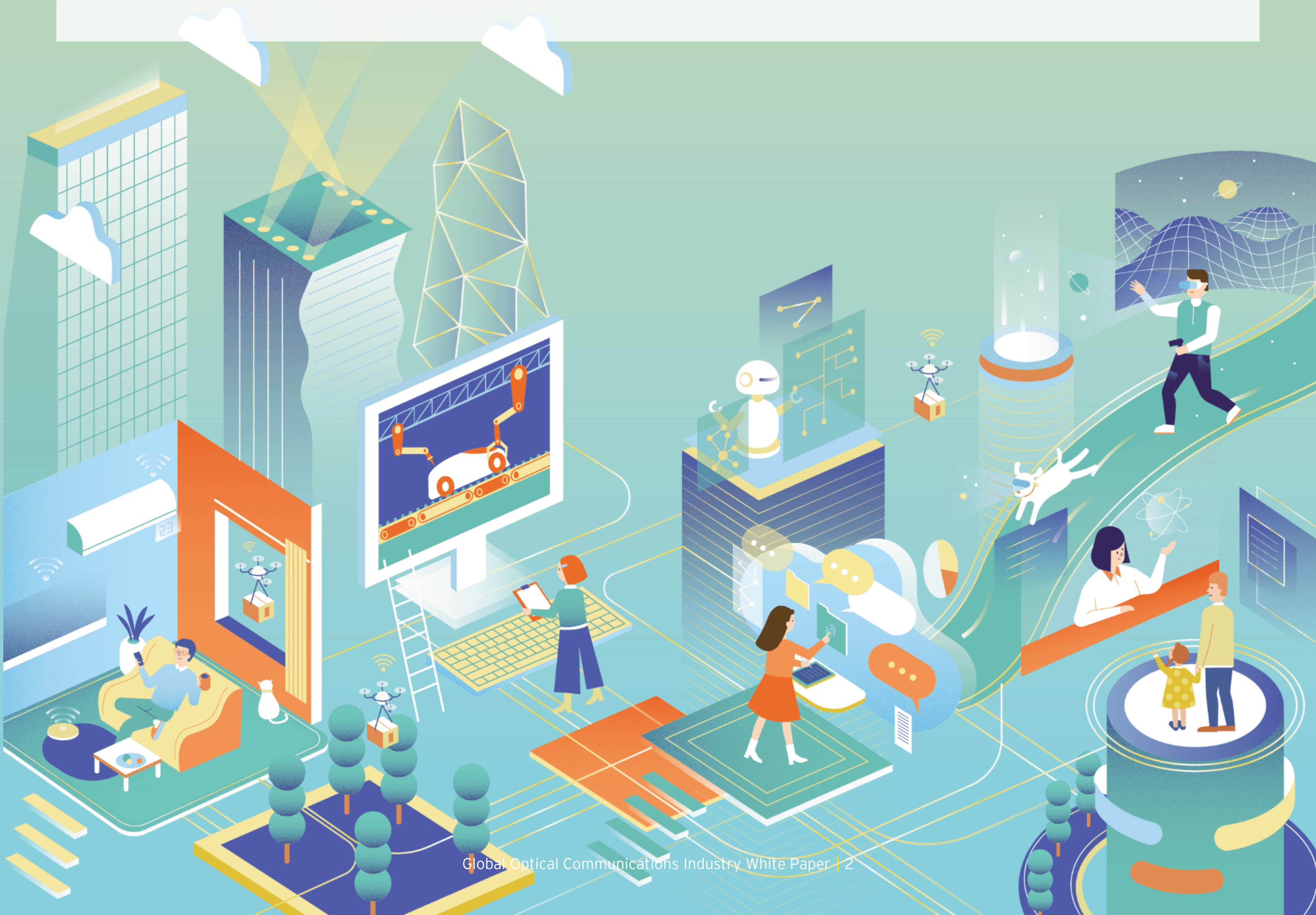
The Backbone of Digital Economies: the Revolution of Global Industries through Optical Communications

EY
Building a better working world

Content

Preface

Similar to the evolution of mobile networks, fiber optic networks have significant improvements over previous generations of fixed networks in connection capacity, bandwidth, and user experience. Driven by both technological advancement and demand in the enterprise market, fiber optic networks featuring all-optical connectivity are creating a new round of infrastructure construction and application opportunities.



Chapter 1

Development History of the Optical Communications Industry

Backtracking the History: Humanity and Technology Must Develop Hand in Hand

Throughout history, science and technology are inseparable from the development of human civilization. The invention of the Watt steam engine oversaw a titanic shift in production methods from manual to automation, boosting productivity significantly. Over the course of history, humanity has shifted from agricultural production to industrialization during the "steam age". The invention and application of electricity followed, and this began to gradually replace steam, bringing even greater benefits to both industry and society. This set the foundation for the invention of the computer and the widespread application of networks, breaking down physical barriers as we shifted into the information age.

We are now entering a new era of informatization and global digitalization, whereby data, communication, and computing power are increasing exponentially. Simultaneously, the demands for a digital world are also rising at an unprecedented rate. We believe that this will lead to five major trends that will affect the future of society and the digital world, as well as the emergence of new technologies, scenarios, and infrastructure. These five trends are de-mobilization, ubiquitous intelligence, ultimate sensation, fluctuating demand, and network polarization.

The COVID-19 pandemic has adversely restricted the movement of people in order to prevent spreading of the virus. In particular, isolation has led to people questioning whether or not offices and schools are really necessary. Another big factor for this shift is technology. If advanced technology is available, enabling remote interaction and processing, and thus fulfilling our needs, the importance of being 'onsite' will diminish. We believe this is known as the **first trend: de-mobilization**, and this is evident as more and more people are choosing to stay at home. From 2015 to 2021, global e-commerce sales will have increased from 7.4% to 17.5% of the total global retail sales volume. This trend highlights that consumers see less need in visiting shops in person and no longer value the sales experience as much as they used to. This definition of 'onsite' is very broad, and can include schools, hospitals, offices, banks, government agencies, stadiums, concerts, gyms, and other places. These places may be centralized or de-centralized, or may be located in urban areas or remote areas. Similarly, users connected to the network may also be scattered around. Therefore, to implement de-mobilization and provide real-time connections between sites and users, a powerful optical communication network is required to connect a huge number of terminals and support real-time network interconnection and ultra-large bandwidth in certain scenarios.

The **second trend is ubiquitous intelligence**. Electronic devices around us are becoming more intelligent with greater functionality. Many of these functions can be implemented only through remote networking, such as digital twins, which can be used to dynamically simulate digital objects to improve efficiency and reduce costs. Such operations require fast and reliable signal transmission from the human brain to the device processor, of which the optical communications network acts as the bridge for these signals. As the number of connected smart devices increases, we are able to realize our ideas about the future. Some operation instructions can be flexibly edited during execution, while others may include many complicated steps and instructions. These smart devices are a key part of our lives, so it is paramount that optical networks are able to deliver stability, reliability and massive terminal connections.

The **third trend is maximum sensation**. Reality hinders our endless pursuit of superiority and desires. In the past, we enjoyed watching standard-definition videos or being able to download them to hard disks or USB flash drives, but now, technological advancement has driven our demand for better, crisper, richer videos. Consumers nowadays can no longer tolerate poor quality videos. Instead, they pursue 8K videos, an interactive ultra-HD VR experience, and large-scale cloud games with little delay. Following the launch of 8K TVs, the compound annual growth rate (CAGR) of global shipments was expected to reach 134%, while the growth rate of 4K TV shipments slowed down to approximately 18%. It is evident that new technologies will alter people's shopping habits and offer superior experience. In terms of visual technology, display resolutions are reaching a level of richness that makes it almost impossible for us to differentiate it from what we see with our naked eyes, and reduced latency blurs the border between what is real and not. Entertainment in the future will embody an ultra-HD, immersive, real-time, and interconnected experience. Interestingly, rapidly changing consumer habits and growing social expectations mean that the demand for a better sensory experience is growing. To meet this demand and deliver game-changing content, our networks must be upgraded as soon as possible to guarantee higher bandwidth and overcome the barriers to delivering the ultimate experience that customers seek.

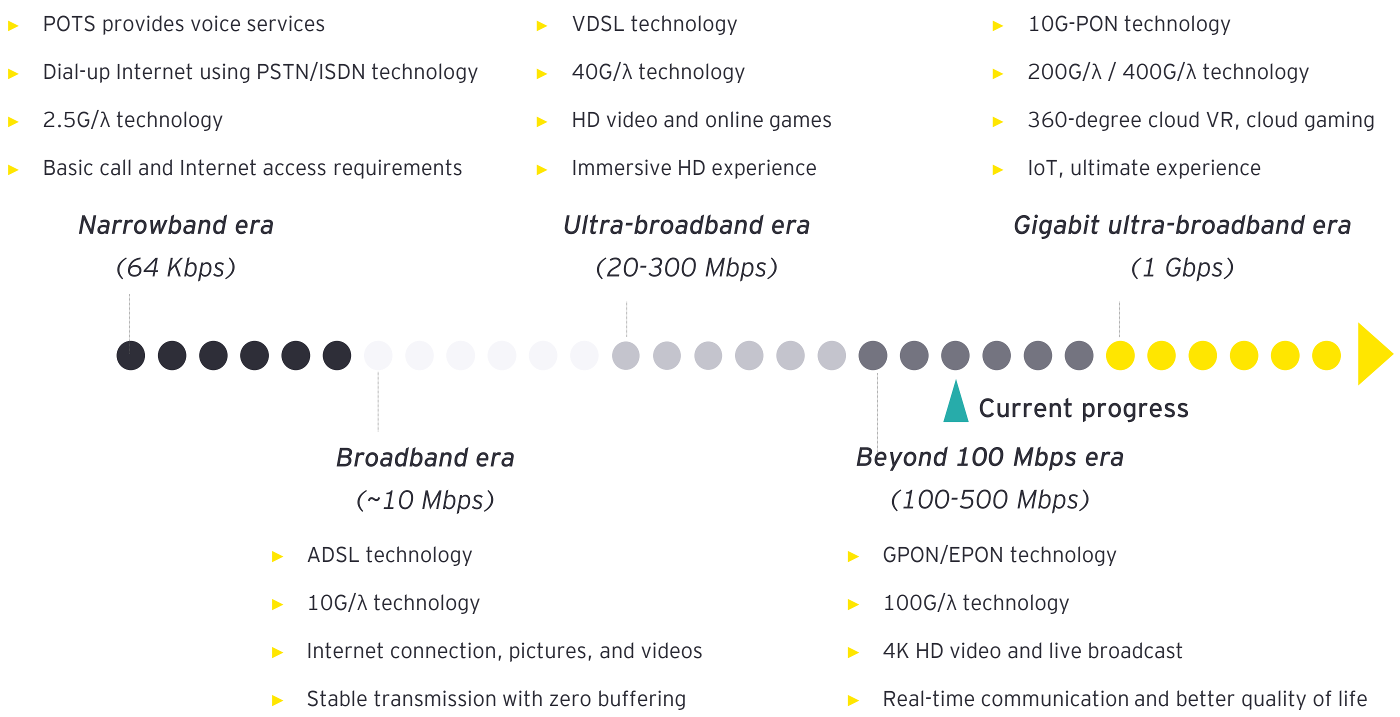
The **fourth trend is known as fluctuating network demand.** Looking back, we can see that until 10 years ago, consumers' choice in home networks was still demand-driven. However, improved optical communication capabilities increase speed, boost efficiency, and reduce the costs of communication networks, bringing tangible benefits to consumers. Operators are also more active in large-scale home broadband construction, opening the door for people to fully enjoy broadband. Despite this, the demand for connectivity is becoming higher. Major online shopping events, as well as live news and event broadcasting mean that information is no longer transmitted through traditional text and images, but through ultra-HD video, or even real-time interaction. Therefore, this trend places huge pressure on networks. A solution needs to be devised in order to prevent sites from crashing and users being unable to access content. Bursting upstream and downstream traffic requires flexible network resource scheduling and concurrent processing during peak hours, which drives the upgrade of optical networks.

