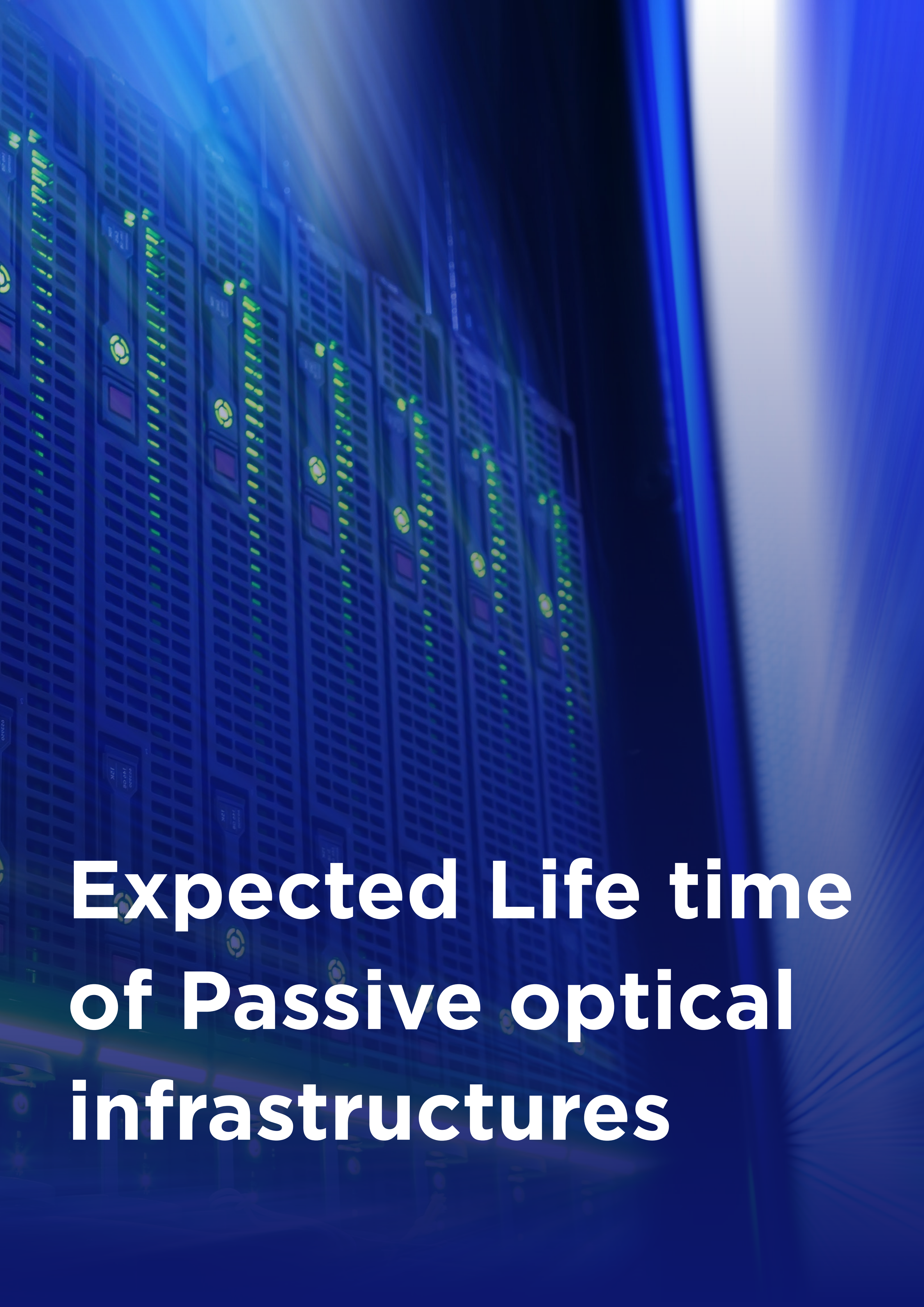

Expected Life time of Passive optical infrastructures

Executive summary

The expected life-time of passive optical infrastructure is a critical factor that will dramatically impact network OPEX over the subsequent 30 to 50 years.

In most of the cases where operators are planning the installation of new passive optical infrastructure to support FTTH or upcoming 5G applications, they are extremely focused on CAPEX while being minimally concerned with OPEX. However, it is critical to consider the dichotomy between network CAPEX and network OPEX, when prioritizing between deployment practices and component selection. CAPEX activities are oft prioritized since tangible decisions in the short run (typically during the 1-2 years of construction phase) can lead to a reduction in capital outlay. However, a point that is easily overlooked is that the critical point will be the OPEX, which will bleed the operator for many years.

The quantum of the OPEX will be tightly correlated with the quality of the initial infrastructure: quality of civil works; quality of the architecture; quality of passive components (optical fibers, cables, connectivity); quality of the installation which in turn depends on the quality of the training received by the installers. All these parameters are key factors to be carefully considered if OPEX over the 30 to 50 years of the passive infrastructure life time is to be minimized. This paper will explain the important role played by the quality of passive components.

In addition to the OPEX element, it is imperative to consider the strategic importance of our networks. Passive optical networks will be the **“central nervous system” of our 21st century** society and the bedrock of information, industrial and societal management in the subsequent century. Any minor accident or major disaster will have strong negative consequences on our digitally evolving society. Therefore, it is the responsibility of our government, industry and society to have robust and reliable passive products and installations in our network development.

