FIBER TO THE X FUNDAMENTALS

A complete overview of principles, technologies, architectures and business models for future networks.

COMMSCOPE®

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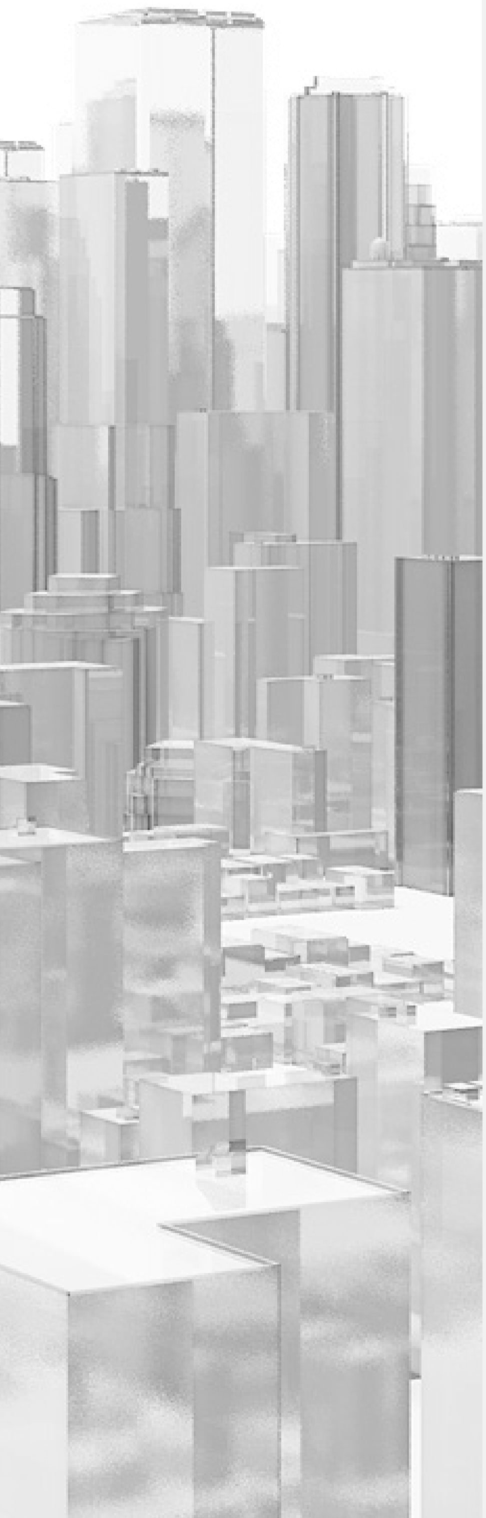
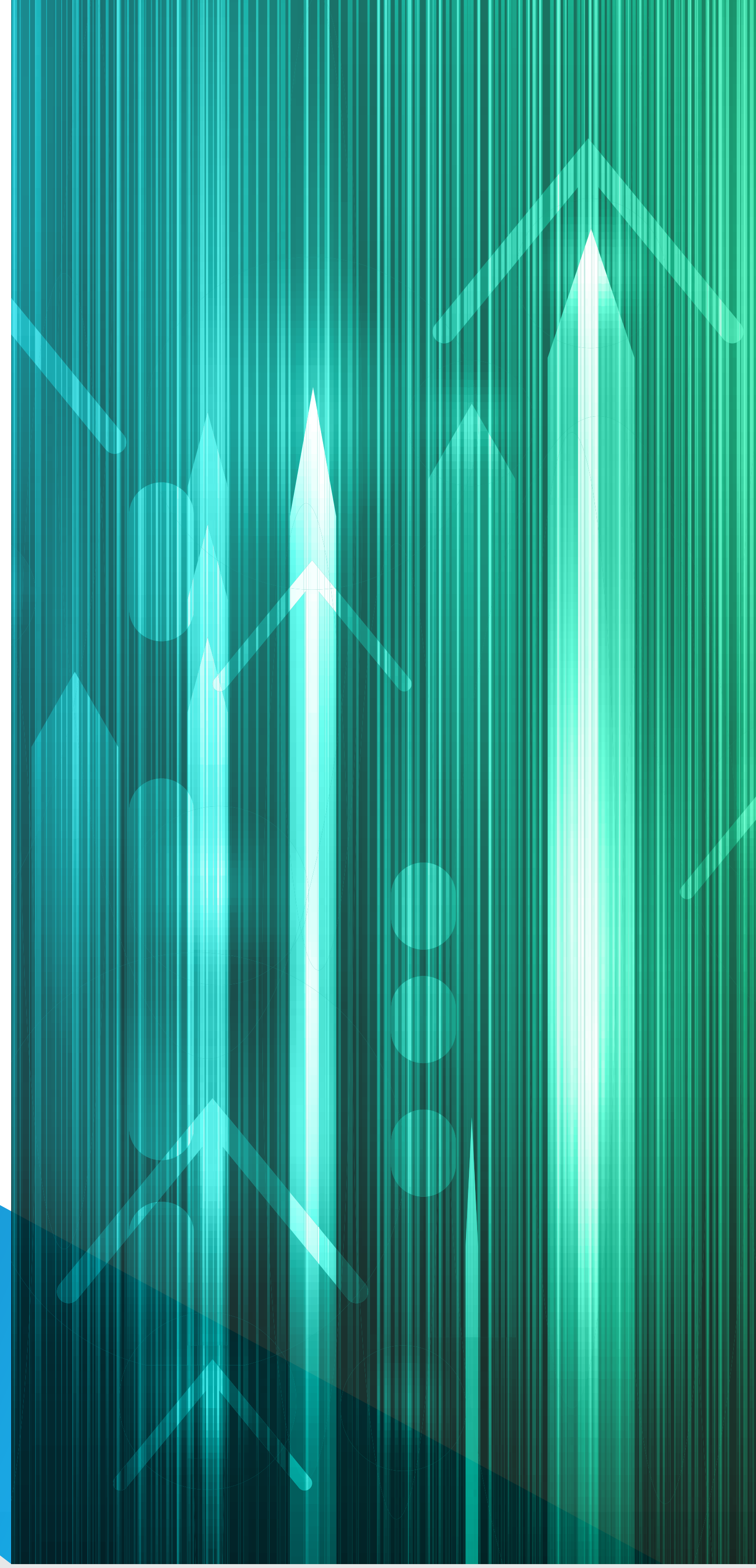


CHAPTER 1

The history and future of fiber to the X

The history and future of fiber to the X



Welcome to the gigabit revolution!

At increasing speed, we are evolving into a global digital society. This is profoundly transforming the way we live, work, learn and thrive.

Around 15 to 20 years ago, home and business internet connections were pretty slow. Downloading a single image would take hours. And, since the internet was usually accessed via telephone lines, you'd have to choose between making a phone call and using the internet—you couldn't do both at the same time.

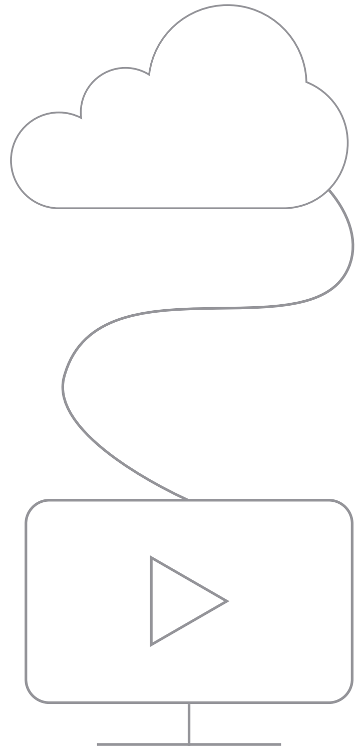
The arrival of broadband changed that forever. Finally, it was possible to transmit information over multiple channels simultaneously. Data could be sent and received over the long-awaited, multi-lane "information superhighway"—using just one cable.

From the outset, fiber-optic technology has enabled broadband speeds. "Gigabit," which has become a household word, is practically synonymous with "fiber to the home" (FTTH). One gigabit is one billion bits, and, when delivered in one second, that's 1 Gbps or 1,000 Mbps—about 100 times higher than the average downstream internet speed in the United States.

Gigabit service adoption, pioneered in the early 2000s by a handful of communication service providers, is on full upswing today. According to Viavi's recent study, 57.5 million U.S. consumers have access to gigabit internet service. Gigabit applications are all set to revolutionize the delivery of government services, health services, business, education and more. Providing broadband speeds is crucial—but this is just the beginning.

Bandwidth: What is it—and why do you want it?

But why would you want gigabit connectivity in the first place? Well, for one thing, bandwidth consumption in homes and business is growing fast. In the early 1990s, when 14.4 kbps modems were standard, many people wondered why we'd need faster connectivity. However, as available bandwidth increases and technology progresses, all bandwidth on offer will eventually be used as developers introduce applications and services that are more bandwidth-hungry than their predecessors.



Today, Netflix recommends a 25 Mbps connection for Ultra HD quality viewing. A family of four streaming on different devices can potentially use the full capacity of a household's 100 Mbps connection.

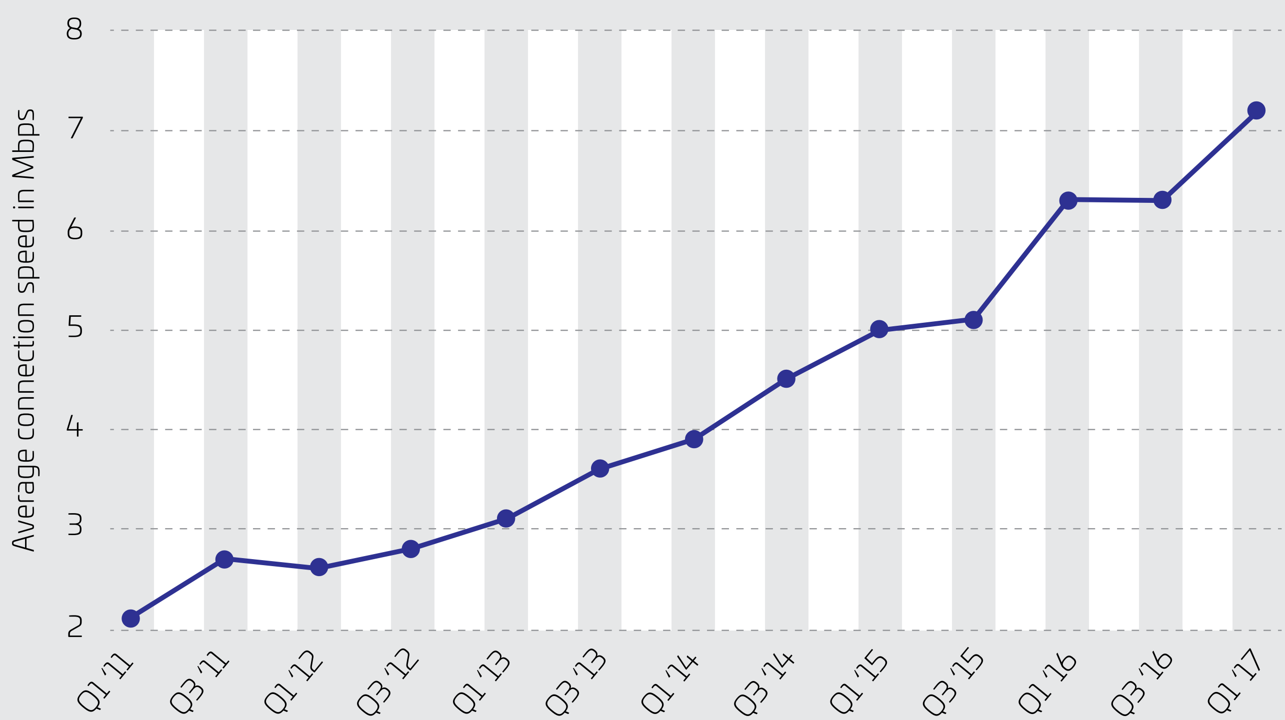
Global internet traffic, which has been doubling every two years, is set to grow even faster due to the increased uptake of mobile computing and smartphones.

5G, the next standard in mobile technology, is expected to deliver speeds in excess of 10 Gbps. Data transfer could be up to 150 times faster than 4G. This will be further driven by the already vast need for HD video streaming to mobile devices.

Video requires high bandwidth and network reliability to present a smooth stream of images—especially as multiple people increasingly watch different things at the same time on a single network.

We're also seeing the arrival of 3D HDTV, 4K and even 8K, and virtual reality (VR) video. Not to mention bandwidth-hungry innovations such as the internet of things, cloud services and applications, smart buildings, virtual and augmented reality, autonomous traffic, and blockchain technology.

AVERAGE GLOBAL INTERNET CONNECTION SPEED



Additional Information: Worldwide; Akamai Technologies; 1st quarter 2011 quarter 2017; IPv4
Source: Akamai Technologies © Statista 2017

The evolution of fiber networks
But what's so great about fiber?

With the rise of the cloud, the internet of things and smart city applications—as well as the arrival of 5G—the need for high-bandwidth, low-latency, future-proof networks is increasing further. In addition, demand has grown significantly for symmetrical bandwidth, offering comparable performance for download as well as upload. Users expect ubiquitous connectivity, which simply always works.

