IDATE

GREEN ALL-FIBER NETWORK FACILITIES GIGABIT EXPERIENCE

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CONTENTS

Introduction

The outbreak of the pandemic has led to an inevitable surge in the use of digital technologies and placed broadband networks as a key enabler for various digital applications in home and enterprises, including teleconference, online education, 4K / 8K ultra-high-definition video, VR / AR games, cloud computing, etc. Meanwhile, the industry 4.0, focusing on digitalizing manufacturing to improve operation, generate a large amount of data for the decision making and other operations such as predictive maintenance.

Facing the rapid bandwidth demand and the strict network requirement of new services like 4k or HD videos, operators need to update their existing network infrastructure to meet our customer service requirements. Moreover, operators need to address various challenges with their existing network, such as insufficient capacity to support future growth, large equipment footprints and high-power consumptions, and low operation and maintenance efficiency.

Fiber-powered broadband solution can help address these problems through providing high speed, low latency connections with high reliability and energy efficiency. More operators have focused on fiber networks to support the continued increase in traffic.

According to IDATE, as of December 2021, there were 780 million FTTH/B subscribers worldwide and 1093 million FTTH/B home passed. FTTH promises connection speeds of up to 1000 Mb/s, 20 to 100 times faster than a typical cable modem or DSL connection. With the innovations of fiber technology, fiber connection will extend to everything everywhere, including rooms, enterprises, industry 4.0 and 5G backhaul.

This whitepaper provides an overview of all-fiber network and the recent development of fiber technologies. It also explains how innovations can help operators to support the sustainable development. The whitepaper contains five main parts:

- Part 1 provides an overview of current broadband market trends, covering data-heavy in-home applications, digital transformations of enterprises, and Industry 4.0;
- Part 2 presents the latest advancement of fiber technology, including ETSI's F5G fixed broadband framework, evolution of (N) GPON technologies and optical component innovations on transmission networks, such as OTN.
- Part 3 illustrates the use of fiber networks in different scenarios, such as fiber to the room, fiber to SMEs and fiber to industry to achieve Industry 4.0, as well as all-fiber work for fixed mobile convergence.
- Part 4 discusses how fiber networks contribute to the achievement of sustainable development by reducing energy consumption in fixed networks, as well as helping industries to reduce carbon emissions. The section also provides quantitative forecasts of CO2 emissions reductions by 2030.
- Part 5 is the conclusion of the whitepaper.

1. Current broadband market status

1.1. Increase of in-home gigabit broadband demand through new data-heavy applications

The outbreak of pandemic has led to an inevitable surge in the use of digital home technologies. People require high quality of internet connection to meet various bandwidth-hungry digital applications requirements, such as 4K / 8K ultra-high-definition video, VR / AR, cloud games, for entertainment activities. At the same time, remote working and online education have become commonplace, which require to access a plethora of online collaboration and productivity tools, including email, video meetings, and several cloud-based applications, from home.

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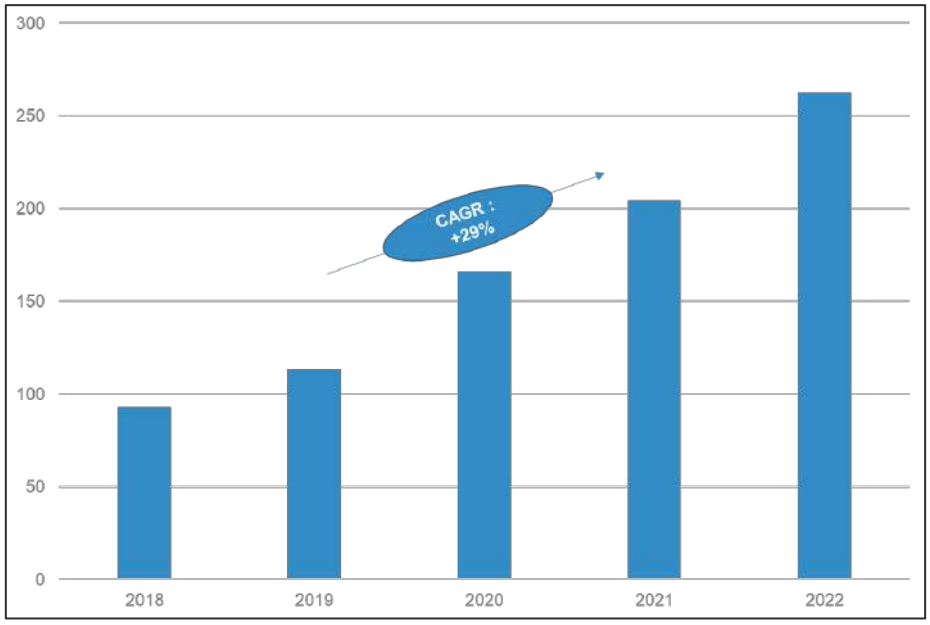
Since the outbreak of Covid 19, home broadband has experienced a surge in internet traffic. The average Internet traffic reached 226 Terabytes per second in 2022, increasing at a CAGR of 29%. Average traffic growth increased from 22% between 2018-2019 (before Covid-19) to 30% between 2021 – 2022 (post Covid-19), while peak traffic growth raised from 20% to 28% over the same period. Traffic growth can be attributed to a variety of Internet video services, such as video conferencing, online education, and telemedicine. At one of the biggest internet Exchange Points in Frankfurt, video conference traffic increased 120% and online and cloud gaming increased 30%.

Figure 1: Global International Internet Traffic (Terabytes per second)



Source: Telegeography

The experience quality of broadband networks has become more critical than ever. Although superfast broadband entertainment is sufficient for most household needs, the demand for services that use a lot of data, such as online video streaming, continues to increase even after the pandemic. COVID-19 has further highlighted the need for widely available and reliable digital connectivity. The pandemic fueled necessity of home office, homeschooling, and home entertainment which will continue to drive the need

not just for higher speeds, but also for lower latency and increased data volume consumption driven by increased use of video calls, cloud services, and media.

High-speed broadband is a major prerequisite for the enjoyment of high-quality entertainment content, access to companies' resources through clouds, and supports a variety of smart home devices. High-quality

entertainment content such as 4K/8K, online gaming, and VR/AR are gaining popularity at home. The outbreak of the pandemic accelerated the adoption of remote work. Smart home devices are also gaining traction globally.

Adding upstream capacity will be increasingly important as people use more high-bandwidth two-way communications-like video conferencing and upload more and more video to the cloud. Customer demand and expectations for higher peak bandwidth levels will also increase. Network interaction during busy times leads to congestion and longer queues, which results in higher latency and jitter.

1.2. The digital transformation of the industry continues to accelerate, and thousands of businesses require high quality broadband connection.

Businesses and vertical industries are increasingly relying on ultra-reliable low-latency networks to keep them to stay competitive and support future growth. From digital marketing to improved collaboration, high speed internet is the starting point for SMEs to embrace digital transformation. For vertical industries, along with the volume of Industrial Big Data is expanding exponentially, high-speed internet relies on the foundation of industry 4.0.

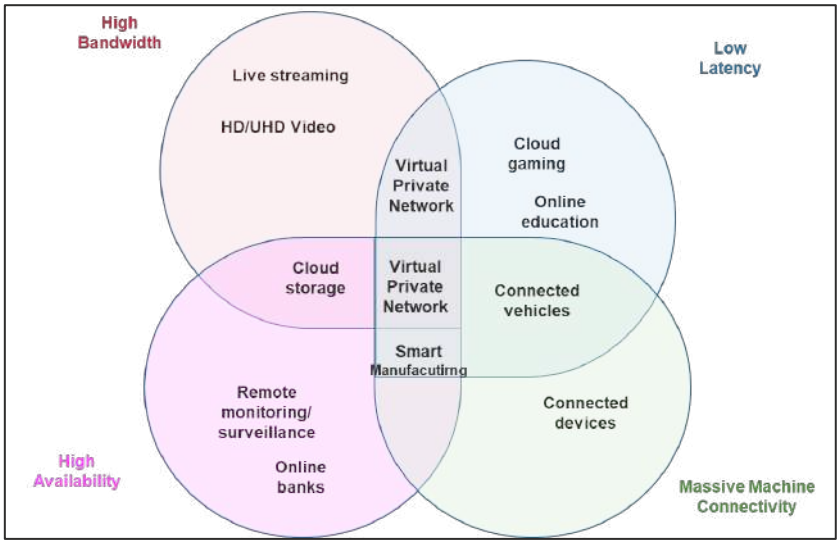
High-speed connectivity is the prerequisite for to embracing the digital transition and effective adopt digital technological future of companies. The pandemic accelerated the digitalization speed of Small and Medium Enterprises (SMEs). Business needs to leverage various digital tools, such as, cloud computing, e-commerce capabilities, and e-banking to promote effective collaboration, improve production efficiency and boost the revenue streams.

High-speed networks accelerate SMEs cloudification steps. As cloud connectivity has become increasingly important to businesses, Cloud-based services will drive this SME digital transition because they support a distributed workforce, improve efficiency, and provide business resiliency. Small businesses can benefit from cloud computing for easy access to data, automatic syncing, remote work facilitation and backups, without the need for on-premises management. Cloud computing provides this anywhere access via an internet connection. Moreover, some cloud-based band-hungry applications will continue to require greater download and upload speeds, as well as a higher level of service consistency. High-speed and reliable internet connectivity is essential for cloud computing architectures as bandwidth requirements increase, which will add significant value for SMEs.

Furthermore, high-speed networks enable to help SMEs generate more revenues. Many SME building their own web site or mobile application platforms to engage on e-commerce, increase their band recognition and booster their revenues. These digital sophistical digital platforms require high-speed Internet access for optimal customer experience**.** To meet and anticipate increasing demand, network capacity needs to be upgraded to meet the potential traffic growth.