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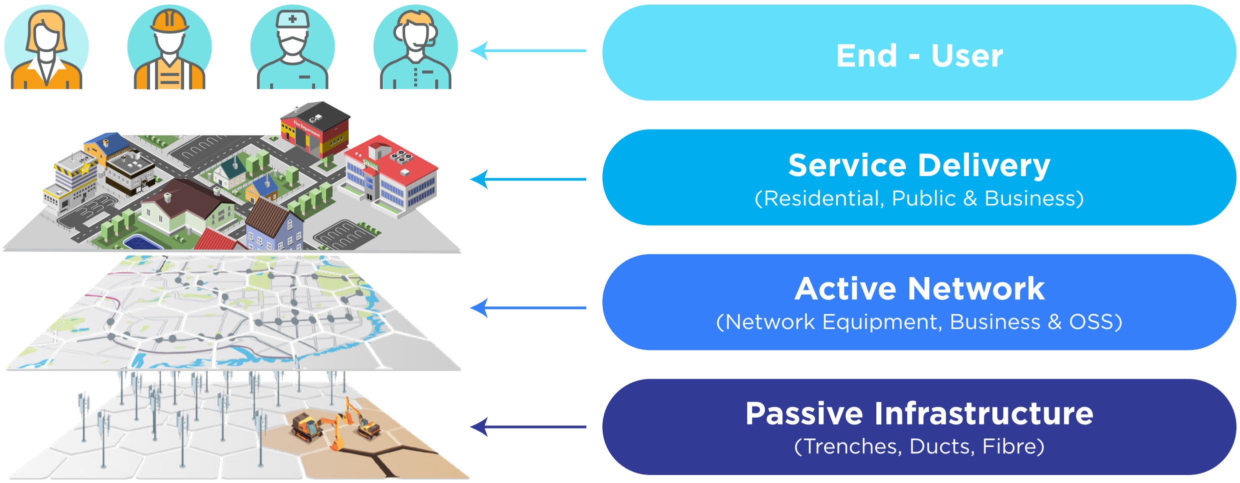
1. The Layered Model

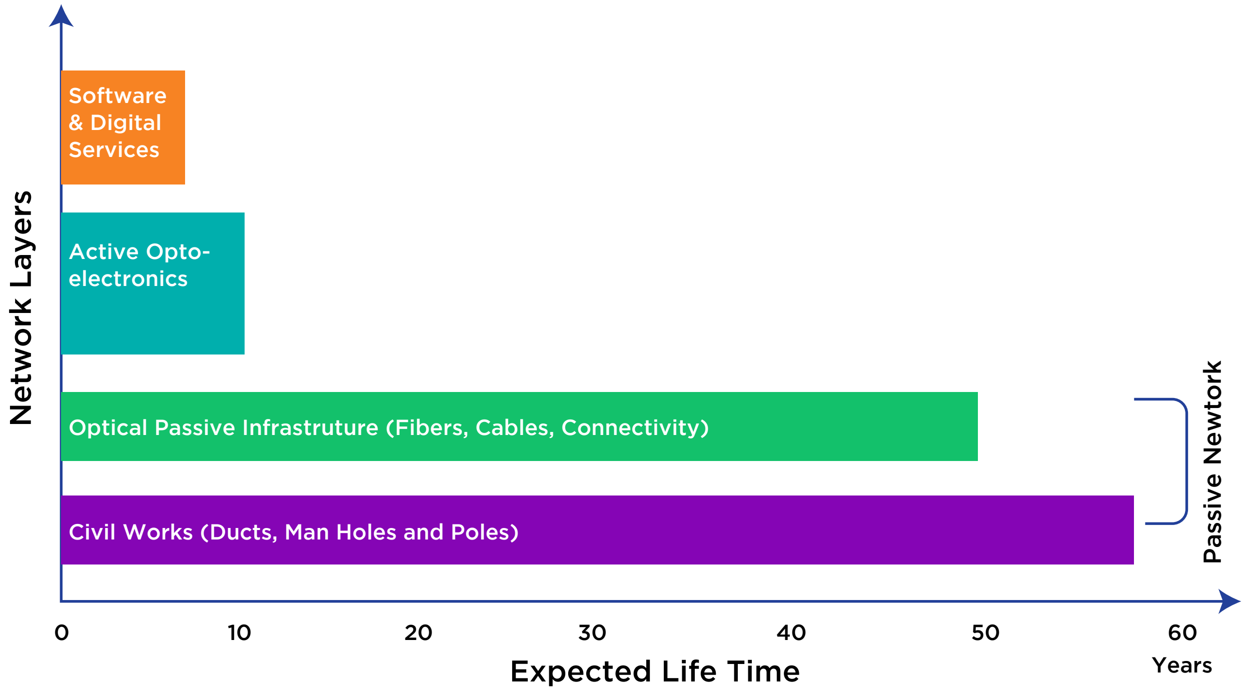
In the telecom industry, the layered model presented in the following diagram is generally accepted. This paper will primarily address the Passive Infrastructure layer.



Reference: FTTH Council Europe

2. Expected life time of an activated optical network

In the telecom sector, it is well recognized that the expected life time of the different layers are extremely different, as presented in the following graph:



Relying on the industry's experience with copper telecom networks (long distance and distribution to any subscribers) of over 60 years, and experience with optical networks (long distances, WAN, MAN, FttX) of over 30 years, one can draw the following conclusions on the expected life time of each network layer:

- **Services:** Expected evolution every **2 to 5 years**. Their upgrades are very easy and inexpensive to implement since they can be done at the data centers and POPs; there is no requirement of changes in the field or at subscriber location.