The **fifth and final trend is the polarization of networks**, and this can exist in three aspects. The first is the gap between the progress of global network deployment and upgrade. With Huawei's 10G-PON, China leads the way in deploying next-generation optical network, but there is still a lack of network coverage in some underdeveloped areas. The second aspect is the polarization of hardware facilities. Some enterprises, such as large Internet organizations, have deployed large data centers. Other organizations, particularly small enterprises, fulfill their networking requirements through clouds and campus networks. And the third aspect is network polarization. Services such as remote surgery and autonomous-driving require high bandwidth, low latency, and guaranteed reliability. Conversely, remote monitoring and applications such as smart meter reading will likely pose only basic requirements on optical communication networks. The polarizing trend of these three aspects requires the reallocation of network resources in the digital world.

In light of these five trends, optical networks must be upgraded as traditional networks cannot meet the requirements of these trends.

Communication networks have evolved from four types. The rapid development of communication technologies has seen network speeds soar from 64 Kbit/s in the narrowband era to 500 Mbit/s, which has in turn led to greater data transmission and enriched applications. In narrowband, analog signals are transmitted through copper telephone lines, facilitating voice calls and providing basic dial-up Internet. In the broadband era, broadband connections were for the purpose of accessing the Internet, offering faster transmission speeds that eventually resulted in the widespread use of websites. This era also set the bench for the popularization of Email in business and life. Additionally, people were able to communicate through online messaging programs. The ultra-broadband era brought multimedia to the forefront, supporting HD TV, IP, IP calls and online gaming. In this period, speeds exceeded 100 Mbit/s, making HD TV, live video, and ultra-HD video conferences available to a wide audience. Now, we are in the age of gigabit ultra-broadband, and it is here where VR/AR, smart grid, smart healthcare/ Internet + hospital, smart agriculture, smart transportation, and smart campus are coming to life.

Figure 1: Generational evolution of fixed networks



Source: ETSI, EY Analysis

Optical networks have higher bandwidth than 5G networks and 90% lower latency than conventional fixed networks, and provide stability and availability levels up to 99.999%. Wireless 5G and wireline optical networks work together to provide ubiquitous connectivity.

- Optical network is future-proof. From a technical perspective, the optical fiber spectrum is 1000 times wider than the RF spectrum. The service life of an optical fiber network is 30 years and it can support smooth upgrade of different generations of optical technologies.
- 5G and fiber networks complement one another. Despite lacking the bandwidth of fixed networks, 5G is indispensable for mobile scenarios such as drones, IoT, and IoG. Conversely, a fixed optical network is more suited to industrial parks and data center interconnection for its high bandwidth, low latency, and high reliability. This will also cover a wide range of indoors situations once Wi-Fi 6 is rolled out.
- Fiber networks are an important infrastructure for 5G. As 5G is mainly used to connect terminals to base stations through wireless connections, base stations still need to be connected to the access network, aggregation network, and transport network through fixed optical networks. Therefore, the optical network is an important basis for the rapid development of 5G.

Looking ahead to the Future: Optical Networks Steer Society into the Era of Optical Connectivity

Unlike the information era, the fiber-connected era allows for the connectivity of everything to be achieved through massive data transmission, breaking its own limitations. Optical communication aids the development of infrastructure, technology, and applications to build a smart ecosystem for ubiquitous optical connectivity.

Technical upgrade

Cutting-edge technologies are the backbone of optical networks in providing the required bandwidth, stability, latency, and reliability they need.

Application upgrade

The fiber-connected era resulted in the widespread use of applications, and these will become more powerful as they leverage the strength of optical networks, delivering ultra-HD video, VR/AR, industrial Internet, and a range of smart services including healthcare, education and home.

Infrastructure upgrade

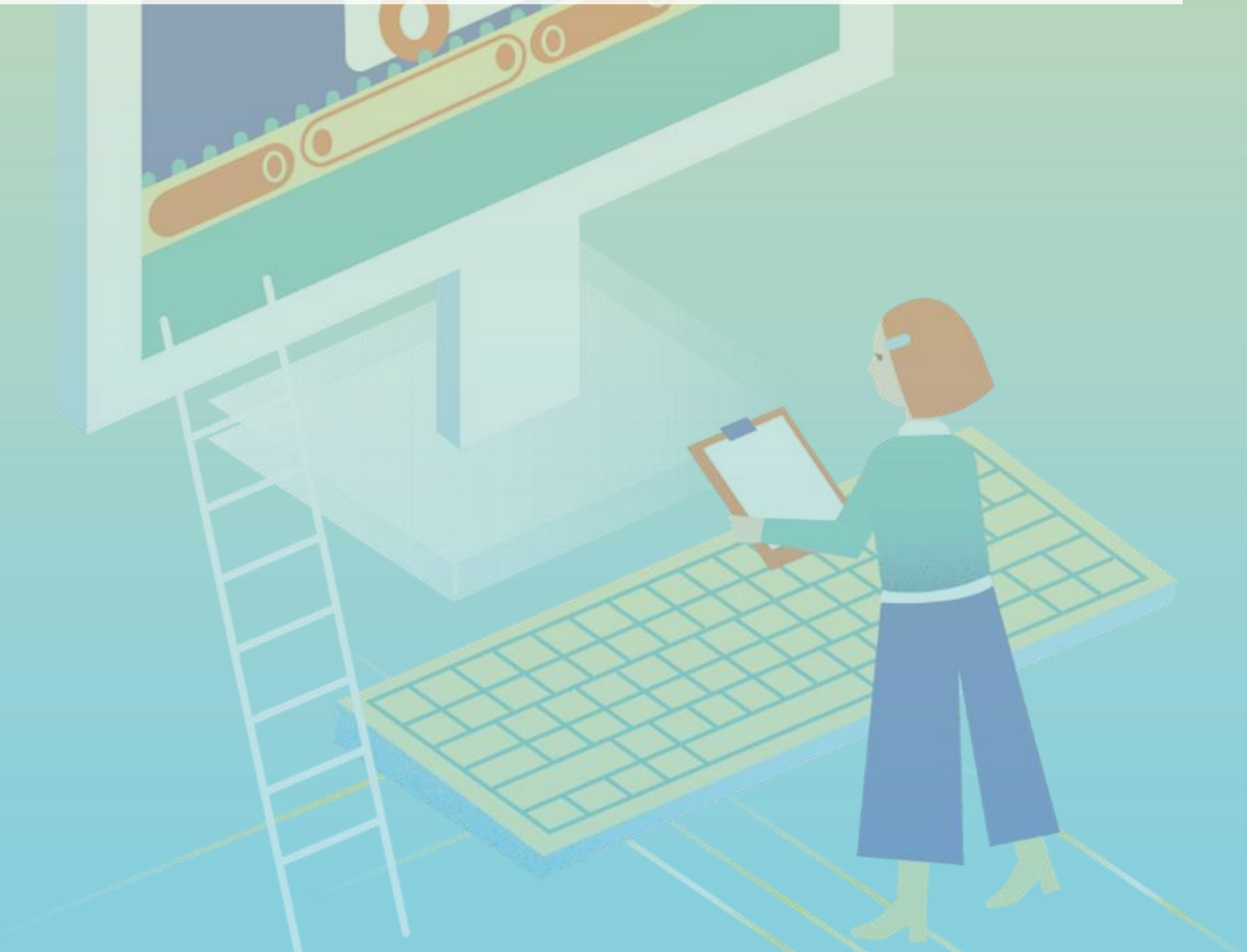
Infrastructure is the very basis for carrying huge data volumes, and the use of optical fibers will upgrade network architecture, pushing it to new levels.

Chapter 2

Technological and Application Advancement: The Prospects of Technologies and Application Scenarios in the Global Optical Communications Industry

Technology spawns scenarios, and scenarios drive new infrastructure construction

The rapid development of emerging applications requires an advanced network. Optical transmission links need to carry increasing data traffic, and the optical access end also needs to ensure optimal network experience with lower latency and higher reliability, all of which put pressure on supporting technologies. In addition, applications have a diverse range of requirements for network services. This requires flexible network resource scheduling technologies (such as network slicing) to ensure intelligent and on-demand allocation of terminal access quantity, bandwidth, latency, and quality of service (QoS) capabilities. These requirements promote the development of technologies such as Wi-Fi 6, 10G-PON, 200G, 400G ultra-high-speed transmission, and next-generation OSU-OTN.



Technical Upgrade:
Promoting the Advancement of World Leading Technologies in Creating a New Era of Communication

The transmission link of optical communications, from upgrading the bandwidth of the traditional backbone network and metropolitan area network to the introduction of optical communications equipment in the access network, lays the way for FTTH to enter the market, achieving ubiquitous optical connectivity.

The emergence of new technologies such as Wi-Fi 6, 10G-PON, 200G, 400G ultra-high-speed transmission technology, and next-generation OSU-OTN propels the industry toward all-optical networks. This white paper will define each of the major types of technology, understand its features and intergenerational advantages, and clearly define its role in improving the optical communications industry.