For vertical industry players, high speed internet lay the foundation for the Fourth Industry Revolutions. smart manufacturing and industry 4.0 require cloud-based services and connectivity. Enhanced digital services require differentiated network capabilities. High-speed broadband connectivity can result more efficient business process and promote innovation, including the introduction of new products and services, as well as innovative business models. Moreover, high-speed connectivity with low latency will facilitate the collaboration across long-distance through collaboration tools, and it is essential for remote control some industry specific devices.

Figure 2: Enhanced digital services require high quality network



Source: Earlswood Marketing

Manufacturing: Industry 4.0 is highly dependent on data exchange. Smart manufacturing for Industry 4.0 relay cloud-based services and seamless and high reliable connectivity to collect data and connect different equipment. For instance, visual inspection for Quality Control requires a network connection with bandwidth more than 300 Mb/s and sub -millisecond level latency.

Healthcare: Data sharing of various healthcare information, include hospital records, medical records of patients, results of medical examinations, require large bandwidth and reliable connection. Moreover, the outbreak of Covid-19 has accelerated the adoption of telemedicine, which also requires high-performance network connectivity with low latency.

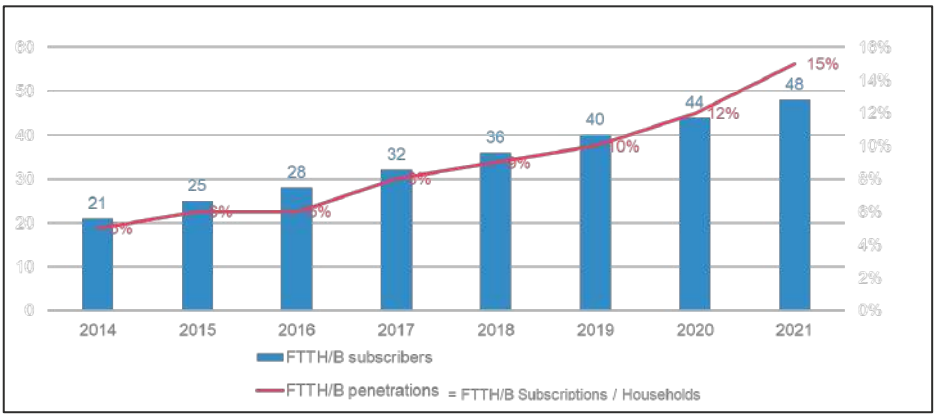
Online Education: Online classes require zero buffering and zero dropping to ensure the quality of education. Enhanced network connectivity will also enable to support more interactivity and hybrid models of online and in-person activities like augmented reality/virtual reality.

2. The evolution of fixed broadband technologies

Evolution of average EU network performance

Over the past decade, the European commission and its member countries support the development of fiber networks and full forward full-fiber strategies and allocate funds to speed up fiber network development. In recent years, incumbent operators have started to announce their copper switch-off dates and to implement the decommissioning of their legacy networks. Meanwhile, Fiber optic laying in homes in the European Union has tripled in the last five years, reaching 99 million subscribers and 118 million homes passed in 2021, according to FTTH Council Europe with data from IDATE.

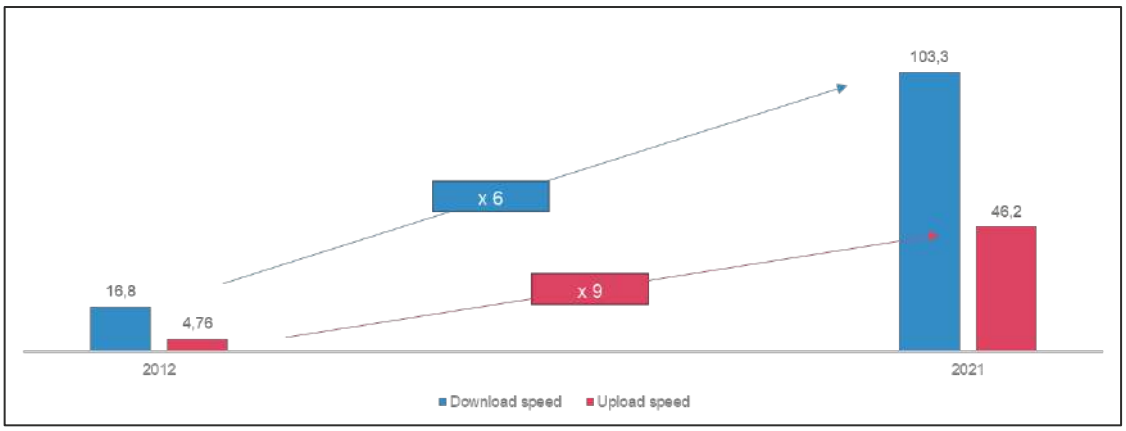
Figure 3: Europe FTTH subscribers (million) and FTTH/B penetration rate (%)



Source: IDATE, *World FTTx Markets – 2H 2021*

Average internet performance in Europe has improved dramatically over the past ten years. Average fixed line download speeds increased six-fold, from 16,8 Mb/s in 2012 to 103.3 Mb/s in June 2021, while upload speeds increased by 9 time, from 4,76 Mb/s to 46.2 Mb/s.

Figure 4: European countries' average internet speed (Mb/s)



Source: IDATE organized based on SpeedTest information

Since December 2019, the European Telecommunications Standards Institute (ETSI) established ISG F5G, the fifth-generation fixed network (F5G) Standard Industry Specification Group (ISG) with the vision of "Bring fiber to everything everywhere", to define fixed network generations based on typical applications and key enabling technologies from core networks to access networks, establishing the direction for future fixed network evolution. The establishment of the World Broadband Alliance (WBBA) at the end of 2021 marks a new beginning of F5G from standards to industrial applications. In September 2022, the F5G Advanced Standard white paper was released in ETSI to promote the continuous evolution of the F5G industry. The Standardization work for F5G Advanced has begun since 2022.

Fixed networks have evolved from F1G to F4G over the past decades. Thanks to the advancement of network technology, network communication speed has increased from 64 Kb/s in the F1G era to 100-500 Mb/s in the present day.

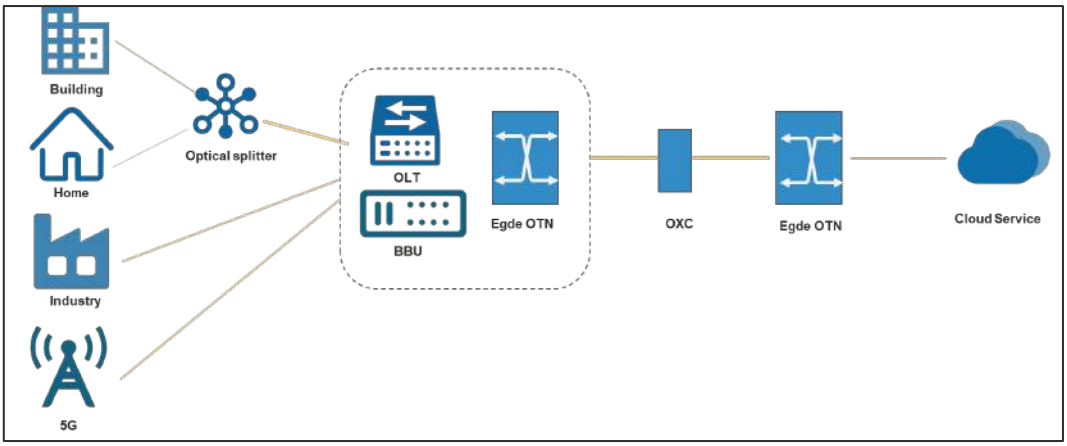
Figure 5: Fixed network génération

Fixed Network Generation	F1G	F2G	F3G	F4G	F5G
Reference Wave	Kilobits		Megabits		Gigabits
Reference Downstream Bandwidth per User	<2 Mbps	2-30 Mbps	30-100 Mbps	100-1000 Mbps	1-10 Gbps
Reference Upstream Bandwidth per User	<2 Mbps	1/2 Mbps	15-100 Mbps	50-500 Mbps	1-10 Gbps
Reference Services	Voice (PSTN/ISDN) Dial Internet	High Speed Internet (HSI) SD Video	HD Video	UHD 4K Video	VR Video Cloud Gaming Smart City
Reference Characterization	Narrowband (NB)	Basic Broadband (BBB)	Fast Broadband (FBB)	Ultra Fast Broadband (UFBB)	Gigabit Broadband (GBB)
Reference Architecture	CO LE	CO DSLAM	FTTC/FTTB	FTTH/FTTdp	FTTH/FTTR
Access Network Technology Reference	PSTN/ISDN	ADSL/ADSL2+	VDSL2	GPON/G.fast	10GPON
Technical Specifications Reference	I.100-I.699	G.992.x	G.993.x	G.984.x G.9701	G.987.x (XG-PON) G.9807.x (XGS-PON)
On-Premise Network Technology Reference	RJ11/RJ45	FE+ WiFi1/WiFi2 (802.11b/802.11a)	FE+ WiFi3 (802.11g)	FE/GE+WiFi4/WiFi5 (802.11n/802.11ac)	GE/10G+WiFi6 (802.11ax)
Radio Frequency (RF) Video over Fibre (LAN Coaxial) Reference	No	No	No	Yes	Yes
Specification Timeline Reference	1988-1993	1999 (ADSL) 2003 (ADSL2+)	2006	2006 (GPON) 2014 (G.fast)	2017
Production Timeline Reference	1990	2000	2007	2010-2012 (GPON) 2016 (G.fast)	2018

Source: ESTI, F5G Generation Definition Release #1

F5G introduces key technologies for the next generation of fixed networks, such as 10G PON, fiber to the room (FTTR), Wi-Fi 6, and 200G for optical transmission and optical cross-connect (OXC). Furthermore, ETSI has proposed a vision for the evolution of fixed networks towards "Fiber to Everywhere" and introduced the F5G concept, which outlines the future of fixed networks.