- **Active layer** (electronic / opto-electronic): Expected evolution every **6 to 9 years.** Their upgrades are easy to perform as they are executed within data centers and POPs. The labour and equipment costs, as well as any risks to execute these changes are low because they are executed inside controlled environments within buildings. The life span of the active layer, especially when multiple generations of active equipment is considered, is lengthened through the installation of a carefully designed passive optical network. As long as operators and installers future-proof the passive optical network (use of high fiber count, and all fiber transmission bands – from 1260 nm to 1625 nm, and even 1650 nm for monitoring), multiple generations of active system can be deployed on the same fiber network. This source of long term savings should be considered when designing or selecting the network components and when provisioning the network optical power budget.

- **Passive Optical infrastructure** (Hardware: Optical fibre, optical fiber cables and connectivity components such as enclosures, pigtails, splitters, etc.): Unlike services and active layer, the installation and upgrades of the passive optical infrastructure is typically very long, arduous, complex. Replacement of hardware in a live network is extremely complex when all subscribers are connected, since quality and continuity of services is of utmost importance to credible operators and data centres. Consequently, the installation, operation and maintenance costs of the passive optical infrastructure is very high. Quality of materials is also correlated to the performance of installation and network 1equipment. Therefore, the quality of the components and the expected lifetime of the hardware is of unparalleled importance.

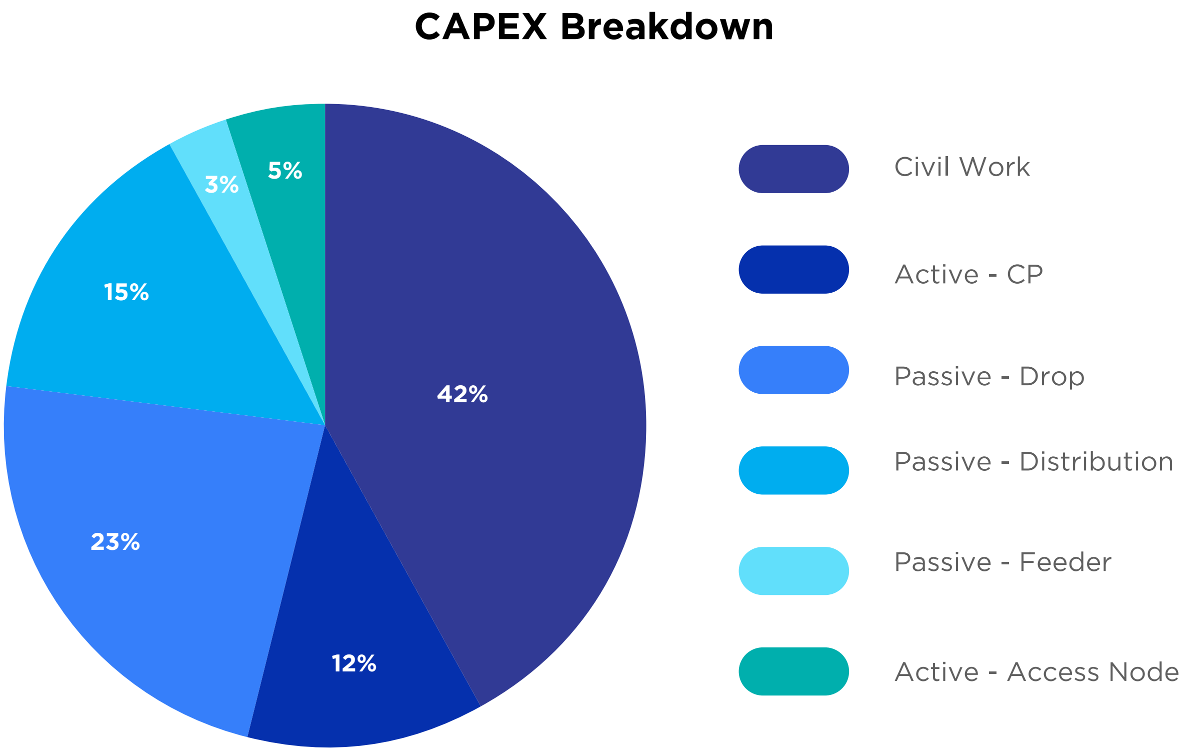
- **Civil works** will have an important impact on the life time of the optical network. It is intuitive that high quality civil works, especially trenching and ducting at 1 to 1.2-meter-deep will have very few quality issues (due to minimal environmental impact) for 50 or 60 years. However, civil works that are only 20 cm deep and constructed with low cost / quality materials can quickly develop many issues resulting in costly operation and maintenance.

  Inarguably, the ducts in the very high quality civil works implemented 50 or 60 years ago to install copper networks in most of the European countries are still perfectly re-useable today to install optical networks.

  On the other side, recent deployments conducted in some large countries with very low cost and light civil works have forced some operators to abandon this solution. The incentive of lowered, short-term CAPEX was eclipsed by the burgeoning OPEX to the point that the situation become totally unacceptable within one or two years.

3. CAPEX Breakdown

A plethora of studies have been carried out by different organizations on the network CAPEX breakdown. It is easy to argue that in any 2 different countries the CAPEX breakdown will not be identical given differing geology, labour market, equipment availability and regional/ municipal codes. However, after normalizing for variances, the industry can reach a consensus, or guiding principles, on the CAPEX Breakdown. Provided below is the analysis that the FTTH Council Europe carried out a couple of years ago, taking into account results coming from the main European countries. The following graph shows the conclusion of this study.



