-ground footprints, as well as being less conspicuous 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** – Installation labour costs of FTTH deployments often dwarf the material cost of the network components. Cabinets can be a cost-effective method of providing a network access point, if compliant with the build specification and methodology. A scalable or

modular cabinet solution can help moderate project costs as cabinets can easily be extended if and when the need arises.
- **Network accessibility** – Depending on the geographical location, the splice closure installation will fare better and remain reasonably dirt-free if mounted above ground. Wet conditions can turn traditional hand and manholes into miniature mud pools, prolonging installation times and cold winters may make access to underground installations difficult or impossible due to ice.

Regular access to a cabinet may be required but location issues remain. The solution is an underground installation that allows the cabinet to be raised out of the ground for access and returned to its original underground placement when it is no longer needed. The only visible indication of its location is a manhole cover.

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

A typical street cabinet has three functions:

1. **Duct management** is placed 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 102: Duct management

Figure 103: Base management

Figure 104: Fibre management

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

Figure 105: Examples of street cabinets in a range of sizes

Street cabinets can also be equipped 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 with a patch panel for simple plug-and-play connectivity. This facilitates speedy installation and greatly reduces the incidence of installation faults on site.

Compact pedestals and cabinets designed as the last premise distribution/termination point can be located 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.

8.7 Other deployments options using rights of way

In addition to traditional cabling routes, other right of way (RoW) access points can also be exploited if they are already in situ. By deploying cables in water and sewage infrastructure, gas pipe systems, canals and waterways as well as other transport systems, savings can be made in time as well as costs.

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

8.7.1 Fibre-optic cables in sewer systems

Sewers may be used for access networks as not only do they access almost every corner of the city they also pass potential subscribers. In addition the utilisation of the sewage system negates the need to seek digging approval and reduces the cost of installation.

Tunnel sizes in the public sewers range from 200mm in diameter to tunnels that are accessible by boat. The majority of public sewer tunnels are between 200mm and 350mm in diameter which is a sufficient cross-section for installation of one or more micro-duct cables.

Various installation schemes are possible depending on the sewer cross-section. One scheme uses steel bracings that fix corrugated steel tubes, which are used to transport the cable, to the inner wall of the smaller sewer tube without the need to drill, mill or cut. This is done by a special robot based on a module used for sewer repairs.

8.7.2 Fibre-optic cables in gas pipes

Gas pipelines can also be used for deploying optical fibre networks without causing major disruption and requiring extensive road works to the community which is the norm in the case of 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.

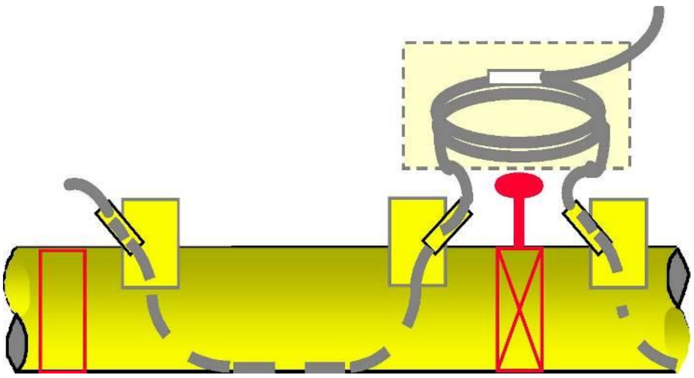


Figure 106: Gas pipeline section, including I/O ports and the bypassing of a valve defining one point-of-presence for the fibre-optic cable

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.

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

8.7.3 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 for gas pipes.

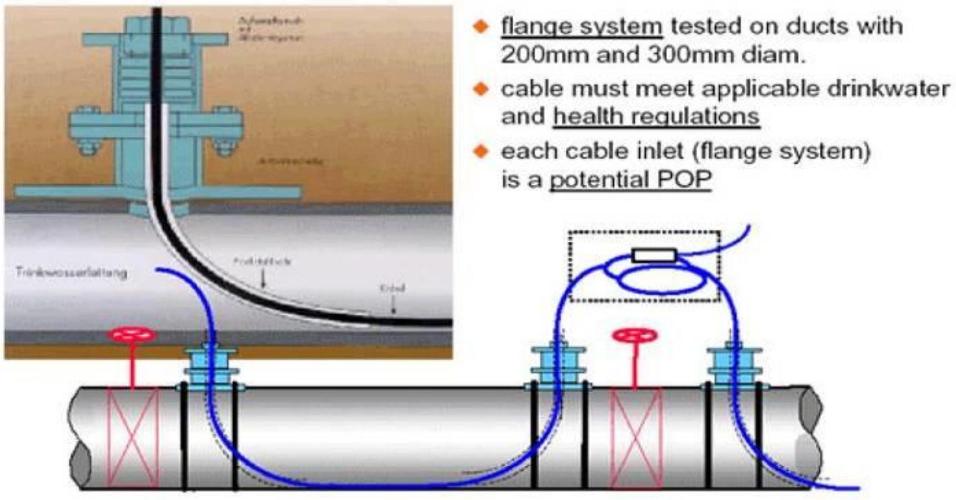


Figure 107: Cross-section showing fibre installed in a drinking water system

8.7.4 Canals and waterways

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

8.7.5 Underground and transport tunnels

Fibre optic cable can be installed in underground tunnels, often alongside power and other data cabling. These are most frequently attached to the wall of the tunnel on hangers. 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, 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 hinder evacuation.

Figure 108: 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 and therefore may need extra protection in the form of corrugated steel tape, for example.

9 Fibre and Fibre Management

9.1 Choice of FTTH optical fibre

Several types of optical fibre are available. Future proofed FTTH schemes are usually based on single-mode fibre; however 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 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 number of premises served by the network. However, in this context it refers to the physical distance across the network. The available power budget will determine how far the POP can be located from the subscriber. Power budgets are influenced by all the components in the optical path including the fibre.
- **The existing network fibre type** – If an existing network is expanded, the optical fibre in the new network segments must be compatible with the fibre in the existing network.
- **Expected lifetime** – FTTH networks are designed with a lifespan of at least 30 years. Therefore, it is imperative that investments to the FTTH infrastructure are suitable for future needs. Changes to the choice of fibre during the expected lifespan of the FTTH network are not a realistic option.

9.1.1 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 undergone major development and, as it is now standardised, has become a reliable and proven foundation of today’s modern telecommunication transmission systems.

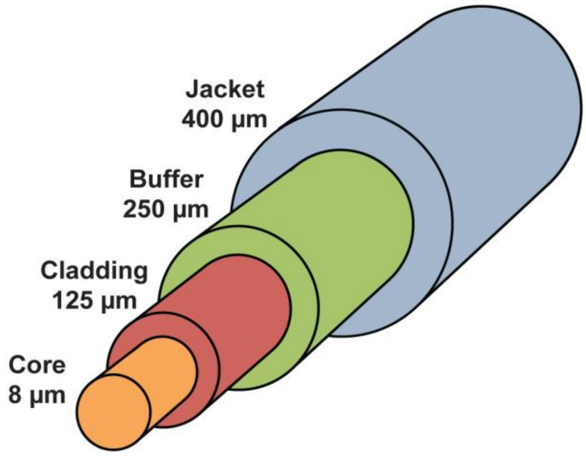


Figure 109: Single-mode optical fibre construction

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

Fibre consists 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 and an outer coating, usually made of a polymer, is applied during the drawing process.

Fibres are subsequently packaged in various cable configurations before installation. Details relating to the cables are available in other chapters of this handbook.

Whilst there are many different fibre types, this document concentrates on fibre for FTTH applications.

The fibre core can be designed in various geometrical sizes which depending how the light pulse travels, produces different optical performances.

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 extremely 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, also known as the attenuation coefficient or attenuation rate.

Dispersion can broadly be 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.

9.1.2 Single-mode fibre

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

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

For FTTH applications, the ITUT G.652 recommendations for single-mode fibre are sufficient to cover the needs of most networks.

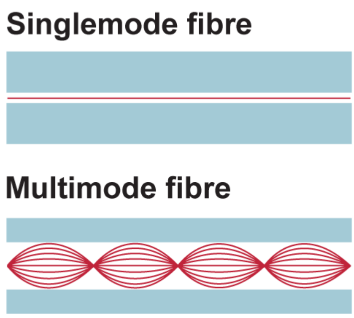


Figure 110: Light paths inside fibre

For quite some time now a newer type of single-mode fibre has been available on the market that reduces optical losses at tight bends. These fibres are standardized in the ITU-T G.657 recommendation. The in-force version, edition 3, was published in October 2012 and can be downloaded at: http://www.itu.int/rec/T-REC-G.657-201210-I/en.

9.1.3 Graded-index multimode fibres

Multimode fibres have a larger core size (50 or 62.5µm) 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; however the fibre itself is more expensive than single-mode. Multimode fibre is used extensively in data centres and sometimes used in campus networks. 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.

9.1.4 Bend insensitive fibre

When cabling inside buildings, many areas prove difficult for conventional fibres resulting in possible poor optical performance. To avoid this very careful and skilled installation practices are required or special fibre protection is needed with ducts and cable designs. However, for some time fibre types with the ITU-T G.657 standard have been widely available allowing fibre-optic cables to be installed 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 recommended G657 describes two categories of single-mode fibres which are suitable for use in access networks. Both categories A and B contain sub-categories which differ in macro-bending loss thus the difference between these fibres is in the permissible bending radius:

Category A contains the recommended attributes and values needed to support optimized access network installation with respect to macro-bending loss. However the recommended values for the other attributes still remain within the range recommended in G.652.D and emphasizes backward compatibility with G.652.D fibres. This category has three sub-categories with different macro-bending requirements: G.657.A1, G.657.A2 and the recently proposed G.657.A3 fibre.

Bend radius	G.657.A1	G.657.A2	G.657.A3*
10 mm	0.75 dB/turn	0.1 dB/turn	
7.5 mm		0.5 dB/turn	
5 mm			0.15 dB/turn

Loss specified @ 1550nm; G.657.A3 is not finalized.

Category B contains the recommended attributes and values needed to support very low bending radii particularly applicable to in-building installations. For the mode-field diameter and chromatic dispersion coefficients, the recommended range of value might be outside the range of values recommended in ITU-T G.652 and thus NOT necessarily backward compatible. This category has two sub-categories with different macro-bending requirements: G.657.B2 fibre and G.657.B3 fibre.

Bend radius	G.657.B2	G.657.B3
10 mm	0.1 dB/turn	0.03 dB/turn
7.5 mm	0.5 dB/turn	0.08 dB/turn
5 mm		0.15 dB/turn

Loss specified @ 1550nm

9.2 Fibre optic termination

All outdoor cables used in any fibre-optic network deployments are terminated at both ends. This section covers issues related to the large fibre counts termination and management in the POPs, Access Nodes and street cabinets where the challenge of managing large fibre counts is met.

9.2.1 Optical Distribution Frames

An optical distribution frame (ODF) is the point where all fibres from the outdoor cables become available to interface with the active transmission equipment. ODFs are usually situated in the POPs, bringing together several hundred to several thousand fibres. A single ODF cabinet can connect up to 4,000 fibres using SFF connectivity. Large POPs will use multiple ODF cabinets.

Typically, outdoor cables are terminated before the ODFs and transfer cables are used, though in some cases, the ODF is used as well for outdoor cable termination. In either case, to access each fibre of the outdoor cable, a connectorised fibre pigtail is spliced to each individual fibre end.

In most cases, the ODF offers flexible patching between active equipment ports and the outdoor cable termination. Fibres are identified and typically stored in physically separated housings or shelves to simplify fibre maintenance and to protect or avoid accidental interference to fibre circuits.

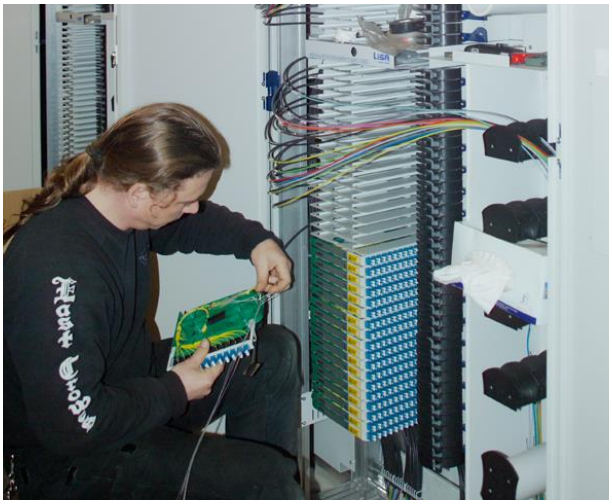


Figure 111: Splicing work on an ODF

Figure 112: Active and Passive ODF's in a POP

Figure 113: Small POP

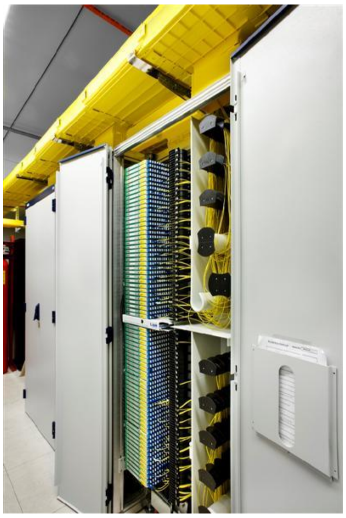


Figure 114: Example of ODF units

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Internal optical cables are run between the ODFs and the active equipment. A fibre-guiding platform (fibre containment) is built between the active equipment and the ODF cabinets which provide a protected path for the internal cables to run between the two locations. Unlike conventional metal trays or baskets, fibre containment encapsulates the fibre with a robust fire resistant material which prolongs the recovery time in disaster situations. Cables can be pulled quickly and easily through the fibre containment system and optical performance is optimised through comprehensive bend-limitation and lateral support. This ability to deploy cables quickly will improve the planning and procurement process when different cable lengths need to be added to the network.

Figure 115: Examples of overhead fibre containment

An uninterruptible power supply (UPS) provides emergency power back-up if an external power supply fails. The Access Node may also require a second diverse external power supply, which may form part of local and statutory requirements (provision of emergency services). UPS modules are available in various sizes depending on the power requirement to be backed-up.

Suitable air conditioning equipment is needed to maintain the temperature of the active equipment within environmental operating limits. The size and capacity of the unit will depend on the size of the room to be served.

Figure 116: Uninterruptible power supply

Figure 117: Air-conditioning unit

9.2.2 Street cabinets

Street cabinets are metal or plastic enclosures, which serve as distribution/access points between the distribution fibre and the drop fibre to the subscriber. These are usually located to allow for relatively easy and rapid access to the fibre circuits and are capable of handling larger capacities than fibre joint closures. Access/distribution points often serve from 24 to 96 subscribers, whilst compact pedestal cabinet alternatives typically serve 1 to 24 subscribers.