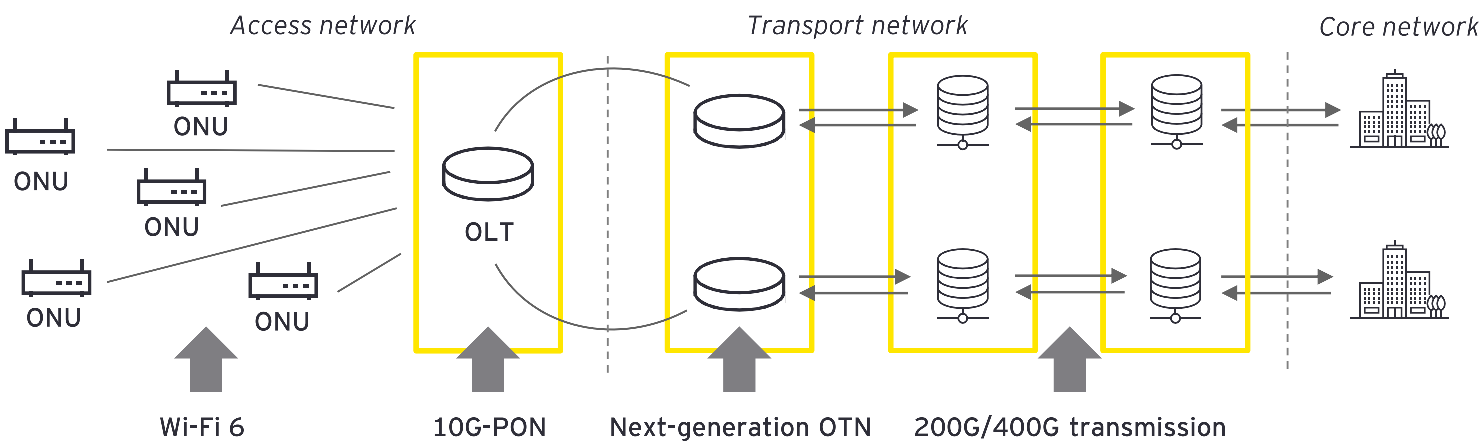
Wi-Fi 6

After 20 years of development, Wi-Fi technology has evolved to its sixth generation (Wi-Fi 6), which was launched in 2019. Wi-Fi 6 can reach a maximum transmission rate of 9.6 Gbps, which is approximately 900 times that of Wi-Fi 1.

Compared with Wi-Fi 5, Wi-Fi 6 has the following features:

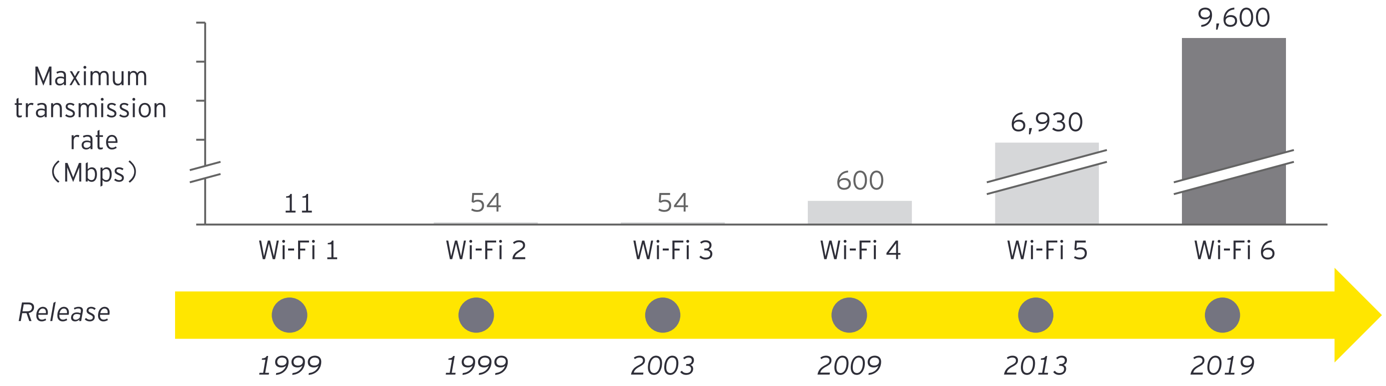
- **1024-QAM modulation.** Compared with 256QAM in Wi-Fi 5 wave 2, 1024QAM in Wi-Fi 6 has higher bandwidth utilization and supports higher transmission speed.
- **OFDMA technology is used.** Wi-Fi 6 uses OFDMA, which has significant improvements over OFDM in the previous generation of Wi-Fi technology, to integrate different types of optical transmission information into the same optical cable for transmission, resulting in higher spectrum utilization, transmission efficiency, and transmission speed.
- **More complete uplink and downlink MU-MIMO.** Wi-Fi 5 supports MU-MIMO only in downlink connections. By contrast, Wi-Fi 6 supports MU-MIMO in both upstream and downstream connections. This means that Wi-Fi 6 enables eight terminals to share uplink and downlink MU-MIMO data packets, thereby connecting multiple terminals.
- **Supports TWT technology to conserve power.** Wi-Fi 6 uses the Target Wake-up Time (TWT) technology to allow terminal devices to hibernate when they are not transmitting data. This reduces power consumption to one seventh of the original value.
- **Supports spatial multiplexing technology to improve immunity to interference.** When a mobile phone receives signals from the same frequency band and the same wireless LAN, spatial multiplexing technology enables Wi-Fi 6 to identify and stop signal interference.

Figure 2: Schematic diagram of optical communication transmission link



Source: ETSI, EY Analysis

Figure 3: Evolution of Wi-Fi generations



Source: ETSI, IEEE, EY Analysis

10G-PON and faster optical transmission

Our increasing demand for faster network speeds is driving network innovation. As the successor to GPON, 10G-PON is the next-generation ultra-high-bandwidth network access technology that achieves gigabit transmission. Compared with GPON, 10G-PON has the following advantages:

- **Gigabit broadband increases the transfer rate.** Compared with the maximum 100 Mbit/s bandwidth of the current EPON and GPON networks, the 10G-PON-based OLT can provide a downstream rate of 10 Gbit/s.
- **Doze mode and cyclic sleep technologies conserve energy.** The Full Service Access Network (FSAN) Group uses the doze mode and cyclic sleep technologies to reduce power consumption when transmission volume is low.

The large-scale commercial use of 10G-PON promotes upgrades in applications, and as a result, edge and backbone traffic increases greatly. In the future, backbone and metropolitan area transmission networks will achieve 200G or even 400G ultra-high bandwidth.

Next-generation OTN technology

A next-generation optical transport network (Optical Transport Network, OTN) will promote the development of an "on-demand bandwidth" network that has higher resource utilization efficiency and is more economical. As a core technology used in optical networks, OSU-OTN is the basis for promoting the evolution of FTTH to ubiquitous optical connectivity. Compared with traditional OTN, next-generation OTN has the following advantages:

- **Ubiquitous all-optical connection.** OSU Flex, which is a flexible and new container, aids next-generation OTN in increasing the granularity of network hard slicing to 2 Mbit/s and the number of network connections by 500 times.
- **Hitless bandwidth adjustment.** Next-generation OTN supports hitless bandwidth adjustment from 2 Mbit/s to 100 Gbit/s and allows users to adjust the network at any time without interrupting services. This underlines the high flexibility and full resource utilization abilities of next-generation OTN.
- **Ultra-low transmission delay.** Next-generation OTN simplifies network transmission layers and provides differentiated latency levels, reducing single-site latency by 70% and achieving millisecond-level or even microsecond-level ultra-low latency.

Summary:

The entire industry must implement technologies to ensure technologies mature

Despite the huge potential that optical fiber technology can bring, there is a bottleneck to its rapid maturity and industrialization. Take Wi-Fi 6 as an example, which requires a routing device and a terminal, both of which are relatively expensive. Likewise, 10G-PON also suffers from high deployment costs. Such bottlenecks are not only limited to these technologies, but rather an expansive range of technologies. Another example is the standardization process for OSU-OTN, which needs to be promoted by users in industries concerning private network communication.

The majority of technology is dependent on industries applying it into their business. This white paper will provide suggestions on how an industry can work together to implement and develop technology.

Upgrade in Application Scenarios of Optical Communications: Driving the Implementation of Internet of Everything (IoE)

New technologies enable the emergence of new scenarios. As the impact of intelligence and digitalization deepens, the original interconnection modes between "people", between "people" and "things", and between "things" will be redefined, with all entities converged in an enormous, highly integrated digital ecosystem. This will involve optimally transmitted data and information, affecting how our requirements are met in various subtle ways. It goes without saying that new applications scenarios have successively emerged, delivering new methods of meeting these requirements. Some of these application scenarios include smart healthcare, smart factory, smart grid, and autonomous driving, as well as ultra-high-definition (UHD) video and augmented reality (AR)/virtual reality (VR).

Identification of Emerging Application Scenarios and Methodology used

We believe that the data transmission speeds and low latency brought by fiber optic networks and 5G will create various emerging application scenarios, which mainly exist within the following aspects:

- **Continuous enablement of entertainment**
- **Intelligence and networking in business scenarios**
- **Gradual implementation of daily life scenarios**