Reference: FTTH Council Europe

It is clearly evident that there are 2 key activities contributing to the CAPEX:

- Civil works: 42%
- Passive network: 41% (Feeder + Distribution + Drop, including installation)

It should be noted that the installation cost of the passive optical network is far more significant than the hardware cost itself (optical fiber cables and connectivity).

However, if selected hardware is not well designed, is of low quality and does not have the right reliability level to achieve 30 to 50 years of expected life time, the global performance of the network will be impacted and the OPEX will increase dramatically. It's on these specific points that this paper will focus in greater detail.

4. Hardware expected life time vs design, material properties and process

4.1 Generality

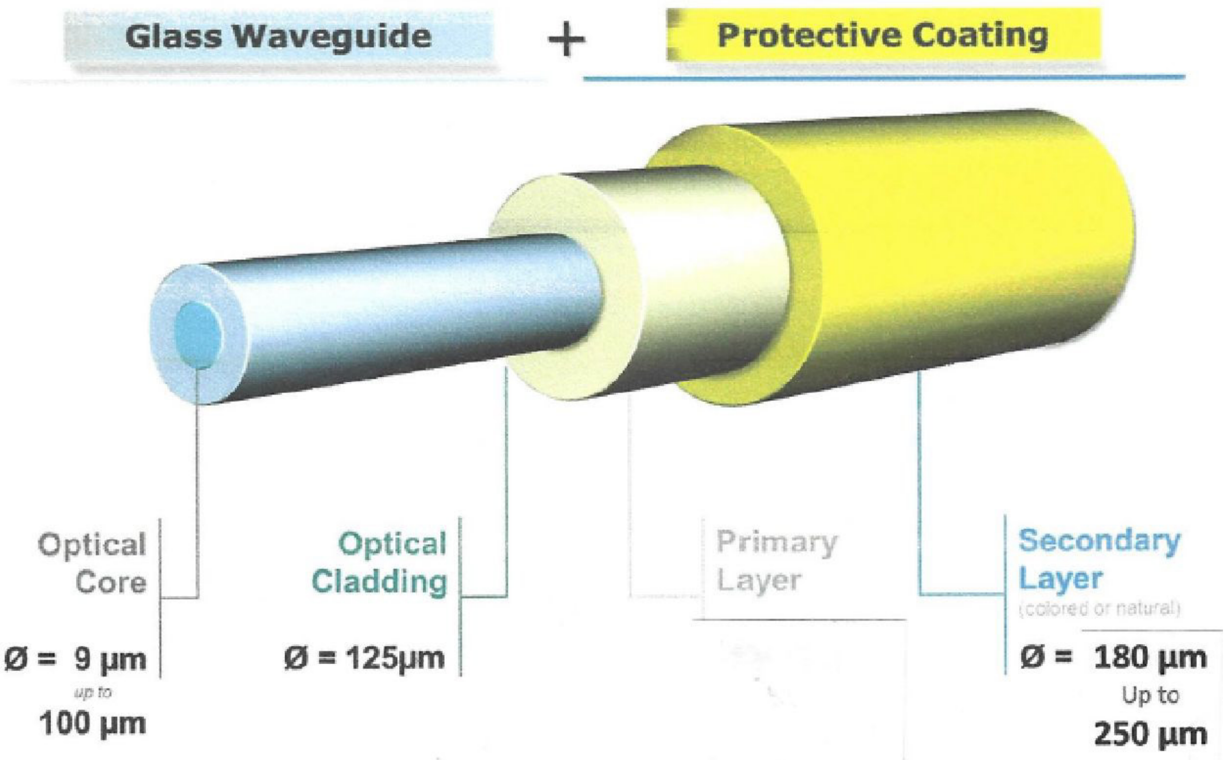
All engineers working on “designs”, “materials” and “processes” understand easily how these 3 parameters are important to be able to reach 30 to 50 years expected life time under varying environment conditions and installation solutions.

This paper will not delve into too much details about such principles, explaining which would require a book of about 200 pages.

Right and reliable products are the result of very long R&D activities and more than 50 years experience. Consequently, we will provide only a few examples to illustrate what to do to reach the targets: reliability, 30 to 50 years expected life time and consequently an OPEX well under control for operators.

4.2 Optical Fibers

Everyone involved in optical networks knows the optical fiber anatomy as presented below :



Before drawing fiber from optical preforms, these preforms must be produced with extremely pure materials in which impurities are at ppb (part per billion) level. The Preform is the key element in producing optical fibers. From a preform, it’s possible to draw more than 2000 Km of fiber (depending on the size of the preform). Raw material quality, high performance processes and high-level controls are key to produce high quality fibers.

The fiber quality is the result of more than 150 parameters and controls that must be kept perfectly under control in the fiber production plant.

Let’s examine a few of these parameters and illustrate their importance:

The quality of the optical core is responsible for the transmission properties which can affect the attenuation. Some parameters, such as chromatic dispersion, are nearly independent of the environment where the fiber is deployed. However, the situation is different for parameters like attenuation. Attenuation depends strongly on the stresses experienced by the optical fiber. Cable materials or cable deployment conditions can also induce macrobending or microbending losses.

The index profile of the preform’s core is the main parameter that will provide the fiber resistance to microbending and macrobending.

- For long distance applications fibers are well protected in strong cables. These cables are installed with a lot of care so that the fibers within are not subjected to a lot of bending effects. Consequently, a standard single mode fiber (ITU-T G.652.D, IEC B-652.D) can do the job with good performance. This kind of network is a “static” network.