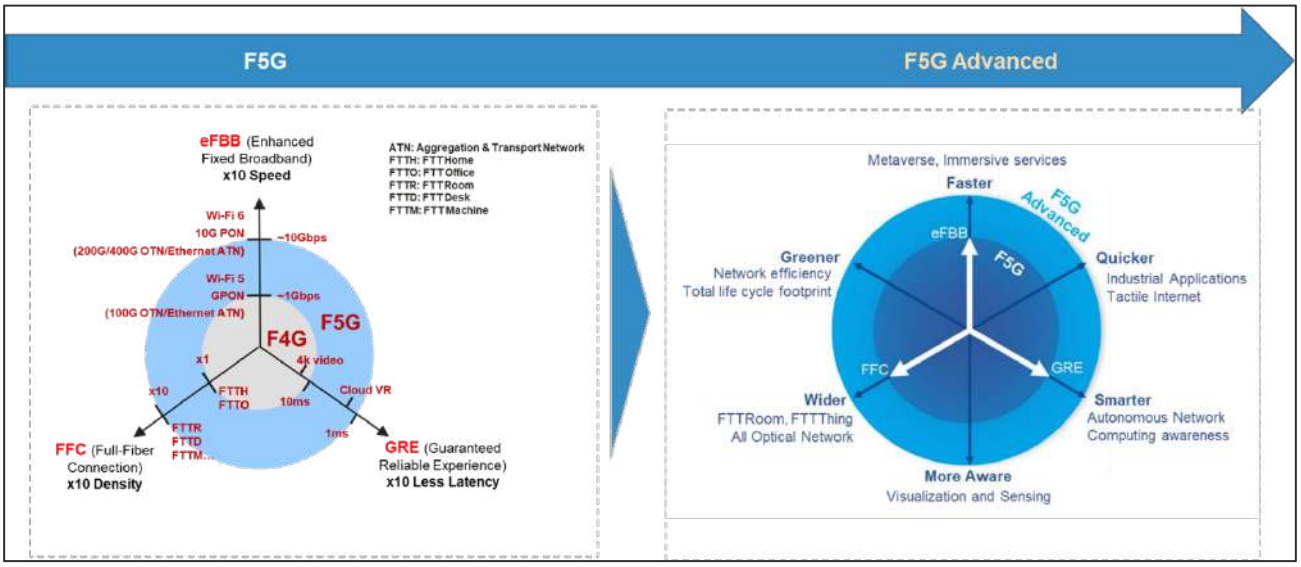
Figure 6: All-fiber network architecture



Source: IDATE, Green all-fiber network facilitates giga experience

The characteristics of an F5G network can be characterized by enhanced Fixed broadband (eFBB), Full Fiber Connection (FFC) and Guaranteed and Reliable Experience (GRE). The latest ETSI's F5G whitepaper "F5G Advanced and beyond" published by September 2022 describe the main applications and industries trends as drivers for the evolution from F5G to F5G Advanced. Compared to F5G, F5G Advanced will continue to improve fixed network performance with focus on optical fibers, OTN sites, and Wi-Fi spectrum.

Figure 7: The six dimensions of F5G Advanced



Source. ETSI, Fifth Generation Fixed Network (F5G) related white papers

F5G Advanced will leverage new technologies such as fiber to the terminal, latency control, energy efficiency, distributed computing networks, autonomous network, network-based sensing, and other network technologies to meet the demands of various application scenarios and enable network transformation.

2.1. Future PON technologies moving beyond 10G PON

During the last decade, the passive optical network (PON) has been the key enabler of fixed network optical access worldwide. PON system is an optical-fiber-based network architecture that can provide much higher bandwidth in the access network compared with traditional copper-based networks and allow the distribution of fiber optics to multiple users without the requirement of using active devices that need external power sources. PON can be used for different FTTx solutions, including fiber to the building (FTTB), fiber to the curb (FTTC), fiber to the door (FTTD), fiber to the home (FTTH). The futuristic applications include the fiber to the everything (FTTE) scenario.

The initial version of the GPON standard was released in 2004 by the ITU-U, and the technology has been deployed since 2009. In 2012, the first phase of the XG-PON standard was published and operators have begun to launch 10G PON since 2016 around the world, especially in Asia and USA. In 2020, the IEEE standard organization has first approved 25G/50G EPON standard. The ITU-T, a major standard organization begun to develop 50G PON technologies solution and standard since 2018.

Improved bandwidth powering the evolution from GPON to (N)GPON

The main driver for each PON technology upgrade has been bandwidth demand increase. New digital services, such as video services, gaming services, residential and professional cloud services, and new wireless technologies such as 5G or Wifi6 have been requiring faster transport and symmetric bandwidth.

The first-generation GPON technology, gradually replacing the existing copper cable access technology, can provide 100 Mb/s-capable bandwidths to users. 10G PON is the start of the second generation and has taken over GPON. 10G PON technologies are queued up to overtake GPON as the dominant PON

solution. Bandwidth per users (FTTH scenario) can go up to 1 Gb/s or higher. 50G PON has already been defined by ITU-T as next generation PON and released by September.2021. Next generation PON (NG PON) will provide flexible bandwidths to meet various service needs and achievable. For example, the bandwidth 50G PON technology per users (FTTH scenario) can go up to 10 Gb/s.

GPON solutions support a limited number of true gigabit broadband customers and are not designed to support premium cloud, enterprise, and mobile backhaul and fronthaul services. XGS-PON is a higher bandwidth, symmetric version of GPON and can co-exist on the same fiber with GPON.

Figure 8: Summary of PON technological characteristics

GPON	XG-PON	XGS-PON	50G PON
Gigabit PON	10G asymmetrical PON	10G symmetrical PON	50G symmetrical PON
→ 2.5 Gb/s ← 1,25 Gb/s	→ 10 Gb/s ← 2.5 Gb/s	→ 10 Gb/s ← 2.5 or 10 Gb/s	→ 50 Gb/s ← 12.5/25/50 GB/s
Upstream: 1,25 Gb/s	Upstream: 2.5 Gb/s	Upstream: 2.5 or 10 Gb/s	Upstream : 12.5, 25 or 50 GB/S
Downstream: 2.5 Gb/s	Downstream: 10 Gb/s	Downstream: 10 Gb/s	Downstream: 50 Gb/s
Enabler of Gigabit broadband	Asymmetrical bitrates. Co-exists with GPON. Same λ as XGS-PON	Dual rates: symmetrical or asymmetrical. Co-exists with GPON,	Dual rates: symmetrical or asymmetrical. Co-exists with GPON, XGS-PON
Deployments: Most widely deployed PON worldwide since 2007	Deployments ; worldwide, main China, Japan, US, South Korea	Deployments: Worldwide. Main PON flavor today.	In trials and pilot stage. Deployments expected to start after 2023

Source: IDATE, *The future of (N)GPON*

XGS-PON dominate the market in the short-medium terms.

GPON is achieving its peak deployment while an array of 10G PON technologies are queued up to overtake it as the dominant PON solution. XGS-PON is becoming the most popular 10G PON variant based on port/unit shipments. In Europe, a parallel transition is taking place at the same time involving the transition from copper to fiber and from GPON to XGS-PON. Telecom operators and fiber service providers are focused on 10 Gb/s symmetrical PON standard XGS-PON for their next-generation deployments. XGS-PON trials are quickly moving to production deployments. IDATE expects XGS-PON OLT ports shipments to dominate among other technologies in the short to medium term.

Co-existence elements and the combo/universal blades, supporting both GPON and XGS-PON simultaneously, allow operators to upgrade on a per-ONT basis as service triggers arise. XGS-PON is also being chosen by telcos for mobile backhaul/fronthaul as well as the aggregation of remote access node traffic in support of accelerating 5G mobile service deployments.

Moving to next generation PON technology

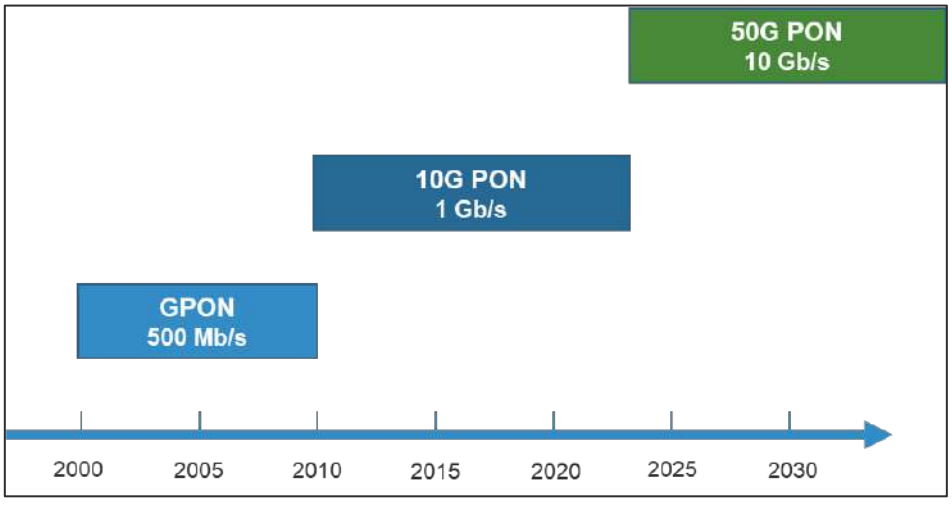
In the APAC region, the choice for 50G PON is clear. European telecoms are with eyes open on the equipment prices while upgrading first to XGS PON. Most leading operators in Europe are supporting 50G PON such as Telefonica, Orange, TIM, etc. In addition to that, 50G PON is expected to be the most cost-effective solution when deployed on a large scale in the future.

50GPON developments are moving fast. In 2018, the ITU-T approved the initiation of the 50G PON standard to define requirements and layers and approved 50G PON standard in September 2021. 50GPON deployments is expected as of 2023. Equipment vendors such as Huawei and Nokia are involving actively on the research of 50G PON standards.