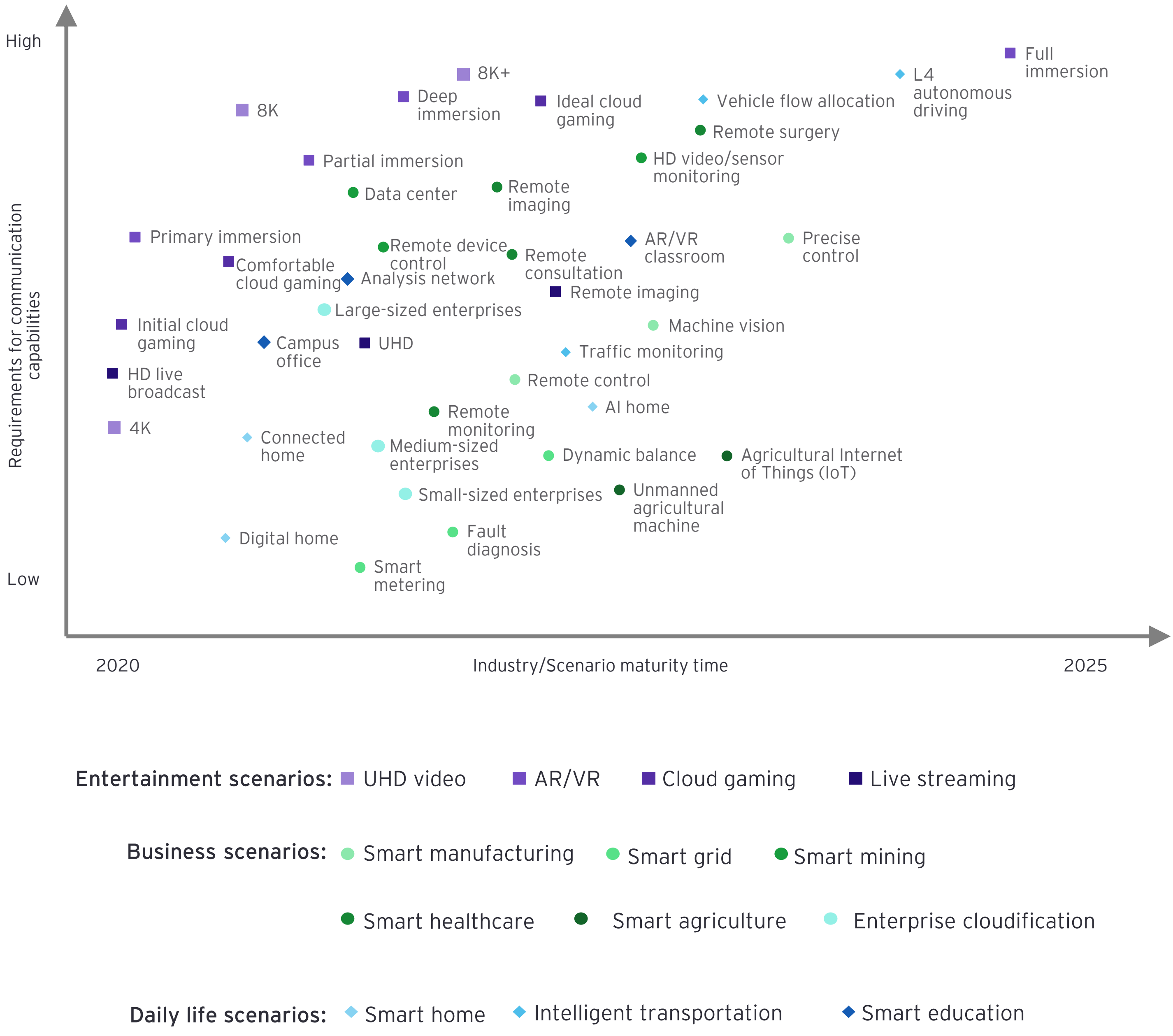
We will conduct further selection of scenarios based on communication requirements and industry maturity.

Figure 4: Identification methodology for the core application scenarios of optical communications

First Dimension	Second Dimension	Third Dimension
Communication requirements (fiber optic networks/5G)	Network performance requirements	Bandwidth, latency, and supported number of concurrently-connected devices
	Cloud computing capability	Requirements for multi-access edge computing (MEC) capabilities
Industry maturity time	Industry chain maturity	Abundance of content/IPs and hardware maturity
	Opportunity for large-scale commercial use	Time needed to achieve a mature business/operation model
	Schedule for implementing policies and regulations	Comprehensive supporting policies and regulations

Source: EY Analysis

Figure 5: Recognition results of critical optical communications application scenarios



Source: EY Analysis

Logic behind the Correlation Between 5G and Fiber Optic Networks and Different Scenarios

Based on the 5G and fiber optic networks performance and network requirements in application scenarios, this white paper analyzes the corresponding correlation in each scenario. Specifically, fiber optic networks outperform 5G in terms of high bandwidth, low latency, low jitter, anti-interference, and high reliability; whereas the reverse is true with regard to mobility and the number of connections. Therefore, the correlation with 5G and fiber optic networks in each scenario will be calculated accordingly.

Based on a comprehensive analysis of the network feature requirements in each scenario, smart manufacturing and smart grid may become major fiber optic network scenarios. On the other hand, smart agriculture and enterprise cloudification may accompany the popularization of fiber optic networks + Wi-Fi 6, which will gradually replace 5G, to serve as potential fiber optic network scenarios.

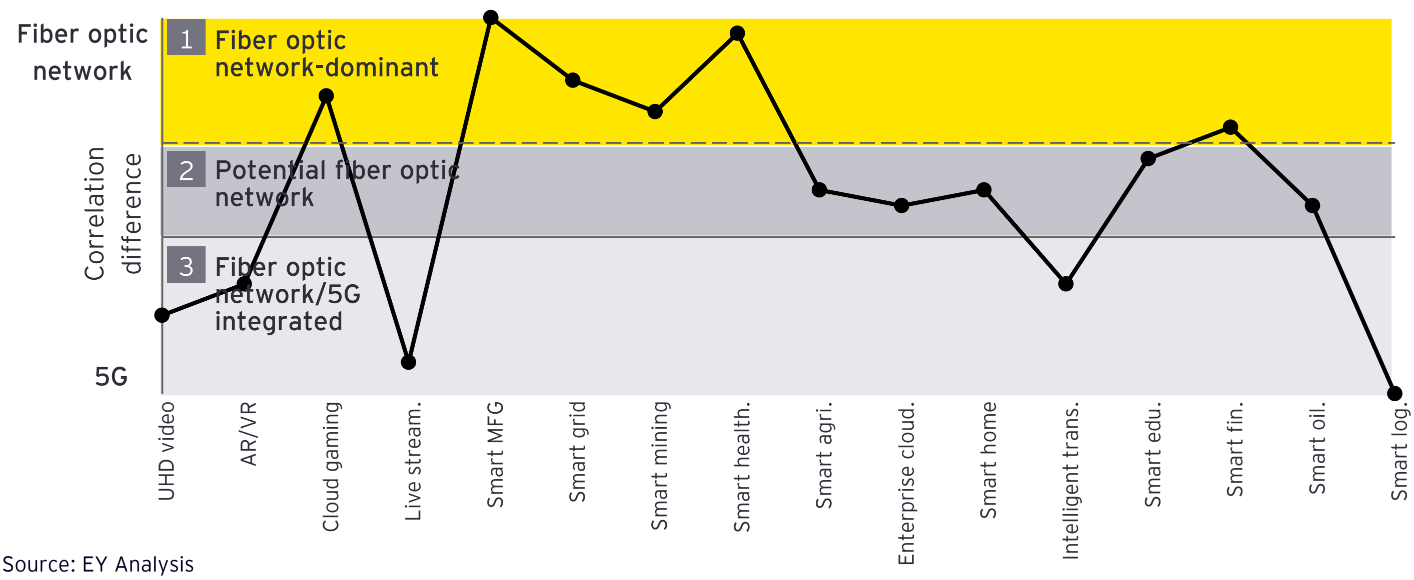
According to the correlation difference between 5G and fiber optic networks, we can categorize the application scenarios as follows: fiber optic network-dominant scenarios, potential fiber optic network scenarios, and fiber optic network/5G integrated scenarios. (The following figure illustrates this categorization.)

Fiber optic network-dominant scenarios: In these scenarios, smart manufacturing, smart healthcare, cloud gaming, and smart finance are extremely latency- and jitter-sensitive, which are requirements that 5G cannot meet. In addition, due to the strong electromagnetic interference of power grids, as well as the fact that 5G signals are weak and prone to triggering explosion underground, fiber optic networks are more fitting for smart grid and smart mining scenarios.

Potential fiber optic network scenarios: Fiber optic networks have the potential to gradually replace 5G in scenarios such as smart agriculture, enterprise cloudification, smart government, smart home, smart education, and smart oilfield, where the connected devices are mobile but usually within fixed locations. With the popularization of fiber optic networks + Wi-Fi 6, 5G will gradually be replaced.

Fiber optic network/5G integrated scenarios: Based on different terminals and access modes, UHD video, AR/VR, smart live broadcast, and smart logistics are all included within these scenarios, where fiber optic networks and 5G have different applications but collaborate without replacing each other. For example, in home and indoor scenarios, Wi-Fi is usually used to access the network, serving as a major driving force of fiber optic networks.

Figure 6: Identification of correlation to fiber optic networks



Source: EY Analysis

Continuous Enablement of Entertainment

UHD Video

UHD video will be widely used as a "basic" application

The development of the video industry can be divided into the following four phases: HD era, 4K era, 8K era, and ultra-8K era. In that regard, video technology has evolved from analog to digital standard definition (SD), HD, and UHD, which it is now developing beyond. UHD video includes 4K and 8K resolution standards. It is worth noting that the comprehensive improvement of technical standards will provide immersive audio-visual scenarios that are true to life.

8K videos and above pose disruptive requirements on networks

An increasing number of scenarios are emerging with the combination of UHD and fiber optic network technology. 4K/8K video will cover all aspects of future fields and become a basic application with broad market prospects.

Within this context, UHD videos can meet users' visual requirements for large screens, high resolution, as well as low latency, and growing consumer requirements are the driving force of the UHD video industry.

Featuring high rates, large capacity, and low latency, fiber optic network is stepping on the scene, and it not only solves the transmission rate problem, but also meets the high image quality and latency requirements of AR/VR applications.

In addition, as UHD video resources and video terminals increase in number, more UHD videos are used, and fiber optic networks meet the corresponding requirements for massive data communication.

UHD video promotes comprehensive deployment of next-generation optical networks

According to general industry standards, the bandwidth requirements of UHD videos have increased from tens of Mbps to over 100 Mbps. On top of that, the bandwidth requirements of emerging application scenarios (such as multi-user concurrent transmission) are increasing exponentially. That said, looking at the current network environment, neither 4G nor 100 Mbps fiber to the home (FTTH) can meet UHD bandwidth requirements.

Moreover, there is an imbalance between the supply and demand of applications for large-scale events, which require tens of thousands of connections and numerous HD cameras or terminals for video transmission. This makes fiber optic networks the perfect candidate for meeting these requirements, as it features ultra-high network speed, ultra-low latency, and massive connectivity. On the basis of UHD live broadcast, the demand for base station optical modules and DCs is increasing considerably, which in turn accelerates the deployment and upgrade of optical fibers and cables.

Figure 7: Generational evolution of UHD video scenarios

	HD Era	4K Era	8K Era	Beyond
Technical specifications	**Resolution:** 1280 × 720 pixels and above **Frames:** 60	**Resolution:** 3840 × 2160 pixels **Frames:** 60	**Resolution:** 7680 × 4320 pixels **Frames:** 120	**Resolution:** 11520 × 2160 pixels and above (Taking 12K as an example)
Network requirements	4-8 Mbps	40-60 Mbps	135-500 Mbps	1 Gbps and above

Source: Expert Interviews, Desk Research, EY Analysis

"There's No Business Like Show Business" – rapid growth of UHD video scenarios in South Korea

South Korea's entertainment and media system is relatively mature, with the entertainment industry leading the country's five economic pillars. The country is well-renowned for its pop idol culture, which has spread across the world, and is driving the increasing penetration rate of UHD videos.

In addition, South Korea launched the Gigabit Internet Project to fully promote the development of the fiber optic gigabit fixed network and provide strong network bandwidth assurance for live TV and video transmission.