- For FTTx or 5G applications the situation is very different: cables and fibers are subjected to a lot of macrobending during installation. Subsequently, a lot of workers frequently perform new cable installations or repairs and maintenance tasks along the existing network. Each time the optical fiber must support new stresses and strains. This kind of network is a “dynamic” network. Compared to long distance networks, here the installation is executed with less care.

In such environments, ITU-T G.657 / IEC B-657 bend insensitive fibers are used to enhance the network reliability. ITU-T G.657.A1 / IEC B-657.A1 and G.657.A2 / IEC B-657.A2 types guarantee the compatibility with G.652.D / IEC B-652.D fiber based networks.

G.657.A2 / IEC B-657.A2 offers additional bending performances, notably at the highest wavelengths. This performance is relevant in case of accidental bends (as illustrated in the below figure) or when the next generation systems that will use the highest wavelength ranges, up to 1625 nm, are introduced.

Macrobending loss induced by 2 turns around a pencil

Two other fiber parameters that are very important are:

- Quality of the glass for mechanical properties: stress corrosion factor, resistance in harsh environment

- Quality of the coating: the double layer coating, whatever the final diameter of the fiber (200 or 250 µm), is extremely important for fiber reliability. A lot of parameters are crucial to get the right performance. For examples:
  - An accurate composition of the curable materials. This composition is the result of a lot of R&D tests, very long-term aging, temperature aging, water aging, sun light aging, color stability
  - A perfect high-speed curing process at the right temperature, with the right UV wave length and the right power
  - A strict control in the manufacturing process

It is substantially evident that that the production of preforms and fiber drawing are very sensitive processes. Fiber quality and reliability are directly dependent on raw material quality and process quality.
As an example, the process to change the fiber coating from an existing, approved one to a new one will require a lot of R&D activity and a lot of very long-term aging in different environments (wet and dry conditions, submerged in water, exposed to filling compounds, UV light, etc.) and in temperatures varying between – 40°C and 85°C. Performance against temperature and harsh conditions is especially important because the fibers may be deployed in street cabinets, which act as cooking ovens. Color change as a function of aging is also very critical. Consequently, a change of coating will require minimum 3 years to be able to factor in most of the situations that the resultant fibers will experience during their life in duct or aerial optical cables, street cabinets, splice boxes, etc.

4.3 Optical cables

Optical cables are the "corner stone" of our passive optical networks. They will have to protect the optical fiber, the fundamental medium of transmission, for the next 30 to 50 years with consistent efficiency and efficacy. Therefore, R&D engineers must integrate so many parameters and execute so many tests, including long-term aging tests, to be able to demonstrate that the targeted lifetime is achievable.

Here too a strong competence and expertise on design, materials, processes and qualification procedures are mandatory parameters needed to develop the right products for the right applications.
It is difficult to succinctly describe the long and complex process related to the development and qualification of optical cables. This paper will study only 2 examples: one in relation with the design and the other with materials.

1 - Optical Cable Design

It is important to consider the structure of the optical cables in order to choose the most suitable design with respect to environment conditions and the desired long-term performance. For example, some countries have chosen the micromodule cable structure, since this structure has advantages over the loose tube designs in terms of compactness, preparation time of the cables for splicing, and thermal stability of the cable ends spread out in the splice boxes or in mid span access.

Any expert in optical cable knows very well that the important point in the design of such products is to ensure minimum strain and stress on the optical fibers for their entire lifetime: during the installation, and during its entire life in the static or dynamic network. The design process is further informed by the environmental conditions in which the cable is expected to be deployed. Cable designers know that:

- Coefficient of thermal expansion are very different between optical fibers and polymeric materials (difference > 1000)
- Young's modulus of materials is very different (difference > 1000)
- Hardness of polymeric materials increases over time
- Optical fiber is sensitive to Microbending and Macrobending. These effects are mainly responsible for the attenuation increase that is sensitive at 1310 nm, very sensitive at 1550 nm and extremely sensitive at 1625 nm. As already explained, in "dynamic" networks like FTTH, there is a significant advantage to use ITU-T G.657 / IEC B.657 fibers and not ITU-T G.652.D / IEC B-652.D fibers. ITU-T G.657 fiber is a significant asset bringing a strong and additional guarantee that the FTTH network will keep a low attenuation, even after 30 years and at 1625 nm.
- Fibers are sensitive to elongation: the risk of fiber breaks needs to be taken in account. Therefore, when optical aerial cables are designed the maximum fiber elongation must be kept lower than 0.2% for long span applications and lower than 0.3% for short span applications **whatever the climatic conditions.** The cable design must also take into account the maximum fiber elongation during the installation phase.
- Production processes must be also integrated in the cable design phase.
- Costing and design are strongly related: one can easily understand that it's easy to reduce the cost of optical cables if the manufacturer overlooks some of the above parameters, including **material quality,** where large variability is possible. But one can also easily deduce that "low cost" optical cables, for which design and material quality are questionable, will present a significant disadvantage vs "premium cables" in their expected life time. Poor quality products will never meet the expected life time of the hardware, and in turn **will dramatically impact the OPEX of the passive infrastructure.**