Vis-à-vis other PON technologies, 50G PON promise to improved bandwidth by 2 times compared to 25G PON. Additionally, it can efficiently reuse the existing 10G PON ODN resources and reduce network deployment costs. Moreover, 50G PON will use a similar wavelength as 25G PON - 1270nm and 1300nm wavelength bands because of low fiber dispersion.

50G PON is a natural step towards the next PON technology which also favored by standardization. There is quite limited market space for 25G PON. On top of standardization, equipment price evolution should also be considered. Economies of scale is key to assess equipment pricing evolution. Considering the number of telecom operators having expressed an interest, IDATE estimates that their joint coverage of the market represents close to 70% of the total FTTH market. Chinese telecommunications operators weight close to two third of this market potential. Therefore, IDATE expects the price of 50G PON equipment to fall steadily in the medium term, at least in line with the fall in the price of 10G PON. Until the 50 GPON matures, there is quite limited market space for 25G PON as 50G PON will be mature quickly.

Figure 9 : evolution of PON technologies



Source : IDATE, Green all-fiber network facilitates gigabit experience

2.2. Optical Transmission network innovations

- **OTN to the network edge**

5G, local applications, and the number of connected IOT devices will drive network edge area traffic growth in the next few years. According to IDC, more than half of new enterprise IT infrastructure will be at the edge

by 2023. In addition, increasingly emerging applications have very strict performance requirements such as delay sensitivity. Operator are looking for better solution to transfer data in network edge in an efficiency way with limited environmental impacts.

OTN (Optical Transport Network) is another key optical technology of fiber network as PON. OTN can efficiently support different kinds of services such as SDH, ethernet and 5g transport etc. and is widely used in backbone transmission networks due to its efficient DWDM (dense wavelength-division multiplexing) transport capability. It has been defined in various ITU Recommendations, such as G.709 and G.798 and provides an efficient way to transport, switch, and multiplex different services onto high-capacity wavelengths across the optical network.

OTN provides guaranteed bandwidth with no congestion, zero packet loss and deterministic latency. Moreover, OTN supports fast service restoration and offers a roadmap for scalability beyond 100 Gb/s rates with guaranteed service levels for all users. From 2020, various standards organizations began to develop small-granularity technical standards with OTN bandwidth of 2 Mb/s to lower than 10 Gb/s to make it more suitable for carrying a large number of low-bandwidth services. Over the last few years, there's been significant industry efforts to extend OTN to the edge to replace low bit TDM networks with small granularity OTN solutions.

The penetration of OTN to network edge to central offices site levels is s very important to provide the premium experiences for connected home application with large bandwidth requirement, industry 4.0, and 5G backhaul. The innovations of OTN technologies enables flexible deployment, high integration and smooth evolution for future generation of PON technologies, allowing to help operators to cope with challenges in the current networks, especially in aggregation and access layers, such as lack of space and high-power consumption, and insufficient capacity for future capacity growth.

Flexible deployment: the penetration of OTN to network edge can support different traffics types and adjust the connection capacity for the fast provisioning of new service , which enable improve the agility and scalability of network with guaranteed service levels with high bandwidth and low latency requirements . In addition, the solution is suitable for both indoor and outdoor deployment scenarios, which can better adopt different network design practices.

High integration: The extension of OTN to the network edge can replace aggregation switches, enabling a flattened network architecture and reduced space and power consumption through more efficient use of wavelengths. OTN uses an integrated photonics module and opto-electronic integration design to ensure high bandwidth, low heat dissipation, and reduced rack space at a comparatively cost-effective way.

Future evolution: the adopt of OTN to network can also support network update from 10G to 100 G and 200G. this will squeeze the cost per bit associated with the solution for 40% with the 50 gigabits.

- **the proliferation of ROADM technology**

ROADM (Reconfigurable optical add-drop multiplexer) is an important optical technology that provides operators with the flexibility to remote provision and manage the wavelengths on a fiber network. ROADM have evolved three generation. the fourth generation of ROADMs is characterized four main new functions, namely colorless, directionless, contention less and flex spectrum.

ROADM technology offers operators the ability to improve the efficiency of the whole network and respond quickly to meet future traffics and service demands at the optical layer by simplifier network design, remote reconfiguration while reducing operation and maintenance costs.

Operators benefit from the combined use of OTN and ROADM to improve, network performance, avoid congestion, improve service availability and reduce costs. The combination of OTN and ROADM provide great network agility to automatically adapt to traffic changes and new service requirement, and flexible expand network capacity based on traffic growth, without human intervention. In addition, in case of network failure, OTN support error correction function, while ROADM enable to re-routing wavelengths around failures to improve network resilience.

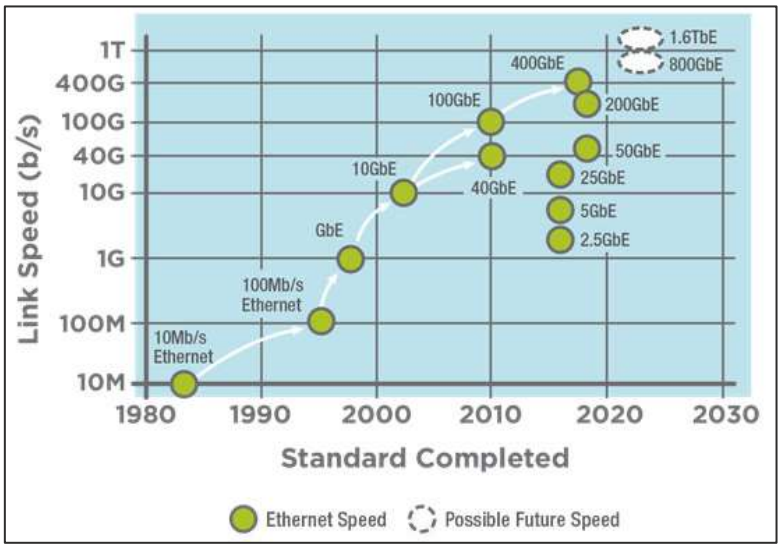
A transparent optical network, with the implementation of ROADM in various locations enable to build scalable, resilient, highly available, and flexible network architectures at cost-efficient way to meet traffic growth and new service requirements.

2.3. Innovations unlocking the Potential of Backbone Networks

- **400G Internet trends**

The demand for higher transmission capacity, lower per-bit transmission costs, and power consumption has always driven optical modules towards higher transmission rates. With the explosion of internet traffic and new service requirement, the backbone network need also to upgrade to meet further bandwidth requirements. Currently the most internet backbone can handle traffics at 100 G and 200 G. However, the increasing in traffic growth will made 100G and 200G insufficient to meet bandwidth requirement anymore. 400G is expected to replace 100G and 200G deployments in the near future.

Figure 10: Ethernet roadmap



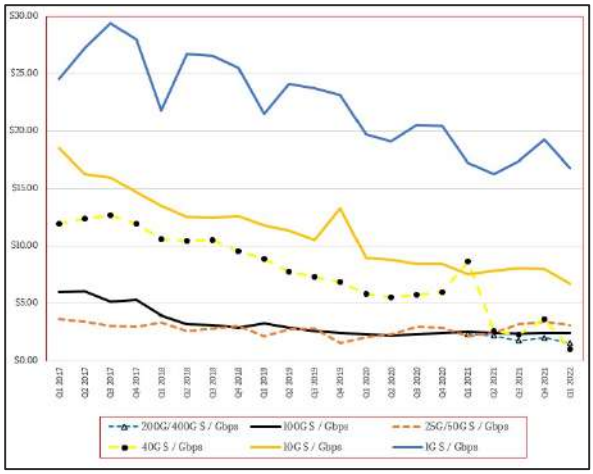
Source: Ethernet Alliance

A shift towards 400G internet backbone is underway, which is driven by following factors:

- Emerging applications and services: 400G backbone Internet will significantly improve bandwidth, to support data-hungry applications such as high-definition video streaming, cloud computing, and big data analytics
- Cloud computing: with the massive adoption of cloud computing technologies, and cloud-based service with demand for increasing bandwidth capacity and low latency, 400G is essential provide high speed connection to connect between data centers as well as data centers and users.
- 5G network and edge computing: Edge computing is a crucial part of the 5G to bring cloud capability to closer of end users. The extension of 400G fiber connection to edge nodes provide the foundation to support 5G services demands requirement, such as autonomous vehicles, VR/AR and 4K video streaming.

Compared to previous generations backbone transmission technologies, 400G technology provides better network capacity and transmission efficiency. Since its larger network bandwidth, it can fourfold increase the maximum data transfer speed over 100 G, enable higher fiber capacity using higher spectral efficiency, while keeping the same transmission reach. By delivering four times more bandwidth per optical transceiver, operators can reduce the cost per bit by delivering the same bandwidth. Additionally, a 400G port costs less than four 100G port connection, which can also lower the energy requirement.

Figure 11: Cost per G of different generations of Transmission technologies



Source : nextplatform

- **C+ L band**

To increase the bandwidth capacity of optical fiber, operators are also embracing Coherent (Wavelength Division Multiplexing) transmission technology to increase the bandwidth per optical fiber. WDM (Wavelength Division Multiplexing) is an optical transmission technology that enable simultaneously transmit multiple optical carriers of different wavelengths in optical fiber communication.

The wavelength of fiber can be divided into several bands. The ITU-T standards specified that a single mode fiber with band range from 1260 nm to 1675 nm, covering O/E/C/L/U six bands, for optical transmission.