To take it a step further, the country's government strengthened its cooperation with private telecom companies, with SK Telecom fully integrating both upstream and downstream resources to promote the commercialization of fiber optic networks.

Continuous Enablement of Entertainment
Virtual Reality and Augmented Reality

VR and AR accelerate integration of digital and real worlds

VR utilizes a computer-generated simulation environment to deliver an immersive experience to the user end. It achieves dynamic environment modeling, as well as real-time 3D graphics and display.

As a technology that supplements VR, AR integrates data with the real world, ultimately presenting an "augmented" real world to end users.

It is worth mentioning that the global impact of COVID-19 further highlights the importance of VR. Put differently, irrespective of time and place, we can utilize AR/VR devices in any space to experience the atmosphere of events without having to be there in person. AR/VR also delivers a more convenient and flexible experience to modern consumers. For example, consumers can now experience AR-based virtual fitting rooms and makeup mirrors, as well as VR-based remote shopping and sensation of touch.

AR and VR are mainly used for entertainment (including games, shopping experience, and live broadcast), and are also widely being applied to education and training, healthcare, and industrial manufacturing.

Fiber optic networks and Wi-Fi 6 enable multi-terminal scenarios

The two main methods of connecting AR/VR entertainment devices to networks are wireless and wired. The ultra-large bandwidth of fiber optic networks can provide better image quality for VR games; while the ultra-low latency ensures the real-time dynamic effect of AR makeup; and the low packet loss rate and low network jitter guarantee smooth experience for VR games.

As AR/VR applications continue to develop, we will depend more on the high-speed and highly reliable fiber optic networks.

Figure 8: Generational evolution of AR/VR scenarios

	Initial phase	Comfortable phase	Ideal phase	Optimal phase
Phase characteristics	Mainly 4K content, with poor visual perception, which is unable to meet user requirements	Gradual popularization of 8K content and near SD-level visual perception, meeting basic user requirements	Gradual popularization of 12K content and near HD-level visual perception, providing a relatively ideal experience and meeting most user requirements	24K content becomes mainstream and near UHD-level visual perception, providing an almost perfect experience and meeting all optimal user requirements
Bandwidth	≥80 Mbps	≥ 130 Mbps	≥ 540 Mbps	≥ 1.5 Gbps
Latency	≤ 20 ms	≤ 20 ms	≤ 10 ms	≤ 8 ms
Packet loss ratio	$\leq 10^{-6}$	$\leq 10^{-6}$	$\leq 10^{-7}$	$\leq 10^{-7}$

Source: Expert Interviews, Desk Research, EY Analysis

Fully immersive VR experience poses extremely high requirements on optical communications

With improving AR/VR immersion levels, users' expectations and requirements for corresponding authenticity and interaction are also increasing. To increase long-term consumption and improve people's willingness to purchase AR/VR, these technologies must meet user expectation for video definition. To this end, the high bandwidth and low latency requirements of AR/VR devices can be met by applying fiber optic network technologies, as well as by investing into optical communication infrastructure.

The US has an extensive content ecosystem for AR/VR scenarios

The AR/VR industries in the US are developing rapidly and leading globally, with a large user group. It is therefore highly worth exploring the development process and main factors driving the continuous development of these industries.

Within the global gaming market, the US has the largest amount of revenue, and it is reaping rewards as the market expands. On top of that, as industrialization brings larger economic benefits, more capital is being put into the VR industry.

From a supply perspective, the US is equipped with well-developed AR/VR technologies, and technology unicorns (such as Oculus) have taken the lead in researching and developing VR headsets, with their cutting-edge technologies promoting the entire industry's development.

In terms of content, in addition to gaming, sports are an important part of modern US culture. This presents a huge market for AR/VR applications in sporting scenarios, which in turn will promote industry development.

Continuous Enablement of Entertainment
Cloud Gaming

Users can play games anytime, anywhere

Based on cloud computing, cloud gaming is an application that allows users to play games remotely from the cloud. This concept originates from the idea behind "Play Anywhere" and aims to enable users to play games anytime and anywhere, thereby expanding the gaming market. Technically speaking, video streaming is the most popular solution.

Fiber optic networks empower online game developers and operators

Cloud gaming has disrupted traditional games' reliance on hardware specifications. With its relatively basic hardware requirements, cloud gaming brings more excitement to the gaming industry. To achieve cloud gaming, using fiber optic networks is the way forward.

- **Cloud gaming delivers higher quality games**

  Games are always adapting to higher aesthetic quality, more complex rules, and increasing numbers of concurrent players, leading to higher requirements on memory and bandwidth. This translates into high-configuration hardware with excessively high costs for users, creating a gap between supply and demand. With fiber optic networks featuring high bandwidth and low latency, users can play any game on the cloud without downloading, installing, or updating them. In addition, supported by an all-optical construction, fiber optic networks can transmit HD game images and low-latency operation information to the cloud server, providing users with cost-effective and high-experience games.

- **Fiber optic networks connect developers to achieve distributed game development**

  Wi-Fi and the current networks cannot carry large-scale development programs, limiting collaborative development such as basic code sharing. This means that a fiber optic network is needed to support the game development platform and basic software reuse.

Cloud gaming urgently requires network upgrade

Home to advanced gaming industries, the U.S. is considered the country for the most likely scale implementation of cloud gaming. Although cloud games do not require download or storage, they need 500 Mbps or higher uplink and downlink rates, and an average enhanced bandwidth of 1 Gbps.

Mature ecosystem helps optical communications market

In the U.S., unicorn tech companies and large Internet vendors have mastered cutting-edge cloud computing technologies to help move games to the cloud.

In a well-established gaming industry with abundant funds, leading vendors (such as Google) invest heavily in the R&D and infrastructure for cloud gaming.

The U.S. offers a vast market for gaming. Driven by demand, cloud games are poised to generate huge economic benefits.

Figure 9: Evolution of cloud gaming

	Initial phase		Comfortable phase		Ideal phase	
Characteristics	60 fps frame rate and 1080p resolution: slow download		144 fps frame rate and 1080p resolution: comfortable experience		240 fps frame rate or higher and 2K resolution or higher: superb experience	
	Computer screen	*TV screen*	*Computer screen*	*TV screen*	*Computer screen*	*TV screen*
Broadband	*≥ 32 Mbps*	*≥ 32 Mbps*	*≥ 48 Mbps*	*≥ 96 Mbps*	*≥ 88 Mbps*	*≥ 320 Mbps*
Round trip time (RTT)	*≤ 30 ms*	*≤ 30 ms*	*≤ 20 ms*	*≤ 20 ms*	*≤ 15 ms*	*≤ 15 ms*
Jitter	*≤ 16 ms*	*≤ 16 ms*	*≤ 7 ms*	*≤ 16 ms*	*≤ 4 ms*	*≤ 8 ms*

Source: Venturebeat, Expert Interviews, Desk Research, EY Analysis

Continuous Enablement of Entertainment
Live Streaming

Real-time video sharing and interaction

Live streaming refers to online media that is simultaneously recorded and broadcast in real time.

With fiber optic networks, end-to-end network latency can be reduced from 60–80 ms to less than 10 ms, and network speeds can reach 10 Gbps, meaning that users can enjoy and share streams with a resolution of 4K, and even 8K, advancing from 480p. 360-degree streams are also supported, offering users additional viewing experiences.

Figure 10: Evolution of live streaming

	HD 1080P	UHD 4K/8K	Panoramic 8K/3D
Bandwidth	≥ 10 Mbps	≥ 100 Mbps	≥ 500 Mbps
Latency	≤ 50 ms	≤ 20 ms	≤ 10 ms

Source: Expert Interviews, Desk Research, EY Analysis

Diversified downstream scenarios

In recent years, constantly improving mobile technology and people's stronger desire to express themselves have endowed live streaming with various platforms. Compared with the play end of live streaming, the collection end attaches greater importance to content transmission. As such, the bandwidth for uploading streams must be guaranteed. With gigabit fiber optic networks, this problem is perfectly solved. Live streaming has been rising in popularity and expanded to more scenarios during the course of the global pandemic.

- **Comprehensive e-commerce:** Favorable government policies, heavy investments, and fiber optic network support.
- **E-sports and entertainment:** Quality user experience enabled by optical transmission.
- **News:** Live broadcasting of international news carried by wide-spreading optical transmission technologies.
- **We media:** Diversified platforms for people to stream live events and express themselves.

Joint development of uplink and downlink networks

Content production drives the upgrade of uplink networks

UHD panoramic live streaming requires real-time and stable transmission of content from the collection end to the cloud, which needs to be completed through a high-quality uplink network.

Downstream network upgrade driven by the play end

- **Second site:** Transmission of UHD live feeds to a second site results in a large number of concurrent users. Therefore, a private line must be configured between the content distribution network (CDN) node and site.
- **Household:** Gigabit home broadband and high-performance Wi-Fi 6 are used to ensure the watching experience of UHD panoramic live videos.

Otaku economy promotes live streaming and optical communications in Japan

Japan has one of most developed entertainment industries in the world. It enjoyed an early start in live streaming that took off in 2017. High transmission rate and low latency brought by fiber optic networks are two contributors to user experience and market competitiveness.

Japan plays a leading role in the international live streaming market. Its rich live streaming categories (such as video game live streaming) promise a huge market potential.

Japan's Otaku culture only makes it natural for people to stream their lives or watch someone else's streams, offering a new way of communications.

The advanced Internet in Japan provides technical support for the acceleration of the live streaming industry.

Smart Manufacturing

ICT enables smart manufacturing with industrial all-optical networks

Smart manufacturing is an in-depth integration of next-generation ICT and manufacturing technologies. It aims to build a new network infrastructure that connects people, machines, and things through full connectivity centering on data and an industrial all-optical network base.

Fiber optic network is the prerequisite for the upgrade in the manufacturing industry

In smart factories, a fiber optic network implements real-time monitoring and scheduling with high bandwidth, massive connections, and high reliability, and supports remote monitoring and precise control with low latency and packet loss rate.

Smart manufacturing requires lower latency and higher reliability

Smart manufacturing can be split into three scenarios: data collection, remote monitoring, and precise control. All of these require fiber optic networks with high bandwidth as well as low latency and jitter. In the actual manufacturing process, jitter for remote monitoring and precise control in the engineering domain must be kept below one millisecond.

While technologies and business models are gradually unified, technological upgrade for industrial all-optical networks is necessary. Specifically, different industries require targeted upgrade of technologies, such as network slicing, edge computing, converged network architecture, industrial security system, industrial network monitoring, and industrial network standardization.