Figure 118: Typical street cabinet

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 method is needed to enable cleaning and provide efficient access.

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

Figure 119: 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 offering 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.

Climate controlled street cabinets can provide a flexible solution for compact ODF systems. These cabinets can be equipped with the same security measures and uninterrupted power supply as in large scale access nodes.

Figure 120: Combined POP/ODF with climate control

9.3 Connectors, Patch cords and Pigtails

After the termination of OSP cables, individual fibres need to be accessible for distribution and/or connection to active equipment. The transformation of cable bundles in individual manageable circuits is achieved by splicing each individual fibre from the OSP to one end terminated flexible cable called pigtail. Additional distribution and/or connection between these fibres to/from the active equipment require two end connector terminated patch cables. These cables are generally available in two different constructions:

- Pigtails are 900µm semi-tight buffer with strip ability ≥ 1.5m and a typical length of 2.5m
- Patch cords are 1.6—3.0mm LSZH jacket jumper cable having aramid yarns as strength members

In contrast to their electromechanical counterparts, there is no differentiation between plug and jack with the fibre-optic connectors. Fibre-optic connectors contain a ferrule to accommodate and for the exact positioning of the fibre end, and are attached to one another via a coupler with a sleeve. A complete plug-in connection consists of the combination connector/coupler/connector. The two ferrules, with the fibre ends, must connect as precisely as possible inside the connection to hinder the loss of light energy or its reflection (return loss). Determining factors are the geometric orientation and workmanship of the fibre in the connector.

The extremely small core diameters of the optical fibres demand the highest mechanical and optical precision. With tolerances of 0.5 to 0.10µm (much smaller than a grain of dust), manufacturers operate at the limits of precision engineering, accessing through their processes the realm of micro systems technology. Compromises are not an option.

Core diameters of 8.3µm for single-mode or 50/62.5µm for multi-mode fibres and ferrules with 2.5mm or 1.25mm diameter make a visual inspection of the connector impossible. Naturally it is possible to determine if a connector is correctly snapped in and locked however, for all other characteristics – the “intrinsic values” – for example insertion loss, return loss, or mechanical stability, users must be able to rely on the manufacturer's data.

9.3.1 Common connector types

ST connector (also known as BFOC, IEC 61754-2)

Connectors with bayonet lock were the first PC connectors (1996) and, coupled with this design and their extremely robust design, they can still be found world-wide in LAN networks (primarily industrial). ST is the designation for “straight” type.

Figure 121: ST connector

Figure 122: ST adaptor/coupler

DIN/LSA ([German: fibre-optic cable connector], version A, IEC 61754-3, DIN 47256)

These compact connectors with threaded couplers are commonly predominately used in German-speaking countries.

SC connector (IEC 61751-4)

This type of connector with a quadratic design and push/pull system is recommended for new installations (SC stands for Square Connector or Subscriber Connector). The compact design of the SC allows a high packing density and can be combined with duplex and multiplex connections. Although it is one of the oldest connectors, due to its excellent properties, the SC continues to gain in popularity and to this day. SC is still the most popular WAN connector world-wide, mainly due to its excellent optical properties. SC is also used widely in the duplex version, particularly in local area networks.

Figure 123: SC connector

Figure 124: SC Adaptor/coupler

MU connector (IEC 61754-6)

Arguably the first small form connector, it is based on a 1.25 mm ferrule and its appearance and functionality is similar to the SC but is half the size.

MTP / MPO (IEC 61754-7)

The MPO (multi patch push-on) is based on a plastic ferrule capable of holding up to 72 fibres in one connector. The connector is distinctive due to its compact design and simple handling.

Figure 125: MPO Connector

FC (Fibre Connector, IEC 61753-13)

A first generation connector that is robust and proven. This is the first true WAN connector still in use in millions of applications. However, due to its threaded coupling it is not optimal in cramped circumstances, and therefore not popular in modern racks with high packing density.

Figure 126: FC Connector

Figure 127: FC Adaptor/Coupler

E-2000™ (LSH, IEC 61753-15)

The LSH has an integrated protective shutter protects against dust and scratches as well as laser beams. The connector is fitted with a locking latch retention mechanism that is both colour and mechanically coded and is the first connector to achieve Grade A* performance.

Figure 128: E-2000™ Connector

Figure 129: E-2000™ Adaptor/coupler

MT-RJ (IEC 61751-18)

The MT-RJ connector is commonly used in LANs and has a similar appearance to that of the RJ45 connector found in copper networks. It is used as a duplex connector.

LC connector (IEC 61754-20)

Developed by the company Lucent (LC stands for Lucent Connector), it is part of the new generation of compact connectors. The construction is based on a ferrule with a 1.25 mm diameter. The duplex coupler is the same size of an SC coupler (SC footprint) thus allowing for very high packing density and making it attractive for use in data centres and Central Offices.

Figure 130: LC duplex connector

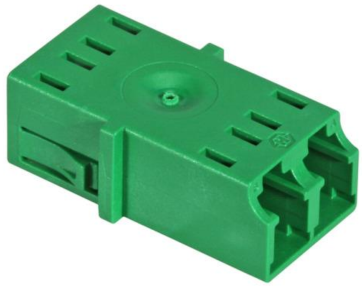


Figure 131: LC duplex adaptor/coupler

F-SMA: (Sub-Miniature Assembly, IEC 61754-22)

Threaded connector without physical contact between ferrules. It was the first standardized fibre-optic connector, but today is only used for PFC/HCS or POF.

BLINK (IEC 61754-29)

This is a small form connector with the same ferrule (1.25mm) as LC and is designed and best-suited for the connection between the OTO (Optical Telecommunication Outlet) and the ONT or CPE. The BLINK has integrated automatic shutters which protect against dust and scratches as well as laser beams. Furthermore it has an automatic self-release mechanism which prevents damage of the OTO or the ONT/CPE.

Figure 132: BLINK connector

Figure 133: BLINK to LC hybrid adaptor/coupler

Figure 134: BLINK to CLIK hybrid adaptor in Keystone-format

LX.5 (IEC 61754-23)

Similar in size to the LC with the same 1.25mm ferrule, it has the same features as the E-2000 connector. The duplex coupler is the same size as an SC coupler (SC footprint).

Figure 135: LX.5 connector

Figure 136: LX.5 adaptor/coupler

SC-RJ (IEC 61754-24)

As the name already indicates, this product is based on the RJ45 format. Two SCs form a unit the size of an RJ45. This is equivalent to the SFF (Small Form Factor). 2.5 mm ferrule sleeve technology is used as this is more robust and reliable that the 1.25 mm ferrule. The SC-RJ impresses not only with its compact design, but also its optical and mechanical performance. Seen as an all-rounder, its versatility means it can be used in many areas, from Grade A* to M, from single mode to POF, from WAN to LAN, from laboratory to outdoors.

Figure 137: SC-RJ connector

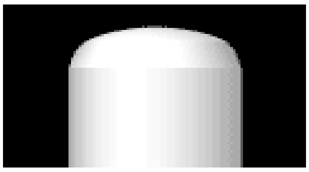
Figure 138: SC-RJ adaptor/coupler

9.3.2 Return loss

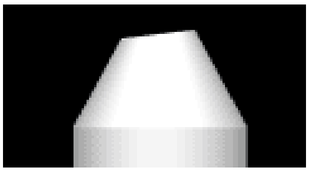
The return loss, RL, measures the portion of light that is reflected back to the source at the junction, expressed in decibels (dB). The higher the RL, the lower the reflection. Typical RL values lie between 35 and 50 dB for PC, 60 to 90 dB for APC and 20 to 40 dB for multimode fibres.

In the early days of fibre-optic plug-in connectors, the abutting end faces were polished to an angle of 90° in relation to the fibre axis, while current standards require PC (Physical Contact) polishing or APC (Angled Physical Contact) polishing. The term HRL (High Return Loss) is frequently used, but has the same meaning as APC.

PC (Physical Contact)



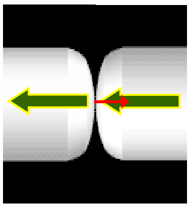
APC (Angled Physical Contact)

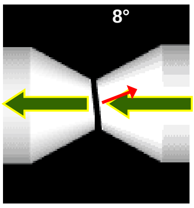


In PC polishing, the ferrule is polished to a convex end to ensure the fibre cores touch at their highest point. This reduces the occurrence of reflections at the junction.

A further improvement in return loss is achieved by using the APC polishing technique. Here, the convex end surfaces of the ferrules are polished to an angle (8°) relative to the fibre axis. SC connectors are also sold with a 9° angle. They possess IL and RL values identical to 8° versions, and for this reason they have not established themselves worldwide.

Return loss due to reflection





As a result of the junction between the two fibres, eccentricities, scratches, and contaminants, portions of light or modes are diffused at the coupling point (red arrow). A well-polished and cleaned PC connector exhibits approx. 14.7 dB RL against air and 45-50 dB when plugged in.

With the APC connector, although the modes are reflected, due to the 8° or 9° angle they occur at an angle greater than the acceptance angle for total internal reflection. The advantage is that these modes are not carried back in the fibre.

A good APC connector exhibits at least 55 dB RL against air and 60-90 dB when plugged in.

By comparison, the fibre itself has an intrinsic return loss of 79.4dB at 1310nm, 81.7dB at 1550nm and 82.2dB at 1625nm (all values at a pulse length of 1 ns).

9.3.3 Insertion loss

For losses at the connection of two optical fibres, a distinction is generally made between “intrinsic” losses due to the fibre and “extrinsic” losses resulting from the connection. Losses due to the fibre occur, for example, when different core radii are used, with different refractive indexes or eccentricities of the core. Losses resulting from the connection occur due to various reasons including reflections and roughness on the end faces, pointing errors or radial misalignment. The following notes and information refer to connection losses; not considered are the influence of fibre tolerances and fibre-optic cable quality.

The technical transmission grade of a fibre-optic plug-in connector is primarily determined by two characteristics: the insertion loss IL and the return loss RL. The smaller the IL the larger the RL value thus the better the signal transmission in a plug-in connection.

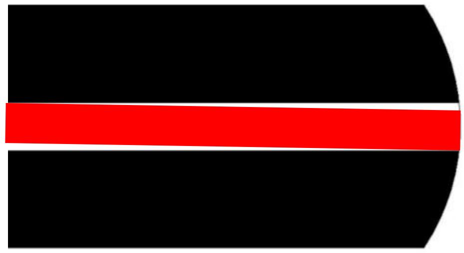
Insertion loss is a measurement of the losses that occur at the connection point. It is calculated from the ratio of the light power in the fibre cores before (P_{IN}) and after (P_{OUT}) the connection and is expressed in decibels.

The smaller the value, the lower the signal losses. Typical IL values lie in the range from 0.1 to 0.5dB.

In the marketplace, specifications with the designation -dB and +dB are also used; for example, a patch cable could be specified with -0.1 dB or 0.1 dB. In both cases, the physical loss is identical.

9.3.4 Extrinsic losses

Less light energy is lost if the fibre cores meet more precisely. For this reason, high-precision fibres are glued in precise ceramic ferrules. The connection-dependent extrinsic losses result from reflections, roughness on the end faces, angular errors (angular pointing error) or radial misalignment (concentricity). Reflections and roughness play a subordinate role in the loss. Primary causes are misalignment and pointing errors.

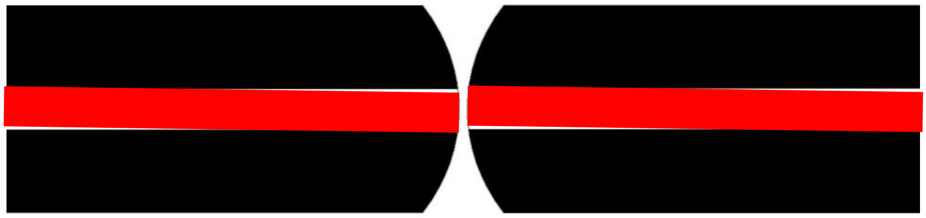


The ferrule hole must be larger than the fibre to allow the fibre to be inserted. As a result, the fibre always has a certain clearance in the core. This causes additional concentricity, but also a pointing error.

Angular pointing error:
The so-called angular pointing error should be <0.3°. Greater pointing errors cause stress on the fibre that can lead to fibre breakage.

Concentricity:
According to IEC 61755-3-1+2, the maximum concentricity may be, depending on grade, between 1.0 µm and 1.6 µm (measured from the fibre axis to the ferrule exterior diameter).

If two ferrules or plug-in connectors are plugged together without taking additional steps, there is a risk that the concentricity and angular pointing error together increase the loss.



To minimise insertion loss of plug-in connections, the radial misalignment of two connected fibres must be as small as possible. This is achieved by defining a quadrant of the ferrule in which the core must lie. Connectors which can be tuned make it possible to turn the ferrule in 60° or 90° steps. If two tuned connectors are connected to each other, the deviation of the core position is reduced in the ferrule, which leads to significantly improved performance compared with untuned connectors.

An angular pointing error >0.3° should be avoided to prevent stress on the fibre. Stress loads reduce the service life and optical properties of the fibre – particularly BER (Bit Error Rate), modal noise and high-power tolerance.

Precision work, first-class materials and total quality control are required for the manufacture of reliable high-performance fibre-optic plug-in connectors. Stresses on the tiny components of a fibre-optic connector are highly demanding. Products should be constructed for a service life of 200,000 to 250,000 hours, or 25 years. For patching, the connectors must also withstand high sheering forces and should easily withstand 500 to 1000 plug cycles.

9.4 Fibre optic splicing

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

9.4.1 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.

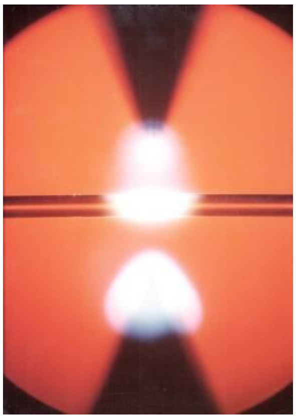


Figure 139: Fusion arc in

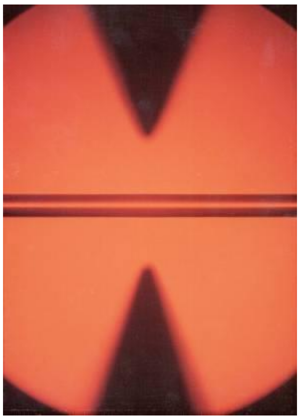


Figure 140: Splice complete

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) to one another. These machines produce splices with losses typically in the region of <0.05dB.