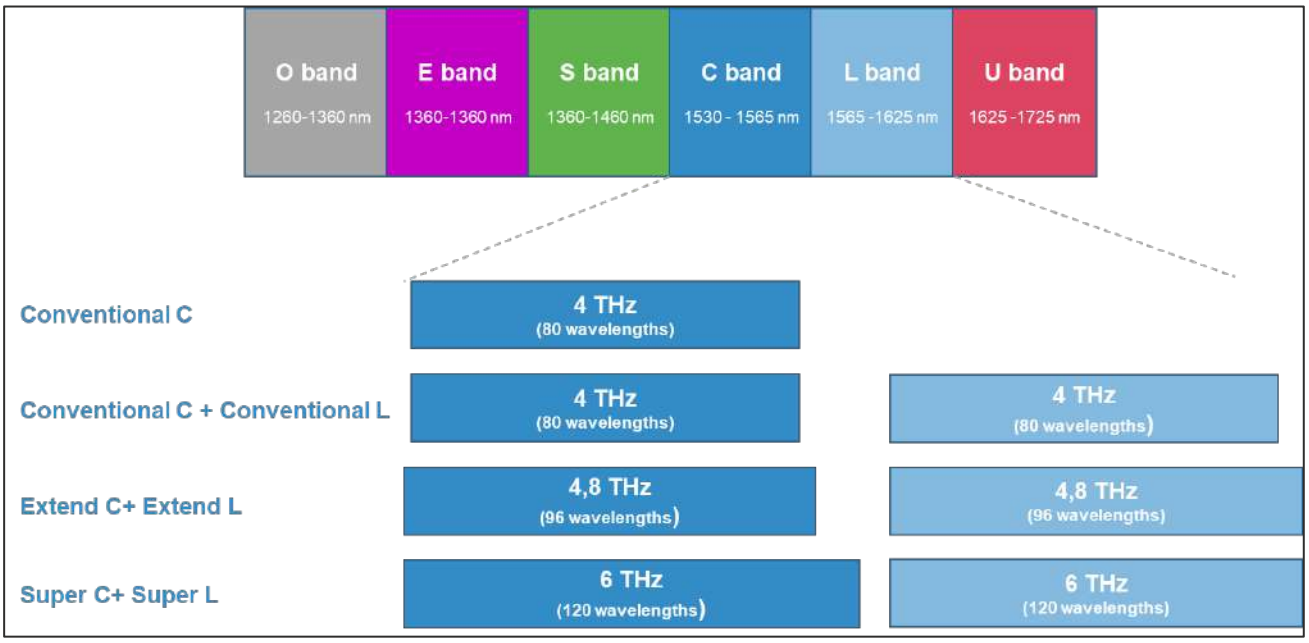
The C-band (1530 - 1565 nm) is widely considered the conventional band for long distance transmission among European telecom operators due to its significantly lower loss compared to other bands. The L-band (1565-1625nm) is the wavelength band immediately adjacent to C-band with the second lowest-loss wavelength band and is often used when the C-band alone is not enough to meet bandwidth requirements.

The C+L is the combination of conventional C-band and L-band, which provide a wide bandwidth range from 1530 to 1625 nm for data transmission over fiber optical. It is commonly used for long-haul transmission to support the sustain traffic transmission in long-haul backbone communication. The combination of C+L band are becoming increasing important and provides several benefits:

- Larger Bandwidth: The C+L band offers a wider bandwidth, covering wavelengths from approximately 1530 nm to 1625 nm, corresponding to a total wavelength range of about 95 nm. It can support more wavelength channels on a single fiber, resulting in higher transmission capacity and higher data rates.
- Better fiber resources utilization efficiency: The C+L band provides a wider range of bandwidths than C-band alone, allowing a greater number of wavelengths to be transmitted over a single fiber cable.
- Reduce fiber deploying cost: the C+L band provide scaled capacity transmission without the need for deploying or acquiring new fiber, which can further reduce deploying costs.
- Smaller footprint in terms of space and power consumption: the C +L band systems use a common set of transmission components for both the C-band and L-band signals instead of duplicating transmission components for two C-bands, which can help to reduce total space and power consumption.

Recently advancements in C+L band technologies have the potential to great expand the transmission capacity and speed of optical backbone networks. Compared to the conventional C+L band covering the wavelength range of 1530-1625 nm, the super C+L band extends this range to 1450-1700 nm, which can support 240 wavelengths, offering a larger wavelength range. For example, compared with the conventional C-band transmission of 4THz (80 wavelengths), the super C-band can support up to 6THz (120 wavelengths), thereby increasing the capacity of each pair of fibers by 50%. Additionally, the Super L band can support 6THz (120 wavelengths). The Super C+L band enables transmission of 80 to 240 wavelengths per fiber pair, expanding the total operating frequency spectrum to 12 THz and doubling the capacity of a single fiber.

Figure 12: Different wavelengths of fiber optical communication band



Source: IDATE, Green all-fiber network facilitates gigabit experience

The integration of C+L band capabilities into one ROADM is a recent advancement in optical transmission technology that provides enhanced capacity and more flexible management of optical signals. The integration of C+L band capabilities into one ROADM enables network operators to manage and route C+L band optical signals more efficiently, improving bandwidth efficiency and increasing transmission capacity.

In addition, ROADMs allow network operators to adjust the optical paths remotely and dynamically in the network, including adding or dropping individual wavelength channels without interrupting the traffic. Therefore, operators are able to better manage the flow of traffic on their networks, thereby optimizing usage of network resources and reducing operating costs.

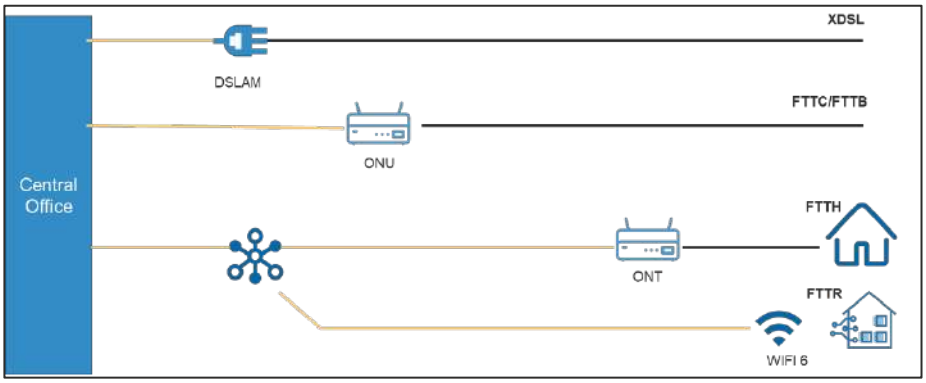
3. All-fiber network scenarios

3.1. All-fiber network: fiber network extension to fiber to everything

The flexible feature of fiber and the advancement of fiber optical technologies pave the way for fiber to everything. Fiber is the most prevalent technology in most countries' fixed network deployment. IDATE estimates that FTTH/B accounts for more than half of global broadband connections by the end of 2021. PON technologies deliver huge bandwidth to support different services all one fiber infrastructure. Recent advancements in PON technologies have significantly improved fiber infrastructure capabilities, enabling fiber connections to extend from home to everything, such as Fiber to the room, Fiber to Office/campus and even Fiber to machine.

Fiber to everything will provide ultra-high bandwidth, low latency and high reliability to address different scenarios needs, in order to achieve "ubiquitous all-optical infrastructure". For residential customers, traditional FTTH (Fiber to the home) connection can be further extended to every room (FTTR) to provide gigabit connectivity to every corner of room via Wi-Fi 6. For businesses and industries, all-fiber network demonstrates its benefits when traditional LAN architecture is challenged to handle high bandwidth and massive numbers of connections, exceeding network security and reliability requirements, while saving space and maintenance costs.

Figure 13: Extension from fiber to home to Fiber to ROOM



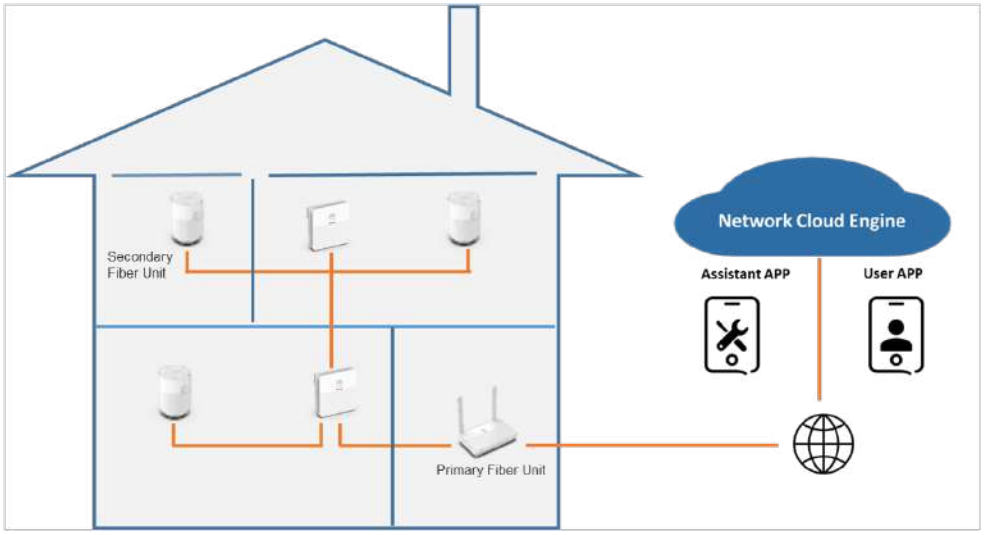
Source: IDATE, Green all-fiber network facilitates gigabit experience

3.2. Fiber-to-the-Room offers a high-speed full fiber connection for a variety of new home applications.

Since the outbreak of pandemic, home Broadband is moving from the entertainment center to the multifunctional center. High speed broadband is a major prerequisite for enjoyment of high quality of entertainment content, access to companies' resources through clouds and supports a variety of smart home devices.