Industry 4.0 in Germany highlights optical communications

Germany has long been famous for manufacturing, which accounts for about 20% of its GDP. It provides several favorable fundamentals for implementing smart manufacturing:

First, Germany takes a proactive part in the Industry 4.0 strategy. Smart manufacturing has gained nation-wide attention from government institutions, companies, research institutes, and education establishment. Thanks to supportive policies and leading technologies, Germany has built a world-leading smart manufacturing industry.

Second, Germany is among the leading figures in Europe and even the world in terms of economic strength. Therefore, it has both the will and capability to invest in smart manufacturing.

Figure 11: Three core scenarios of smart manufacturing

	Big data collection	Remote monitoring	Precise control
Characteristics	Connected devices and closed-loop from production to sales	Devices enabled by fiber optic networks for real-time remote monitoring of working status and fault detection	High-frequency multi-antenna technology and millisecond-level latency for efficient and precise industrial control
Bandwidth	≥50Mbps	≥500Mbps	~1Gbps
Latency	≤100ms	<10ms	1-10ms
Jitter	-	<1ms	<100μs

Source: Expert Interviews, Desk Research, EY Analysis

Smart Grid

Data-based grid optimization

A smart grid refers to a smart supply system that optimizes power distribution control and power storage. It uses bidirectional data transmission to improve the efficiency of power supply at the user end.

A smart grid integrates data collection, data analysis, and downstream distribution capabilities, achieving high information transparency and convenience of centralized control.

Smart grid requirements on fiber optic networks

The popularization and application of smart grids have stringent requirements on network infrastructure construction. Unlike traditional grids, smart grids implement automatic, intelligent, and millisecond-level information processing for power production, storage, transmission, and distribution. From the system level, bandwidth, latency, and reliability must be supported by a more complete infrastructure.

In a smart grid, the main applications are automatic fault detection and re-distribution. They aim to quickly restore power supply in case of outage and effectively identify potential risks before they evolve into faults. In this way, backup supply can be adjusted to avoid affecting the power consumption of users. To deploy smart grids in scale, powerful data processing capabilities and ultra-high data transmission efficiency are imperative. The smart grid's requirements for networks are met by constructing terminal access networks 5 km away from each client area. End-to-end delay must be in milliseconds for terminal access, the availability must be higher than 99.999%, and ultra-high bandwidth must be provided for real-time information transmission.

Access and real-time analysis of massive amount of data

Capacity and latency need to keep pace with enhanced functions and wider coverage of smart grids. The central control system of the smart grid receives power consumption data from all over the country and processes data based on big data analysis and machine learning technologies. Based on the analysis results, power supply is distributed to different power plants and service areas.

Smart grid in the U.S. promotes optical communications

To handle strong magnetic fields and complex working conditions, power systems require improved anti-interference capabilities. The all-optical fiber optic network perfectly solves this problem by safeguarding communications quality in a more cost-effective way.

The U.S. is the first to build a smart grid architecture. After years of device update and iteration, its smart grid has achieved full coverage. Facing large power consumption, the U.S. urgently requires further development in terms of power transmission, distribution, and storage. The Institute of Electrical and Electronics Engineers (IEEE) has been providing strong technical support for smart grid development in the U.S..

Smart Mining

Automatic and intelligent mining

Smart mines are based on automation and intelligence. The intelligent monitoring system is highly integrated with unmanned mining operations equipment to ensure efficient mining with low latency and reliable real-time perception.

Smart mining includes two scenarios: surface mining and underground mining. Surface mining requires effective technologies to handle complex geological conditions, whereas underground mining involves tackling potential risks in enclosed environments. In response, fiber optic network uses industrial optical network with video/sensor monitoring, big data processing center, and unmanned device control in enclosed scenarios.

- **Video/Sensor monitoring:** HD cameras are deployed both inside and outside the mine for information uploading to ensure personnel safety.
- **Big data processing center:** A decision-making brain aggregates, analyzes, and makes decisions on massive amount of real-time data, and delivers instructions to mobile devices.
- **Unmanned device control in enclosed scenarios:** Unmanned devices are remotely controlled through the all-optical network to enable automated mining.

China is one of the leaders in smart mining. With the support of national policies, various mining enterprises have increased their investment in smart mining, driving new applications.

Figure 12: Network requirements of major applications in smart mines

Scenario	Bandwidth	Latency
HD video (4K)/Sensor monitoring	50-100Mbps	<100ms
Data center	500-1000Mbps	<20ms
Remote device control	>70Mbps	<20ms

Source: Expert Interviews, Desk Research, EY Analysis

Fiber optic network is indispensable for smart mining

Smart mining is essential to eliminating safety risks

Subject to worker shortage, high costs and risks, and low efficiency, the mining sector urgently needs to go automatic to achieve efficient and high-quality development. In addition, susceptible to gas and dust explosions, traditional mines call for the replacement of electrical signals with optical ones.

Massive amount of critical data needs to be collected and processed

Based on technologies such as fiber optic networks and Wi-Fi 6, network coverage is improved and data from all kinds of terminals is transmitted to the cloud, implementing efficient management.

The working conditions in mines require extremely high transmission reliability

Traditional networks are established with the interconnection of people, machines, and things; however, higher informatization and automation level tests the bandwidth and latency indicators of services such as HD video monitoring and remote control. With high bandwidth, low latency, and high reliability, fiber optic networks serve as an ideal supplement to existing networks.

Smart mining progress in the U.S.

Benefiting from previous planet landings and existing mining experience, the U.S. has pooled advanced technologies into smart mining.

To gain a competitive edge, the U.S. has formulated plans for "smart mines" and "unmanned mines".

Building on the efforts of the government and mining sector, the U.S. has become the first country in the world to make breakthroughs in the research of automatic positioning and navigation for underground coal mines, and has quickly realized commercial applications.

Intelligent and Networked Business Scenarios

Smart Healthcare

Evolution from remote consultation to more

Smart healthcare uses IoT, Internet, cloud computing, and big data technologies to build a medical information sharing platform based on electronic health records (EHRs). This platform enables interaction between patients, medical institutions, medical personnel, and medical devices, thereby realizing rational resources allocation.

Compared with the current networks, fiber optic networks achieve 1 Gbps bandwidth and high reliability, driving smart healthcare to more advanced applications, such as remote surgery.

Fiber optic networks facilitate medical resource allocation

Networked devices, platform-based management, and resource sharing are key to resolving existing problems in the healthcare system.

- **Resource shortage**

  China's shortage of skilled practitioners and uneven regional development are prominent problems that hold back the adoption of telemedicine.

- **Reliability and bandwidth requirements**

  Telemedicine scenarios need to be supported by high quality communications. Specifically, remote surgery is sensitive in terms of reliability indicators, such as latency, jitter, and packet loss rate. These requirements need to be met by fiber optic network upgrade.

Five scenarios drive the optical communications industry

The five scenarios for smart healthcare include the following: remote monitoring, remote consultation, remote imaging, remote surgery, and AV/VR healthcare.

From the perspective of patients, smart healthcare can be classified into emergency treatment, chronic disease management, and routine physical examination. Remote consultation and remote surgery are most relevant in these cases, and it goes without saying that network performance is essential.

Policy support and user demands for technological development in the UK

The UK has a mature National Health Service (NHS) system that is further developed with help from digital healthcare companies.

In addition, the UK's population is aging. In 2035, the number of elderly people in the UK is expected to reach 17 million. It is hoped that remote consultation and monitoring can be used to help the elderly obtain medical treatment.

Currently, the UK has developed a mature system owing to traditional healthcare strength and long-time research on smart healthcare applications.

Figure 13: Network requirements of application scenarios in smart healthcare

	Remote monitoring	Remote consultation	Remote imaging	Remote surgery	AR/VR healthcare
Characteristics	Medical monitoring through cameras and wearables	HD conferencing and data sharing to reach more areas	Remote ultrasound solution	Robots and HD audio-visual interaction	3D pathological model for remote high-precision surgery
Bandwidth	≥200Mbps	≥400Mbps	≥800Mbps	≥1Gbps	≥1Gbps
Latency	≤200ms	≤150ms	≤20ms	≤10ms	≤10ms

Source: Expert Interviews, Desk Research, EY Analysis

Smart Agriculture

New agriculture based on informatization and intelligence

Centering on informatization, smart agriculture leverages multiple technologies such as sensor networks, big data, and cloud computing, and uses intelligent devices and mobile platforms to implement information collection and full-coverage monitoring.

Although existing networks are sufficient to support current application scenarios at 50–100 Mbps, they cannot handle massive data and intelligent device control of smart agriculture.

The implementation of fiber optic networks promotes the development of smart agriculture in a more comprehensive and faster manner. This greatly saves the workforce and underpins a more complete, accurate, and efficient IoT system for agriculture.

Typical scenarios are as follows:

- **IoT-based agriculture:** In general, agricultural IoT devices include temperature and humidity sensors, soil water sensors, CO2 sensors, and monitoring probes. Empowered by fiber optic networks, agricultural IoT saves device costs while ensuring transmission quality.
- **Unmanned equipment:** The low latency feature of fiber optic networks has unleashed the potential of intelligent and unmanned devices. This includes unmanned aerial vehicles (UAVs) for crop protection, which meet diversified requirements such as chemical spraying.

Fiber optic network improves efficiency and yields

We need food to survive. To feed the world's increasing population, smart agriculture is introduced to ease food shortages and environmental pressure.

Through real-time monitoring, agricultural IoT uploads the real-time data of indicators, from soil acidity to temperature and humidity, to the data center. The received data is then analyzed and converged to identify the most efficient and comprehensive planting method.

As for workforce shortages caused by urbanization and social development, fiber optic networks enable unmanned devices that can be controlled remotely and precisely to replace human labor in some areas.

All-optical fiber optic networks with high bandwidth and low latency enable smart agriculture

Smart agriculture mainly relies on three features: high bandwidth, low latency, and all-optical connections.

During the development of smart agriculture, a large number of data files are generated through various channels. In a project by KPN in the Netherlands, HD photos of potatoes are taken and transmitted to the server through high-speed networks. After analysis results are obtained, protection measures are taken accordingly. With the help of fiber optic networks, the collection and transmission time is greatly shortened, effectively improving the crop yield.

With millisecond-level latency, fiber optic networks also strongly support unmanned devices in agriculture, such as intelligent chemical spraying and water supply. Various sensors and HD cameras are deployed in the farm to collect real-time data before sending it to the data center for processing. The data can then be used by managers to make decisions and deliver instructions.

Agricultural IoT needs to be supported by a large number of widely-deployed devices. Fiber optic networks are bound to upgrade these devices to achieve lower construction costs and more applications.

Smart agriculture in the U.S.

With world-leading technologies, the U.S. can feed its people with 1% of its population. This achievement of low labor input and high output relies on the adoption of smart agriculture. Mechanized agriculture in the U.S. is now mature after years of development. Farmers are also highly educated; they are more willing to embrace new technologies. These factors help accelerate the scale deployment of smart agriculture. Meanwhile, more than 100 data centers have been built to summarize and share information, providing powerful data support for smart agriculture.