Fiber-optic cable is a key solution to accommodate today's applications, as well as future technologies. Autonomous vehicles, for example, will produce vast amounts of data—of which a great deal will be sent to the cloud. What's more, drivers will have ample work and leisure opportunities in the car, which means even more bandwidth consumption.

The capacity fiber offers is large enough to provide the backbone of all current key networks: internet, cable TV, telephone (including mobile), private business and data centers. Fiber accommodates the fast-growing demand for streaming video, which currently accounts for 70 percent of internet traffic.

Without fiber, many things we rely on every day would be impossible: banking, working from home, online shopping, streaming audio and video, using mobile phones and tablets, and healthcare applications.

DID YOU KNOW?

35% of operators say they will transition the majority of network users to FTTH between 2017 and 2020

+25%

An additional 25% of operators expect to have made the transition by 2025

Source: Broadband Outlook Report 2016

The need for speed

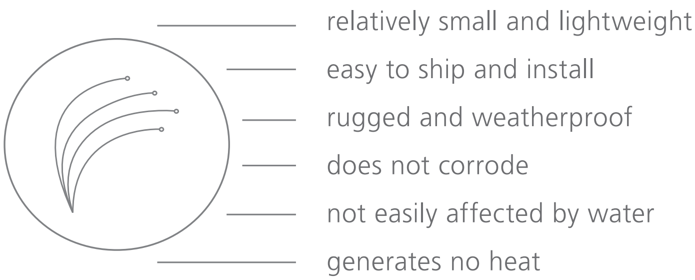
To offer private and professional end users the services they want, developers and providers need fiber. The ability to provide always-on, reliable, high-speed, low-latency, ubiquitous connectivity is necessary to survive and prosper—especially as today's consumers have unprecedented control over the customer relationship and greater choice.

Over the next few years, global operators are expected to push toward FTTH as their main broadband delivery platform.

Some *very* practical benefits

Very high bandwidth makes it possible to transport huge volumes of data with low latency (or delay). Any data transport delays are practically unnoticeable, ensuring applications run smoothly, without interruption. Fiber works well across long distances (65 kilometers or more) without signal degradation. There is no need to boost the signal along the path.

Deployment is relatively easy—fiber can be packaged in various cable profiles and hidden easily under surfaces or in walls. Once installed, fiber performance can be upgraded by changing the electronics that create and receive light pulses transmitted by the cables, without needing to replace the cable itself.



What's more, unlike other cable types, fiber is immune to electromagnetic interference. This immunity makes fiber cabling inherently more secure, since transmitted signals cannot be simply "sniffed" or interfered with.

No "one size fits all" approach

Fiber cabling provides the foundation for today and tomorrow's communication networks. A fiber backbone might run right up to a wireless access point or it could terminate in a company's basement, a distribution point on a street corner or in an apartment building. There are different approaches to making the final connection from the fiber backbone to the user in the home or business.

Although there are various options to choose from, in many cases, fiber cabling is used to link the backbone directly to the end-user device, offering the highest speed and lowest latency.

Different types of fiber to the X

FTTH — Fiber to the home

FTTC — Fiber to the curb/cabinet

FTTB — Fiber to the building/basement

FTTN — Fiber to the node/neighborhood

Convergence—the next frontier

Through fiber network convergence, a service provider can deliver a wider range of services, offer innovative services and enter new markets faster. Simply put, network convergence means developing one build-out that is utilized for multiple service delivery platforms.

The process of network convergence is driven primarily by the development of enabling technologies and the need for higher efficiencies. Large incumbent service providers with both wireline and wireless operations are moving toward a single network to maximize asset utilization and leverage economies of scale. Smaller providers, with more limited budgets, can address multiple market segments, add revenue streams, and de-risk the business case with more stakeholders, more sources of funding and greater ROI.

Benefits:

- Sharing physical assets between fixed and wireless.
  With small cells moving deeper into the network and CRAN (centralized RAN) allowing pooling of baseband resources, sharing of fiber cables and physical real estate becomes more important. Building a new FTTH network—followed several months later by the same construction crew having to dig up the same street to lay fiber for a cell site—won't be an issue.

- Sharing data stream for fixed and mobile.
  Additional efficiencies are gained for companies willing to share fibers for multiple applications. Furthermore, WDMs, NGPON2 and other technologies are allowing the merging of bit streams and enhanced network efficiency. Spare capacity can be marketed as "virtual dark fiber" or wavelength services—less costly and faster to deploy.

- Sharing processing and management resources.
  The trends toward SDN/NFV allow network operators to share processing and management of the network regardless of the end application.

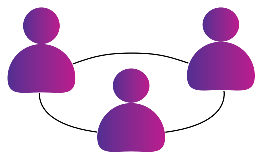
Important to note is that, as multiple services are delivered from a single network, reliability becomes paramount—and quality and standardization will increasingly play a critical role.

Fiber is essential to today's innovation economy. A 2014 Analysis Group study* found higher per capita GDP (1.1 percent) in communities offering gigabit internet. GDP in these communities was roughly $1.4 billion higher than similarly situated communities. In a similar vein, a 2017 study by RVA LLC for the Fiber Broadband Association USA linked widely available all-fiber networks to new business formation, a better economy and more jobs. Research in other regions shows similar results—in France, for example, 4.8 percent more start-ups were created in municipalities equipped with ultrafast broadband than in municipalities with slower access.

Fiber is foundational to economic future

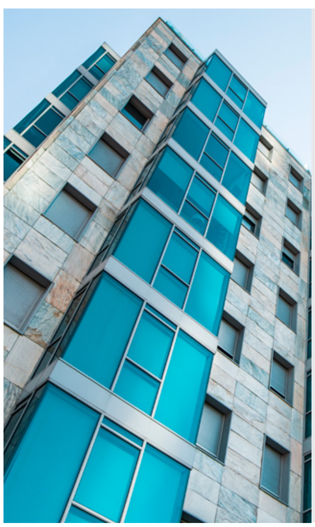
+1.1%
per capita
GDP

GIGABIT
INTERNET
COMMUNITY



+$1.4 BILLION
GDP

* Source: *EARLY EVIDENCE SUGGESTS GIGABIT BROADBAND DRIVES GDP*
http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/gigabit_broadband_sosa.pdf



DID YOU KNOW?

Inhabitants of multidwelling units are willing to pay 2.8 percent more to purchase a condo or apartment with access to fiber-optic service. Renters are willing to pay a premium of 8 percent, based on a $1,000 monthly rent for access to fiber, a significant result, as some 30 percent of U.S. residents live in some form of multifamily housing. What's more, access to fiber may increase a home's value by up to 3.1 percent according to a report by researchers from the University of Colorado and Carnegie Mellon University. In fact, even in places where there isn't a gigabit service yet, home values may increase by 1.8 percent if a local network operator has deployed fiber infrastructure capable of supporting 100 Mbps or higher.

Fiber can also help in the following areas:

88% NEW EMPLOYER ATTRACTION

85% EMPLOYER EXPANSION

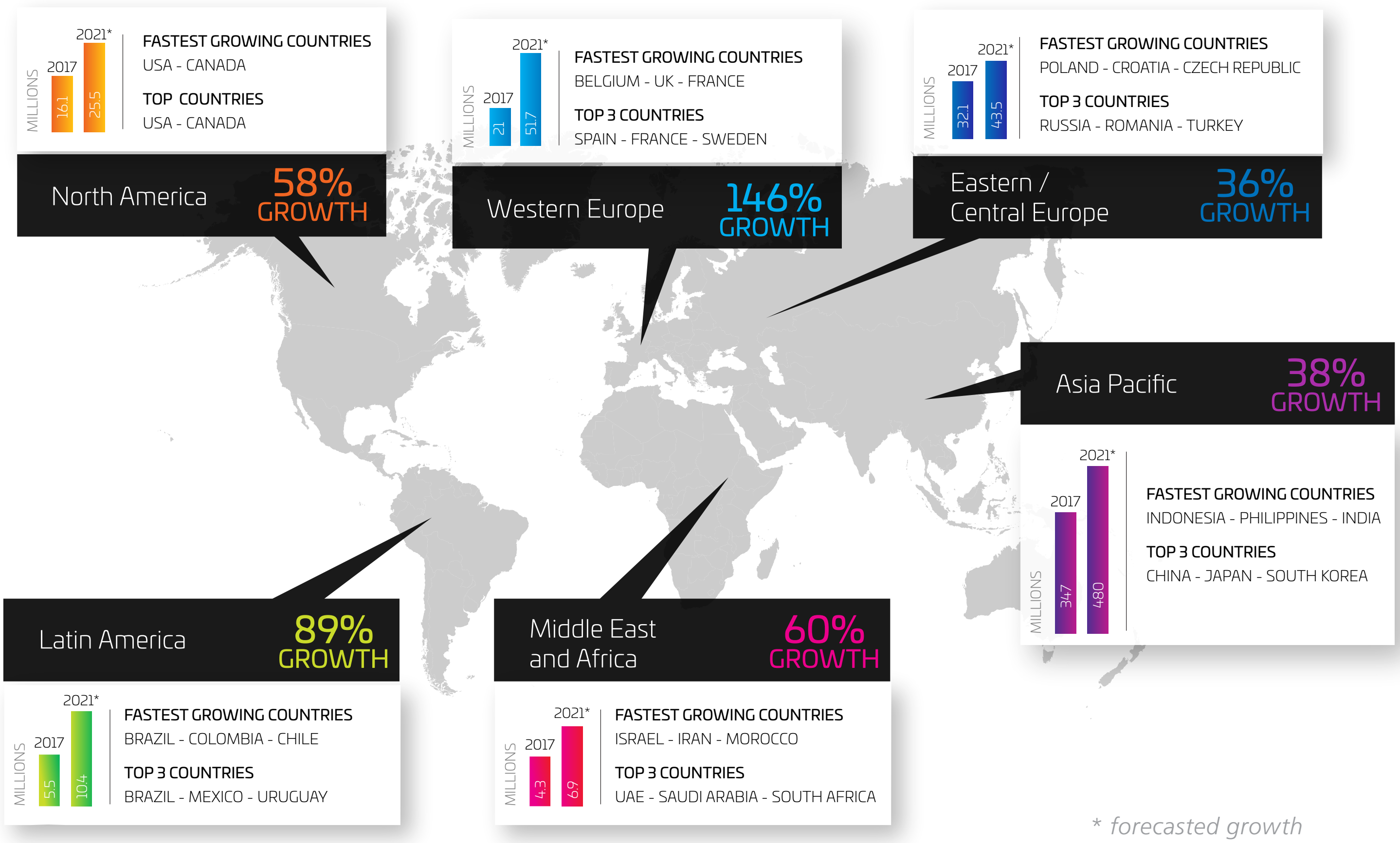
77% EMPLOYER RETENTION

52% HOME-BASED BUSINESSES

According to local economic experts and policymakers surveyed by RVA, LLC for the 2017 Fiber Broadband Association

Global race to the future

FTTX subscribers now and in 2021



** forecasted growth*
Source: IDATE DigiWorld

1 billion subscribers by 2021

In terms of broadband access technologies, FTTX now accounts for the largest market share worldwide, with a few industry analysts estimating more than 1 billion homes passed by 2021.

Increasingly, countries are viewing developments in broadband infrastructure as a utility—similar to models used for gas, electricity and water. Deployments based on fiber to the premises continue to gain momentum as countries continue to develop national broadband networks (NBNs). In addition, global broadband prices are declining in many markets around the world, making it more affordable and more obtainable to the greater population. While fiber-to-the-home deployments continue to accelerate globally, regional differences exist with a variety of factors such as public policy, legislation and standards affecting speed of adoption.

CHAPTER 1 SUMMARY

Enabling the digital transformation and delivering future prosperity

The need for bandwidth is growing fast—driven by 5G, cloud, IoT, mobile computing, HD video, and bandwidth-hungry applications. Worldwide, we're seeing a gradual upsurge of fiber, as this is the primary technology that will support the applications of today and tomorrow.

Fiber's very high bandwidth makes it possible to transport huge volumes of data with low latency. The trend toward convergence of different types of network and functionalities onto a single network promises increased efficiencies.

What's more, studies and years of experience show that the presence of broadband brings a wealth of benefits—from increasing GDP and employment to supporting job retention and new business creation. In fact, fiber isn't just "nice to have"—it is essential to our economic and social long-term future.