FTTR is the next step in the evolution of FTTH solutions. In the FTTR architecture, a Primary Fiber Unit (PFU) is connected via optical fiber to multiple Secondary Fiber Units (SFUs) placed in different locations. Both the PFU and SFUs can provide Wi-Fi 6 access, enabling gigabit speed access in every corner of the house. Mobile apps are used for monitoring, maintenance, and management of the entire network. The PFU, located between the Optical Line Terminal (OLT) and the SFU at the local end, serves as the main control center of the home network, enabling unified management and configuration of all the SFUs. Multiple SFUs serve as home distributed Wi-Fi access points, distributed to each room in the home. They connect to the PFU via fiber optic cable and provide Wi-Fi 6 access to various smart home appliances.

Figure 14: FTTR architecture



Source: : IDATE, *In-Home Broadband,* June 2022

Compared to traditional FTTH technology, FTTR shows various advantages:

Enhanced network speed and guaranteed indoor network coverage: By leveraging fiber and Wi-Fi 6 connectivity, FTTR promises to deliver up to more than 2 Gb/s internet speeds with roaming latency of less than 20ms. The technology also can provide sufficient bandwidth to connect to support 16 Wi-Fi access points and 128 smart device terminals online. Compared to a traditional home networking-based Wi-Fi network with an average internet speed of around 100 Mb/s, FTTR can increase the connection speed by 900%, achieving full-house Gigabit Wi-Fi coverage.

Intelligent planning, acceptance & maintenance: Implementation, acceptance, and maintenance of FTTR solutions can be entirely managed through a mobile application, which can be used to simulate the deployment of master and slave FTTR equipment, as well as support network topology and speed acceptance tests. Furthermore, operators can use the mobile application to get alerts, and to locate and troubleshoot abnormal problems remotely, making maintenance visits less frequent.

Easy installation and greener solution: Fiber is easy to deploy in-house because of the lightweight and small diameter of optical fiber cable. On average, it takes only 20 minutes to complete a hotspot deployment. Additionally, FTTR is also a “greener” solution, reducing energy consumption by 30% compared to cable connection, enabled by the low loss of optical fiber

FTTR technologies, combining with latest Wi-Fi 6, redefine high quality of digital home Life and enable to support multi-service concurrency scenario, paving the way for next-generation immersive life experiences.

Quality of service: FTTR use network cable to extend fiber connection to each room. Fiber serves as a backhaul link for supporting multiple Wi-Fi 6 access points. The combination of the two technologies promise to delivery up to more than 1 Gb/s internet speeds with roaming latency of less than 20ms. Compared to traditional Wi-Fi network with average internet speed around 100 Mb/s and considerate roaming latency, FTTR can increase the connection speed by 900% and reduce latency by 30%, achieving full house Gigabit Wi-Fi coverage.

Environmental benefits: Compared to conventional fixed broadband access technologies, FTTR is based on passive fiber component, enabling reduce 30% energy consumption than cable. Furthermore, because of the super-flexible physical feature of fiber, the solution is easy to install and deploy. The rollout of FTTR indoor can deliver higher speed and more reliable internet connection while making the internet connection more environmental-friendly to help operators to achieve carbon-neutral target.

For operators, FTTR will be a robust technology to realize differentiated for its premium quality of network services and enhance ARPU value of users and reduce churn.

- **Higher ARPU:** FTTR promise a superior in-house Wi-Fi network experience with guaranteed speed and coverage. FTTR could become a new source of growth for operators’ home broadband revenue. For instance, based on number of Wi-Fi access points and house type, Operators can

offer in-door Wi-Fi network plans with tiered coverage and speed. Consequently, higher Wi-Fi speeds and better in-door coverage plan would be more expensive. Operators could use FTTR to tap customers who are willing to pay premium prices for a premium usage experience to double ARPU. On average, China Telecom charges 30% more for additional FTTR edge devices.

- **Low churn:** FTTR solutions can provide full-house Wi-Fi coverage, which improves user experience and customer satisfaction. Higher customer satisfaction tends to lead to improved customer retention and lower churn.

3.3. All-fiber networks accelerate the digital adoption of SMEs

All-fiber network is the key infrastructure components for supporting and promote enterprise cloud and remote working applications. It promises to bring a more flexible and efficient working experience by interconnecting offices in different locations and by supporting digital applications, such as high-quality connection to cloud, remote collaboration, and access to multiple private clouds. Moreover, all-fiber network upgrade existing GPON or 10G PON to 50G PON to provide perfect support for high-band Wi-Fi 6 and future generation Wi-Fi access, as ethernet cable can hardly support the required bandwidth for various bandwidth-hungry applications.

Moreover, all-fiber networks enhance enterprise cloud adoption and optimize work efficiency. As enterprises are increasingly turning to cloud computing, data centers require high-speed, reliable, and secure connections to support various cloud services and big data applications. It can provide high bandwidth, low latency, and high reliability connectivity to enable secure and flexible access to enterprise cloud data, improving productivity.

All-fiber network also enables employees to communicate and work efficiently remotely. Video Conferencing and some remote collaboration scenarios require high quality network connectivity. Wi-Fi 6 network slices will allow network resources to be prioritized for the most important services, such as voice and video traffic to guarantee the quality and stability of HD video conferencing. Additionally, the millisecond latency allows enterprises to facilitate the collaboration of multi-teams across significant distances and multiple time differences.

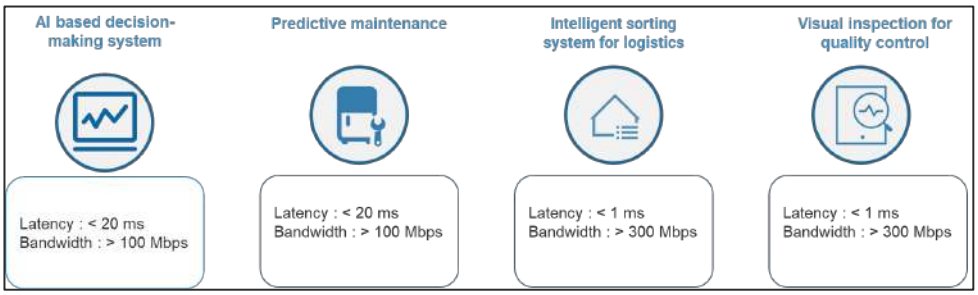
FTTR for SME is a solution that enables the efficient extension of fiber connectivity to commercial areas using existing FTTH infrastructure, delivering benefits for both SMEs and network operators. The FTTR for SME solution is designed to meet the connectivity needs of small and micro businesses by building upon the FTTR for Home solution. This is achieved by making use of the existing fiber-to-the-home (FTTH) infrastructure, which allows for a fast and cost-effective extension of fiber connectivity to commercial areas. With this approach, network operators can leverage their existing assets and quickly develop the market for SMEs while also improving their ARPUs. In addition, The FTTR network is based on the same technology as PON and FTTH networks. Operators can leverage their existing fiber investment to maximize the retour on investment.

3.4. All-fiber networks provide foundation for industrial 4.0 revolution.

Industry 4.0 is a new wave of digitization in the manufacturing sector. New industrial applications, such as 3D machine vision quality inspection, cloud-based PLC, and centralized remote-control applications will making industrial processes autonomous, to better meet challenges such as adapting to individual customer requirements, improving quality, and responding more quickly to market demands. However, these applications have stringent network requirements, such as uplink bandwidth of 1–10 Gb/s, 99.9999% reliability, deterministic latency within milliseconds, and production network expansion in minutes.

All-fiber network brings the best benefits such as large-bandwidth capacity, ultra-low latency and jitter, energy efficiency, strong anti-interference ability, high reliability, long-distance coverage, future-proof capacity, quick deployment, and flexible expansion to ensure the premium networks quality at industrial levels. For instance, all-fiber networks with high bandwidth can enable manufacturers to achieve accurate and effective remote-control operations, improving operating productivity and enhancing their business results. results and business models.

Figure 15: Selected industrial applications network requirements



Source: IDATE, Green all-fiber network facilitates giga experiences.

3.5. All-fiber network drive Fixed-Mobile network convergence

Fixed-mobile convergence (FMC) is a prevalent trend in Europe, with more than 37% of broadband households using a converged service today[1]. Fixed Mobile Convergence aims to finally remove the barrier between fixed and mobile networks, providing a seamless, ubiquitous experience by combining fixed broadband and wireless technologies to meet their needs of various scenarios. Fixed-mobile convergence delivers seamless service experiences and ubiquitous connectivity to optimizes transmission of data traffic and communications to end users, regardless of location or device. FMC enable to help operators to sav network construction cost, reduce customers churn rates, and enabling new converges services. In 2018, ITU specifies the requirements of fixed mobile convergence (FMC) in IMT-2020 networks. 3GPP also develops specifications for 5G Core (5GC) networks to support the convergence of fixed and mobile networks.

The fiber network can be a complementary solution of 5G to provide gigabit indoor connectivity. 5G is appropriate for outdoor connection needs, such as connecting cars, tablets, robotic machinery, smart cities amongst others. However, the technology has a poor indoor coverage. The convergence between Wi-Fi 6 based on all-fiber network and 5G is critical for enabling new range of applications and seamless wireless experience, such as such as home connectivity, Industry 4.0, augmented and virtual reality (AR/VR), connected cities and edge computing, etc..[2] The convergence of WI-FI 6 and 5G is also a win-win scenarios for end users, operators. Wi-Fi and 5G convergence offer improved visibility into Wi-Fi networks, allowing operators more control over customer experiences and the ability to provide better service. Further, mobile operators are in a better position to provide enterprise Wi-Fi network management solutions to enterprise customers[3].

At the same time, fiber network provides high transmission capacity and low latency, making it an ideal choice for 5G backhaul cabling. Increasing number of emerging applications require low latency connection to run at optimal performance, such as livestreaming and online bank. The latency requirement is even more critical for autonomous driving, which require high-capacity bandwidth and near-zero latency. In the industries sectors, various applications, such as application based on cloud for real-time decision making and automation, require high speed and low latency connection. All-fiber networks can respond effectively increasing bandwidths and low latency demand for 5G backhaul.