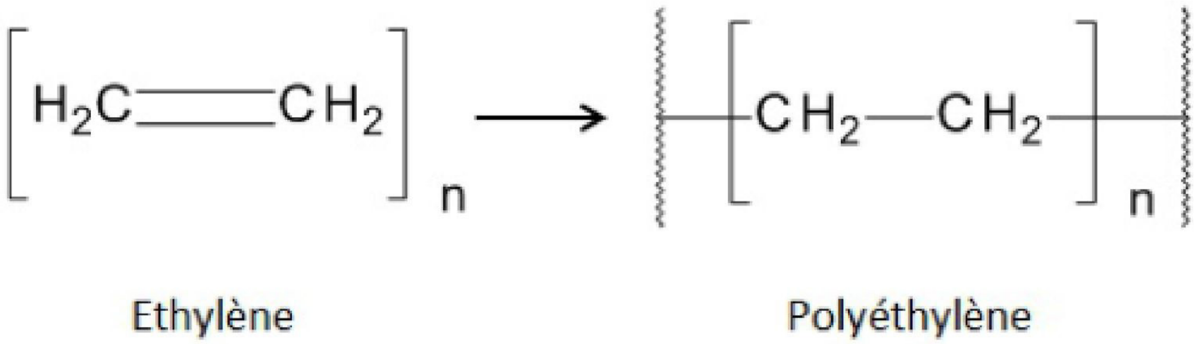
Today some operators, through their purchasing departments, are focusing mainly on upfront cost but are easily forgetting two key parameters in Total Cost of Ownership: product reliability / expected life-time and OPEX over the network's lifetime. Since OPEX may significantly increase if the network hardware is of poor quality, **reliability and long life-time of any kind of hardware should be the "corner stones" of the network rollout process.**

2 - Materials

To produce optical cables a large variety of non-optical fiber materials will be used, mainly:
- Metals
- Glass
- Polymers

Again, it's impossible to succinctly explore the scientific nuances of this wide subject. The important point is to understand how the choice of materials is important to produce high quality hardware. To draw an analogy with the culinary arts, chefs will tell you "high quality of ingredients" is mandatory for "high quality cooking". In the cable design and manufacturing industry, it's the same story: high quality raw materials are mandatory to produce high quality optical cables.

This point can be illustrated with a well-known material in the cable industry: polyethylene.



If the basic formulation is simple, the production of polyethylene blend with the right macromolecular weight, the right poly-dispersion index, the right stabilization with appropriate antioxidants such as phenolic antioxidants BHA, BHT, AO 2246, AO 425, Ethanox 330, Irganox 1010, Irganox 1076 or others, and with the right concentration, is a lot more complex.

The different grades of polyethylene (LDPE, LLDPE, HDPE, copolymers) don't offer the same extrudability, which means that during the extrusion process the polymer may be damaged by a wrong process. The material reliability may be affected.

Similar to the above illustration, there are a whole host of material parameters that influence the expected life time of hardware.

- The friction coefficient is an important parameter to manage the pulling force of cables in ducts or to optimize blowing properties.

- The UV resistance of jacketing materials is also very important, particularly for aerial cables. The expected lifetime of the polyethylene jacketing materials will strongly depend on the carbon black concentration, quality of the dispersion in the PE matrix, and size of carbon black particles.

It is clear that even a single material requires many studies, tests, and long term aging to understand if it can achieve the targeted long lifetime.

Any kind of polymeric materials used to produce optical cables requires the same care as the one presented above (polyethylene as an example), to be sure that the final reliability of the optical cable will be in line with expectations.

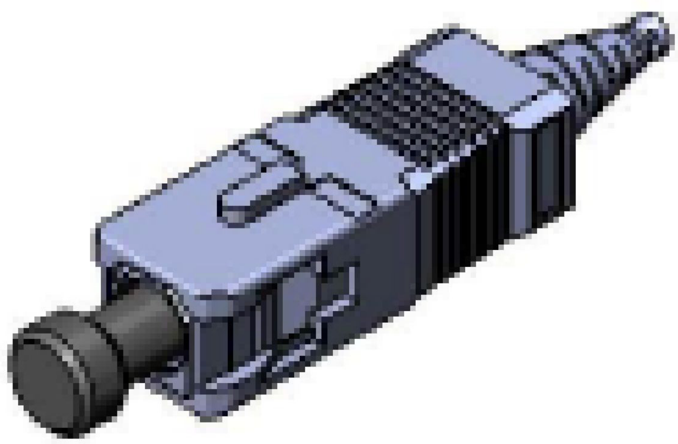
On top of the material quality, any possible interaction between materials included in the cable, and between the jacketing material and the external environment must be carefully investigated. This deep investigation and experimentation, part of material science, is foundational to R&D in cables.

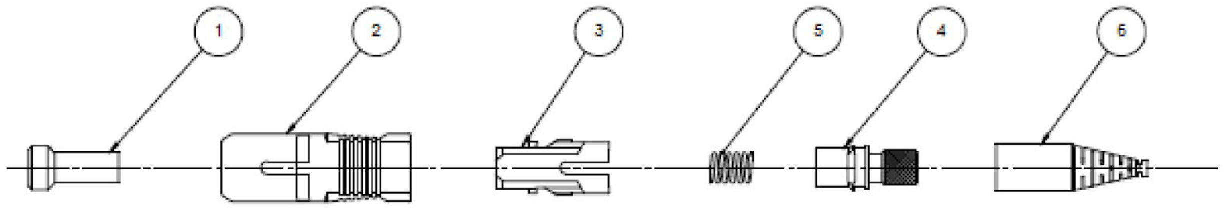
4.4 Connectivity

Connectivity is another very important range of hardware that may positively or negatively impact the expected life time and the OPEX due to its quality.
ODF, street cabinets, splice boxes, distribution points, subscriber boxes, splitters, connectors, adaptors, accessories for aerial cables, are all types of Connectivity components, which also require special care during their design, material selection, production and qualification phases.