Figure 141: 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 increase the occurrence of errors as the dimensional tolerances of the cladding are larger. Typical insertion loss values for these splice machines are better than 0.1dB.

9.4.2 Mechanical splicing

Mechanical splicing is based on the mechanical alignment of two cleaved fibre ends to allow a free flow of light. This also applies to terminating fibres onto connectors. To facilitate light coupling between the fibres, an index matching gel is often used. Manufacturers have different methods to terminate the fibres in the mechanical splice.

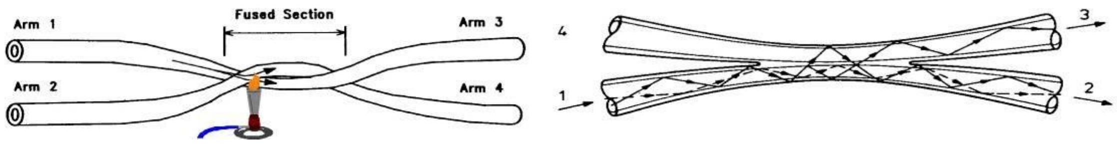
Mechanical splices can be angle cleaved or non-angle cleaved, but the former has a higher return loss. The insertion loss of a mechanical splice is typically <0.5 dB.

Figure 142: Mechanical splicers

9.5 Optical splitters

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

9.5.1 Fused bi-conic taper



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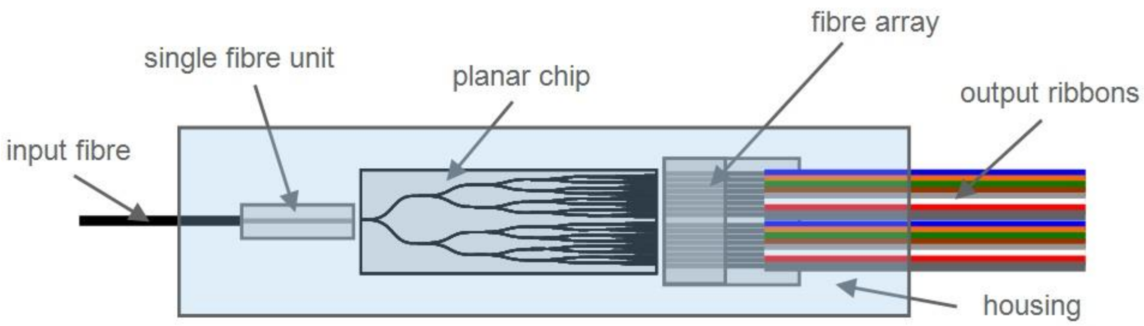
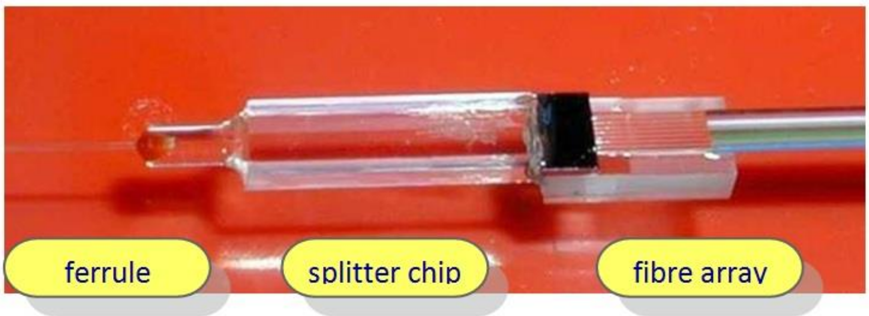
- FBT splitters are made by fusing together two wrapped fibres.
- Common production process.
- Proven technology for OSP environments.
- Monolithic devices are available up to 1x4 split ratio.
- Split ratios greater than 1x4 are built by cascading 1x2, 1x3 or 1x4 splitters.
- Split ratios from 1x2 up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

9.5.2 Planar splitter





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

9.6 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 below). Clear, grade identification and necessary IEC test method aids planners as well as 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 informed purchasing decisions. This also avoids purchasing of over-specified products which do not deliver the expected loss values claimed.

The current requirements list is based in part on IEC 61753 and defines loss values. Additionally, the standards IEC 61755-3-1 and IEC 61755-3-2 play a role as they define geometric parameters for fibre-optic plug-in connectors. The interaction of these three standards forms 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: Overview of performance criteria of the new performance 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	✗	✗	✗	(✓)

9.7 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 used in testing situations with, every connector in a lot being connected to every other connector and the loss of the combination connector/sleeve/connector is measured.

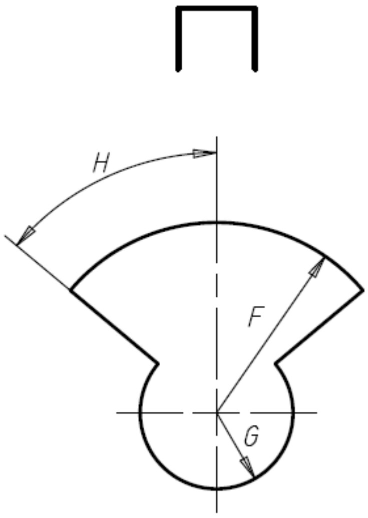
The rational for this model is: loss values generated according to the IEC specification for random connector pairs is much closer to actual operating conditions than manufacturer-specified loss values that, in many cases, are based upon a best-case measurement under laboratory conditions. In best-case 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)

9.8 Mean values

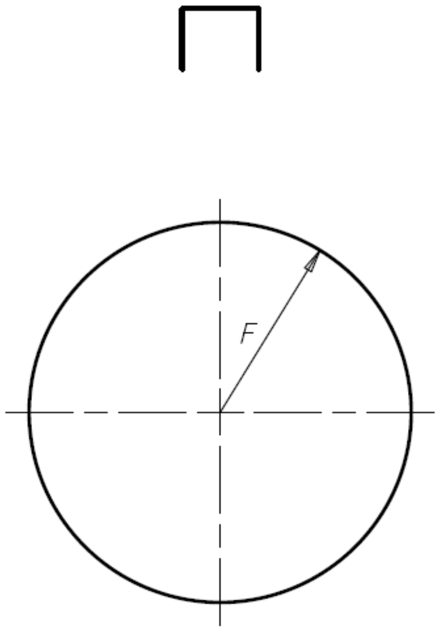
A new development resulting from grades is the demand for mean values. This is an optimal basis for the calculation of link attenuation and is particularly relevant in large networks. Previously it was necessary to calculate attenuation using the maximum value, which was already noted as having low reliability for each-to-each connections. Now the stated mean values can be used for calculation and in this way, every planner uses the proper class to meet existing needs, thus guaranteeing 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

9.9 Manufacturer specifications and real usage conditions

The following is taken from real life and 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, often occurring real life, serious discrepancies originate?

The manufacturer had determined the value found in the product specification in a best-case environment. Used in this scenario are low-loss reference or master cables 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 and thus 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 discover that the calculated insertion loss budget cannot be met. Delays in initial start-up and expensive replacement purchases are unavoidable.

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 an extensive training. Therefore it is recommended the appropriate certification of the specialist firm or personnel be considered.

10 Operations and Maintenance

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

During network construction, a probable requirement of the building contract is to ensure that as little or no disturbance within the FTTH area occurs which affects the general public and the surrounding environment. This is achievable only through careful planning and execution and will ultimately encourage the deployment of efficient building methods to the benefit of the FTTH business case. Inefficient planning will result in the opposite and potentially lead to poor network and building performance.

Whilst fibre has been in service over a number of decades and is a proven and reliable medium, it is still susceptible to unexpected breakdowns that require mobilisation and rapid and efficient repairs. During such times immediate access to network records is essential. All documentation and records relating to the network build should be collated and centralised to support all subsequent network analysis.

Maintenance procedures must be planned in advance and contractual arrangements put in place to ensure appropriate manpower is available when needed.

10.1 Deployment planning guidelines

10.1.1 Site control and installation operation planning

Work with underground duct systems or sideway installations or poles require careful planning and often cause disruption to traffic therefore liaison with local authorities is necessary 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 constructing a duct type installation.

10.1.2 General management considerations

Familiarity and experience with underground, aerial duct and cable systems is necessary as is respecting best practices and conducting work flow studies.

Careful planning of the installation and liaison with local authorities, will lead to an efficient and safe operation. A full appreciation of locally located power supply services must be obtained from the local authorities and also through the use of on-site confirmation detection equipment.

10.1.3 General considerations related to safety

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

Possible traffic disruption should be coordinated with local authorities. All manholes and cable chambers should be identified and those intended for access should be tested for flammable and toxic gases before entry.

With regard to 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 possibility of damage and exposed conductors.

10.1.4 General considerations about constructions and equipment

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

Unacceptably high water levels in cable chambers and sewage/water tunnels must 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 their suitability for coiling slack cables, provision of cable supports and space for mounting splice joint closures.

A plan should be established for the optimal positioning of the cable payoff, mid-point fleeting and cable take-up/ winching equipment. The same also applies to those cables that are to be blown into the duct and which might require a blowing head and compressor equipment.

Allowances for elevation changes should be taken into consideration.

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 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 thus protecting the cable. A mechanical fuse protects the cable from excess pulling forces by breaking a sacrificial shear pin. These pins are available in different tensile values.

A pulling winch with a suitable capacity should be used and 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 of the operation.

Uses of midpoint or assist winches are 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.

10.1.5 General considerations about cabling methods

10.1.5.1 Duct and micro-duct 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 lifespan 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, therefore cable and duct supplier/s must be contacted for installation guidelines.

10.1.5.2 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.

10.1.5.3 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 construction 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.

10.2 Operation and maintenance guidelines

Consideration should be given to:

- measurements
- fibre cable and duct records
- marking 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)

11 FTTH Test Guidelines

11.1 Connector care

11.1.1 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 an installation 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' quality
- 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 worst case scenario, 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, one component that is often overlooked is the connector, sometimes overused (test jumpers). This can be controlled using the proper procedure.

CONNECTOR CONTAMINATION IS THE FIRST 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.

11.1.2 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 as small as 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 become attached to 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.

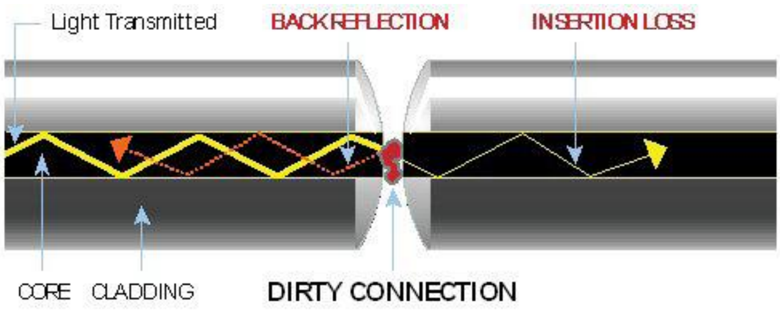


Figure 143: Increased insertion loss and back reflection due to dirty fibre connection.

A 1µm dust particle on a single-mode fibre core can block up to 1% (0.05 dB loss) of the light, a dust particle the size of 9µm can incur considerable damage. An additional factor for maintaining end faces contaminate free is the effect high-intensity light has 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 an unclean 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 144). The inner-most zones are more sensitive to contamination than the outer zones.

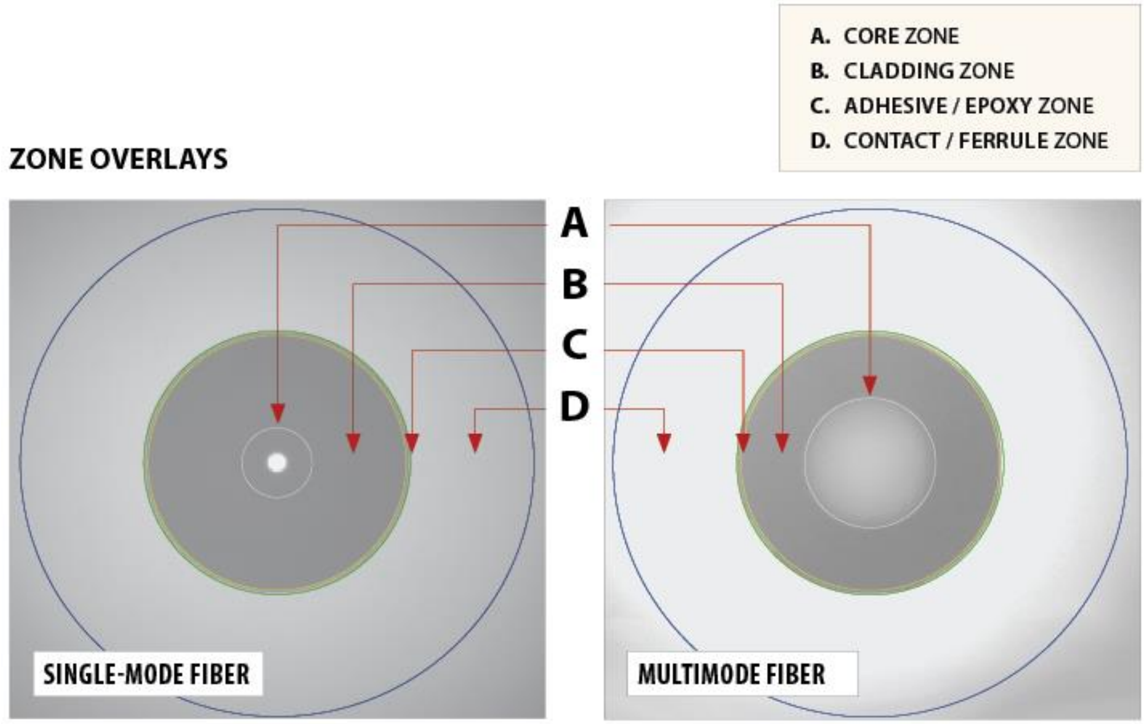


Figure 144: Connector end face inspection zones

To avoid connector failure and to provide some guidelines as to what is acceptable or what is not, the IEC has defined a standard (61300-3-35) to define acceptance criteria based on the number and size of defects applicable to each of the zones (A-B-C-D) of a connector. This standard also defined acceptance criteria for each type of connector available on the market (ex: MM, SM, UPC, APC).

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 and, regardless of appearance, the most critical areas to inspect are the core and cladding regions where contamination here can greatly affect the quality of the signal. Figure 145 illustrates the end face of different connectors that have been inspected with a video-inspection probe.