[1] https://www.telecomtv.com/content/access-evolution/fixed-mobile-convergence-takes-root-in-europe-46306/

[2] http://www.eitc.org/research-opportunities/5g-and-beyond-mobile-wireless-technology/wi-fi-6-and-beyond-wireless-technology/the-convergence-of-wi-fi-and-5g

[3] 5G and Wi-Fi RAN Convergence, Wireless broadband alliance

4. Green all-fiber network

Global greenhouse gas (GHG) emissions have risen dramatically over the last three decades and are of major concern for our societies. Their malign environmental impact is pushing governments, enterprises, and civil society to reorganize and find cutting edge solutions to meet this challenge. The development of ICT and digital technologies opens many opportunities to tackling the environmental challenges such as climate change and reduction of carbon emission.

4.1. Fiber is a key enabler to reduce network carbon footprint and environmental impact goal

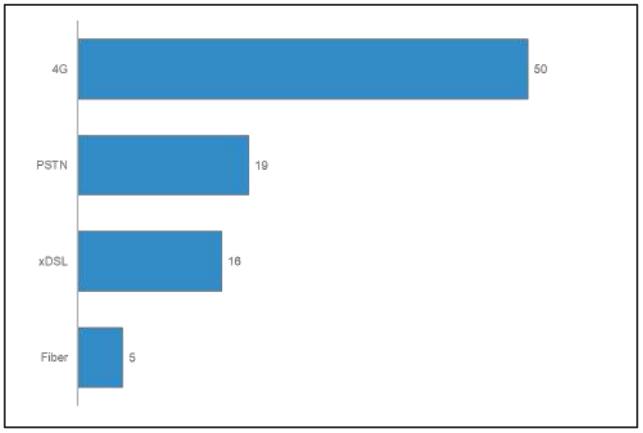
Fiber is a future-proof medium that provides the high-performance demand from different scenarios and 5G uses cases. Fiber network is a sustainable infrastructure, which provide not only faster, more secure, and more reliable connection, but also promote passive infrastructure to improve energy consumption and made of on eco-friendly recycling raw material. Fiber is more sustainable material and have longer lifecycles. Intelligent operations and maintenance also contribute to carbon reduction.

Compared to traditional copper cable, fiber network delivery network connection in an energy- efficient way. Fiber consumes 3 times less energy than xDSL, while internet speed is generally 10 times faster.

The lower scale of infrastructure utilization results in lower electric power consumption, thus reducing the emissions of CO2, methane and other harmful pollutants. Low fiber reshapes network architecture.

Figure 16: Comparison different network technologies yearly energy consumption in kWh per line

(Based on 7GB monthly data consumption per line)



Source : IDATE based on ARCEP report,
Réseau du futur, empreinte carbone numérique.

All-fiber network networks contribute to achieve green agenda.

Compared to conventional network architecture, all-fiber network brings significant energy efficiency improvements in three areas:

All-fiber connectivity: fiber networks provide better high transmission efficiency. Finds show that fiber networks emit 88% less greenhouse gas emissions per Gigabit compared to legacy technologies. The fiber network reduces the energy consumption by 1 Watt (for every 300 meters) compared to 3.5 Watts for the copper network (for every 100 meters) in the data transmission service[4]. For instance, As Copper switch-off is a growing trend among operators around the world, the transition from copper network to fiber-based networks will enable operators to achieve energy efficiency targets and save energy-related costs. Additionally, fiber network use passive optical components to replace electrically powered components, enabling saving energy consumption tenfold. In residential and scenarios, optical fiber extend to each room can be used to replace copper cable, reducing energy consumption up to 75% and cater to immersive digital experience at home; In enterprises and vertical industries scenarios, all-fiber network is the most energy efficient solution , which extend fiber connection to office and factories to provide high speed and low latency connections to benefit the digitalization, while reducing energy consumption on network ; In

[4] https://www.linkedin.com/pulse/fiber-optic-projects-reduce-energy-costs-operators-help-graterol/

Mobile backhaul scenarios, fiber is also the most convenient technology for backhaul infrastructures in term of energy consumption[5].

Simplified network architectures: The innovations on key components of the optical network simplifies network architecture, contribute to the reduction of the energy consumption. For example, edge OTN use highly integrated photonic-electrical platform to improve space utilization rate and save energy consumption. The optical cross-connect (OXC) is another component that allows transparent mesh optical connections to be realized by replacing traditional fixed optical add/drop multiplexers, which require less cable and hardware and use light to transmit data, thereby enabling space-saving and energy-saving.

Intelligence: All-fiber network optimizes power consumption by using advanced AI setting mechanisms to support sleep mode and select transmission path based on network power consumption, the traffic volume and allocation policies.

4.2. Fiber is empowered all industries for the reduction of carbon emission.

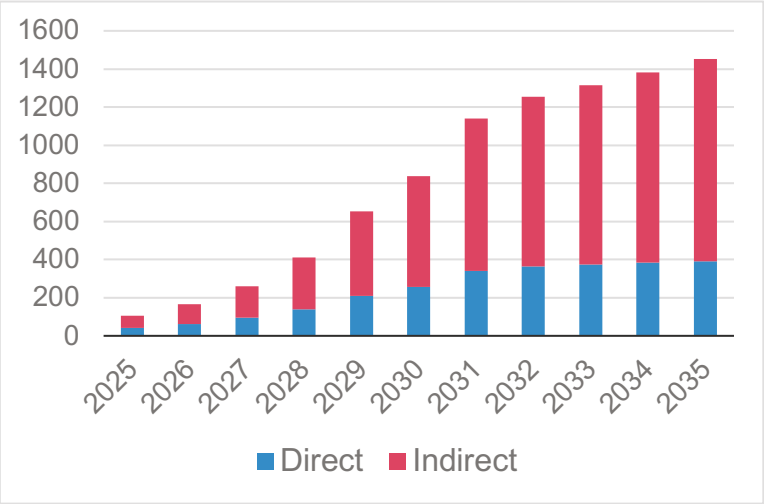
The impact of fiber network in CO2 abatement goes beyond the telecoms industry. Full fiber connection can benefit a wide range of vertical industries to reduce CO2 emission. From smart homes to larger settings like optical smart campuses (let it be airports, hotels, university campuses, etc.) as well as smart grids and factory floors, we have identified a long list that industrial should consider. Full fiber network will Promote large-scale intelligent upgrading of business and public service, optimizing utility production energy consumption of different industries, especially for manufacturing, energy, transport and agriculture sector, which are the largest source of (direct) CO2 emission.

- **Manufacturing**: Full fiber networks will empower smart factories by enabling communication with users and with machines, automated processes, and mechanisms to facilitate real-time communication between the factory and the market to support dynamic adaptation and maximize efficiency, to achieve reducing human intervention and improving energy efficiency.
- **Energy**: All-fiber network promises low latency and high-speed connectivity to meet latency-sensitive smart grid applications demand. The data on electricity consumption and usage can be transmitted in real-time to all network operators to optimize the production and distribution of electricity, to save energy, to reduce losses, and to improve grid reliability.
- **Transport**: All-fiber networks can interconnect different cities' traffic network infrastructure to facilitate real-time communications between a wide variety of remote field devices and traffic control centers. Using video transmission to monitor intersections helps reduce traffic congestion, improve traffic management, and lower carbon emissions.
- **Agriculture**: fiber optics expand internet connectivity in farms, which enable internet of things (IoT) technology to refine and automate farming processes. This process can significantly improve operating costs and reduce waste. Moreover, full fiber connectivity with higher speeds and lower latencies allows surveillance cameras and sensors to effectively gather farming environment, and then transmit the collected data to IoT backhaul devices for intelligent analysis, thereby reducing investment costs and saving energy.

According to IDATE forecasts, fiber deployment commit to 30 per cent carbon emission reductions by 2030 (from a 2021 baseline) across industries.

[5] Energy efficiency of fiber versus microwave, mmWave, copper, satellite and laser for the transport of the fronthaul and backhaul in 4G and 5G mobile networks Full Deliverable

Figure 17: Worldwide fiber Deployment cumulated CO2 savings (Since 2021, CO2 Mton)



Source: IDATE, Green all-fiber network facilitates giga experiences.

5. Emerging best practice and market forecast

5.1. Case study of successful gigabit broadband deployment experience in China

China is among the top countries in terms of the construction of full fiber networks. China has the world's largest fiber network and the largest number of net additions of FTTH broadband subscribers. According to IDATE, China has 920 million FTTH ports and 479 million FTTH/B subscriptions as of December 2022. Additionally, China ranked as one of leading country with the global performance ranking.

The construction of gigabit internet cities is also gaining momentum in China. From 2020 to 2025, China is expected to spend in total 9,9 trillion RMB investment on broadband, including 1.6 trillion yuan from government and 8,3 trillion yuan from industrial market. Gigabit broadband access network has been deployed in more than 300 cities throughout the country. As of December 2022, the number of 10G PON ports reached 15,23 million, increasing nearly 60%, while the gigabit fixed broadband subscribers has been fourteenfold, increasing from 6,4 million to 91.75 million[6].

All-fiber network solution has been applied across various scenarios, covering home, business and a board range of industries.

The FTTR market in China is booming

After its launch in September 2021, FTTR quickly attracted the attention of many Chinese operators, showing a strong growth trend. By December 2022, 87 province operators published FTTR commercial packages with 2 million subscribers. According to the experience in China, customers are more likely to purchase FTTR package with one or two slave FTTR devices, representing over 80% of total FTTR subscribers. Furthermore, 20 other operators around the world have also launched the pilot programs of FTTR solution.

In order to meet the application requirements of various industries, leading Chinese telecom vendors launched F5G related all-optical Network products, which can create more than 40 scenario-based solutions covering more than 10 industries such as energy, transportation, mining, communications, construction, education, healthcare and manufacturing.