It is not warranted to explore every detail of each individual component. Instead, this paper will look at connectors and adaptors to illustrate how they are critical and how they impact the long life-time of networks.

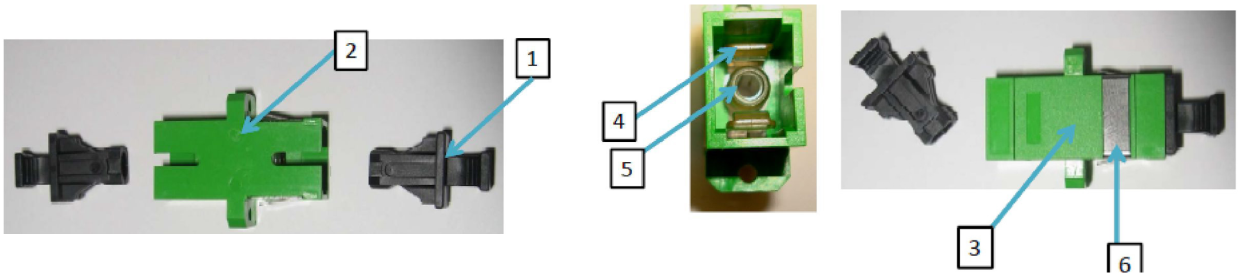
The following drawing presents an SC-APC connector:





Item No.	Description	QTY.
1	Dust Cap, White (See DWG # EN06 - 134)	1
2	SC Outer Housing (See DWG # EN10 - 024)	1
3	SC Inner Frame (See DWG # EN10 - 023)	1
4	Back Post (See DWG # EN10 - 020)	1
5	Spring (See DWG # EN10 - 019)	1
6	900µm Slotted Fiber Boot (See DWG # EN10 - 032)	1

The following drawing presents a SC-PC adaptor:



1. Dust Cap, PP
2. SC one piece adapter housing with flange, no shutter, PBT
3. SC one piece adaptor cover, PBT
4. SC one piece adaptor hook, High Tg Engineered Plastic
5. Alignment Sleeve, Zirconia
6. SC Simplex Adapter mount Plate, SUS

By examining these drawings and descriptions we can see that different materials are required for their production:

1. Different type of polymers including technical polymers
2. Different metals
3. Ceramics like Zirconia for ferrule inside the connector or the alignment sleeve inside the adaptor.

In addition, since the optical fiber is fixed inside the ferrule through the usage of a special thermal curable glue, the quality, the application and the polymerization of this glue are extremely important factors for the final quality of the adaptor.

These connectors and adaptors will be located at different points of an FTTH network. Some of them will be in street cabinets. Temperature inside street cabinets can exceed 70°C with saturated humidity: street cabinets are like cooking ovens.

Repeatedly and overtime, components will be submitted to a harsh environment with saturated humidity and high temperature.

It can be concluded that if each individual material is not carefully selected, the long term expected life time will not be achievable:

- Polymers may suffer premature aging with potential cracks and reduction of mechanical properties

- Metals may suffer potential corrosion. Spring characteristics, and consequently pressure on the ferrules, may suffer variation vs time.

- Zirconia ceramic may present different issues such as broken sleeves, bad aging performances with surface corrosion, and poor machining quality resulting in bad attenuation performances. (Zirconia ceramic is produced from zirconia powder plus sintering and machining processes. It's easy to find a lot of suppliers of zirconia powder but very few around the world can deliver the required quality to produce high grade of ferrules and sleeves.)

On the international market, it is easy to find connectors and adaptors with wide differences in price, but, unfortunately there is a large range in quality level. It is nearly impossible to identify these physical differences without deep testing and long-term aging in specialized qualification labs.
Without incorporating strong technical expertise, it is extremely easy to deliver any kind of low-cost components. Undesirable results may not be identifiable during the initial years but they will become increasingly frequent overtime. These accelerating issues will also balloon the OPEX.

4.5 Hardware summary

Hardware reliability is a must-have parameter to offer durable, high quality of service while minimizing the maintenance cost. As illustrated above it is a complex topic.

The IEC and CENELEC standards provide relevant guidance on the performances to achieve and the tests to be passed. The completion of these tests is a mandatory step towards reliable components. As well, it is mandatory to check whether the suppliers have the technical skills, the resources and the willingness to maintain consistent performance over the entire production process over time.

5. Civil works and passive optical network installation

Civil works and passive optical network installation are two other parameters that may dramatically impact the global network life time expectation. This paper will not cover these two key parameters but it is intuitive to understand how these parameters are important to achieve a 50 years expected life time, with full functionality beyond the life time.