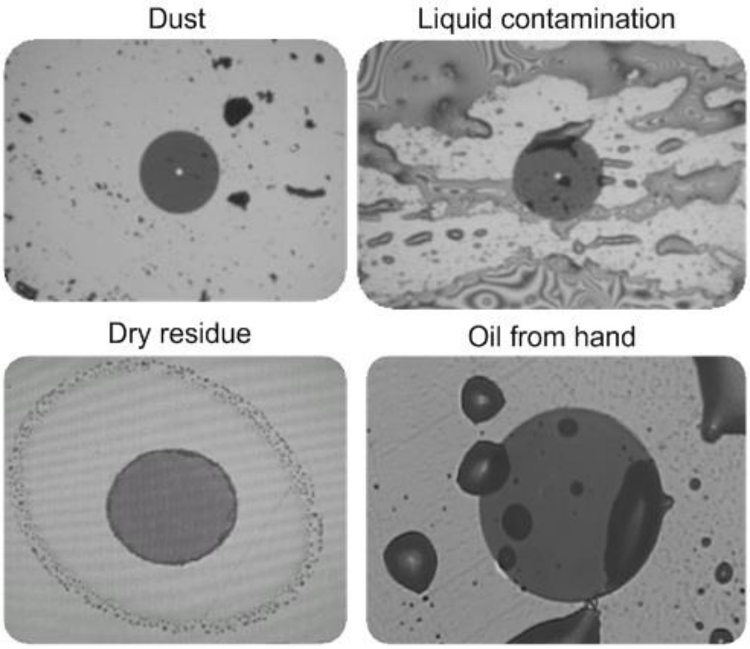


Figure 145: Appearance of various contaminants on a connector end face.

11.1.3 What components need to be inspected and cleaned?

The following network components should be inspected and cleaned:

- all panels equipped with adaptors where connectors are inserted in one or both sides
- test patch cords
- all connectors mounted on patch cables or pigtails

11.1.4 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:

- after installation
- before testing
- before connecting

11.1.5 How to check connectors

To properly inspect the connector's end face, a microscope designed for the fibre-optic connector end face is recommended. The many types of inspection tools on the market 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 is displayed 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 individual connectors mounted on patch cords or pigtails and multi-fibre connectors (e.g. MPO/MTP). Various degrees of magnification are available (100X/200X/400X). Adapter tips for all connector types are available.
Optical microscopes	Safety filter* protects eyes from direct contact with a live fibre. Two different types of microscopes are 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).

To help remove subjectivity from the connector inspection and to ensure a common level of acceptance between suppliers and installers, one could use a fibre inspection probe combined with an automated analysis software. As shown in figure 146, the automated analysis software will measure size and location of each defect present on the ferrule and it will tell if the connector respects the selected IEC standard.

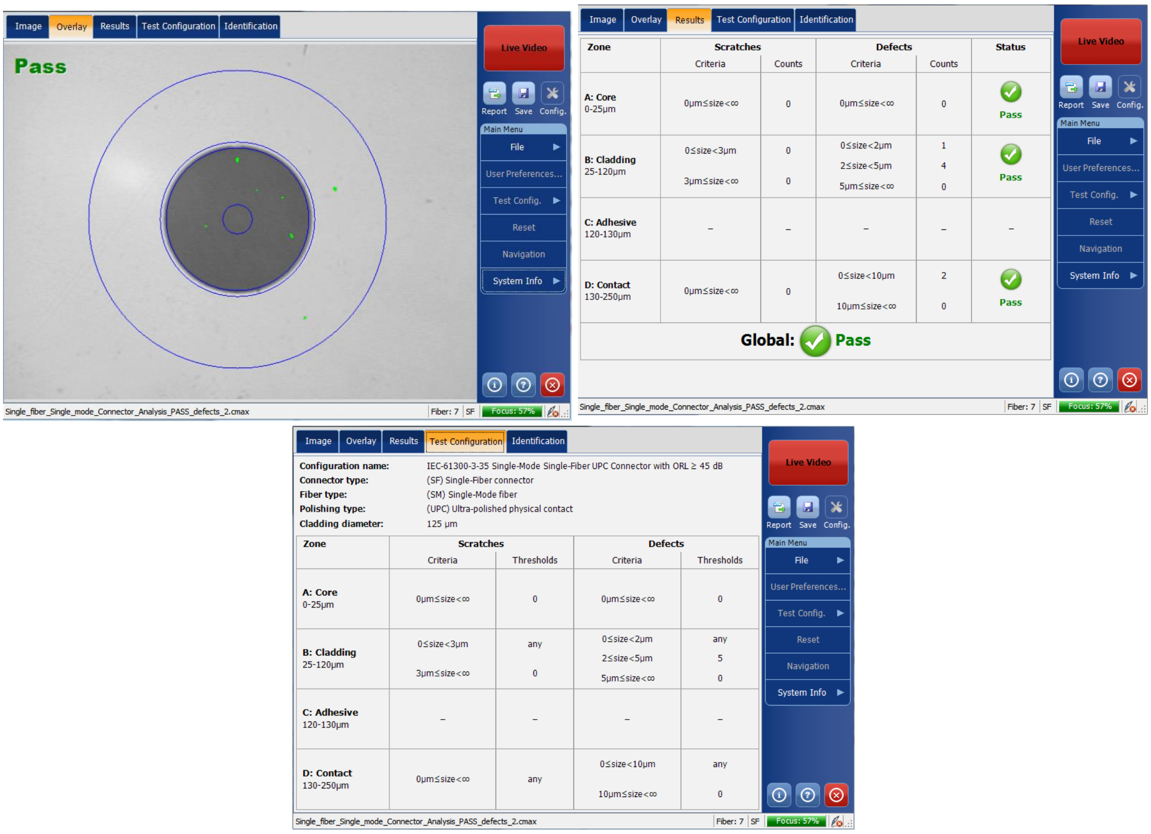
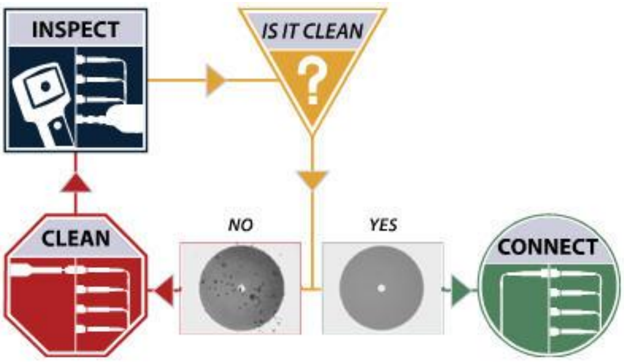


Figure 146: Automated connector analysis software

11.1.6 Inspection instructions

Visual fibre interconnect inspection is the only way to determine the cleanliness of the connectors prior to mating. A video microscope magnifies an image of a connector's end face for viewing on a laptop or a portable display, depending on the product used.



INSPECT	Select the appropriate tip for the connector/adaptor to be inspected. Inspect both connector end faces (patchcord/bulkhead/ pluggable interface) using the microscope.
IS IT CLEAN?	
CLEAN	No. During inspection defects are found on the end face; clean the connector using a designated optics cleaning tool.
CONNECT	Yes. If non-removable, non-linear features and scratches are within acceptable criteria limits according to operator's thresholds or standards, the fibre interfaces can be connected.

11.1.7 Tools needed for inspection

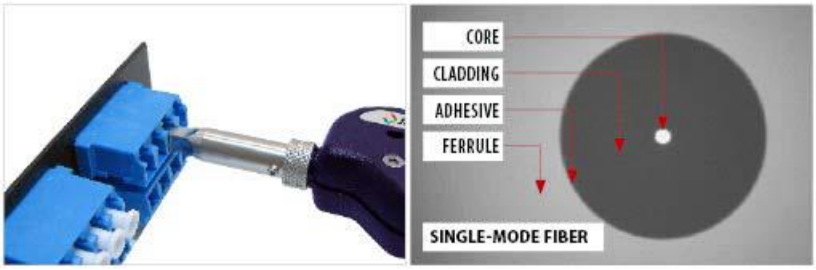
There are two methods for fibre end face inspection. If the cable assembly is accessible, insert the connector ferrule into the microscope to conduct the inspection; this is generally known as patch cord inspection. If the connector is within a mating adaptor on the device or patch panel, insert a probe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

11.1.7.1 Patch cord 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.
  (Last line in drawing: single-mode fibre)

11.1.7.2 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.
  (Last line in drawing: single-mode fibre)



11.1.8 Cleaning wipes and tools

11.1.8.1 Dry Cleaning

Simple dry cleaning wipes, including a number of lint free wipes and other purpose-made wipes, are available. This category also includes purpose-made 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. Do not open until just prior to use.

Wipes should be used by hand or attached to a soft surface or resilient pad. Not applied using a hard surface as this can cause damage to the fibre. If applying by hand, do not use the surface held by the fingers as this can contain finger grease residue.

Figure 147: Examples of dry cleaning wipes and tools for fibre-optic connectors

Figure 148: Examples of cleaning fluid and wipes

11.1.8.2 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 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 leave solvent on the side walls of the ferrule as this will transfer onto the optical alignment sleeve during connection.
- Wipes must be used by hand or on a soft surface or resilient pad.
- Applied using a hard surface can cause damage to the fibre.

11.1.8.3 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; it does not however 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 the contents of the port prior to cleaning. Take care to avoid damage when cleaning transceiver flat lenses.

Figure 149: 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 being tested should be uncapped—protective caps should be replaced immediately after testing.
- Unused caps should be kept in a small plastic bag.
- Lifespan of a connector is typically rated at 500 matings.
- Test jumpers used in conjunction with test instruments should be replaced after a maximum of 500 matings (refer to EIA-455-21A).
- If using a launch cord 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 returned to manufacturers for re-polishing after 500 matings.
- Do not allow unmated connectors to touch any surface. Connector ferrules should never be touched other than for cleaning.
- Clean and inspect each connector using a fiberscope or, preferably, 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.

11.2 Testing FTTH networks during construction

During network construction, some testing occurs in the outside plant. When fibre is laid down new splices have to be performed and tested 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 testing methods, some of which are presented here. Each has specific advantages and disadvantages. Selecting the most appropriate method depends on the constraints faced: labour costs, budget loss, testing time combined with service activation time, maximum acceptable measurement uncertainty, etc.

An additional factor that must be considered when determining extent of testing is the skill levels of the technicians. Employing unskilled fibre-optic technicians during construction phase is very costly if mistakes need to be rectified ahead of and after service is added.

11.2.1 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 units should be referenced prior to measuring IL.

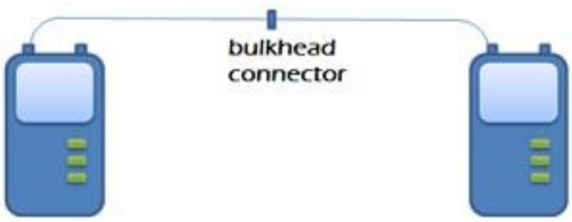


Figure 150: Test sets should be referenced prior to measurement

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.

Measurements can now be taken 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 any transposed fibres and to measure the IL and ORL to guarantee that the loss budget has been met.

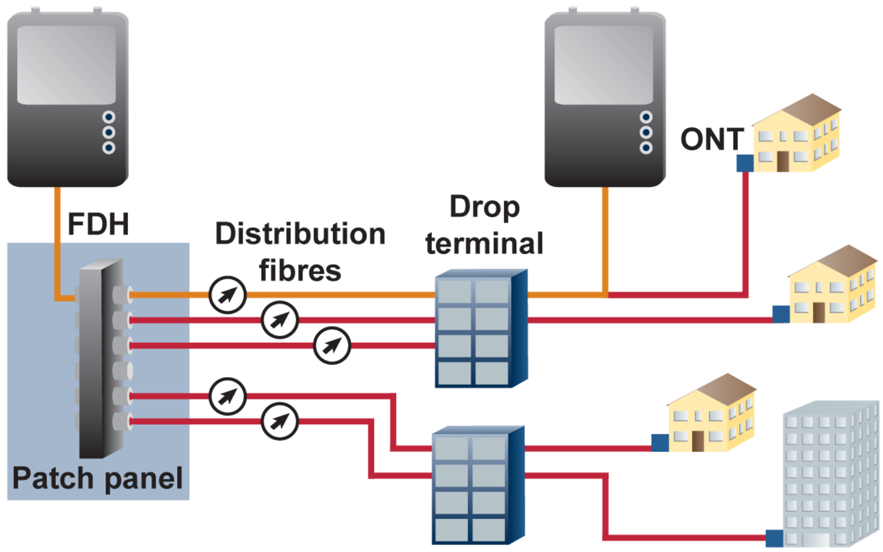


Figure 151: Measuring distribution fibre IL and ORL using two OLTSs

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 into account two connections. FTTH networks often comprise of multiple connection points and, as reflectance values are very sensitive to dust and scratches, these values can easily be influenced 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 due to 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 a point-to-multipoint network, a single OLTS close to the OLT can be used for all subscribers within the same network)
Bidirectional IL and ORL values	Communication required between technicians (when switching fibres)
Possibility to test every distribution fibre	A point-to-multipoint network requires one technician to move from drop terminal to drop terminal
Macrobend identification during testing is performed at 1550 and 1310 nm or another combination of wavelengths including the 1625 nm wavelength	In the event 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	

11.2.2 Method 2: Use of an OTDR

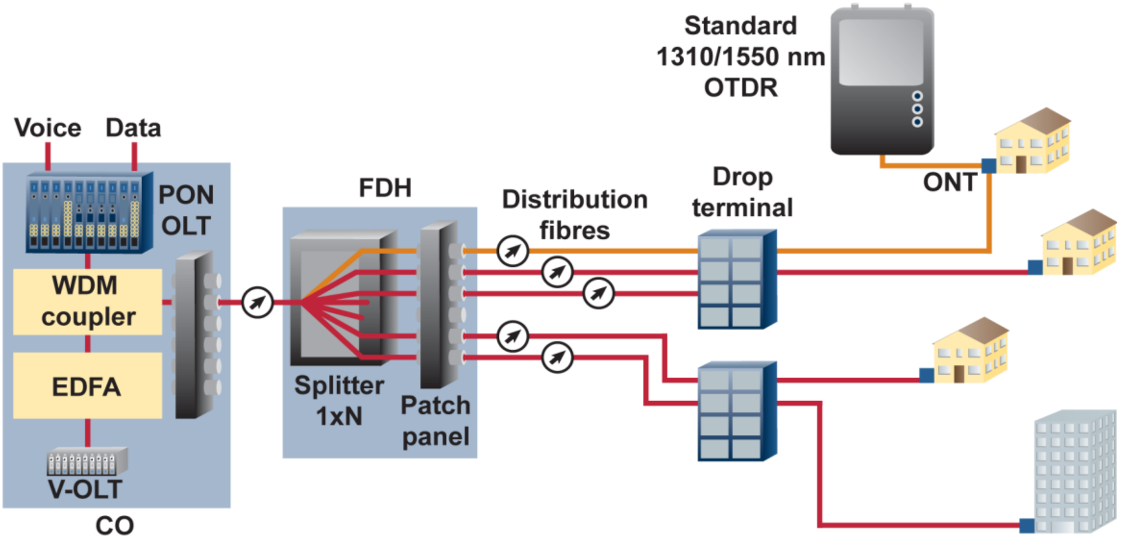


Figure 152: Measurement with an OTDR

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, as well as 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 locate macrobends. The test can be conducted to cover 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 subscriber activation by certifying end-to-end link integrity.