CHAPTER 2

From fundamentals to real-world choices

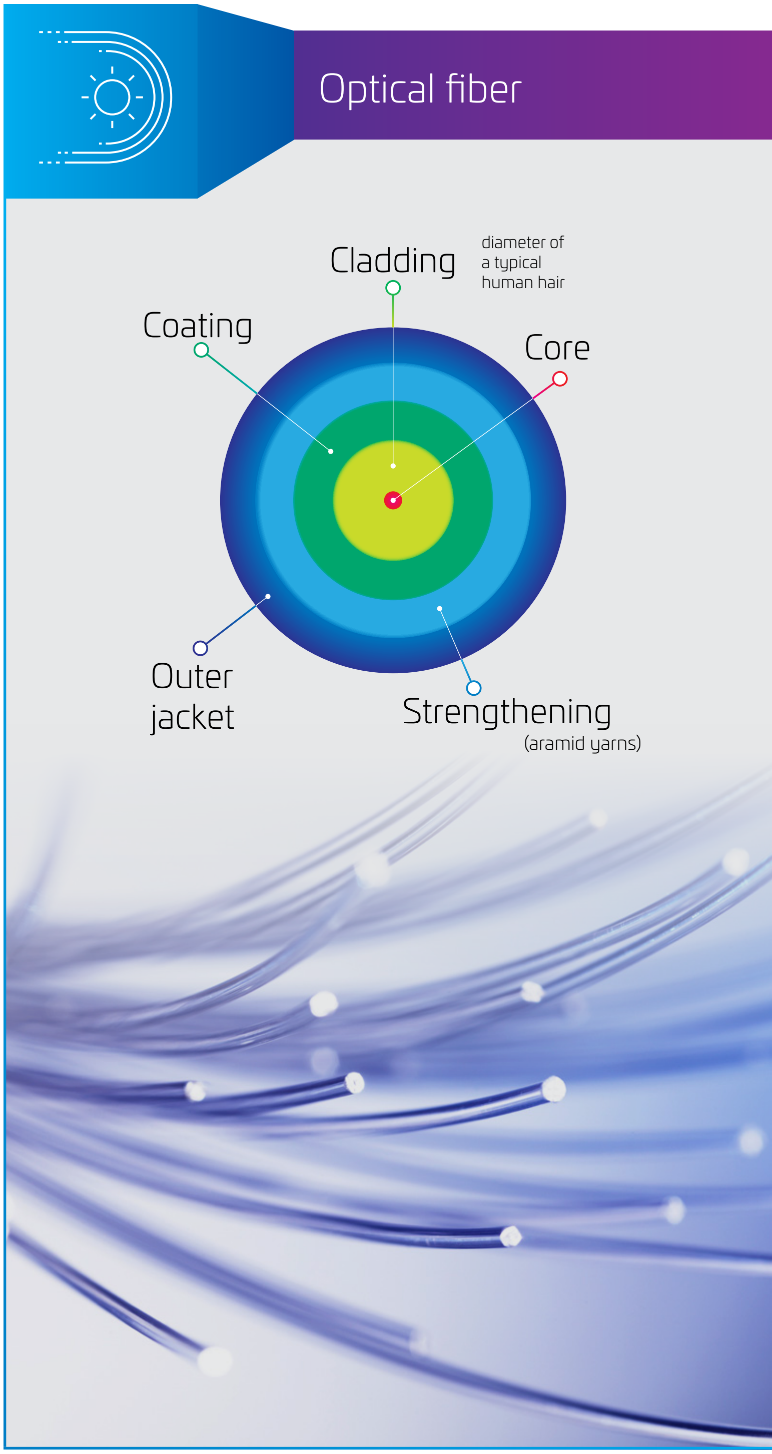
From fundamentals to real-world choices

Why light?

Why transmit data using light instead of, for example, electric pulses? Simple: light is incredibly fast. The speed of light in a vacuum is some 300,000 kilometers per second, and just one-third slower, or about 200,000 kilometers per second, when travelling through a fiber-optic cable. There are some coax cables that perform better than this, but these coax transmission lines need many more amplifiers than the optical fiber lines, making optical fiber technology the fastest transmission solution for long distance lines.

An optical fiber contains a glass core through which light travels. Around this core is another layer of glass called the 'cladding', which ensures light doesn't escape from the core. An optical technique known as 'Total Internal Reflection' keeps the light inside the core. A protective polymer coating protects the glass of the cladding from moisture, dirt and damage. The total diameter of an optical fiber is 250 µm or 1/4th of a millimeter.

On its own, the thin optical fiber is not robust enough to be handled and exposed to the outer world. In fiber optic cables, the optical fiber is protected from mechanical strain by a tougher strengthening material (aramid yarns). The outer covering, or outer jacket, provides environmental protection from the elements such as dust and water.



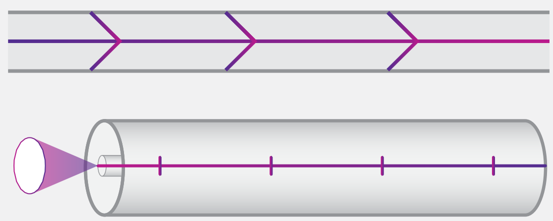
Key benefits of fiber optics

- Very high bandwidth – transport huge volumes of data
- Low latency – delays in data transport unnoticeable
- Minimal attenuation
- Small and lightweight – easy to ship and install
- Immune to electromagnetic interference
- Minimal security risk (difficult to 'tap off' light without being noticed)

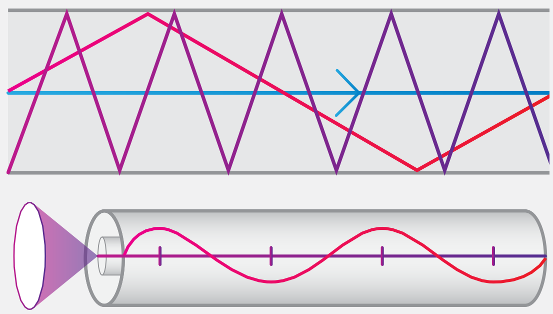
Propagation of light: single mode or multi mode?

A 'mode' is the path a beam of light follows as it travels along an optical fiber. Multi mode fiber allows light to travel along many different paths in the core of the fiber. Single mode fiber, used in all long distance lines and FTTH deployments today, carries just one mode.

In a **single mode optical fiber**, the signal travels straight down the middle. This makes it possible to transport signals over distances of up to 100 km and still be useable. Typical applications include telecom networks, campuses, TV cable or industrial estates.



Multi mode fiber has a larger core (typical diameter 50 um) compared to single mode fiber (diameter approximately 9 um), which makes it less costly to make connections and allows the use of VCEL light sources, which can be significantly less expensive than lasers. However, although the cost of connection is lower than that of single-mode, the distance over which data can be transmitted is much shorter. Multi mode is commonly found in short distance audio/video transmission and broadcast applications, Local Area Networks and data centers.



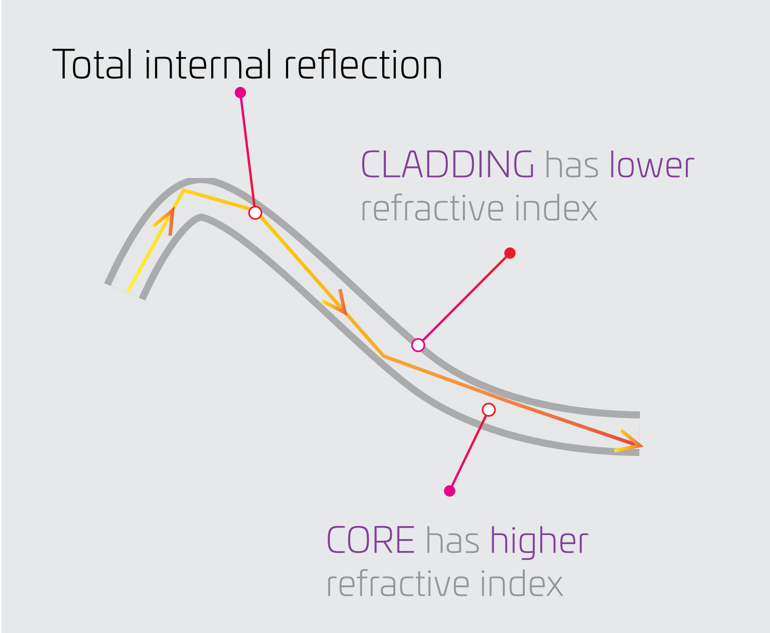
Wavelengths

Light, like sound, is made up of vibrating waves. Light can have different wavelengths, and we perceive these as different colors in the visible spectrum. These wavelengths can be expressed in nanometers (nm) - one billionth of a meter. Our eyes see wavelengths between 420–440 nm as shades of blue. Longer wavelengths, from 650 – 700 nm, we see as red.

As light travels, it loses some of its intensity. This is called ‘attenuation’. The greater this attenuation, the weaker the signal at the end of the line. In fiber optics, longer wavelengths means less attenuation, resulting in a better signal quality. Wavelengths in the infrared region, invisible to the human eye, are used. At around 1550 nm, attenuation is relatively low in glass, which is why this wavelength is commonly used for long distance networks.

Single mode fiber uses wavelengths between 1260 nm and 1625 nm. Light propagates along a single path because its wavelength is more or less equal to the core diameter (~9 um) of the fiber.

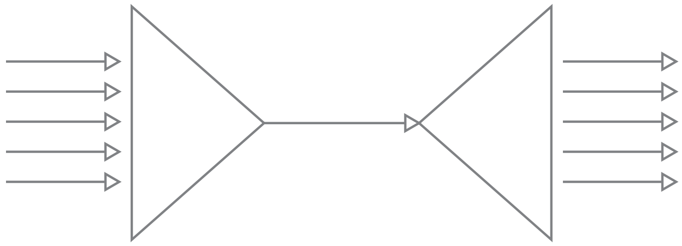
Multi mode fiber operates at wavelengths between 850 nm and 1300 nm. We can distinguish two types of Multi mode Type 1: Step-index – Core (diameters 50 um and 62.5 um) and Cladding material have a different refractive index. Type 2: Graded Index – The refractive index of the core material is variable. This is a parabolic function of the radial distance from the center.



Total internal reflection

Multiplexing techniques

The total transmission capacity of an optical fiber is vast and ideally should be shared by multiple customers. A technology called 'multiplexing' allows a single fiber to be used to transport multiple signals or services.

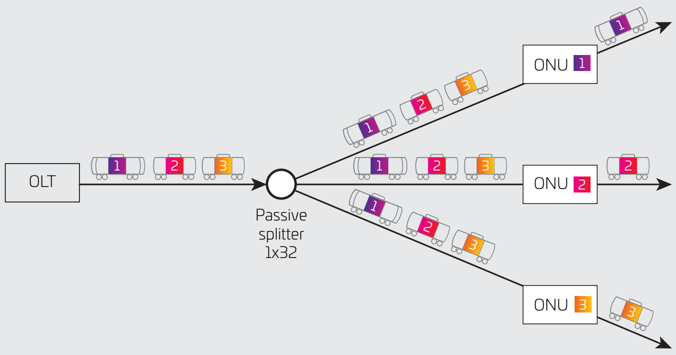


Time Domain Multiplexing – creating a train with wagons on the information railway

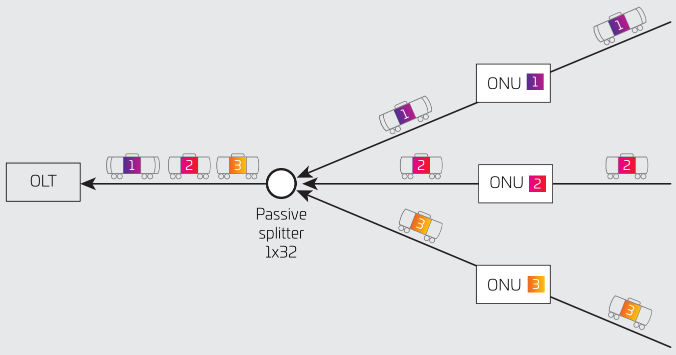
With Time-Domain-Multiplexing (TDM) the services for different customers are sent and received as packages in specific 'time-slots'. TDM can be compared as a train with several wagons, with each wagon containing a certain amount of information for a specific customer. The wagons travel in sequence over the information railway. At the end of the line, the wagons are separated and delivered to the correct customer.

TDM techniques are used in long haul point-to-point networks, but also in the FTTH Passive Optical Networks (PON). The multiplexing and demultiplexing is done in the electronic equipment such as the OLT (Optical Line Termination) in the central office and ONU (Optical Network Unit) at the subscriber.

Example of TDM in PON (Downstream traffic):

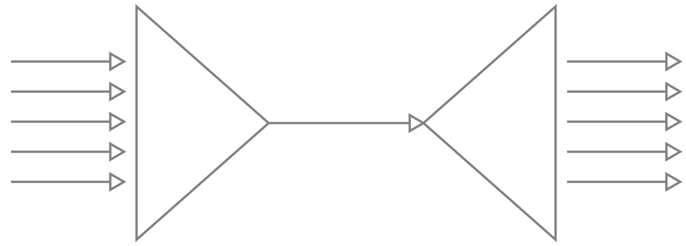


Example of TDM in PON (Upstream traffic):



Multiplexing techniques

.... continued

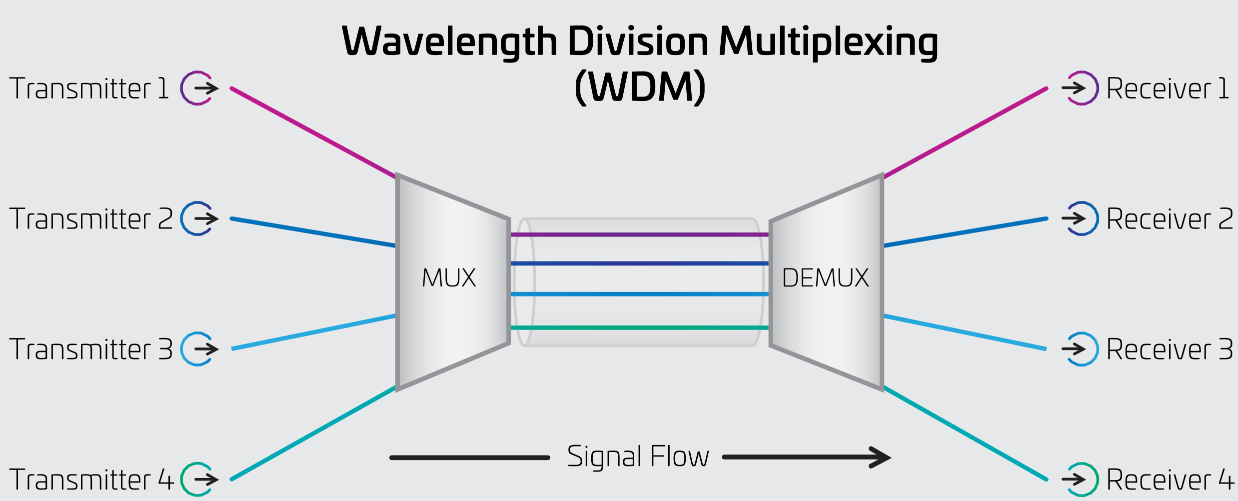


Wavelength Division Multiplexing - creating multiple lanes on the information highway

With Wavelength-Division-Multiplexing (WDM) the different services are transmitted at different wavelengths and these signals will not interfere with each other. We could compare WDM to a futuristic multi-lane highway. Each car on the highway would have its own lane, where it can travel at its own speed without interference from traffic in the other lanes.