Vertical Industry Applications of All-Fiber Networks solution in China

The application of all-fiber network can support a board range of digital applications across different vertical sectors. Following are some examples of all-fiber networks applications across different industries in China:

In small business and enterprises scenarios, FTTR for SMEs solution promise to delivery up to gigabit internet speeds to support their digital transmission and daily operation. Including cloud computing, e-commerce, and videoconference collaboration tools. Chinese telecom operators actively promote the use of FTTR technology for SMEs. For instance, China Telecom has launched a range of FTTR-based solutions, including the "Gigabit Fiber Enterprise" service, which provides SMEs with high-speed and reliable internet access, as well as various cloud-based services.

In education sector, all-fiber networks have been deployed in schools and universities to meet teaching needs and students' various digital applications and online learning demand. All-fiber network provides up to 10 Gb/s network connections to support various digital applications as well as digital interactions and collaborations tools. For instance, Shenzhen University has deployed an all-fiber network throughout the campus to support various activities, including online learning, access online research databases and conducting research. In another example, the deployment of an all-fiber network in a Chinese college reduced energy consumption by 30%, to reduce carbon emission and save on energy costs.

In healthcare sector, all-fiber network is the backbone for various smart hospital applications run. All-fiber network promise to delivery high-capacity bandwidth, low latency, high reliable network enabling support a large number of connected devices to provide comprehensive digital service access, such as

[6] https://www.miit.gov.cn/gxsj/tjfx/txy/index.html

teleconsultation, remote surgery, remote patient monitoring, HD virtual consultations and sharing of medical record information. For example, Shen Zhen hospital use all-fiber network to upgrade its legacy network to realize sharing patience records, which save around 9 million sheets of paper and 200,000 sheets of film (equivalent to more than 4 million RMB) per year; in addition, all-fiber network allows real-time image, document, and video data transfers for video-based medical consultations. Using the new all-optical network architecture, 1,000 medical images can be read in one second.

In manufacturing sector, all optical networks have been widely used in many manufacturing segments, such as automotive, electronic equipment, semiconductor, home appliance manufacturing, tobacco, heavy industry, etc. All-fiber networks provide high speed and reliable connection to support a range of digital applications and services, including automation, machine vision, and data analytics to improve productivity while reducing energy costs.

In automotive sector, the deploying of all-fiber network in BYD's new factory provide high-speed and reliable connection for different scenarios, including production line automation, real-time data analytics and quality control system. In addition, all-fiber network replacing traditional copper network in BYD's new factory has resulted in reduce cabling costs by 50% and energy consumption by 40%.

In energy sector, Chuzhou Smart Factory of Dongfang Risheng has deployed all-fiber industrial solutions to update their product inspection system. The solution helps the company to support large number of data transmission and improve the tolerance of network, but also reducing energy consumption. For example, the inspection system generates terabytes of data per day. The all-fiber industry solution can provide large capacity to support the transmission of large volume of data. Moreover, networks have the capability to achieve fault recovery within 50 milliseconds, thus ensuring uninterrupted production. Most but not the least, all-fiber networks improve the energy efficiency by 40%, reducing the energy consumption and related costs.

5.2. Market forecast for future global broadband.

Achieving gigabit connectivity by 2030 is key in Europe. The deployment of FTTH is still ongoing in most European countries to meet European Commission's Digital Compass objectives, by promoting Europe's digital leadership and global competitiveness, to help the EU, reach the transformation targets in 2030. As part of EU of ambition by 2030, all European households will be covered by a Gigabit network, with all populated areas covered by 5G7. At the same time, The EU aims to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions by 2050 and economic growth decoupled from resource use. The last point requires to cut down carbon emission from network infrastructure, as well as across industries sectors.

All-fiber network will support the economic growth through delivering ultra-high bandwidth network, low latency, high reliable connection to individuals and business. Findings show that doubling the broadband speed for an economy increases GDP by 0.3 percent. All-fiber network delivery premium gigabit connection experience for in-home low applications, such as gaming, video, etc. Most importantly, all-fiber network contributes to the growth of businesses and benefit the economy growth by accelerating the cloudification steps, optimizing productivity, facilitating remote work, and speeding up services and products innovations.

All-fiber network is also the most sustainable network choice to help all the industry to achieve green agenda. Fiber network is the future-proven with high capacity and flexibility to meet future demand. All-fiber network extends fiber connection to fiber to everything, including homes, businesses, vertical industries, smart cities, and 5G cells etc. enabling to deliver gigabit connectivity, while significant reducing energy consumption. Last but not least, all-fiber networks provide the digital foundation for all sectors to leverage digital technologies to combat carbon emissions for Zero emission target by 2050.

Forward-looking and perspectives of FTTR technology

FTTR, as one of the important all-fiber network technologies, is a very immature offering and is only available to the mass residential market in a handful of countries across the world. However, with the accelerating growth in FTTH subscriptions, and service providers' desire to market premium-quality broadband services, IDATE forecasts a significant growth of FTTR subscriptions in all regions which will reach about 28 million by the end of 2026. FTTR penetration is likely to be linked to income levels and will

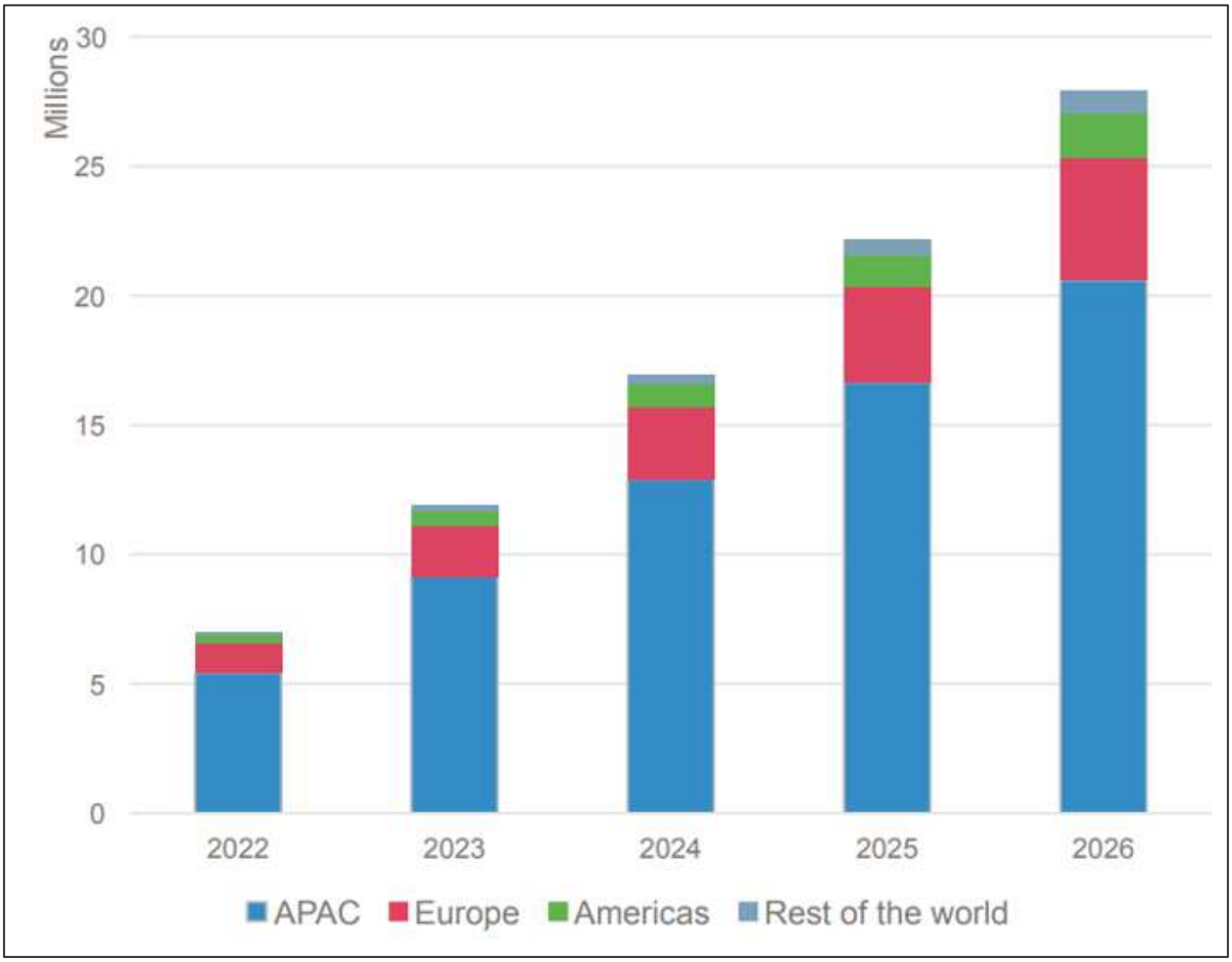
[7] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021DC0118&rid=4#footnote17

at least initially be a premium service, while other households will be content to rely on single-router or mesh Wi-Fi solutions.

Several operators around the world have launched pilot programs for FTTR solutions. FTTR Home users' take-up trends will be higher in countries or in areas of countries in which fiber connection or FTTH has a good level of coverage. In the first phase, the new connection technologies will be installed in some new residential buildings across the world.

The take-up rate will be higher in the countries of the APAC region with a high level of FTTH coverage than in other regions. FTTR has quickly attracted the attention of the three main Chinese operators, showing a strong growth trend. By April 2022, FTTR had already been launched commercially in 65 cities in China. By the end of 2021, the number of subscribers reached 200k between the three major operators in the country, and by the first half of 2022, they had attracted 400k FTTR subscribers. By the end of 2022, the number of subscribers is expected to exceed 2 million and by the end of 2026, it is expected to reach about 16 million. According to the experience in China, customers are more likely to purchase FTTR packages with one or two slave FTTR devices, representing over 80% of total FTTR subscribers.

Figure 18: Worldwide FTTR subscriptions (millions)



Source: IDATE, *In-Home Broadband,* June 20