The recommended OTDR technique is to start by using a short pulse width to qualify the first part of the link (the drop cable), up to the splitter. A short pulse width provides high resolution to make sure that the front-end connector, the drop point connector/splice or any other closely spaced events along the drop fibres meet predefined specifications and that all splices are within acceptable limits.

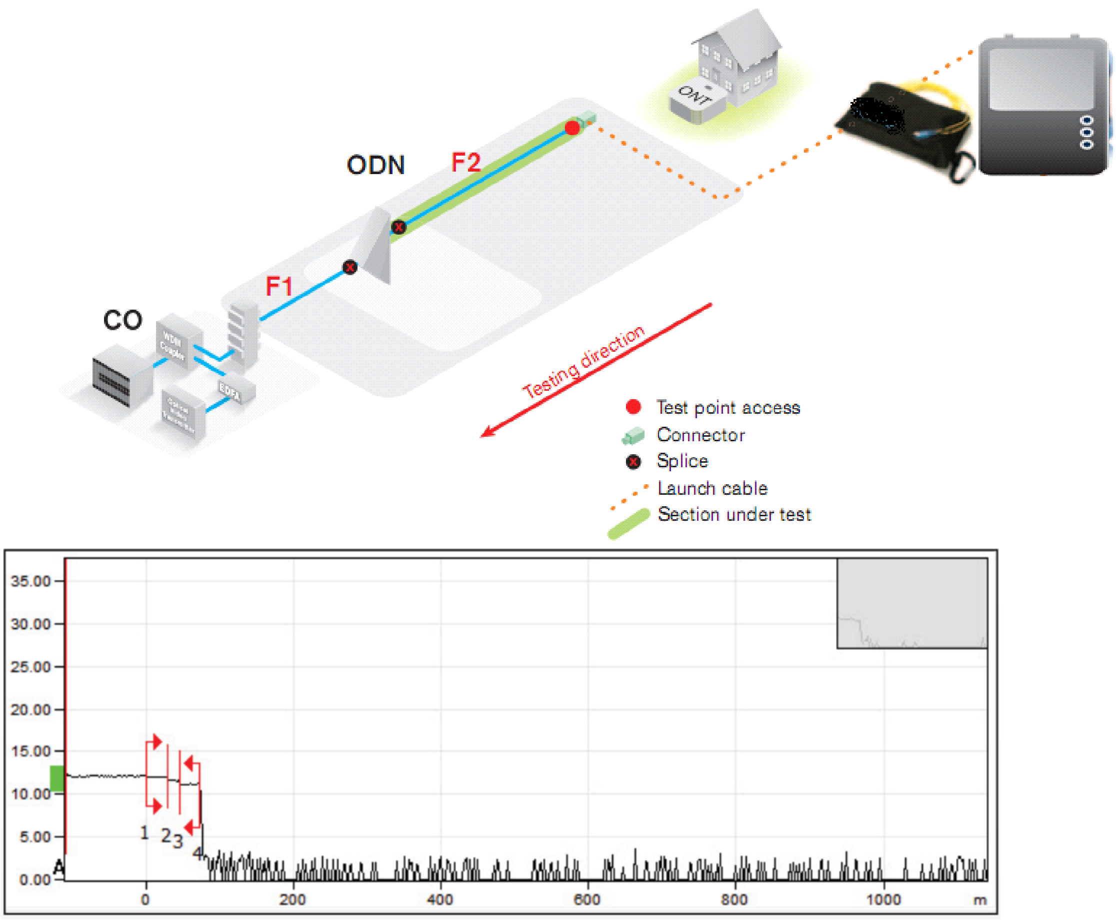


Figure 153: OTDR trace using a short pulse width

Using a 5 ns to 10 ns pulse width, an experienced technician verifies the first connector and identifies all elements on a link up to the splitter; using a short pulse width provides better resolution and easy pinpointing of problematic connectors or splices.
Then, a second acquisition is launched using a medium pulse width; this provides a better dynamic range while maintaining good resolution. The technician measures loss at the splitter to verify that it is within acceptable limits.

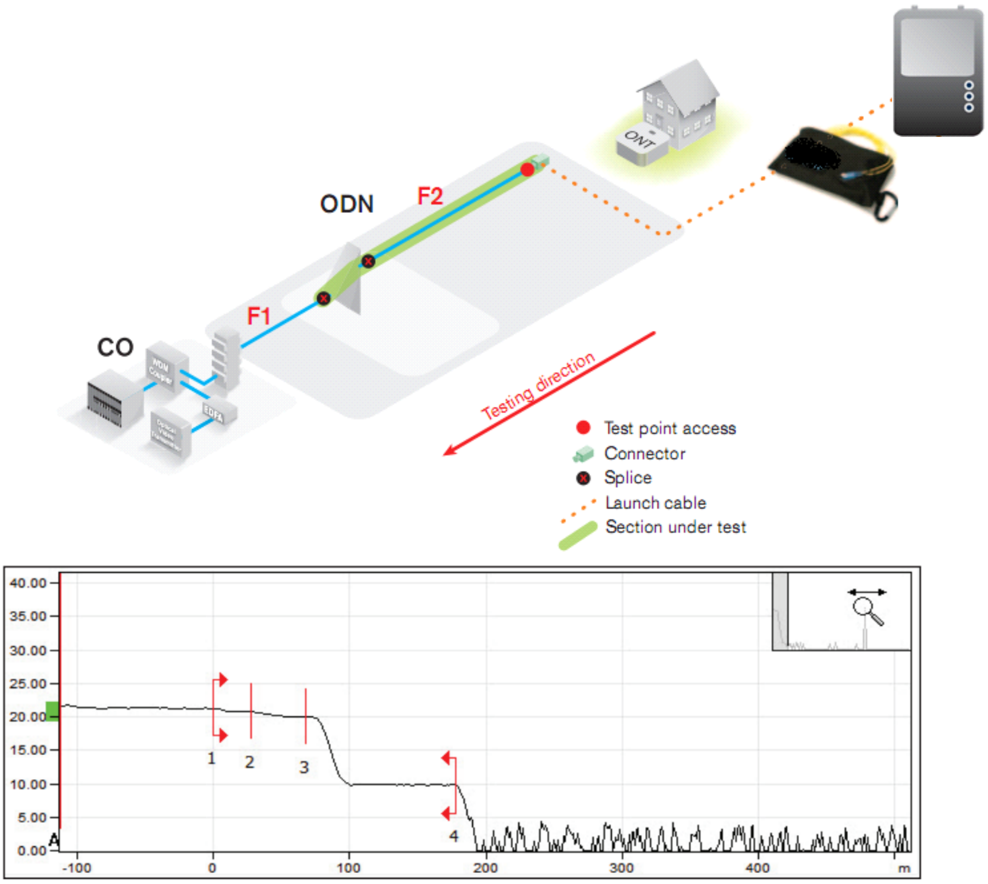


Figure 154: An OTDR trace using a medium pulse width

Using a longer pulse width than for the first trace, an experienced technician qualifies the splitter area and possibly the portion between two splitters. Depending on the results, the technician may need to repeat this second step to find the optimal pulse for measuring the splitter loss and/or the end-to-end loss.

Finally, the technician completes the test with a pulse width that has enough dynamic range to allow end-to-end loss qualification. A long pulse width provides the required dynamic range but offers lower resolution; this can also be related to a longer dead zone which will not identify closely spaced events located at the front and possibly the first stage of the splitter.

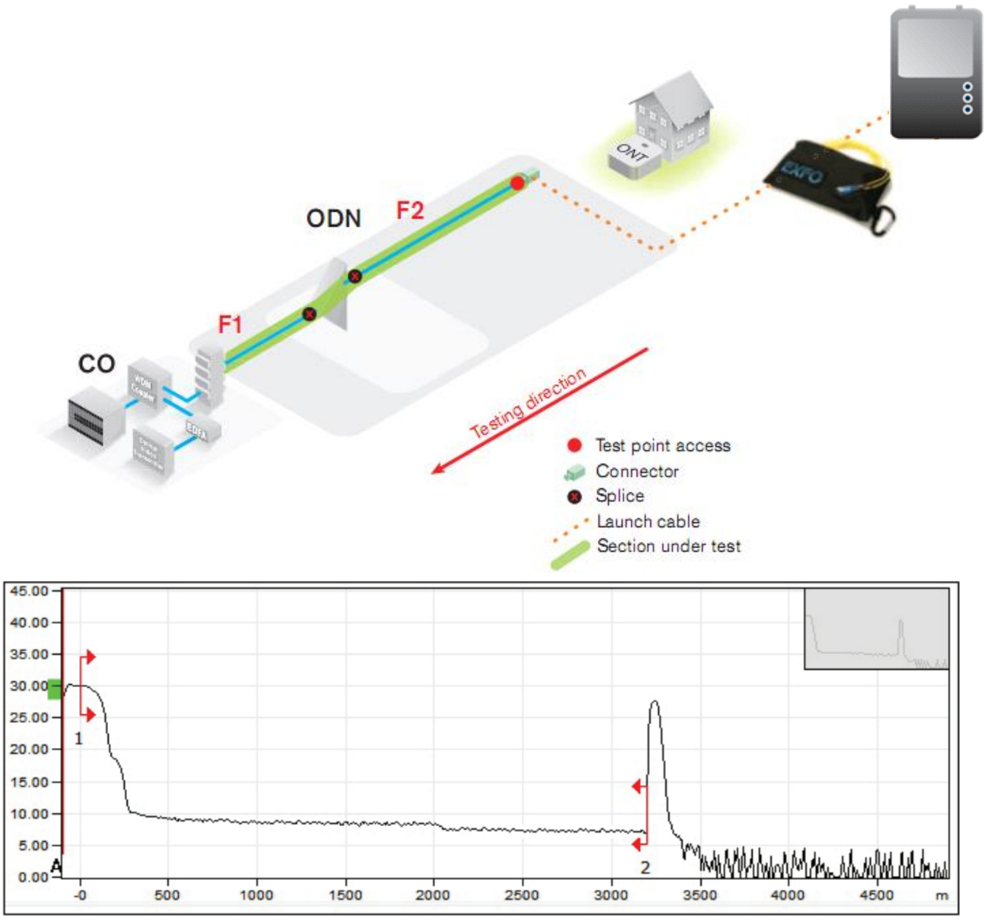


Figure 155: OTDR trace using a long pulse width

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).
Possibility 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 another combination of wavelengths involving the 1625nm wavelength.	Several tests may be required to test the entire link.
In case of a cut fibre or macrobend, the fault can be located.	A skilled technician is required to interpret the trace.
Only one technician required.	
Fast testing	

The method 2 results in three or four OTDR traces that will need to be consolidated. Good OTDR skills are required to set the proper pulse widths to test the link as well as to analyze the OTDR results. Quite a lot of time will be spent comparing results at the different pulse widths to determine which one provides the best measurement for each section and event. Plus, if a single report must be provided at the end, extra time will also be required to extract information from the different traces and input the data into a custom report template. Overall, the entire process could take between 5 to 10 minutes, depending on the network complexity and the technician's skills.

To reduce testing time and aid less skilled technicians in performing the tests, some OTDR manufacturers have introduced new testing tools that greatly simplify the acquisition process and traces interpretation. Based on the same technology used in an OTDR, these tools will automate the test sequence by performing the test using several pulse widths at all test wavelengths.

Once completed, the tools will then consolidate all this information into a single comprehensive icon based View; the operator is not required to manually compare results at different pulses as is necessary in a traditional OTDR. These tools provide the link's loss and ORL. In addition to identifying all network elements such as splices, splitters and connectors, it also provides the loss and reflectance values of the identified elements. If a specific element or the link itself gets a "fail" verdict, some tools will offer a diagnosis to help the operator solve the problem. The whole routine takes 30 to 60 seconds, depending on network complexity.