Enterprise Cloudification

Enterprise cloudification enables cloud-based and intelligent services for enterprises

Based on leased or self-built clouds, enterprise cloudification helps enterprises achieve online and intelligent management of services, talent, and funds, thereby reducing investment in information-based infrastructure, optimizing management architecture, and in turn accelerating smart economy development.

Infrastructure as a service (IaaS) and platform as a service (PaaS) provided by cloud service providers are moving towards integrated software as a service (SaaS), helping enterprises migrate their services to the cloud. This migration poses higher requirements on network bandwidth and promotes investment in the optical communications industry.

Enterprise cloudification is an inevitable trend, and fiber optic network is ready to help enterprises move to the cloud

Enterprise cloudification is the actual application of data centers and cloud computing, and is the technical prerequisite for the industrial Internet and smart manufacturing. As the infrastructure of enterprise cloudification, data centers pose high requirements on fixed network bandwidth due to their huge data storage, computing, and transmission volumes. With the further development of enterprise cloudification, the utilization of cloud services is improved. Enterprises gain new service development opportunities and raise new requirements on reliability and latency of fixed networks. Featuring ultra-high bandwidth, high reliability, and ultra-low latency, fiber optic networks meet enterprises' requirements on fixed network transmission capabilities required by cloudification.

Enterprise cloudification significantly drives growth in the optical communications market

Currently, the overall cloudification rate of global small- and medium-sized enterprises (SMEs) is low, and some large-sized enterprises have already migrated their services to the cloud. In terms of industries, the cloudification rate of primary and secondary industries is lower than that of the tertiary industry. As various types and sizes of enterprises have different requirements for the uplink and downlink rates of networks, customized services at different levels are provided to meet the communication requirements of different private networks.

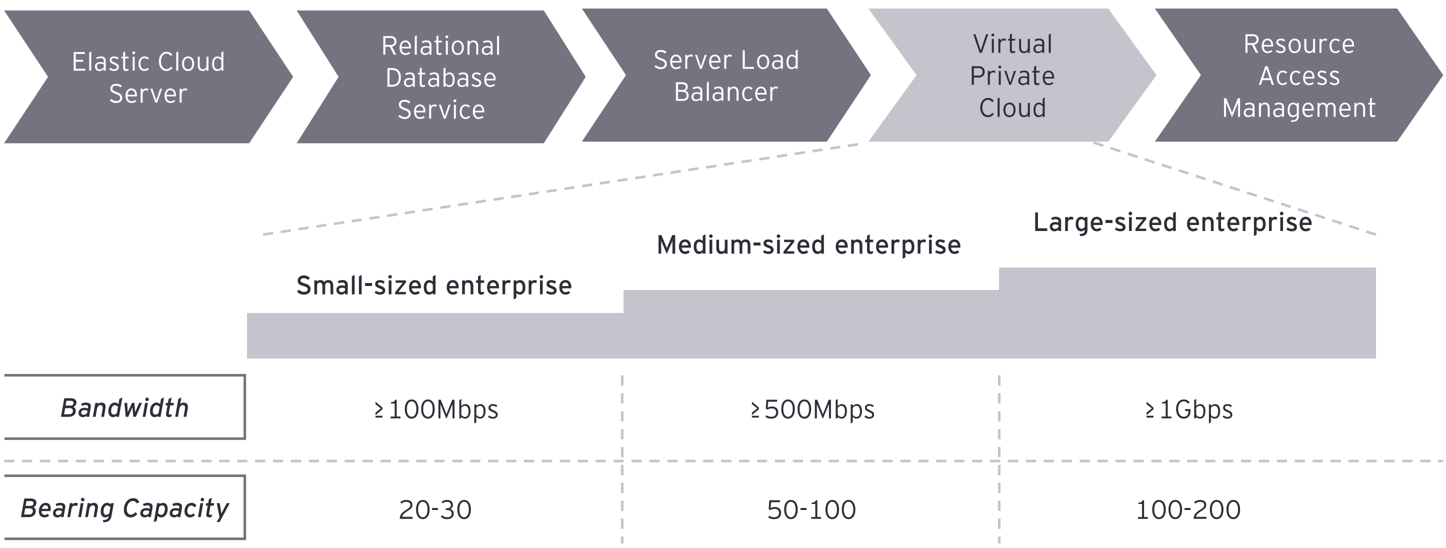
With an increasing number of SMEs migrating their services to the cloud, the demands for medium- and low-configuration networks increase. Compared with the high-configuration networks of large-sized enterprises, medium- and low-configuration networks require lower bandwidths but pose high speed, anti-interference, and accurate access requirements on fiber optic networks, which greatly promotes the optical communications industry's requirements for customized private networks. In addition, fiber optic networks provide higher confidentiality and significantly boost downstream Gigabit broadband optical transmission, resulting in the emergence of huge opportunities for fiber optic network development.

A large number of SMEs in Germany have a pressing need for migration to the cloud, bringing benefits to the optical communications industry

In Germany, optical communications and cloud computing technologies are mature. Enterprise cloudification significantly drives growth in the optical communications industry due to:

- **Strong economic growth:** Germany leads in global economic development and invests a lot in enterprise cloudification.
- **SMEs' strong desire to migrate services to the cloud:** SMEs serve as important pillars in Germany's national economy, accounting for 99% of the country's total number of enterprises. To achieve more efficient data interchange, SMEs have a strong desire to migrate services to the cloud.
- **Enhanced cloud computing capabilities:** Local cloud computing service providers in Germany develop rapidly to meet the increasing demands of enterprise cloudification for Internet data centers (IDCs).

Figure 14: Network requirements of enterprise cloudification



Source: Expert Interviews, Desk Research, EY Analysis

Gradual Implementation in Daily Life Scenarios
Smart Home

Intelligent and connected home devices

Smart home refers to an intelligent terminal system that connects household appliances using the Internet to implement remote monitoring and management. As an important part of the Internet of Things (IoT), the Smart Home system is built on a sensing system with sensors, actuators, and controllers covering the entire home.

Smart Home requires fiber optic networks to provide a high-speed network experience

Smart home devices can be interconnected through wired connections or Wi-Fi for network control. As the core of the smart home system, the smart home control center (smart home hubs such as Google Smart Home and Apple HomeKit) implements intelligent interconnection between multiple devices and systems through high-speed and stable network signals. The specific applications of smart home include intelligent device linkage, device maintenance and repair, and home security protection.

Smart home promotes the development of the optical communications industry

The further popularization of smart home around the world drives the requirements for Internet coverage and bandwidth. The increasing variety and intelligence of smart household appliances, such as gesture and voice control, pose higher requirements on network reliability and latency.

The popularity of fiber to the home (FTTH) and implementation of technologies such as Wi-Fi 6 better meet the network performance requirements of smart home devices. The explosive growth of demands drives synergistic growth in the optical communications industry.

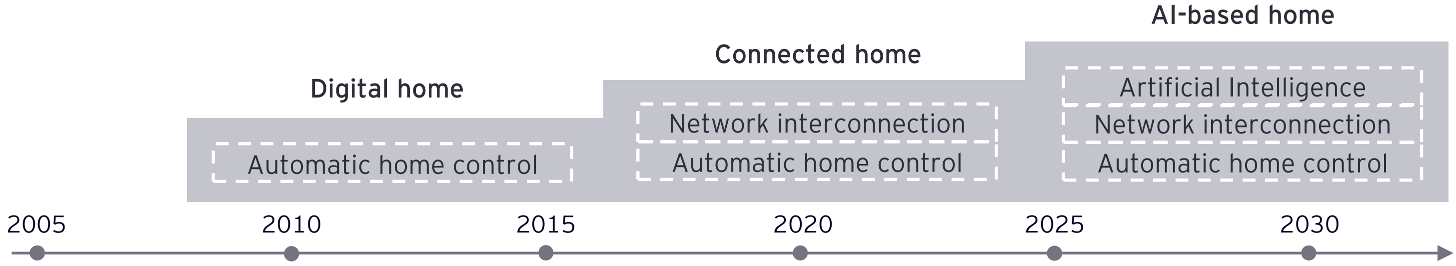
Supplies and demands increase simultaneously, and smart home develops rapidly in the United States

The smart home industry in the United States is more mature with higher industrialization and popularity among its people. Originated in the United States, the booming Internet industry facilitates the intelligent transformation and upgrade of American homes.

In addition, Amazon and Google are global leaders in technology and smart home appliances. They are continuously developing innovative and cost-effective products that drive people's demands for smart home appliances.

With smart home products warmly received by American consumers in recent years, the utility of smart home appliances has been further demonstrated, and customer acceptance is further improved. The fact that American customers tend to live in detached houses increases the demands for security protection. In this context, smart home has developed rapidly in the United States, driven by intelligent surveillance.

Figure 15: Smart home development timeline



Source: Expert Interviews, Desk Research, EY Analysis

Gradual Implementation in Daily Life Scenarios
Intelligent Transportation

Five major systems and IoV build an intelligent transportation system

Based on data analysis, collection, and transmission, the intelligent transportation system enables campus and urban traffic management systems, and can be classified into the emergency management system, advanced passenger information system, advanced public transportation system, advanced toll collection system and advanced transportation management system.