Many different wavelengths can be combined onto a single fiber using a device called 'multiplexer' (MUX). On the receiving end the combined signal is 'unscrambled' by a demultiplexer (DEMUX). In this way, many different signals can be transmitted across a single fiber at the same time. Instead of one data stream, you can send and receive many, increasing the cable's capacity.

Dense Wavelength Division Multiplexing (DWDM) refers to signals that are 'multiplexed' within a specific range of wavelengths, around 1550 nm. Erbium doped fiber amplifiers (EDFAs) are particularly effective for wavelengths between approximately 1525–1565 nm and 1570–1610 nm. In this way, large volumes of data may be received and transmitted in just one fiber over very long distances. Typically 40 DWDM channels per fiber are used, but it is possible to go up to 128 channels. Adding channels instead of introducing more fiber and other network components can expand network capacity without the need to install new cables. By introducing optical amplifiers that 'boost' the signal, distances of up to 1,000 km may be achieved. Another variant is Coarse Wavelength Division Multiplexing (CWDM), which allows up to 18 channels per fiber.



CWDM or DWDM?

Both DWDM and CWDM introduce their own advantages and challenges:

CWDM

+ Each CWDM channel uses 20 nm, the combined channels use up almost the entire single-mode operating range
+ Considerably less costly than DWDM
+ Transmitters do not need to be tuned as precisely as DWDM transmitters and are less expensive
+ CWDM is appropriate in applications requiring a limited number of channels, where signals don't need to travel great distances

− CWDM doesn't work with fiber amplifiers and only supports up to 18 channels. This makes CWDM significantly less effective in long-haul networks

− In Outside Plant applications, temperature sensitivity becomes an issue

DWDM

+ DWDM uses either 50, 100 or 200 GHz spacing in the C and sometimes the L bands, allowing more wavelengths across the same fiber. A striking difference compared to the 20 nm spacing used by CWDM (which translates to some 15 million GHz)
+ Ideal for high-density areas requiring a large number of channels or for long-haul applications
+ Works with fiber amplifiers that can amplify the 1550 nm or C band
+ Since 2002, DWDM integration has become easier, thanks to the arrival of the ITU-T G.694.1 grid, a de facto industry standard

− Technology will only operate properly within specific temperature ranges.

− The lasers need to be far more accurate than with CWDM. These factors mean that the overall cost of DWDM is higher.

− A pure low power digital signal can be packed very densely to get a tremendous number of compressed channels onto a particular fiber. However, certain higher power solutions introduce limitations in terms of how many signals can be propagated over a single fiber and how closely they can be placed together.

Connectors: getting the light into and out of the fiber

Optical connectors, as the name indicates, join cables and network components, and may provide the following:

- **flexible interconnection to transmission and receiver equipment**
- **flexible interconnection to passive optical devices**
- **cross-connect function between different fibers from other cables**

The current generation of connectors is based on the physical contact between two well-polished fibers in a ferrule, in order to maximize transmission of the optical power, while minimizing optical reflections. The alignment of the fibers in the ferrules is accomplished with a slitted alignment sleeve in the adaptor.

The ferrule-based connectors will undergo a sophisticated polishing process when terminated to optical fibers. This operation will take place in the factory. The optical performance (attenuation and return loss) of the connectors is checked in the factory.

All connectors have a keying mechanism, preventing the connector ferrule from rotating along its longitudinal axis inside the adapter sleeve.

Commonly used connector types

FC

Ferrule connector

SC

Subscriber connector

LC

Local connector

MPO

Multi-fiber Push-on connector

Commonly used connector types

FC
Ferrule connector

- One of the first-generation single mode connectors with spring-loaded ferrules.
- The FC is a "screw-type" connector with a nickel-plated or stainless steel body, making it a practical choice in vibration-heavy environments.

SC
Subscriber connector

- Polymer square body
- Equipped with a spring-loaded ceramic ferrule and a push-pull coupling mechanism. Originally used for Gigabit Ethernet, but as its cost dropped it became more popular and was long considered the standard connector.

MPO
Multi-fiber Push-on connector

- Rectangular ferrules with 12 and 24 fibers allow multi-fiber connectivity
- Up to 12 or 24 times the density of the standard single fiber connector
- Supports higher bandwidths per connected cable and saves space and cost
- MPO connectors are increasingly used in data centers with the rise of 40/100 Gigabit Ethernet.
- MPO cable assembly often terminates in several smaller cables with a 'fan out', making it possible to change the order of the individual fibers by hand after a connection has been made.

LC
Local connector

- Push-pull type like the SC nut with a small form factor.
- Has largely replaced the SC as standard connector, SC is still widely used at the premises locations of FTTH networks.
- Different connection mechanism and a smaller diameter ferrule.
- Small size makes it practical for current transmission equipment, which features large numbers of connections in a limited space.

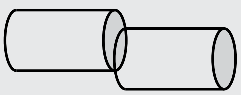
Connections and losses

The strength of an optical signal is always higher at its point of origin than at the receiving end of a line. Light always suffers some degradation over the length of the network connection. To minimize this loss, fiber cables need to connect seamlessly to other devices or cables in a network.

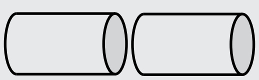
In most cases, fibers are 'fusion spliced' - connected directly together by melting the glass – which will also introduce some optical loss. These fusion splice connections are permanent. Wherever connections may need to be changed in the future, or wherever fiber has to link to a device on the network, connectors are used instead of fusing the cable together. The fiber cable is fitted with a connector plug, which goes into an adaptor or a socket on an active device, and a connection is established. The core of an optical fiber is far smaller than a speck of dust - so making a good connection requires enormous precision in the alignment of the fibers.

In all optical systems, transported optical information can 'leak' if light is lost as it transfers from one fiber to the other. The more precisely the cores are aligned, the less light is lost, and the better the signal at the receiver.

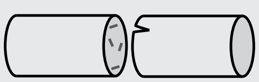
Examples of reasons for light loss:



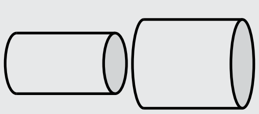
Two fiber cores are misaligned



Air gap between fibers

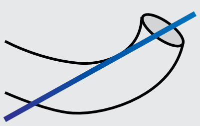


Fiber ends aren't clean or damaged

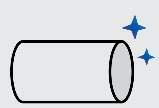


Size or cores don't match up perfectly

Loss of light can be minimized or avoided in several ways:

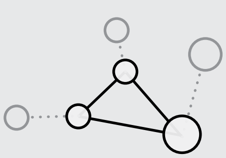


Avoid tight bends, small coils and any pulling or stretching of fiber



Ensure connectors are clean

Only the correct cleaning products and inspection tools should be used



Number of connections and splices in the network should be limited and should have very low connection losses.

RETURN LOSS

Wherever two fibers are joined, dirt or scratches may result in portions of light becoming diffused and reflected. 'Return loss (RL)' expresses the amount of light reflected back to the source at the point where fibers meet. This, too, is expressed in decibels (dB). The lower the RL, the lower the reflection. For multi mode fiber connectors, typical RL values are between -20 and -40 dB. For single mode connectors values of -45 dB (flat polished) and -65 dB (angle polished) are achieved.

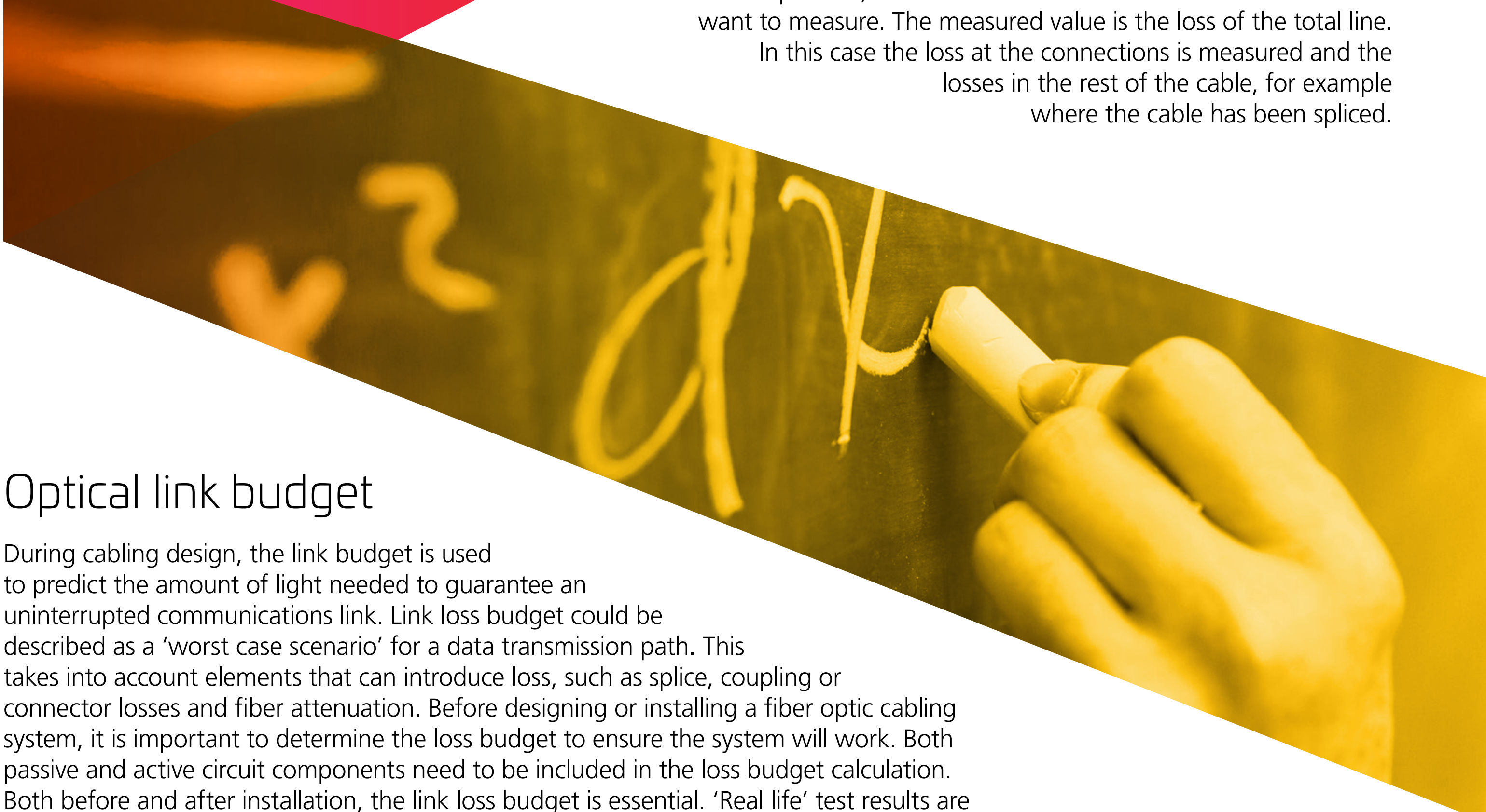
ATTENUATION (insertion loss)

The losses that occur at the point of connection are referred to as 'Attenuation' or 'Insertion Loss (IL)'. The power of the light in the fiber core is measured before and after the point of connection and expressed as a ratio in decibel (dB). Typically, values of 0.1 dB to 0.5 dB are achieved with connectors. The lower the signal loss, the smaller the value in dB.

DO YOU KNOW THE TWO TYPES OF CONNECTION LOSS??

The math of loss measurement

When measuring the attenuation or insertion loss a 'zero dB' reference point is made on selected reference cables using an LSPM (light source and power meter) or OLTS (optical loss test set). A light source (LS) is connected to one end of the cable and the power meter (PM) is connected to the other. Then the connection between the reference cables is separated, and both ends are connected to the line that we want to measure. The measured value is the loss of the total line. In this case the loss at the connections is measured and the losses in the rest of the cable, for example where the cable has been spliced.