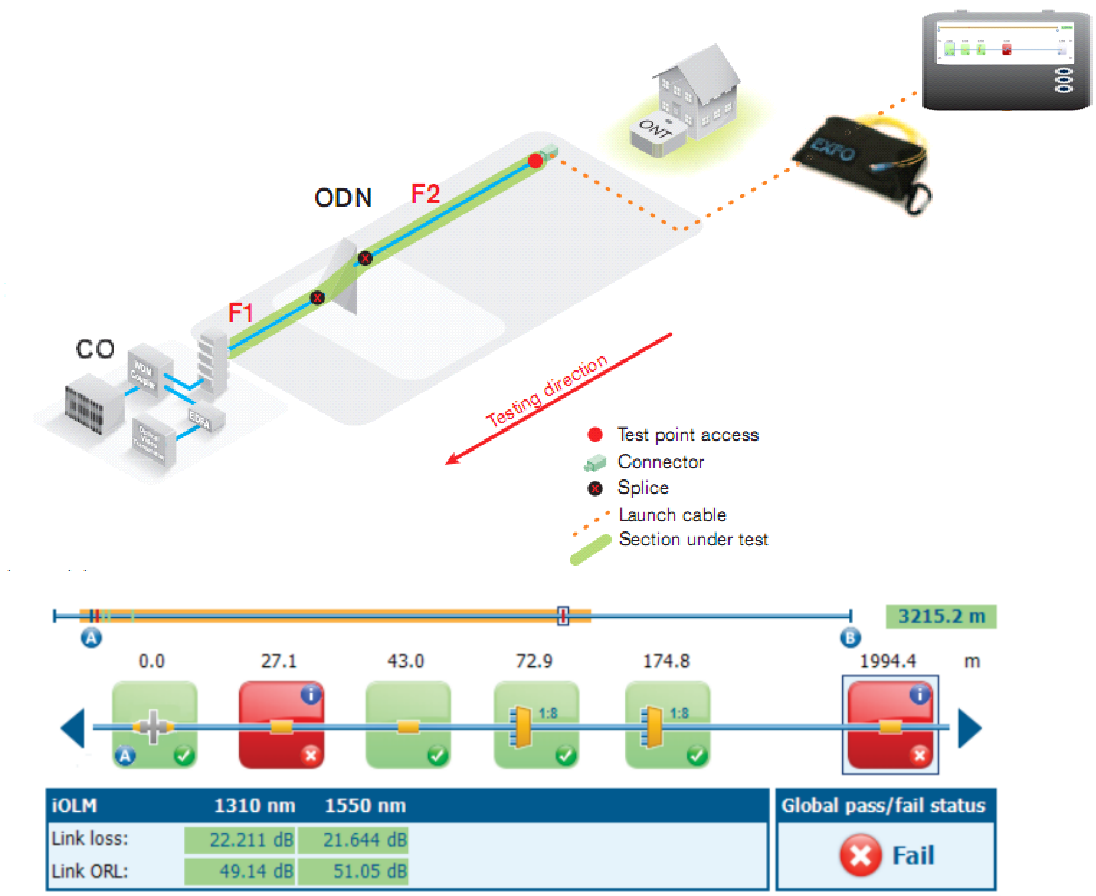


Figure 156: Icon based OTDR

Characteristics	OTDR	icon based OTDR
Number of technicians required	1	1
Technical expertise needed to perform test	Medium to high	Low
Number of acquisitions required to characterize a PON network	An average of three depending on link complexity; each acquisition estimated at an average of 45 s/wavelength	1 (average of 45 seconds; multiple acquisition are done automatically)
Average test time per fiber	Typically 6-15 minutes depending on link complexity and technician's skills	≈ 45 seconds to 1 minute
Physical mapping of the link	Yes	Yes
Graphical representation of the link	Traditionnaly graphical representation	view with icons
Provides insertion loss	Yes	Yes
Provides optical return loss	Yes	Yes
Provides length of the fiber	Yes	Yes
Live-fiber testing port	Yes	Yes
In-line power meter	Yes	Yes
Automatic diagnostics	Macrobend detection and pass/fail status	Yes, global and individual pass/fail status plus diagnosis information for each failure
Test from premises (ONT) to CO (OLT)	Yes	Yes
Test from CO (OLT) to premises (ONT)	No	No
Troubleshooting	Yes	Yes
Live testing	Yes	Yes
Offers easy transpose fiber detection	No	No

11.2.2.1 Service activation

The service activation phase may seem very straightforward initially, however this task should not be underestimated as this is the moment at which the subscriber experience begins. The service activation scheme can be different depending on topology of the fibre network. The trend is for pre-engineered plug-and-play components with multiple connection points, rather than an all-spliced approach, particularly for deployments in MDUs.

In terms of handling data relating to test and measurements in PON, the service activation brings two new dimensions:

- results should be linked to subscribers or ONUs instead of fibres.
- more than one test location may be required, typically two or three.

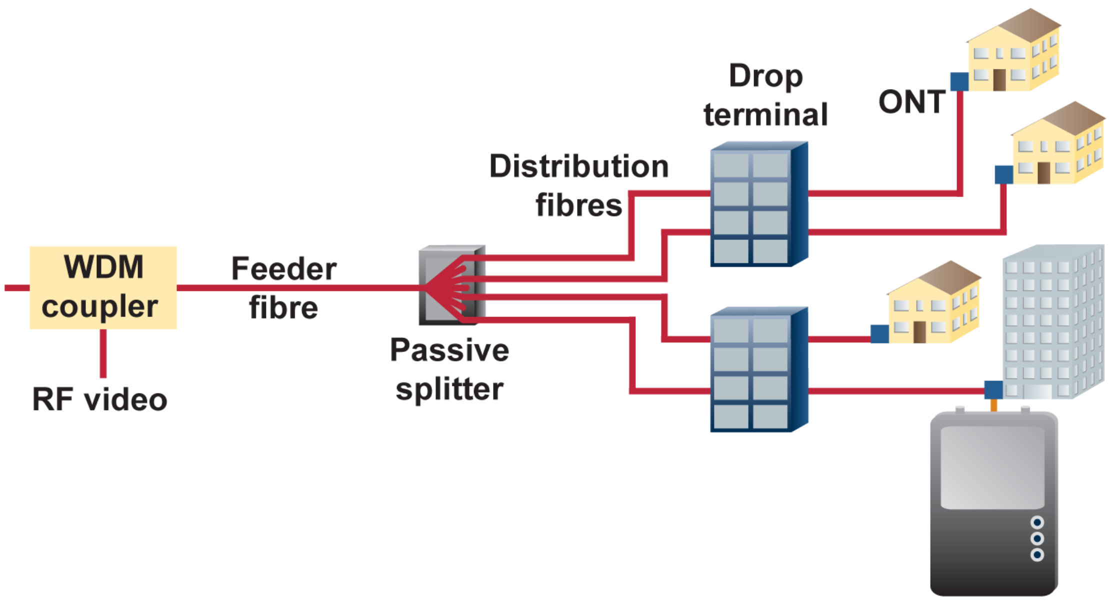


Figure 157: Activation testing using a PON power meter

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.

11.2.2.2 Multiple testing locations

Verifying optical levels at various locations along the same fibre path assists the test engineers in pinpointing problems and/or defective components before activating a subscriber'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 strongly recommended that inspection of each connection point be conducted using a fibre inspection probe before each power measurement.

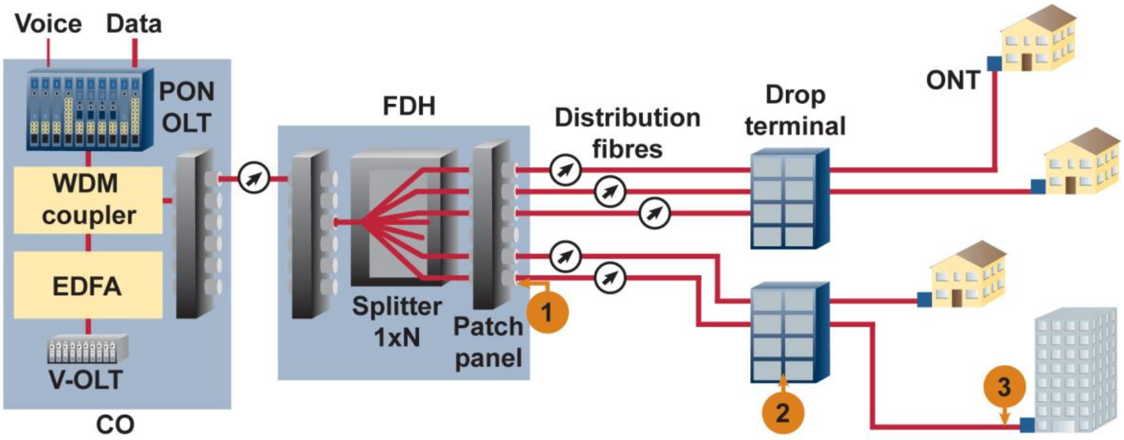


Figure 158: Testing point in PON

11.2.2.3 Testing points

1. By performing a power-level certification at the splitter, or more specifically at the output, enables users to verify if the splitter branch is working properly. This simple assessment makes it possible to confirm whether all network components from the CO (including the feeder fibre) 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 conducting 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 terminals and the subscriber's premises is generally installed during service activation. To ensure reliable services to the subscriber, the network and the subscriber ONU must meet their specifications. The best method of guaranteeing this is to perform a pass-through connection to fully characterize all operating wavelengths (upstream and downstream) in the PON. This can only be achieved at the service-activation phase using a dual-port PON power meter with a pass-through connection; a normal power meter can only certify downstream signals from the CO.

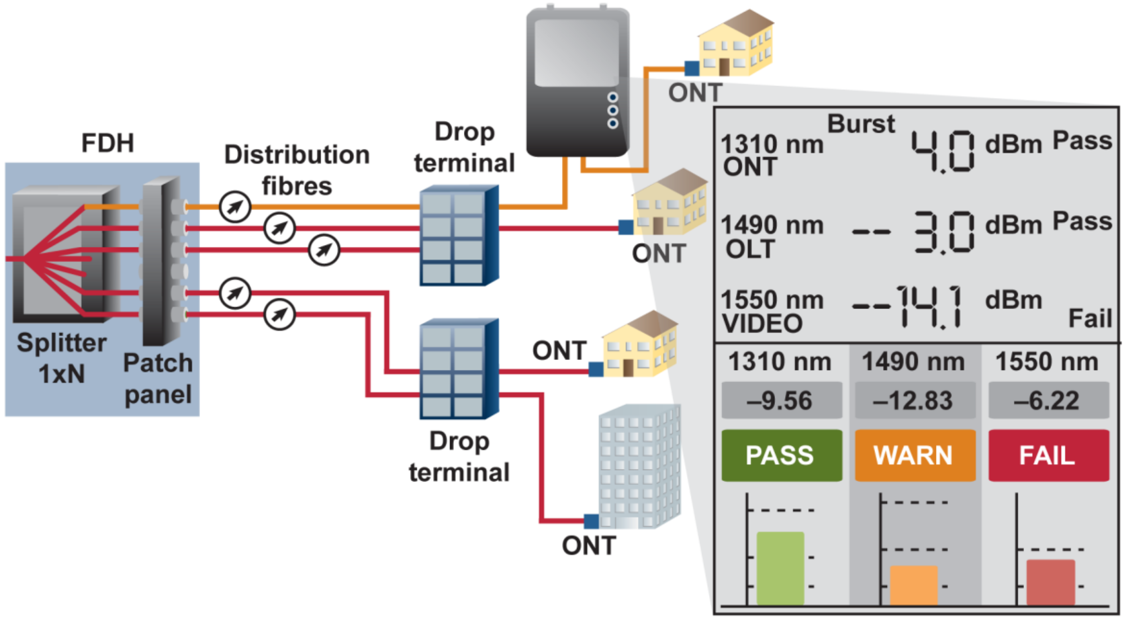


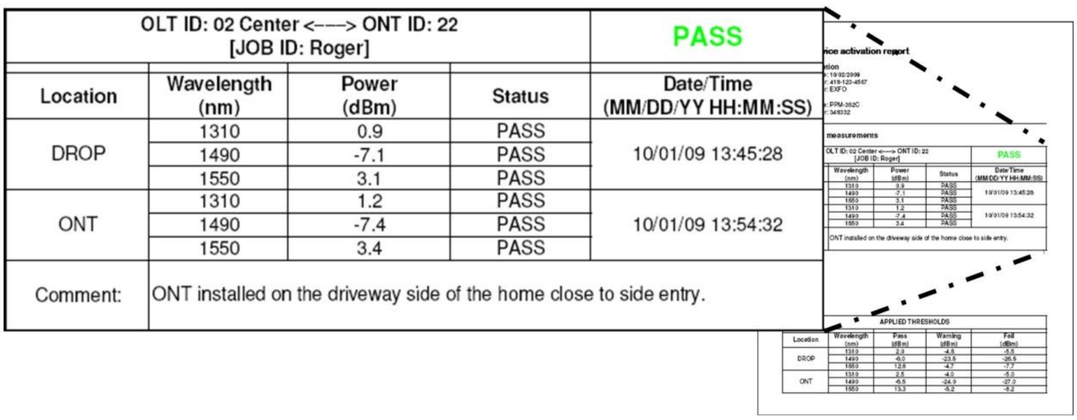
Figure 159: Pass-through testing of all wavelengths

11.3 Service activation reporting

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

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 160: Service activation report

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

12 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 conducted simply with the use of a power meter or OTDR.

A live PON network requires the use of a PON power meter with through mode to ascertain whether signals going downstream and upstream are out of tolerance. To pinpoint any fibre breaks, macro-bending, faulty splices or connectors, an OTDR with a live testing port (also called filtered port) must be used from the subscriber's location.

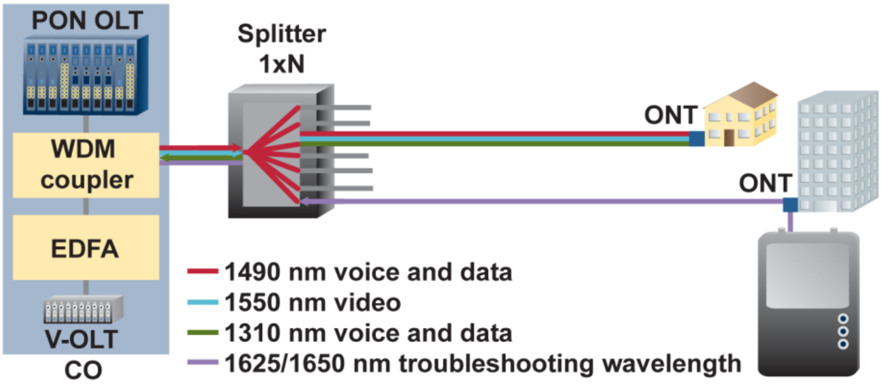


Figure 161: PON network troubleshooting

Ensure the fibre length corresponds to the length in between the drop cable output and the splitter location. If not, this indicates a problem (break or macro-bend) is present at this location.

If the length measurement is correct, every splice point should be checked to see it does not exceed the normal splice values. Any point exhibiting an excessive loss value will indicate the presence of a macro-bend, kink in 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; as well as phone services over twisted pair wiring. Service providers may wish to provide digital video through quadrature amplitude modulation (QAM) or IPTV or a combination.

Premises architecture incorporating 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.

12.1 In-home wiring issues

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

12.1.1 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 previously provided by the central office. Consequently, troubleshooting VoIP covering phone wiring is very similar to troubleshooting POTS.

Common errors affecting in-home wiring installations include:

- opens
- shorts
- crossed wires
- broken wires

12.1.2 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 dedicate to troubleshooting can be attributed to improper terminations. The most common termination faults can be located using a wiring verifier.

Continuity tests include:

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

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

12.1.3 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 to repair or replace portions of the network to meet the triple-play service provider standards is critical in providing reliable services.

12.2 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 with automated Pass/Fail analysis according to IEC standard	Fibre connector assembly check 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 fibre link insertion loss, return loss and tests continuity	Fibre link construction, acceptance testing and troubleshooting
Power meter only	Measures power output of equipment	Equipment and fibre link turn up and troubleshooting
Power meter with clip-on device	Estimates optical power in link	Equipment and fibre trouble-shooting at any location where fibres are accessible, even when connectors cannot be accessed
Clip-on fibre identifier	Identify and track traffic on fibre, may also estimate power output along 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 power levels of equipment and fibre link when OLT/ONT connected	Fibre link and equipment (ONT/OLT) turn-up and troubleshooting
ORL meter	Measures overall optical return loss	Fibre link construction and troubleshooting
OTDR	Measures fibre link characteristics	Fibre link construction, acceptance, troubleshooting

13 FTTH Standardization and Terminology Overview

13.1 Introduction

The background of this new chapter of the FTTH Handbook is to provide an overview of the standardization efforts in FTTH by relevant standardization bodies.