To achieve this target installers must:

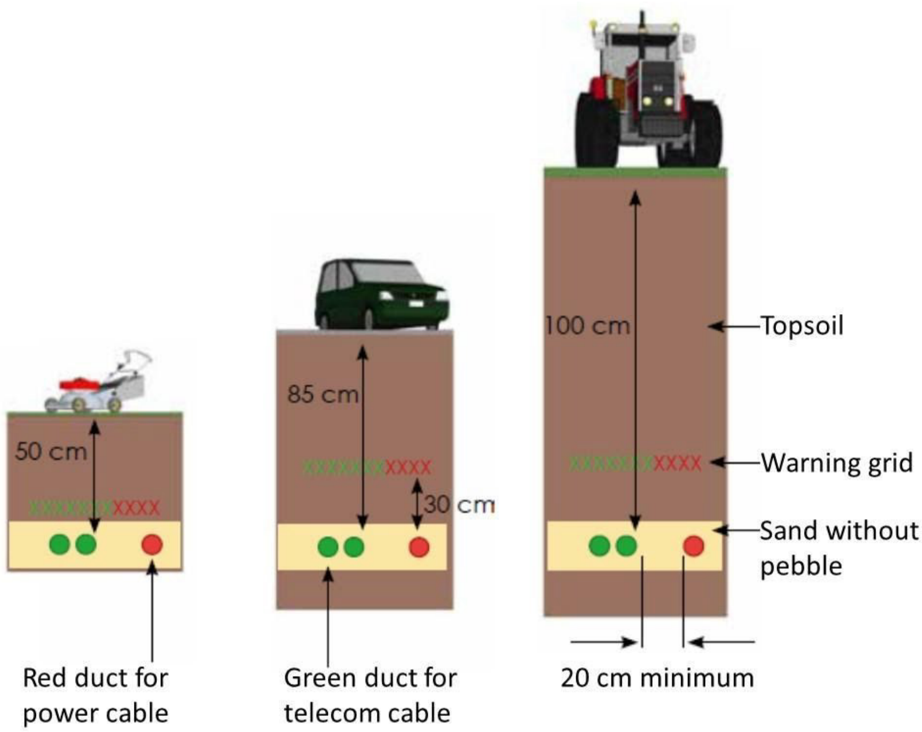
- Use robust optical components: fibers, optical cables and connectivity. Different cable designs are usable but it is well recognized that the micromodule design brings many benefits during the installation process by:

  - Reducing the time for installation compared to other designs due to its small size and very high flexibility (without incurring kink effect)
  - Helping in the miniaturizing of some components, such as splice boxes
  - Securing optical fibers against unacceptable stress due to its very high flexibility and high temperature range stability.

- Have a strong competence with the right training

- Understand the risks and localized crush that ducts may suffer at depth: risks increase drastically when the depth decreases. At 20 cm depth risks are very high, but they become very low at depths of more than 100 cm.

Generally accepted, universal guidelines regarding the depths of telecom ducts are presented in the following diagram:



- Understand the relationship between material quality and expected life time
- Understand the complex issue between friction coefficient between cable and ducts and the pulling force
- Understand the effect of pulling force on the cable while considering environmental conditions in aerial applications
- Understand all environmental factors that affect not only optical cables, but also accessories. This understanding must be strong particularly in cases of aerial installations: extreme temperatures, wind effects, humidity, etc.
- Understand how important quality and care are in the installation of any kind of accessory
- Understand how the final inspections for quality of civil works and installed passive optical networks are important

Any of these points should require a detailed and long instruction coupled with the right training. Generally speaking, low cost civil works and low-cost underground or aerial installations are not compatible with long term expected life time and low OPEX.

6. Conclusion

A lot of lay people around the world are perceive that passive optical infrastructure is the simplest part of the complete telecom network. The reason for this perception is that most people think that it is very simple to have a fiber going from point A to point B. This may the case in a simple environment, like a design document in our office. However, the reality in-field is a different story altogether: a combination of extreme complexity during the initial construction phase, and operations and maintenance over the subsequent 30 to 50 years.

Using just a few examples, this short paper illustrates how important it is to take care of many points from the initial architecture of the network to the final installation and controls.

It is important to consider one important point: opto-electronics located in buildings are very easy to replace. However, passive optical networks, typically located underground or in aerial applications, are extremely complex and expensive to replace. In addition to complexity, end subscribers may suffer poor quality of service during the replacement phase, if proper care is not taken in advance.

Our increasingly digitally connected society will be universally supported by optical infrastructure, regardless of the last-mile solution: FTTx, mobile (4G, 5G, 6G etc.) Passive optical network interruptions will become more and more unacceptable and, in some case, they could have catastrophic outcomes. At an individual level, the customer's expectation regarding the quality of service (service availability) will only keep increasing. This customer expectation will be agnostic to type of customer: public offices, medical/telemedicine, e-education, industry, private individuals.

Consequently, it is very important to be extremely careful during the construction of the passive optical network. One of the key points is the utilization of high quality and reliable passive components that are able to provide 30 to 50 years expected life time and can serve as the back bone of future proof network. Future proofing means that different generations of electronics will be installed, each time with better performances, better bit rate, lower latency by using the existing passive optical network. Another key point is network engineering: keeping in mind the quality of the installation and the required maintenance over the 30 to 50 years of the network life.

A short-term view of building a low-cost network will help minimize CAPEX. While CAPEX is important, it is a one shot activity. On the other hand, OPEX is a revolving situation, incurred repeatedly over the 30 to 50 years of the network life time. This OPEX will be directly dependent on the quality of the network, which in turn is dependent on the quality of the passive components: future proof optical fibers whatever the wavelength used, optical cables and connectivity.

To enable and build high-quality, reliable networks it is imperative that to ensure:

- Detailed product/hardware specifications and qualification processes, taking into account their future proof capability and their availability during the expected life time of the network.
- High quality training for people in charge of the network engineering and network installation.
- Network engineering taking into account the installation process, and the operations and maintenance activity for the next 30 to 50 years
- High quality and reliable civil works. (It represents the biggest contributor to the total infrastructure CAPEX.)
- High quality and reliable optical network installation.
- Accurate final inspection to guarantee that any of the above mentioned points are totally under control.