Optical link budget

During cabling design, the link budget is used to predict the amount of light needed to guarantee an uninterrupted communications link. Link loss budget could be described as a 'worst case scenario' for a data transmission path. This takes into account elements that can introduce loss, such as splice, coupling or connector losses and fiber attenuation. Before designing or installing a fiber optic cabling system, it is important to determine the loss budget to ensure the system will work. Both passive and active circuit components need to be included in the loss budget calculation. Both before and after installation, the link loss budget is essential. 'Real life' test results are compared to previously calculated loss values to make sure a link will operate as intended.

POSITIVE power budget calculation:

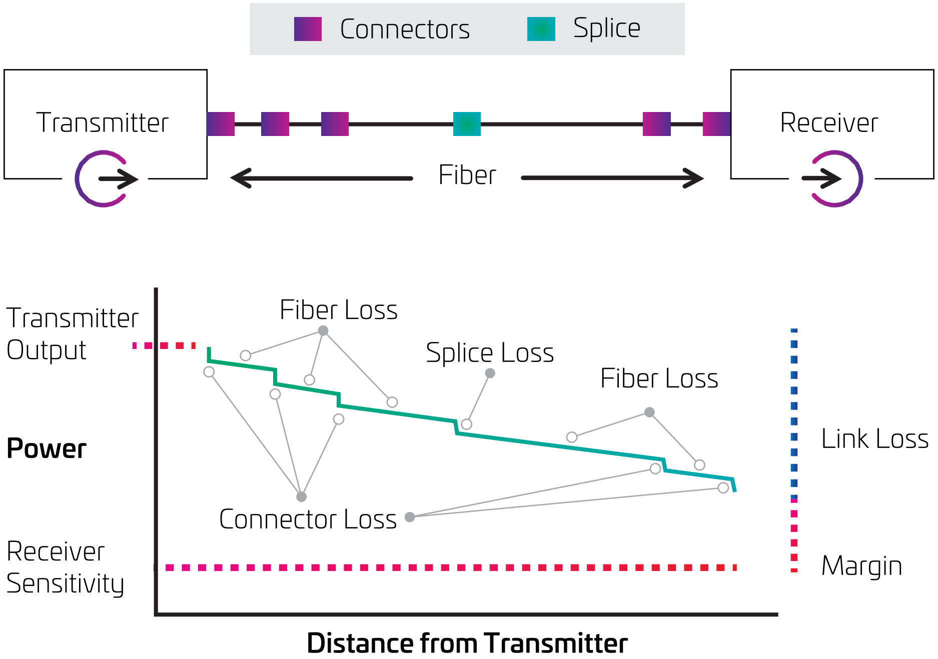
Losses within power budget

Signal will be carried to destination

NEGATIVE power budget calculation:

Losses exceed power budget

Signal will not reach its destination



Source: The Fiber Optic Association, Inc., FOA Guide

Calculating the link budget

+	Transceiver power budget
–	Losses from multiplexing and demultiplexing
–	Fiber losses
–	Splice losses
–	Patch panel and connector losses
=	**TOTAL LINK BUDGET**

Adding capacity- what's best?

As global demand for bandwidth continues to grow, driven by new services, technologies, and increased competition, network operators are reaching capacity limits. Generally speaking, there are two approaches to solving this and enabling the network to meet increased capacity demands: either build more fiber or use WDM. Let's look at the potential benefits and challenges that come with both approaches.

Adding new fiber

When deploying multiple services, and need additional capacity, you can simply add more fiber by rolling out new cables. In many cases, designers, field engineers and the rollout workforce are very familiar with the technologies and procedures available and have developed solid best practices to optimize the process. However, complexities can arise and need to be carefully evaluated upfront.

- Although the cable itself isn't all that expensive, the construction cost of deploying additional cable can be quite high, depending on distances, topologies, geographical and geological conditions and labor rates.
- When adding cables to existing ducts, physical limitations related to duct space or weight, can make deployment impossible.
- While some areas still use aerial cables, most fiber optic cables are installed underground. In the past, it was not uncommon to find city streets being dug up time after time as each new company negotiated rights-of-way individually with the local governments. Understanding how to install the cables with minimal disruption of the day-to-day city operation is the secret to a successful installation and sometimes a successful bid on a project.

Using WDM with existing fiber

WDM allows you to deliver additional separate services across a single fiber by separating them into different wavelength regions. Although DWDM electronics and passives require a significant upfront investment, typically, the overall cost is lower than rolling out new fiber. More, even though WDM is often considered a point-to-point solution, there are also add-drop multiplexer solutions. You can, for instance, multiplex eight different wavelengths at the source and then only pull off two of them at a given location, allowing the rest to travel on. This can be very useful as service providers increasingly deploy small cells providing an extra layer of mobile coverage, for example. However, several factors need to be considered and carefully evaluated:

- For each wavelength pair selected for any kind of service there has to be a unique transmitter on each wavelength: one upstream, one downstream. The receivers do not require high complexity - but the transmitters certainly do. Note that the cost of the dedicated, narrow-width laser sources could potentially be quite high and you might need to keep adding more of them.
- These products increase the cost per stream over the cost of using a dedicated fiber. Each additional dedicated wavelength applied to a WDM filter requires two sources unique to that particular wavelength.
- It is also important to know both the storage temperature and operating temperature of CWDM and DWDM passives. Not adhering to the recommended temperature ranges can result in degradation or failure. This is essential, as many components could end up in unconditioned cabinets.

Having worked with thousands of customers around the world, we know that there is no single best-solution for all situations and we are likely to see a blend of both solutions: continued migration towards higher fiber counts along with additional implementation of WDM. In the end, to make a truly 'smart' choice, one needs to examine the complete picture, fully understanding the options and tradeoffs and, equally important, developing a complete long term enterprise vision and business plan while balancing immediate and future requirements. Talk to our experts to find out how CommScope can enable your future.

The CommScope approach

Case study:
Developing in-house fiber expertise, prerequisite to the future

Clearly, there are many factors to consider when designing and implementing a fiber network: technology choices, labor, type of building and client, scale, specific customer needs… However, it's not only vital to collect this information – it needs to be transferred, shared, understood and developed on an ongoing basis. Education and training are essential to the success of any rollout. To offer some insight into how is might work and what the role of a supplier could be, we would like to share a real-world case history…

Download Case Study

Recognizing the importance of high-speed internet to the nation's economic growth and global competitiveness, the country's president supported an ambitious countrywide FTTH program. The state-owned incumbent telecom provider, which serves millions of citizens with telephony, mobile, and broadband services required large teams of fiber-optic technicians and installers for fiber deployment. However, a program to train technicians was lacking and fiber expertise was limited to a small number of optical backbone specialists.

Before training began, town hall-style meetings were held. Local CommScope engineers who had worked on deployments in other countries shared their experiences. A train-the-trainers program was developed with the local university; installation manuals and training materials were supplied in the local language. CommScope engineers supervised the initial installations, sharing practical advice and tips as well as ensuring that high standards and industry best practices were adopted. Initial resistance from older technicians disappeared as parallels between fiber and copper were drawn, helping them tap into their experience and feel more comfortable.

Working with fiber generally requires specialized cable and splicing tools. The operator dealt with the shortage of experienced technicians by choosing products that could be installed by technicians with limited experience and a basic set of tools. One example is the FOSC 450 fiber-optic splice closure, which requires no electrical tools.

Deployments began in the big cities and moved out to rural areas. CommScope directly trained more than 500 technicians for the project, who went on to train more than 3,000 installers. In deploying this network, the state-owned incumbent telco has achieved something remarkable: the country now has the highest FTTH penetration rate in the region, and it is widely recognized that their Information and Communication Technology (ICT) strategy has had a real impact on the country's economy and future development.

CHAPTER 2 SUMMARY

Making light work for you

The properties of light make it the fastest carrier of information. Light through a fiber-optic cable can be sent down one path (single mode) or multiple paths (multi mode). 'Wave Division Multiplexing' (WDM) allows a single fiber to transport multiple signals or services. Two types of multiplexing - DWDM or CWDM – each have their own uses and applications.

Different types of optical connectors join cables and network components, each has specific benefits and limitations. When working with connectors, it is essential to avoid or at least minimize loss of light.

New services, technologies and increased competition are driving network operators around the world to increase bandwidth. This can be achieved by adding fiber, introducing WDM on existing fiber, or a combination of both. Which option is most appropriate depends on a variety of factors, including intended use, location and budget.

There is no single best solution. To make a truly 'smart' choice, one needs to examine the complete picture, fully understanding the options and tradeoffs and developing a complete long-term business plan while balancing immediate and future requirements. ***CommScope experts*** are happy to discuss the big picture and finer details with you, based on your specific requirements!

CHAPTER 3

Network architectures: options, benefits and considerations

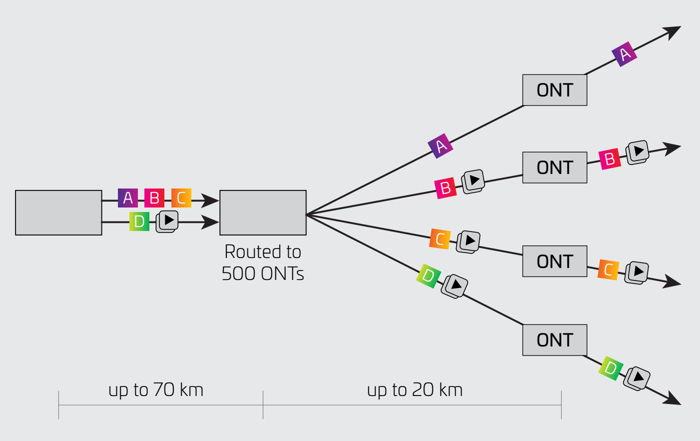
Network architectures: options, benefits and considerations

Which type of network?

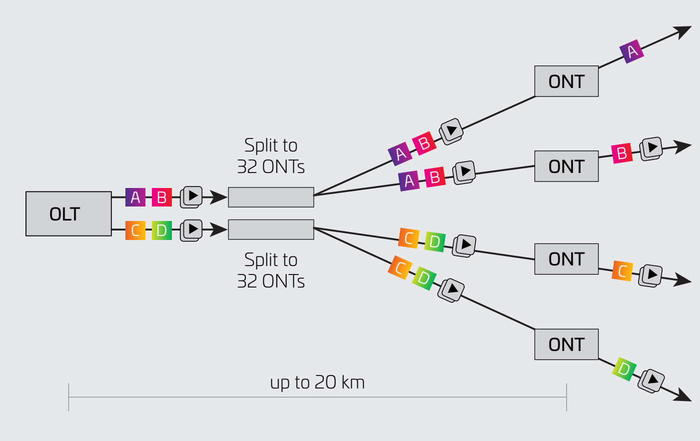
Network architectures are chosen early in the planning process and have a lasting business impact. Therefore, it is critical to assess several internal and external factors before the planning even begins.

One early planning decision relates to choosing either an active or passive network type.

Active optical network (AON)



Passive optical network (PON)



A B C D = Data or voice for a single customer

= Video for multiple customers

- Point-to-point architecture, where a "home run" fiber connection is established between the central office and the end user
- One laser transceiver is placed in the central office while the other one is in the subscriber location
- Covers longer distances and delivers high bandwidth to any single point
- Given the higher cost to maintain the required electronics, this type of network brings in associated complexities and is inherently more expensive to operate

- Point-to-multipoint architecture
- Unpowered fiber-optic splitters enable a single optical fiber to serve multiple end-points
- Consists of an optical line terminal (OLT) in the central office and optical network units (ONUs) or optical network terminals (ONTs) at the end user location
- Compared to point-to-point architectures, PON reduces the amount of fiber and central office equipment required

A closer look at PONs

Two major standards groups—the Institute of Electrical and Electronics Engineers (IEEE) and the Telecommunication Standardization Sector of the International Telecommunication Union (ITU-T)—have been at the forefront of standards development.