There are a vast number of terms and abbreviations concerning FTTH in use with several organizations creating their own. The result is that they are no longer able to understand each other. Therefore an overall list of terms and abbreviations has been compiled and will be published in IEC's Electropedia[1] with the aim of providing all parties with the same technical language and standards.

New applications drive bandwidth demand and eventually fibre will be brought not only to the home, but actually inside it. There are still a wide variety of technical solutions under discussion however more innovative ideas are needed. In addition there exists a large number of brownfield installations which have widely varying technical requirements.

FTTX is still a relatively young industry and some parties active in this market may not fully comprehend the ramifications in over specification or even the risks involved in operating without proper specifications. There are also some builders of small networks who may have insufficient understanding of the need for standardization and suitability.

A standards guidance will help define systems architectures, basic functionalities and product requirements thus ensuring the appropriate selection of solutions, products and suitable network quality. A clear definition of the minimum quality standard of the access network will facilitate deployment and the operation of reliable networks, especially as economic and every-day is highly dependent on an uninterrupted supply of telecom networks. Minimum quality levels should be guaranteed by incorporating standardizing test methods with functional product specifications which include minimum values for all the relevant product parameters.

Through standardization the industry will ensure a competitive market for components and subsystems for the infrastructure as well as providing services that are compatible with these standardised infrastructures that support existing interfaces.

Standardization should reflect the consensus of the market and the voice of the users. Approved standards should be flexible enough to allow developers the opportunity to implement their products and incorporate innovative solutions to the overall system.

During network deployment minimum best practice standards should be followed. This is especially relevant when installing cables for example and also in matters relating to health and safety, such as laser safety particularly when optical fibre solutions enter the home.

[1] The International Electrotechnical Commission (IEC) is a worldwide organization for standardization whose members come from national electrotechnical committees (IEC National Committees). The objective of the IEC is to promote international co-operation on all issues relating to standardization in the electrical and electronic fields. To this end the IEC publishes an International Standards document as well as other publications including The Electropedia. The aim of these publications is to promote the organizations' objectives. Electropedia (also known as the "IEV Online") is the world's most comprehensive online electrical and electronic terminology database containing more than 20 000 terms and definitions.

Standards should specify the minimum functions and performance of subsystems and the basic interfaces (hardware and software) between the various parts of the infrastructure, such as the mating interface between cabling outside and inside buildings.

Since the complete network infrastructure is being considered, the way in which standards are imposed will depend on the particular minimum requirements related to the specific area within the infrastructure and can be subdivided into a number of areas:

1. The central office;
2. The outside plant (OSP): standards should relate to both environmental and optical performance as well as lifetime requirements, without impacting on actual design;
3. Shared building space in an MDU deployment and basement equipment: standards should relate to both environmental and optical performance as well as lifetime requirements, without impacting on actual design;
4. In the home and public space: this is a new area which may require more activity as the public could be affected by deployment and connectivity , essentially creating new demands (and therefore new standards) on the products to be used .

13.2 Major standardization activities and guidelines

Several standardization activities are in progress on international and national levels. Working groups in the ITU, IEC, ISO/IEC JTC1, CENELEC and IEEE, as well as organizations such as the FTTH Council are providing guidance for the design and implementation of fibre optic access networks. In addition, standardization activities are also taking place on the national level. The following is an overview of the key activities.

13.2.1 IEC TC 86, SC 86A, SC 86B, SC 86C

13.2.1.1 Scope of TC 86

Technical Committee 86 ("*Fibre Optics*") and its Subcommittees SC86A ("*Fibres and cables*"), SC86B ("*Fibre optic interconnecting devices and passive components*") and SC86C ("*Fibre optic systems and active devices*") prepare standards, specifications and technical reports for fibre optic based systems, subsystems, modules, devices and components. These are primarily intended, but not exclusively, for use with communications equipment. This activity covers terminology, characteristics, related tests, calibration and measurement methods, functional interfaces, optical, environmental and mechanical requirements with the aim of ensuring reliable system performance.

13.2.1.2 Strategic business plan of TC 86

The work of TC 86 and its Subcommittees has made, and continues to make, a profound impact on the broad communications market. External factors influence fibre optic devices which affect the markets. However, the market has experienced slow but steady growth and there has been diversification of fibre optics applications since the early 2000 s. This has resulted in continued global participation by users and suppliers, as well as a shift from a few large organizations to many smaller companies becoming active in this industry. One of the underlying reasons for this is a market consolidation in developed countries along with the introduction of new and important players in developing countries.

13.2.2 ISO/IEC JTC 1/SC 25

Customer premises cabling: ISO/IEC 15018, *Information technology – Generic cabling for homes*.

13.2.3 ITU

13.2.3.1 ITU-T Handbook on Optical fibres, cables and systems (2009)

This handbook was published in 2009 and is available from < www.itu.int/publ/T -HDB-OUT.10-2009-1/en>. It contains a chapter on the deployment and operation of fibre access networks.

13.2.3.2 ITU-T Study Group 15

The ITU-T Study Group 15 is concerned with optical transport networks and access network infrastructures (further information available from ITU-T Study Group 15).

A draft revision of the *Guide on the use of ITU-T L-series Recommendations related to Optical Infrastructures* has recently been produced by ITU-T Study Group 15. Two new L. series Recommendations related to FTTX have been approved and published:

- L.89: Design of suspension wires, telecommunication poles and guys for optical access networks
- L. 90: Optical access network topologies for broadband services

13.2.4 CENELEC

13.2.4.1 CENELEC Technical Report CLC/TR 50510

Fibre optic access to end-user is a guide to building FTTX fibre optic networks and is available from <CENELEC CLC/TR 50510:2012>.

This technical report was prepared by the CENELEC TC 86 A, Optical fibres and optical fibre cables. The report provides information about passive infrastructure layers of a fibre access network and also contains a glossary of terms.

The three CENELEC technical committees listed below, are involved in work relating to fibres, cables and cable accessories (such as mechanical splices, connectors and enclosures).

13.2.4.2 Activities in CENELEC Technical Committee CLC/TC 86A

- Bend insensitive fibres in cords ,
- The next generation of flex tube riser cables
- Fire resistant cables for in -house applications – test procedures.

13.2.4.3 Activities in CENELEC Technical Committee CLC/TC 86BXA

Work on new activities specific to optical distribution networks (including indoor products). In regard to specific FTTH distribution networks, a taskforce team is looking at the possibility of reducing the stringent testing standards of optical performances to a more acceptable and realistic level in order to further improve the cost and speed of installing enclosures.

A pertinent Performance Specification has been released by TC86BXA W G1, entitled *Type FPFT (factory polished field terminated) simplex connector terminated on IEC 60793-2-50 category B1.3 and B6_A2 single mode fibre, Category C* .

13.2.4.4 Activities in CENELEC Technical Committee CLC/TC 215

- Customer premises cabling.

13.2.5 IEEE P802.3

IEEE is planning to present a specification for application for fibre usage. An on-going dialogue is in progress between IEEE and JTC1/SC25.

This IEEE activity will be strictly limited to fibre cables only.

Work, directly related to the above and concerning EPON is being carried out and described in IEEE Standard.

P802.3 (2008) and P802.3av. At present no further FTTH activities are taking place in P802, however work on the recently started IEEE P1904.1's SIEPON project is in progress.

13.2.6 Broadband Forum

BBF has created the Fibre Access Network Working Group. The following documents are relevant to FTTH:

- TR-156 – Using GPON Access in the context of TR -101t
- TR-167 – GPON-fed TR -101 Ethernet Access Node
- WT-200 – EPON and TR-101
- WT-247 Part 1 – ONT conformance test plan
- WT-247 Part 2 – OLT + ONT conformance test plan
- WT-255 – GPON interoperability test plan

The working texts are available from < www.broadband-forum.org/technical/technicalwip.php >.

13.2.7 ETSI

The Access, Terminals, Transmission and Multiplexing (ATTM) Technical Committee (TC ATTM) consists of three Working Groups (W G).

W G AT2: Infrastructure, physical networks and communication systems is concerned with:

- specifications of network topology and functional requirements
- transmission related optical component specifications, especially optical fibres and passive components
- specifications of requirements for optical fibre and optical cable characteristics related to transmission system performance
- specifications of functional and physic al characteristics of interfaces, including allocations of overheads
- standardization work relating to transport network protection and survivability
- production and maintenance of:
    - legacy ISDN: basic access, primary access and broadband ISDN access,
    - data over cable service interface specification (DOCSIS) and frequency management on Hybrid fibre coax (HFC) access
    - FTTH and fibre access systems
    - Ethernet
- specification for network jitter, delay and synchronization in transmission networks
- certain aspects of the communications part of an interactive broadcast link, e.g. cable television (CATV) and Local Multipoint Distribution Service (LMDS) physical layer
- specifications of functional requirements for transmission equipment, including line equipment, multiplexers and cross-connectors.

13.2.8 Other groups

There are also a scattering of national groups that have worked on FTTH networks, including ATIS (US), CCSA (China), OITDA (Japan) and other groups e.g. in Korea.

13.3 Recommended terminology

To ensure clarity and consistency a common set of terms, definitions and abbreviations should be used. The Glossary to the Handbook provides such a list.

This document was compiled by the FTTH Council in January 2009 and defines the terms used by all the FTTH Councils (North -America, Europe, Asia-Pacific, see FTTH definition of terms) and should be adopted by all companies and organisations operating in this industry.

The IEC provides two services regarding terms and abbreviations:

- the IEV or International Electrotechnical Vocabulary, commonly known as Electropedia, available from www.electropedia.org .
- the IEC glossary, available from std.iec.ch/glossary.

The IEC Glossary (definitions collected from IEC standards) and Electropedia (validated terminology database), will, in time, be merged.

The ITU's database also provides definitions and is available from <www.itu.int/en/ITU -T/publications/Pages/dbase.aspx >.

ITU-T Recommendation G.987 defines some troublesome terms (e.g. ONU/ONT, PON, and ODN) that seem to have a variety of meanings for different people.

The terms and abbreviations provided in Annex 2 of this new chapter of the FTTH Handbook have been compared with those in Electropedia. Whenever a definition existed it has been listed under the column "Definition".

Appendix A: List of standards and guidelines related to FTTH

Note: Each of the standards reported in the table may be composed by several parts, each of which is covering specific aspects of the subject dealt with in the publication. It is the responsibility of the reader to identify the various parts and to make reference to the most updated version or edition of the publications.

Source	Title	Number	Int/Reg
IEC	*Cable Networks for television signals, sound signals and interactive services*	IEC 60728	Int
IEC	*Optical fibres – Part 1: Generic Specifications - Measurement methods and test procedures*	IEC 60793-1	Int
IEC	*Optical fibres – Part 2: Product specifications*	IEC 60793-2	Int
IEC	*Optical fibre cables - Part 1: Generic specifications - Basic optical cable test procedures*	IEC 60794-1	Int
IEC	*Optical fibre cables – Part 2: Indoor fibre cables*	IEC 60794-2	Int
IEC	*Optical fibre cables – Part 3: Outdoor cables*	IEC 60794-3	Int
IEC	*Optical fibre cables – Part 4: Aerial optical cables along electrical power lines*	IEC 60794-4	Int
IEC	*Optical fibre cables – Part 5: Sectional specifications – Micro-duct cabling for installation by blowing*	IEC 60794-5	Int
IEC	*Fibre optic interconnecting devices and passive components - Connectors for optical fibres and cables*	IEC 60874	Int
IEC	*Fibre optic interconnecting devices and passive components - Non-wavelength-selective fibre optic branching devices*	IEC 60875	Int
IEC	*Fibre optic interconnecting devices and passive components – Mechanical splices and fusion splice protectors for optical fibres and cables*	IEC 61073	Int
IEC	*Fibre optic interconnecting devices and passive components - Adaptors for fibre optic connectors*	IEC 61274	Int
IEC	*Fibre optic communication subsystem basic test procedures*	IEC 61280	Int
IEC	*Optical amplifiers - Test methods*	IEC 61290	Int
IEC	*Optical amplifiers*	IEC 61291	Int
IEC	*Fibre optic interconnecting devices and passive components –Test and measurement procedures*	IEC 61300	Int
IEC	*Fibre optic interconnecting devices and passive components – Fibre optic fan-outs*	IEC 61314	Int
IEC	*Fibre optic interconnecting devices and passive components - Performance standard*	IEC 61753	Int
IEC	*Fibre optic interconnecting devices and passive components - Fibre optic connector interfaces*	IEC 61754	Int
IEC	*Fibre optic interconnecting devices and passive components - Fibre optic connector optical interfaces*	IEC 61755	Int
IEC	*Fibre optic interconnecting devices and passive components – Interface standards for fibre management systems*	IEC 61756	Int
IEC	*Fibre optic interconnecting devices and passive components – Interface standards for closures*	IEC 61758	Int
IEC	*Fibre optic - Terminology*	IEC 61931	Int