There are several types of commonly used PON technologies:

GPON (Gigabit PON)

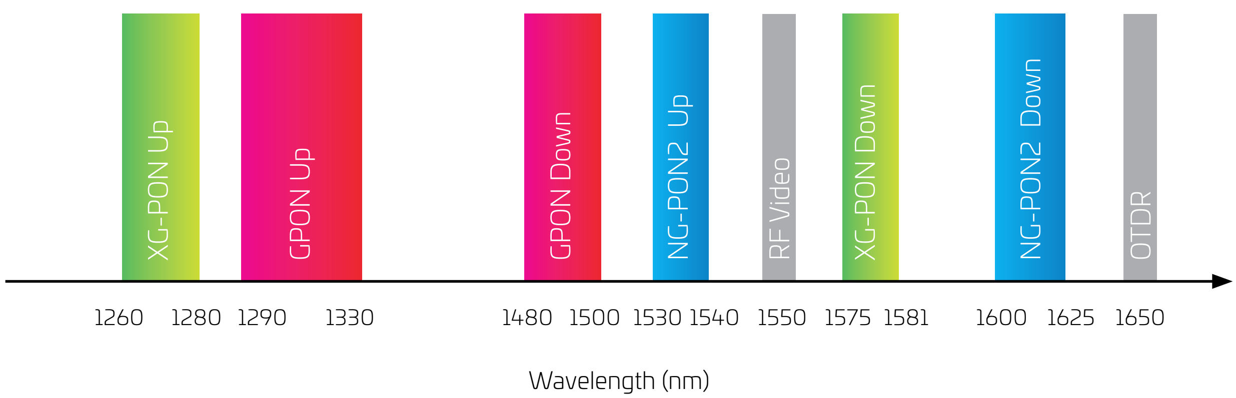
- IP-based protocol, used in most deployments and accommodates today and tomorrow's demanding applications globally
- 2.488 Gbps downstream and 1.244 Gbps upstream
- Mostly single fiber, although the standard is specified as both a single and multi-fiber system
- 10G PON—also called XG-PON, and based on the ITU-T G.987 standard—is designed to coexist with GPON devices on the same network

XGS-PON

- 10 Gbps symmetrical—an improvement from previous generations of XG-PON that offered only 10 Gbps downstream
- Symmetrical bandwidth is ideal for today's business services and mobile backhaul
- Delivers four times the upstream speed of current XG-PON1 technology
- Relatively easy to scale up existing fiber networks in response to demand
- Less costly symmetrical service compared to other PON upgrade paths
- Can co-exist with current generation GPON technology

NG-PON2

- 40 Gbps symmetrical—possibly 80 Gbps in future
- Extremely high bandwidth, multiple wavelengths and software-defined networking allow NG-PON2 to use a single fiber for different purposes
- Hybrid with time and wavelength division multiplexing approach
- NG-PON2 and GPON can share the optical distribution network (ODN), benefiting operators who combine business and residential services
- Optics that can dynamically tune to a provisioned wavelength ("channel bonding") enable a wide range of business, consumer and wireless-wireline services at relatively low operating costs



NG-PON2 spectrum
Source: Rec. ITU-T G.982.2 (12/2014)

A closer look at PONs

.... continued

WDM PON
(wavelength division multiplexed PON)

- Nonstandard type of PON, developed by specific companies
- 10 Gbps symmetrical
- Each wavelength can run at a different speed and protocol so there is an easy pay-as-you-grow upgrade
- Converges wireless and wired services for distribution
- Reuse of existing FTTH infrastructure may be limited
- Temperature control is a challenge because of how wavelengths tend to drift with environmental temperatures

GEPON
(Gigabit Ethernet passive optical network)

- 1-10 Gbps symmetrical
- Uses native Ethernet protocols and components, bringing economies of scale
- Highly scalable and flexible, with a cost-effective single management system
- Can realize very dense networks and serve thousands of subscribers
- Integrated support for Triple Play (internet, television and telephone), QoS (quality of service), IPTV (internet protocol television) and VoIP (voice over IP)
- Less costly than previous GPON equipment
- 10G EPON symmetrical supports 10G downstream and upstream.
- 10G EPON asymmetrical supports 10G downstream and 1G upstream.

Fiber deep networks

More fiber in the network gives cable and broadband operators additional bandwidth along with other important benefits such as lower operational costs, energy use and carbon footprint. Fiber deep networks use a fiber to a point in the network and then transition onto either coaxial or twisted pair copper cables. Over time these transition points have moved closer to the customers. However, the migration path from hybrid fiber coaxial (HFC) or copper infrastructure to all-fiber needs to be carefully evaluated, looking at both pros and cons, short and long term. Today's network technologies provide several options.

DSL
(digital subscriber line)

- The newest DSL protocol, G.fast—which stands for "fast access to subscriber terminals"—is being deployed in brownfield MDU environments to minimize disruption to residents
- Increases connection speeds on existing twisted copper pair lines by using higher frequencies and time division multiplexing as opposed to ADSL and VDSL technology, which use frequency multiplexing
- Active equipment located close to the customers' premises
- Less effective if distances exceed 100-500 meters
- Additional splice closures and terminals required

DOCSIS®
(data over cable service interface specification)

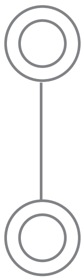
- Practical option in the absence of fiber connections to buildings
- First developed in 1997, the standard is currently at DOCSIS® 3.1 and has evolved to support higher internet speeds using existing coaxial cables
- Evolving full-duplex DOCSIS® 3.1 promises 10G symmetrical data rates

Main PON topologies and architectures

Architecture drives costs in FTTH networks, and there are different types to choose from: point-to-point, centralized split versus distributed split, star versus daisy-chain, and all-spliced versus preterminated connectivity. A typical PON covers an area of 20 kilometers in length.

Let's look at the benefits of different approaches.

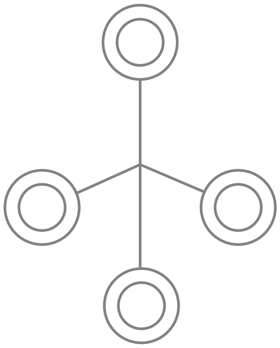
Point-to-point network



In a point-to-point network, nodes are directly connected with a single connection line. No additional functioning nodes are required and there is no redundancy, but this is a cost-effective and reliable solution. This approach is typically utilized for business-grade services or backhaul for converged networks. Bandwidth isn't shared, so each port on a premise offers uninterrupted high speeds. Installation, maintenance and repairs are relatively easy. However, there is no option for branching out and adding more connections. Rollout can take longer and be more costly—and the approach is less than ideal for rural regions.

Point-to-multipoint network

The following network types of FTTH access networks are all point-to-multipoint. The optical splitter used in PON-based point-to-multipoint networks can be placed at different locations in the network.



1 Centralized splitting architecture
2 Distributed split (cascaded) architecture
3 Daisy-chain architecture
4 Star architecture
5 Optical fiber tapping
6 Fiber indexing

1 Centralized splitting architecture

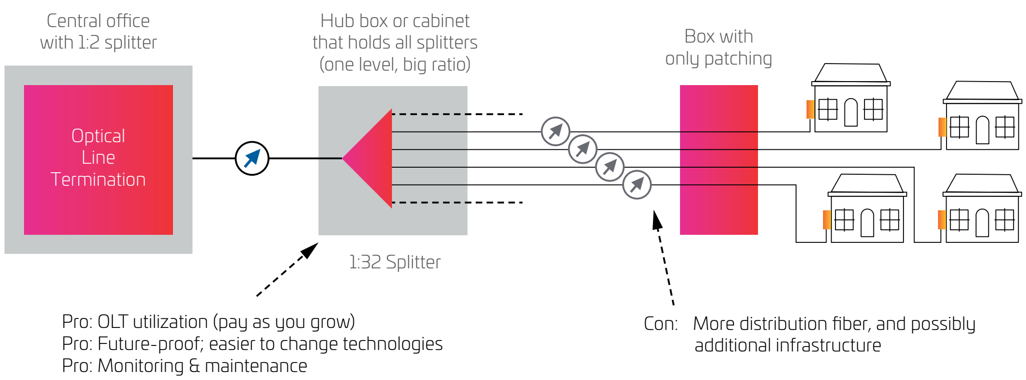
The centralized approach uses single-stage splitters in a central hub in a star or daisy-chain topology. This provides optimal flexibility in management of subscriber connections and utility of connected equipment—and the advantage of having an easily accessed testing point. However, it requires a "fiber rich" network from the splitter location to the premises.

Centralized splitting architecture has been used extensively to reach subscribers in initial FTTH deployments. This approach typically uses multiple 1x32 splitters located in a fiber distribution hub (FDH), which may be located anywhere in the network. The 1x32 splitter is directly connected via a single fiber to a GPON optical line terminal (OLT) in the central office. On the other side of the splitter, 32 fibers are routed through distribution panels, splice ports, and/or access point connectors to 32 customers' homes.

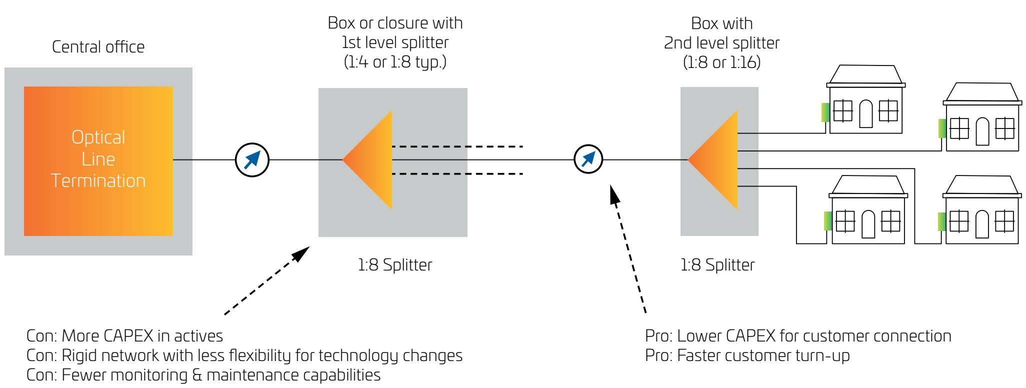
Here, they are connected to an optical network terminal. In this way, the centralized PON architecture connects one OLT port up to 32 ONTs.

Cross-connection capability in the FDH makes it possible to connect any outlet port from the splitter to a port in the patch panel, which can bring savings on labor and material costs. Centralized splitting also introduces a physical location at the center of the optical distribution network, which can conveniently be used for testing. However, in areas with lower uptake rates, building on a per-home basis becomes more costly. To reduce costs and speed up deployments, alternatives need to be considered. Preterminated connectivity is one way of reducing deployment time. The other key solution is using distributed splitting.

CENTRALIZED architecture



CASCADED architecture



2 Distributed split (cascaded) architecture

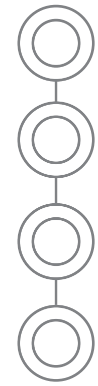
A cascaded architecture utilizes multiple splitters in series to achieve the overall desired split ratio. For example: a 1x4 splitter residing in an outside plant enclosure is directly connected to an OLT port in the central office. Each of the four fibers leaving this Stage 1 splitter is routed to an access terminal that houses a 1x8, Stage 2 splitter.

In this scenario, a total of 32 fibers (4x8) would reach 32 homes. It is possible to have more than two splitting stages in a cascaded system, and the overall split ratio may vary (1x16 = 4x4; 1x32 = 4x8 or 8x4; 1x64 = 4x4x4).

This approach reduces the amount of fiber in the distribution area by moving part of the splitting process to the access point where the subscriber drops are connected. There is, however, a trade-off: a cascaded PON network typically has poorer OLT port utilization than a centralized split architecture. Cascaded architectures are also highly dependent on the "take up rate" and the number of customers being fed from the PON.

Research shows that FDH capacity can be reduced by 75 percent, allowing smaller cabinets, easier placement, and the prospect of moving from a cabinet to a splice closure. The distribution fibers required have been reduced by 75 percent as well, lowering CapEx for cables, splice closures and splicing labor. The access point now includes a splitter, so a modest change here permits significant savings in the entire approach.

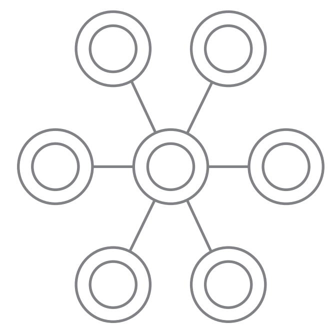
3 Daisy-chain architecture



Daisy chaining can speed up deployments. A multifiber cable—connected through a cascade of fiber access terminals—results in more efficient cable use and labor deployment. However, this approach may require more splicing than a star architecture (see below) as well as special splicing skills. Splicing labor is a key cost factor in FTTH deployments.

In a daisy-chained topology, fiber cable is run through the streets and a hardened terminal is spliced onto the cable at each access point. This design forces compromises in deployment time while increasing costs owing to the need for expensive, specialized splicing labor. Splicing costs for centralized splitting—whether star or daisy-chain architecture—will be generally higher than for distributed splitting, as the splitting outputs are factory terminated. The number of fibers to be spliced at each location is higher (one fiber per subscriber); whereas, in a distributed split network, this ratio can be reduced by mounting factory-terminated outputs to the splitters.

4 Star architecture



A star architecture pulls cables back to a central location using preterminated cabling. This makes it very efficient from a splicing perspective, as splicing takes place at the hub. However, it uses about 35 to 45 percent more cable than daisy-chained architectures—and there can be more part numbers due to different cable lengths. While cable is often viewed as a relatively inexpensive part of the overall cost of an FTTH network, the extra cable required in the star configuration carries additional labor costs for deployment as well as physical space requirements, which can be particularly problematic with ducts or pole mounting.

Star architecture can use a multiport service terminal (MST), a component of preterminated connectivity lines. Dropped fibers don’t need to be spliced at the distribution point. Each terminal tail is brought back to a splice location—hence the name “star.” When used with centralized split, each cable going between the MST and splice case will have one fiber per terminal port.

With distributed split, a single fiber between the terminal and splice case is used, and the terminal incorporates a 1x4 or 1x8 splitter. Distributed split architectures use about the same amount of cable as centralized, but the fiber counts are a fraction, as are, consequently, the splicing costs.

5 Optical fiber tapping

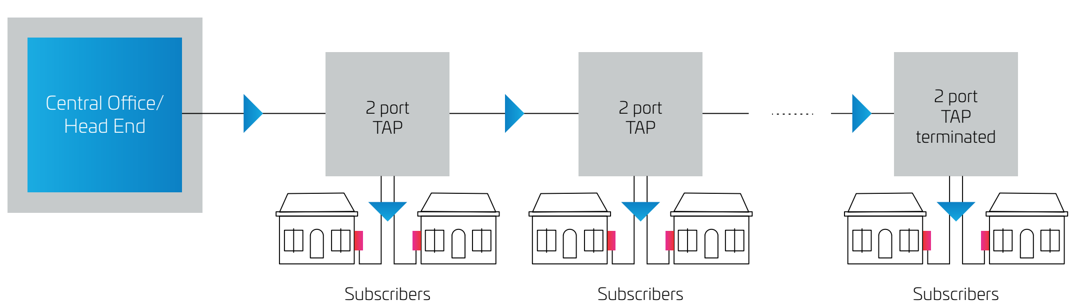
Distributed tap architecture uses fiber-optic taps, instead of splitters, in a linear topology.

Imagine taking the fiber in a fiber-optic cable, cutting it in the middle, and splicing a tap in between. The optical signal passes through the tap and continues down the fiber, while the tap “drops off” a portion of the signal for locally connected subscribers. In this way, the typical PON reach—usually a 20-kilometer radius from the OLT—can be extended. Tap architecture is extremely useful in rural-type applications where housing density is low and distances are typically long.

Multiple taps can be placed down the line until the optical link budget is exhausted or the maximum number of subscribers per OLT port (typically 32, though 64 or more are supported) has been reached. The final “terminating” tap in the chain has no output fiber.

Taps are available in two-port, four-port, and eight-port models, depending on the number of drop ports required. For each model, different tap values (ranging from -4 dB to -21 dB) are available depending on how much optical power should be dropped off at each location. Drop ports from the tap are preconnectorized to facilitate easy connection and disconnection of the customer drop cable.

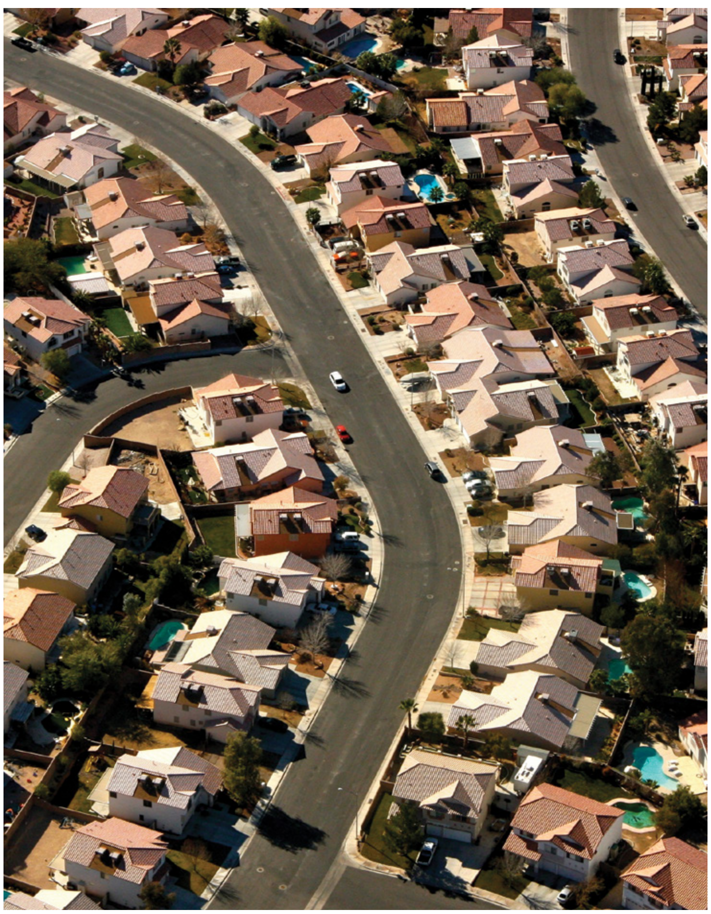
OPTICAL FIBER TAPPING



6 Fiber indexing

Fiber indexing uses connectorized cables and terminals, and enables installers to use a cookie-cutter approach to build out the network. A reduced set of cable lengths is daisy chained together, limiting the need for custom cable assemblies or splicing. The basic building block, which is repeated throughout the service area, could be a 150-foot length of cable (for most terminal locations), a terminal with a built-in splitter, preterminated 12-fiber inputs and outputs, and four or eight drops to the homes.

Fiber indexing has the potential to reduce construction and civil works costs in the distribution network by up to 70 percent and, in the process, significantly both reduce deployment times and speed time to market. One key saving lies in the reduced length of cable needed, made possible by changing the network topology and consolidating the functions of multiple network elements into the service terminal. The other savings come from reducing splicing labor, minimizing site surveys, and reducing inventory management costs.



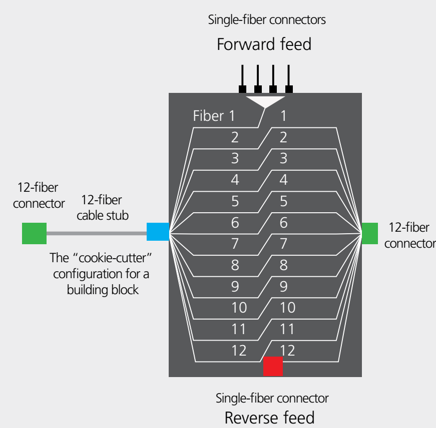
Signals from the fiber distribution hub usually travel from the first terminal to the last. However, connecting a second cable to the end terminal allows the signal to feed back to the first terminal. This "reverse feed" allows operators to connect to the subscriber's drop cables or deliver other services at that terminal location, making it possible to respond to new service demands almost instantly.

Fiber indexing

Fiber indexing is the shifting of a fiber's position from one multifiber connector to another, within each terminal.

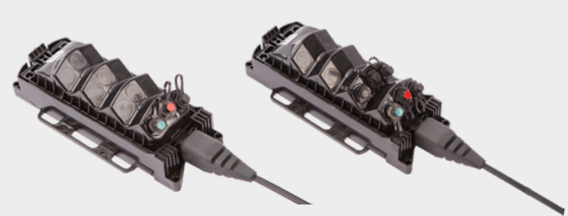
1 The process begins with a 12-fiber cable from the fiber distribution hub (FDH) entering the first index terminal.

2 Inside the terminal, the fibers divide and the signal from the fiber in the first position is routed to a 1:4 or 1:8 splitter for servicing local customers.



3 The remaining fibers are "indexed"—advanced one position in the order—then combined using a 12-fiber HFMOC.

4 The exiting 12-fiber hardened cable connects to the next terminal where the indexing process is repeated.



Want to learn more about Fiber indexing? WATCH VIDEO

Global and regional trends

General observations and trends

As today's network technologies advance, operators can choose among different strategies and approaches for bringing fiber deeper into their network. Overall, we are seeing a shift toward designed-in flexibility and reliability.

Network flexibility is increasingly critical, as operators must be able to respond to fast-changing demands and service requirements. How easily can the plant be upgraded from 1G to 10G and beyond, for example?

Given ever-growing demand to both increase fiber capacity and reduce future civil works costs, more fiber is installed in the network than currently required to accommodate future needs. The amount of excess fiber and its location in the network depend on local regulations and competition. However, besides reducing civil works costs, this approach provides faster connectivity, at times—key to winning new customers.

With today's reliance on ubiquitous connectivity, ultra-high network reliability is no longer a nice-to-have but it is designed in from the ground up.

Typically, we would see customers such as banks, stock exchanges or business parks wanting to operate more than one line and have two separate lines—"main" and "stand-by"—to ensure business continuity. If the main line stops functioning, all traffic is re-routed via the stand-by line, without interruption. However, because of the need for more security—such as required by driverless cars—the use of two lines becomes increasingly important and we anticipate two lines to be pushed further into the network.

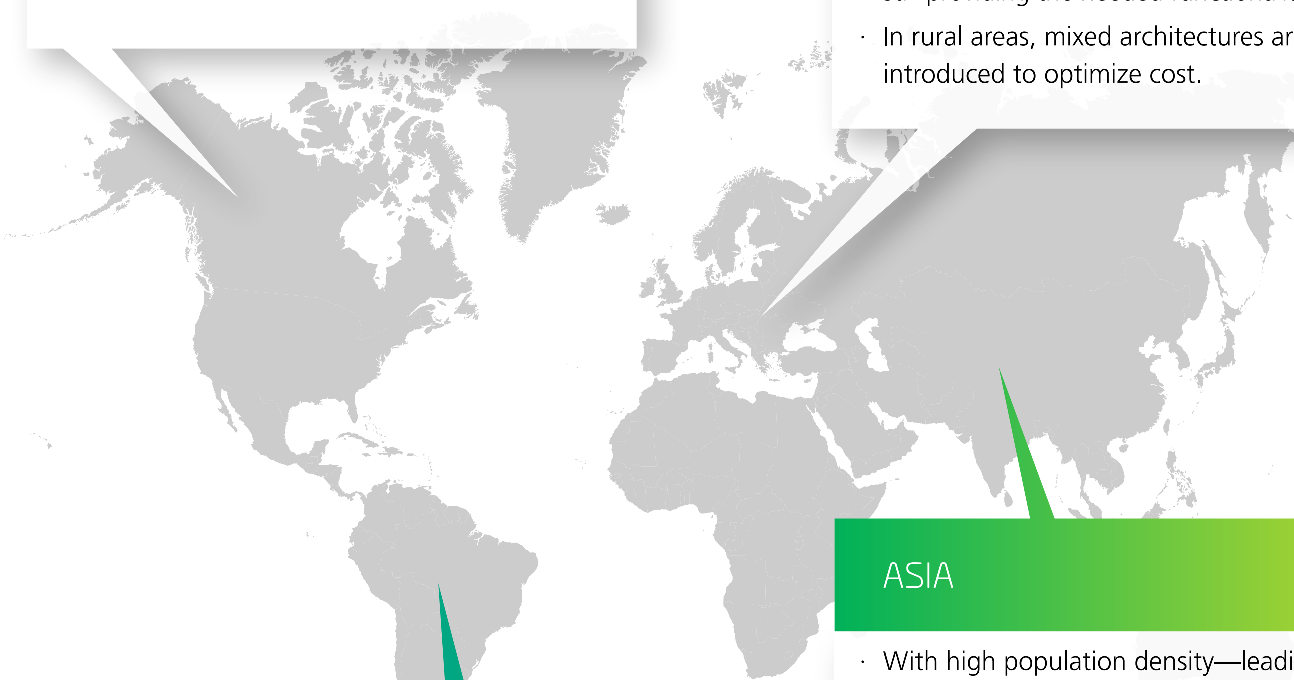
Regional trends and developments

NORTH AMERICA

- Centralized splitting is more commonly used in the US, because of the optimized use of optical equipment in the central office.
- There is high adoption of plug-and-play installation using hardened connectivity, given increased labor rates and shortages.
- Optical tap architecture is becoming popular in applications where housing density is low and distances are typically long, such as rural areas.

EUROPE

- In response to regulations stipulating that multiple service providers are to be given shared access to the network, some operators are installing multiple fibers per customer so that they can maintain a dedicated plant for their operations. Another trend is common interface locations where the customer can be handed off between different networks.
- There is a new trend toward using preterminated fibers to increase deployment speed and reduce provisioning time.
- In urban areas, permitting is becoming increasingly challenging, with operators looking for options to minimize the visual impact while still providing the needed functionality.
- In rural areas, mixed architectures are being introduced to optimize cost.



CENTRAL AND LATIN AMERICA

- Overall, FTTH is the main technology presently deployed in the region, with GPON being the most popular type of network.
- Aerial deployments in distributed architectures and two-level split are becoming more common, leveraging the benefit of lower cost and faster implementation.
- There are new public initiatives, but private operators are leading by far.

ASIA

- With high population density—leading to high congestion on a pole or within the underground infrastructure—cascaded PON networks are more common, with multiple Stage 1 splitters located within a cabinet-type solution to provide a degree of flexibility and the Stage 2 splitter then offering a direct connection to the premises.
- Particularly within metro areas—where MDU living is extremely popular—both centralized and distributed PON are applicable. However, considerations about the ability to access the fibers at floor level and the take-up rate within the building will determine whether a star or daisy-chain network is more applicable.

The CommScope approach

Case study:
National utility goes broadband

A previously-built network can be expanded in different ways—each bringing different benefits and challenges. The considerations and tradeoffs are demonstrated in the following case study.

A utility rolling out broadband faced planning challenges and budget spikes. How did they bring project execution and cost levels back on track?

Download Case Study

A European electrical utility decided to build an open-access FTTH infrastructure offering high-speed internet access to homes and businesses across the country. The network could be leased to partners who would offer subscribers retail internet and other services. The first deployment phase covered about half a million premises.

The utility had an extensive electrical grid infrastructure, rights of way, experience with outside plant deployments, and a fiber backbone supporting leased fiber services. However, FTTH was a new technology. CommScope identified several unique challenges related to building FTTH on top of a live electrical distribution system. Grid maps were sometimes out of date. Rainfall and the propensity for flooding also meant equipment had to be well sealed. Service disruption needed to be minimized and the safety of installers working close to high-voltage equipment needed to be ensured. The scope of these issues pushed installation costs well above budgetary estimates.

Economical solutions were needed that would match the existing grid infrastructure while also accommodating maximum flexibility and growth. CommScope conducted detailed field surveys to optimize the network architecture and product selection. Several smaller cabinets were replaced with closures and splitters. The use of preterminated connectivity products was increased, minimizing the need for training and increasing the deployment speed.