IEC	*Guidance for combining different single-mode fibre types*	IEC 62000 TR	Int
IEC	*Reliability of fibre optic interconnecting devices and passive optical components*	IEC 62005	Int
IEC	*Semiconductor optoelectronic devices for fibre optic system applications*	IEC 62007	Int
IEC	*Fibre optic interconnecting devices and passive components – Fibre optic WDM devices*	IEC 62074	Int
IEC	*Fibre optic interconnecting devices and passive components – Fibre optic closures*	IEC 62134	Int
IEC	*Fibre optic active components and devices – Package and interface standards*	IEC 62148	Int
IEC	*Fibre optic active components and devices – Performance standards*	IEC 62149	Int
IEC	*Fibre optic active components and devices –Test and measurement procedures*	IEC 62150	Int
IEC	*Fibre optic interconnecting devices and passive components – Part 01: Fibre optic connector cleaning methods*	IEC 62627-01 TR	Int
ISO/IEC	*Information technology – Generic cabling systems*	ISO/IEC 11801	Int
ISO/IEC	*Information technology - Implementation and operation of customer premises cabling*	ISO/IEC 14763	Int
ITU-T	*Characteristics and test methods of optical fibres and cables*	G.65x series	Int
ITU-T	*Transmission characteristics of optical components and subsystems*	G.671	Int
ITU-T	*Construction, installation and protection of cables and other elements of outside plant*	L. xy series	Int
ANSI	*Commercial building telecommunications pathways and spaces*	ANSI/TIA/EIA 569-B	Reg
ANSI	*Residential telecommunications infrastructure standard*	ANSI/TIA/EIA 570	Reg
ANSI	*Administration standard for commercial telecommunications infrastructure*	ANSI/TIA/EIA 606-A	Reg
ANSI	*Commercial building grounding and bonding requirements for telecommunications*	ANSI/TIA/EIA 607	Reg
ANSI	*Customer-owned outside plant telecommunications infrastructure standard*	ANSI/TIA/EIA 758_A	Reg
ANSI	*Customer-owned outside plant telecommunications infrastructure standard*	ANSI/TIA/EIA 758-A	Reg
ANSI	*Building automation systems cabling standard for commercial buildings*	ANSI/TIA/EIA 862	Reg
CENELEC	*Family specification – Optical fibre cables for indoor applications*	EN 187103	Reg
CENELEC	*Single mode optical cable (duct/direct buried installation)*	EN 187105	Reg
CENELEC	*Sectional specifications: Optical cables to be used along electrical power lines (OCEPL)*	EN 187200	Reg
CENELEC	*Generic specifications: Optical fibres*	EN 188000	Reg
CENELEC	*Information technology – Generic cabling systems*	EN 50173	Reg
CENELEC	*Information technology – Cabling Installation*	EN 50174	Reg
CENELEC	*Application of equipotential bonding and earthing in buildings with information technology equipment*	EN 50310	Reg
CENELEC	*Information technology – Cabling installation – Testing of installed cabling*	EN 50346	Reg

CENELEC	*Connector sets and interconnect components to be used in optical fibre communication systems - Product specifications*	EN 50377	Reg
CENELEC	*Fibre organisers and closures to be used in optical fibre communication systems – Product specifications*	EN 50411	Reg
CENELEC	*Simplex and duplex cables to be used for cords*	EN 50551	Reg
CENELEC	*Optical fibres - Measurement methods and test procedures*	EN 60793-1	Reg
CENELEC	*Optical fibres - Product specifications*	EN 60793-2	Reg
CENELEC	*Optical fibre cables*	EN 60794	Reg
CENELEC	*Generic cabling systems – Specification for the testing of balanced communication cabling*	EN 61935	Reg

Appendix B: Deploying FTTH today… "10 most frequently asked questions"

Demystifying the deployment (and adoption) of Fibre-To-The-Home

Today, telecommunication market players such as traditional operators, municipalities, utility companies or organisations leading individual initiatives, all of them are seeking to offer high speed access to their end-customers, be it in residential or enterprise environment.

This document intends to give more guidance on the main activities one encounters with the deployment of "Fibre-To-The-Home". Successful FTTH deployment and adoption encompasses a stepwise approach of thinking, analysing, implementing and enabling, starting from the initial business case (justifying the Return on Investment (financially or socially speaking)) and ending by the final adoption of the service by the end-customer.

Issues and solutions are illustrated by means of 10 main questions with respective answers and cover FTTH deployment and clarification of some topics with practical examples. Let this document be a first introduction and sanity check on your ideas for FTTH.

Below are the 5 steps of FTTH deployment:

1. **Prepare and keep detailed documentation of all decisions (go or no go?)**
   Design the business case, specify the geographic market, concretise your business model, choose a network architecture and check regulatory obligations and requirements.
2. **Deploy your outside plant (put your fibre in)**
   Perform the dimensioning of your passive infrastructure, select your components, perform cost synergies, implement your fibre termination
3. **Implement your connectivity (light your fibre)**
   Deploy your active technology, respond your time to market needs, perform interoperability and end to end testing, and implement your management solution
4. **Enable your service directly to the end-customer (retail?)**
   Launch your service bundles, organise your customer support, manage your end-customer's home environment
5. **Enable service models with third parties (wholesale?)**
   Expand beyond your traditional 3play services, negotiate quality of service agreements, and promote application stores

Step 1: Prepare and keep detailed documentation of all decisions (go or no go?)

Ensure all parameters are specified, for making a sound judgement. Why, when, where and how do we go for it? Only the best plan will lead to the better outcome. Some questions:

Question: Which geographical area(s) do you consider for the FTTH deployment?

Different criteria (socio economics, expected take rate…) can be used to select the geographical areas for the FTTH roll-out. Given a certain investment budget, one can opt, for instance, to maximize revenue generation or to realize maximal coverage.

For that purpose, geo-marketing techniques, based upon socio-economic data within a geographical context, are used for the initial network design and for calculating the related business case.

Question: Do you consider partnerships? Which partners can you engage with?

Partnerships are established to deal with the huge investment costs in fibre infrastructure and/or to meet the challenge of the successful exploitation of an FTTH network.

The big difference in investment budget, -life cycle and -risks between the active and passive fibre infrastructure, requires long-term partnership agreements on the operational and business aspects. More specific a fair revenue sharing model has to be worked out, to come to a sustainable business model for all involved partners.

Additional questions:

- Question: What is a reasonable “payback period” for FTTH investments?
- Question: Can you benefit from an “open network” and how do you concretise?
- Question: What basic network design and modelling should you do?

Step 2: Deploying the outside plant (put your fibre in)

The passive infrastructure is the foundation of the FTTH rollout. Consider the best options and anticipate cost-effective implementation. Additional questions:

Question: Are cost synergies possible (imposed or not by regulation) with other infrastructure operators in the public domain?

In general, considerable cost savings can be realized through a better coordination of civil works in the public domain. For that purpose, infrastructure builders are incorporating GIS (Geographical Information Systems) -based network design together with planning and documentation tools. This facilitates the exchange of public infrastructure information and offers a more synchronized workflow management between the various infrastructure builders. Field practices have shown that the cost per Home Connected/Passed can be further decreased with improved OSP project management.

After the deployment phase, a well-documented as-built outside plant leads to less fibre cuts, helpdesk calls and better trouble shooting in case of failure.

Question: What criteria should be used for the selection of passive components such as ODF, cables, enclosures, splices etc…?

As the lifecycle of the passive infrastructure is a multiple of the active technology lifecycle, it is essential to select qualitative passive components which meet future technology requirements (e.g. NG PON). A trade off should be made between the cost, quality and the labour related aspects (intensiveness and skills/tools required) of the components.

Other questions:

- Question: What are the hurdles for in-house fibre wiring?
- Question: What is the impact of local regulation?
- Question: What dimensioning rules should be considered for the passives?

Step 3: Implementing connectivity (light your fibre)

Connecting subscribers involves employing the necessary bandwidths within the FTTH infrastructure. The active network and related technologies will cover that area. Additional questions:

Question: Choosing active technology?

Although fibre technology is subject to rapid evolution, the reality is the market wants the right technology at the right time and at the right price. This should be in line with a realistic view of the services evolution and future bandwidth demands. The need for fibre-to-the-most economical point implies the coexistence and use of different and hybrid fibre technologies.

Independent of the technology choice, technology continuity should be guaranteed to avoid future interoperability issues, the need for truck roll-outs and modifications of the outside plant.

Question: How green is FTTH?

Independent studies show that fibre technology, in comparison with legacy systems, significantly reduces the amount of carbon dioxide which is produced by communication activities. Fibre-optic systems can transport different types of data over one cable and one network, thus eliminating the need for parallel infrastructures and power provisions for CATV, fixed telephony and fixed line Internet. Furthermore, fibre-optic systems can transport data over much greater systems at lower power utilization rate.

Additional questions:

- Question: How can technology continuity be assured?
- Question: How can truck roll be minimised?
- Question: How can interoperability, standardization and end-to-end testing be embedded?

Step 4: Enable services directly to end-customer (retail?)

If the intention is to become involved in the retail market, then potential subscribers need to be convinced and choose this system. Additional questions:

Question: Why choose FTTH?

What is the best application for FTTH in the residential environment? Video? In what form? What is assured is that any offering, providing faster access and delivering an enriched experience, is certainly a good candidate for sales. FTTH is perfectly aligned to provide this.

FTTH brings unprecedented reliability and guaranteed bandwidth to the home, ensuring a more personalized touch for all.

FTTH brings a richer service offering to the connected home, in a multi-room and multi-screen approach. This will increase the demand for service assurance and remote management solutions for in-home devices and services.

Question: How to move end-users from legacy to enhanced services?

End-users need the visual richness offered by FTTH based access. Adding a visual component to legacy communication services (e.g. video telephony) and to future communication and entertainment services (e.g. immersive communication) is considered one of the key elements for creating an enhanced end-user experience.

Furthermore, policy makers consider FTTH a motor for socio-economic development as well as providing the opportunity to introduce services such as e-health, e-learning, e-government to citizens. Providing services relevant to personal lifestyle and bringing added value to society will further accelerate the mass market acceptance of FTTH.

Additional questions:

- Question: How to market the enhanced value offered by FTTH?
- Question: What service definitions and assurance procedures should be put in place?
- Question: What is the target audience?

Step 5: Enable service models with third parties (wholesale?)

It is not a requirement to implement the entire "vertically integrated' model and enter the retail market alone. Partnerships, agreements, working cooperation, etc., can all be incorporated to bring about successful FTTH systems. Additional questions:

Question: How to attract Application, Content and Service Providers?

To build a sustainable business model for FTTH, it is necessary to attract innovative third-party application, content and service providers. This requires dedicated service delivery platforms. Essentially, these platforms, based upon open APIs, hide the complexity of the underlying infrastructure and facilitate a more rapid and transparent service delivery.

Exposure of network capacity in a managed, quality-controlled manner is of special interest to trusted parties such as businesses, energy providers and (semi-) public organizations; these groups are willing to pay a premium for this service.

Following on from a guaranteed bandwidth and QoS, the service level agreement (SLA) may cover a wide range of managed common services, such as hosting facilities, app stores, application life cycle management etc. This approach may attract new market entrants, lacking the scale and expertise, but enriching the FTTH ecosystem with innovative applications, services and content.

Question: How to expand beyond traditional triple play offerings?

Moving beyond the traditional commercial triple play offering requires partnerships between Network Service Providers (NSP), Consumer Electronic (CE) manufacturers and Application & Content Providers (ACP). For example, innovative business models are needed for over-the-top video delivery to coexist with managed IPTV services.

Additional questions:

- Question: How to build a business case for service providers?
- Question: How to manage multiple service providers (Quality of Service, Bandwidth, etc)?
- Question: What role does advertising have in these business models?

More information about deployment and operation of FTTH is available in the FTTH Handbook. The FTTH Business Guide provides information about FTTH financing and business cases.

Glossary

ADSS	All-Dielectric Self-Supporting
AN	Access Node
APC	Angle-Polished Connector
ATM	Asynchronous Transfer Mode
APON	Asynchronous Transfer Mode PON
BEP	Building Entry Point
Bit	Binary Digit
Bit rate	Binary Digit Rate
BPON	Broadband Passive Optical Network
Bps	Bit Per Second
CATV	Cable Television
CPE	Customer Premises Equipment
CRM	Customer Relation Management
CTB	Customer Termination Box
CO	Central Office
CWDM	Coarse Wavelength Division Multiplexing
DBA	Dynamic Bandwidth Allocation
DN	Distribution Node
DOCSICS	Data over Cable Service Interface Specification
DP	Distribution Point
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DWDM	Dense Wavelength Division Multiplexing
EFM	Ethernet in the First Mile (IEEE 802.3ah)
EMS	Element Management System
EP2P	Ethernet over P2P (IEEE 802.3ah)
EPON	Ethernet Passive Optical Network
FCCN	Fibre Cross Connect Node
FBT	Fused Biconic Tapered
FCP	Fibre Concentration Point
FDB	Fibre Distribution Box
FDF	Fibre Distribution Field
FDH	Fibre Distribution Hub (another term for FCP)
FITH	Fibre In The Home
FTTB	Fibre To The Building
FTTC	Fibre To The Curb
FTTH	Fibre To The Home
FTTN	Fibre To The Node
FTTO	Fibre To The Office
FTTP	Fibre To The Premises
FTTx	Generic term for all of the fibre-to-the-x above
FWA	Fixed Wireless Access
Gbps	Gigabits per second
GIS	Geographic Information System
GPON	Gigabit Passive Optical Network
HC	Home Connected
HDPE	High-Density PolyEthylene
HFC	Hybrid Fiber Coax
HP	Homes Passed
IDP	Indoor Distribution Point
IEEE	Institute for Electrical and Electronics Engineers

IL	Insertion loss
IMP	Indoor Manipulation Point
IEC	International Electrotechnical Commission
IP	Ingress Protection (also intellectual property)
ISO	International Organization for Standardization
ISP	Internet Service Provider
ITU-T	International Telecommunication Unit – Telecommunications Standards
LAN	Local Area Network
LI	Local interface
LMDS	Local Multipoint Distribution Service
LSZH	low smoke, zero halogen
Mbps	Megabits per second
MDU	Multi-Dwelling Units
MEMS	Micro Electro Mechanical Switch
MMDS	Multichannel Multipoint Distribution Service
MMF	MultiMode Fibre
MN	Main Node
NGA	Next Generation Access Network
NGN	Next Generation Network
NMS	Network Management System
NTU	Network Termination Unit
ODF	Optical Distribution Frame
ODP	Optical Distribution Point
ODR	Optical Distribution Rack
OE	Optical Ethernet
OLA	Operational Level Agreement
OLT	Optical Line Termination
OLTS	Optical Loss Test Set
OMP	Optical Manipulation point
ONT	Optical Network Termination
ONU	Optical Network Unit
OPGW	Optical Power Ground Wire
OTDR	Optical Time-Domain Reflectometer
OTO	Optical Telecommunication Outlet
P2MP	Point-To-Multi-Point
P2P / PtP	Point-To-Point (communication, configuration or connection)
PC	Physical Contact or Polished Connector
PE	PolyEthylene
PON	Passive Optical Network
POP	Point Of Presence
PVC	PolyVinylChloride
RU	Rack Unit
RL	Return Loss
ROW	Right Of Way
S/N	Signal-to-Noise ratio
SDSL	Symmetric Digital Subscriber Line
SFU	Single Family Unit
SLA	Service Level Agreement
SMF	Single Mode Fibre
STP	Shielded Twisted Pair
STU	Single-Tenant Units
UPC	Ultra Polished Connector
UPS	Uninterruptible Power Supply
UTP	Unshielded Twisted Pair
TDMA	Time Division Multiplex Access

VDSL	Very high bit rate Digital Subscriber Line
VOD	Video on Demand
WDM	Wavelength Division Multiplexing
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless LAN
WFM	Workforce Management
WAN	Wide Area Network
WMS	Workforce Management System

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