A network redesign, optimized product set, and a focus on labor savings helped bring the project back on budget and—by the end of the year—service had been rolled out to seven cities across the country.

CHAPTER 3 SUMMARY

The importance of choosing wisely

Network architectures are chosen early in the planning process, providing lasting impact.

Key decisions include:

- Active or passive optical networks? This is determined largely by factors such as distances and equipment budget.
- What technology is most suitable: GPON, GEPON, WDM PON, XGS PON, NGPON2, DOCSIS®, DSL...? This depends on distance, bandwidth, symmetry and scalability requirements, fiber availability at different locations in the network, take-up rates, and user types.
- Which types of architecture? There's point-to-point versus multipoint, centralized versus distributed split, star versus daisy-chain, and all-spliced versus preterminated connectivity. Choices are related to network size, intended usage, budget and flexibility requirements.
- Finally, network architectures in each region may vary significantly depending on, for example, short-term or long-term intended use, local legislation and best practices.

To avoid costly oversights and errors, it is critical to define requirements, determine budgets, and consider other factors before deciding on specifications. Decisions made in one area will affect several other areas. When in doubt, ***ask the experts!***

CHAPTER 4

How to make an FTTX business plan work

How to make an FTTX business plan work

Why this chapter?

When it comes to networks, the planning horizon can easily be as long as 20 or 30 years—which means every choice made at the outset has long-term implications. Today, on the cusp of a whole new era in innovation, requirements and technologies are quickly evolving—bringing along much higher complexities in business planning.

CommScope's experts have spent thousands of hours over more than four decades supporting customers in designing, building and maintaining their networks in regions around the world. In this chapter, we are sharing these insights with you.

The scope of this chapter covers:

- Essential elements of a business plan
- Industry and market trends that can impact business plans
- Practical tips - with insights and new perspectives

1 Revenue - traditional and new revenue sources and customers

Traditionally, operators have derived revenues from telephone, internet and video services, serving residential, business, government and wireless customers. Today, an increasing number of larger and smaller communications providers are expanding their revenue sources to better serve their customers' new needs for always-on connectivity.

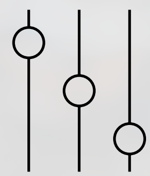
A 2017 global survey of service providers showed that monetizing high-speed broadband is key to a successful business strategy.

New revenue streams

Premium content packages may be developed with content partners, based on target audience interests. "Content convergence" is bringing a wave of mergers and acquisitions between telcos and media companies as well as the development of TV sport rights acquisition strategies

Differentiation strategies

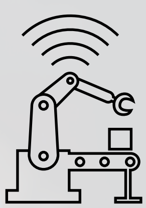
Customized services can be offered to target customer groups (for example, gamers) who are willing to pay for very high-performance symmetry, latency and uptime.



Innovation

Telematics:
A combination of telecoms, transport services and IoT is bringing new service opportunities to fleet management, supply chain logistics and other transport and traffic-related areas.

Fourth Industrial Revolution and IoT:
Connective technologies such as IoT, robotics, artificial intelligence (AI), virtual and augmented reality, and 3D printing require vast bandwidth and data analysis capacities and an unprecedented degree of interconnectivity and convergence.



Being at the forefront of innovation—and developing solutions to serve the needs of these customers—will not just bring new revenue streams but will position companies to be the first to reap the benefits of learning and developing the ecosystem.

Revenue - practical tips

A

Define a clear network revenue objective

The business case and calculations are worked out once the revenue objectives are determined. The outcome may vary depending on network choice. Will you be building a residential-service-only model? A residential-plus-business network? A business-plus-wholesale network?

B

Prepare realistic expectations around take rates

Getting to a realistic assessment of connections in residential or business projects is critical. What penetration and take-up can you really get in a certain market? What happens if you pass 100 homes but only 30 want your services? Predictions of penetration rates that are overly optimistic or too cautious are equally problematic. In Latin America, for example, people can generally choose from multiple operators—none of whom might expect more than 25 percent market share. But, if an operator's solution maxes out at 25 percent of homes passed, they can't easily scale up if higher demand is created, which could mean either making sizeable new investments or turning customers away.

C

Consider a multipurpose vs. separate networks

Networks have typically been "single purpose," designed to provide residential services, business services, or wireless backhaul, for example. Largely, these functions influence business and cost decisions. Previously-separated functionalities are now coming together—making it possible for infrastructure to perform multiple tasks.

CONVERGENCE: THE MERGING OF WIRELESS AND WIRELINE

Converged networks range from shared assets to fully integrated systems

Convergence of network infrastructure

- Leverage locations
  (Co-location)
- Leverage media
  (Power, Fiber)
- Plan and build simultaneously
  (Labor)

Convergence of platforms

- Applications run on COTS
  (Commercial off the Shelf Solution)
- Common hardware for SDN/NFV
- Similar processes

Full convergence: Hardware, Software & Physical network

- Network functions converge
  (all IP)
- Common credentials and politics
- Containerization

Service offerings:

Home

Work

On-the-go

Customers:

Humans

Machines

2 Costs

Typically, communications providers have viewed costs exclusively through CapEx (cost of deployment, materials and installation—actives and passives) and OpEx (cost of network maintenance, leasing and franchising, along with cost of sourcing and licensing content or developing services).

In today's ever-increasing competitive environment, operators are realizing that cost models shouldn't focus just on getting the network in place and passing homes or businesses, but that cost models should also factor in the cost and speed of making individual connections. The costs of offering services, equipment, labor, permissions, maintenance and power also need to be considered.

When developing a business model, it is important to look beyond comparing individual cost elements such as materials and installation, but instead consider total cost of ownership (TCO). At first glance, it might make sense to minimize CapEx when making a buy decision; however, not considering the potentially high cost of operating and upgrading the network (OpEx) can negatively impact the profitability of the overall operation. We see that successful organizations are those in which internal budgeting and other factors influencing the overall outcome are well aligned and optimized for the future network lifecycle.

Practical tips

A

Assess opportunity cost

The opportunity cost is the loss of potential gain from other alternatives when one alternative is chosen. For example, delays in obtaining "right of way" permits negatively impact the time to revenue. Therefore, choosing a solution that minimizes the time to revenue will have positive impact on the overall bottom line even though it might be a higher first cost alternative.

B

Evaluate deferred costs options

(Partially) deferring CapEx can be highly beneficial—especially when dealing with business uncertainties and CapEx pressure. Choosing a network architecture and solutions that allow the flexibility to build up the network as demand and revenue become available provides a huge benefit to operators.

C

Calculate power consumption

Power consumption is an often-overlooked cost factor. This is not an issue in a fully passive network, but it is when you introduce a relatively large amount of active equipment. Having a full assessment of the power consumption can help make smart decisions upfront.

D

Assess network security

Security is an increasing concern, with impact on network access and with potentially massive negative impact on revenue and customer retention. Furthermore, in countries such as the United States, legislative challenges across different areas can also impact network technology choices, as certain decisions must comply with governmental security concerns—especially where operators are applying for or have received government funding.

E

Evaluate cost of poor quality

The 2017 global survey of worldwide service providers showed that, across the board, customer satisfaction and retention were key business priorities. As there is significant competition in the market today, offering customers speed, service, and a service package is crucial to success and priorities at the very highest level.

3 Funding

Fiber networks can be attractive to public-market and private-equity investors alike. Several fiber operators around the world have been fully funded through **private equity.**

In addition, **federal and local government funding** plays a very important role in stimulating development of network infrastructure, tightly connected to GDP growth (see Chapter 1). Furthermore, today, we see an increasing number of fast-developing countries and regions following suit with the developed economies—and providing federal funding support.

The requirements for each program are very specific—and some programs depend upon the agency's focus over the planning period. For example, CAF II (the "Connect America Fund" in the U.S.) aims to accelerate broadband build-out to those lacking access to 10 Mbps download fixed broadband. In Europe, the Digital Single Market strategy announced by the European Commission in May 2015 will largely replace the Digital Agenda as the EU's main digital strategy for 2015 and beyond. This strategy includes 16 new initiatives—of which, one is an ambitious overhaul of EU telecommunications rules, including creating incentives for investing in high-speed broadband and particularly in rural areas where the population density may not be great enough to justify deployment costs.

Emerging **public-private partnership (P3)** models present a promising alternative to the traditional "municipal broadband" models for the many communities that lack the capital or expertise to deploy and operate fiber networks, or to act as internet service providers (ISPs) on their own. Depending on state law, local governments have many tools they can use to finance a project and/or stimulate private investment. By taking on the risk of fiber construction and finding a partner to light the network and provide service, a locality can increase the potential for a universal fiber buildout to every location.

Public-private broadband partnership projects are complicated, as they necessarily involve at least two parties that come from different worlds and have different missions, goals, skill sets, and legal and political obligations.

A public utility may partially transfer ownership of an asset to a private company, or an authority might apply for an equity stake in a private venture. In the case of full divestiture (privatization), government interests in a public asset or a sector are (almost) entirely transferred to private parties.

Promising to bring broadband to 100 percent of Australian premises with a common service cost regardless of technology utilized, National Broadband Network (NBN) is a prime example of a public-private partnership. Government built, owned and operated, it provides wholesale open-access broadband on equal terms to all retail service providers (RSPs). NBN does not sell directly to the public but is one link in the value chain providing connectivity from the content provider to the end user. RSPs have access to premises via access virtual circuits and purchaseconnectivity virtual circuits based on their own internal strategies.

We believe this model has advantages—specifically as it gives the ability to split the risk of the overall network business model for easier financing and offers future potential implementation in other countries and regions.

	MODEL 1 public facilitation private investment	MODEL 2 public funding private execution	MODEL 3 shared investment and risk
RISK	LOW	HIGH	MODERATE
BENEFIT	POTENTIAL BUT NOT ASSURED	HIGH	HIGH
CONTROL	NONE	MODERATE	MODERATE

Trade-offs between risk, benefit, and control in public-private partnership models

Although the number of broadband public-private partnerships is still fairly limited in the U.S., Google Fiber has, through its deployments to date, alerted other companies to the business opportunity in building and operating local broadband networks—and the number of potential investors and partners is increasing.

4 Analysis

Once revenue and costs are fully evaluated, business indicators such as ROI (return on investment), cash flow and NPV (net present value) are used to assess the attractiveness of the business investment. Today, operators are adjusting business plans to shorten payback time to better align with the nature of projects.

Practical tips

A

Run ROI for different network architectures

In Chapter 3, we looked at a number of network architectures, each with its pros and cons. We recommend assessing the business ROI using two or three different architectures as the results can be very different. Furthermore, this analysis can uncover various ways to optimize the business case (e.g., fastest deployment preferred in a very competitive environment).

B

Complete a thorough sensitivity analysis

A sensitivity analysis maps uncertainties to specific sources in the business model. This helps stakeholders see potential impact of real-life situations that may occur during the implementation phase and prepare contingency plans. What happens if a certain segment doesn't meet its revenue targets? How will that affect the rest of the project? How might other areas compensate? While real-life uncertainties cannot be fully eliminated, a thorough full sensitivity analysis prepares one for a successful future.

The CommScope approach

What's right for the customer?

In every region, we listen to clients and figure out what they actually need. As we have a presence all around the globe, we can collect, exchange and leverage knowledge for easier decision making. Plus, because we offer a wide range of passive solutions, we can work closely with customers—explaining the pros and cons in relation to their needs and parameters they have to observe.

As we offer such a broad portfolio of networking products, we can be more objective—providing a solution that is genuinely better for the customer, whether based around fiber, DSL or coaxial. Nobody knows what developments the coming years will bring, or how these may directly or indirectly affect networks. Because we work across so many different areas, we get to see a very wide range of technology developments and have a good idea of where networks are heading in general. We can't predict the "next big thing" after 5G, cloud or IoT, but we can offer advice on preparing your network for the future—another cost factor, but essential to the business plan. We can help people understand what they can do to prepare for upcoming requirements and build in flexibility, specifically for their chosen architecture, in a cost-effective way.

CHAPTER 4 SUMMARY

Network planning horizons can span decades. Choices made at the outset have serious long-term implications. A future-proof business plan takes several factors into account

- Traditional and innovative sources of revenue, clearly defining network objectives, researching take-up potential and choosing between single-use or multipurpose networks.
- Looking at overall TCO and balancing CapEx and OpEx in a smart, flexible way. The most successful organizations are those in which internal budgeting and other factors influencing the overall outcome are well aligned and optimized for the future network lifecycle. With regard to cost, opportunity costs, deferred costs, power consumption, security and cost of poor quality need to be taken into account.
- Different funding models should also be investigated, along with the various factors that determine which would be most appropriate for your rollout. Public-private broadband partnership projects can be advantageous.
- Finally, the business investment needs to be carefully analyzed. Carrying out a sensitivity analysis—mapping uncertainties to specific sources in the business model—is advisable as it better prepares organizations to respond to future uncertainties.

Contact CommScope's experts to discuss your upcoming requirements and see how we can help you realize the potential of your future network.

CommScope pushes the boundaries of communications technology with game-changing ideas and ground-breaking discoveries that spark profound human achievement. We collaborate with our customers and partners to design, create and build the world's most advanced networks. It is our passion and commitment to identify the next opportunity and realize a better tomorrow.

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