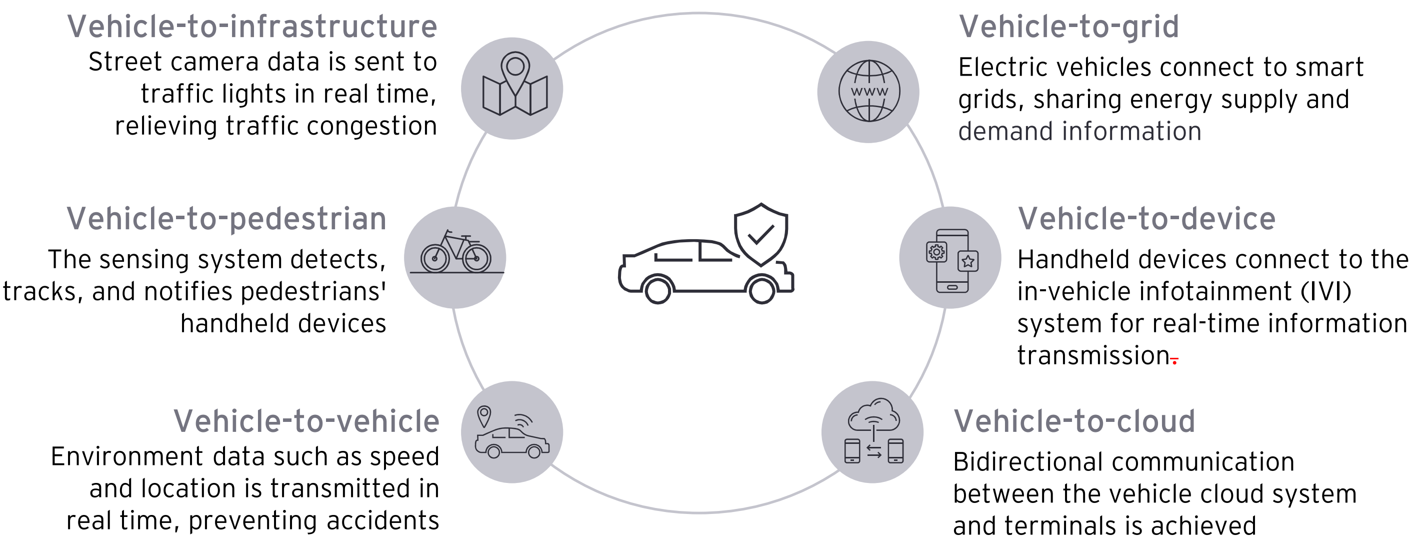
The Internet of Vehicles (IoV) is a major downstream application of intelligent transportation. The "vehicle-to-everything" (V2X) system connects vehicles, power grids, pedestrians, road infrastructure, etc. and provides comprehensive solutions such as route optimization and driving risk prevention and control.

Fiber optic networks are required to support the development of key applications in intelligent transportation

Intelligent transportation poses high requirements on fixed network capabilities and requires support from fiber optic network.

- **Municipal management:** Local governments utilize cloud computing and data centers which make use of fiber optic networks' high-bandwidth and massive-connection capability to store and analyze traffic flow data, supporting municipal planning.
- **Vehicle flow allocation:** Collects data based on traffic lights to calculate the comprehensive driving time, fuel consumption, and waiting time of vehicles. In real-time dispatching scenarios, traffic lights and sensors require higher real-time performance supported by fiber optic networks with lower latency.

Figure 16: IoV facilitates all-round terminal connections in intelligent transportation



Source: Expert Interviews, Desk Research, EY Analysis

- **Safety safeguarding:** Intelligent driving technologies are used to proactively prevent accidents based on real-time detection and quick guidance. Fiber optic networks feature low packet loss rate, which promotes the intelligent upgrade of the transportation safety system.

Intelligent transportation drives the construction of optical communications edge clouds and mobile base stations

With the continuous upgrade of autonomous vehicle technologies, intelligent transportation has increasing requirements on data transmission bandwidth. For example, autonomous driving systems require a latency of no more than 2 ms (lower than the average human response time) and high information accuracy. What's more, traffic lights have anti-interference requirements as they need to work in a stable manner for long periods of time in complex electromagnetically-affected environments, which also imposes higher requirements on signal transmission.

Intelligent traffic control is inevitable, and Brazil's optical communications market is on the rise

Brazil's intelligent transportation services are leading among developing countries, and optical communications development in transportation scenarios in Brazil is promising.

First, the population density in Brazil is high, and urban roads are severely congested. To address these challenges, intelligent transportation has become key. Second, Brazil has gained rich experience from intelligent transportation system applications during the 2016 Rio Olympic Games, laying the foundation for future development. Finally, compared with other countries that have a similar economic level, Brazil has mature intelligent transportation technologies and is leading the world in commercialization, facilitating the rapid development of intelligent transportation.

Gradual Implementation in Daily Life Scenarios

Smart Education

From information-based to intelligent education systems

Smart education is a new type of education that uses emerging Internet functions such as cloud computing, big data, and artificial intelligence (AI) based on traditional education. Smart education enriches traditional teaching modes, achieves refined and immersive teaching, and improves teaching efficiency and learning effects.

Smart education develops from traditional education and information-based education. It features four core scenarios (interactive class, campus office, analysis network, and VR/AR classroom) and several applications.

Sound network infrastructure is required for multi-win of vendors and operators in the industry

In response to an increasing number of smart education applications in multiple scenarios, all parties in the industry need to cooperate with each other to provide communication networks in each phase, thereby driving the development of upstream and downstream industries.

Figure 17: Core applications and network requirements of smart education

		Terminal quantity	Access bandwidth	Latency	Packet loss rate
Campus office	*Desktop office*	3-4/office	≥ 100Mbps	≤ 30ms	≤ 0.1%
	HD video conference	1-/conference room	≥ 200Mbps	≤ 40ms	≤ 0.1%
Analysis network	*Classroom terminal*	3-4/classroom	≥ 500Mbps	≤ 20ms	≤ 1%
	Outdoor terminal	4-6/playground	≥ 200Mbps	≤ 20ms	≤ 1%
VR/AR classroom	*Fair-experience VR/AR*	30-50/classroom	≥ 80Mbps	≤ 20ms	≤ 0.01%
	Comfortable-experience VR/AR	30-50/classroom	≥ 130Mbps	≤ 15ms	≤ 0.01%
	Ideal-experience VR/AR	30-50/classroom	≥ 540Mbps	≤ 10ms	≤ 0.01%

Source: Expert Interviews, Desk Research, EY Analysis

Online learning drives the development of smart education

Affected by the COVID-19 pandemic, schools have adopted remote education on a large scale. Currently, students at home mainly rely on fixed home broadband for online learning. However, because problems such as network frame freezing, image jitter, and unstable connections occur, smart education requires fiber optic network networks.

Global education raises higher requirements on communication network transmission

As global education resource sharing further develops, students from around the world access global high-quality education resources. However, packet loss and network jitter in long-distance communication aggravate network instability. As a result, global education also requires fiber optic networks to improve students' learning experience.

Next-generation optical communications networks effectively promote the development of smart education

Smart education poses high requirements on network bandwidth, latency, and jitter, against which fiber optic networks lay a solid foundation for comprehensive improvement in various scenarios.

Take the interactive class as an example: High-quality, timely, and stable remote multi-terminal interaction is the prerequisite for implementation. To meet these network requirements, the existing hardware facilities of the interactive class must be reconstructed and the cloud private line needs to be connected based on the actual teaching scenario. The access of the private line network helps implement real-time interaction between students and teachers, teachers and remote experts, and students.

The industry environment is mature, and smart education promotes the growth of the optical communications market in Japan

Thanks to the mature industry environment, smart education in Japan promotes the growth of the optical communications market.

Japan has well developed education philosophies. As one of the world's leading countries in education development, Japan develops rapidly in terms of education popularization rate, concepts, and forms. Smart education (such as smart classroom) has also developed early and on a large scale in Japan.

Japan also has many talents in education. It has a large number of high-quality teachers and other education practitioners who are more likely to receive Internet and AI training, promoting the rapid development of smart education.

At the same time, Japan's smart education infrastructure is relatively comprehensive. Japan has multiple big data platforms in education. For example, the big data system of the Learning Analytics Center at Kyushu University collects learning and teaching log data of multiple time and space granularities, providing strong support for the rapid development of smart education.

Other Scenarios

In addition to the emerging scenarios mentioned above, many other scenarios, such as finance, port, oilfield, and logistics, can also play a catalytic role in promoting the optical communications industry.

Smart finance

The financial industry is one that typically requires high network performance. With the rapid development of global finance, increasing volumes of international transactions occur every day, posing higher requirements on network transmission latency. As intelligence and digitalization deepen, the requirements for capabilities such as edge computing are attracting increasing amounts of attention within the industry.

Facing the mass data communication demands of the financial industry, fiber optic networks will undoubtedly provide higher-speeds and faster channels as it aims to solve data information asymmetry and data silo problems caused by limited network bandwidth.

Smart port and smart oilfield

Sites such as ports and oil fields place increasingly high demands on optical communications. Due to their complex working environments and the high skill requirements for personnel operating machines such as tower cranes, the industry is driving the implementation of new scenarios — such as intelligent production — to replace certain manual operations. This alternative offers improved efficiency while also effectively reducing safety risks during production.

In addition, due to the unique nature of these working environments, high requirements are imposed on the quality — with particular emphasis on reliability — of the network for real-time transmission. All-optical fiber optic network networks will undoubtedly be best placed to enable the implementation and development of new scenarios such as smart ports and smart oilfields.

Smart logistics

As consumption habits change and new models such as e-commerce and just-in-time (JIT) distribution continue to emerge, warehousing and logistics are also undergoing fundamental reform.

Indeed, the rapid development of warehousing and logistics technologies has introduced unmanned forklift trucks, automated guided vehicles (AGVs), multi-layer shuttle vehicles, and autonomous mobile robots (AMRs), all of which pose higher requirements on the bandwidth and latency of network communication.

Summary:

Emerging scenarios enable the upgrade of the optical communications industry

Emerging scenarios pose higher requirements on communications: higher rates, lower latency, and more connections. Traditional communications technologies are unable to meet these requirements, necessitating the rapid implementation of new technologies.

Infrastructure Scenario Upgrade:
Evolving Network Architecture and Enhancing Software/Hardware Performance

New scenarios boost new infrastructure construction-- Optical communication networks have become an important part of the new infrastructure, and one of the key elements for the development of the information society to meet the higher requirements of new scenarios on network performance. Fiber optic networks' new communications infrastructure includes the following key aspects: further large-scale deployment of optical cable networks, construction and continuous capacity expansion of data centers, and upgrade of campus POL networks.

Iterative Upgrade of Telecommunication Scenarios

Emerging communication scenarios pose higher requirements on the upgrade of telecommunication infrastructure, such as transmission rate, latency, and number of access terminals, encouraging the iterative upgrade of telecommunication scenarios.

Unbalanced development of global telecommunications

While countries around the world continue to promote the iterative upgrade of telecommunications, actual telecommunications development remains unbalanced between regions due to significant differences in technology accumulation, investment, and industry development. Specifically, the network coverage rate and fiber penetration rate differ greatly among countries at different development levels.

Policies support the construction of all-optical networks in cities

With the acceleration of smart cities and all-optical cities, governments have vigorously launched the "City Optical Network" initiative, formulated policies to promote industry upgrade, and are encouraging investment by operators to improve fiber access bandwidth and penetration rate, moving towards "All-optical City 1.0".

In its Future Telecom Infrastructure Review released in 2018, the UK was committed to have 15 million premises connected to full fiber by 2025 and nationwide coverage by 2033, and provides a £200 million Local Full Fiber Networks (LFFN) Challenge Fund for local bodies to bid into, to stimulate commercial investment in full fiber networks in both rural and urban locations across the UK. A further £67 million would fund the Gigabit Broadband Voucher Scheme for small businesses and the local communities to contribute to the cost of fiber installation. The National Telecommunications Agency or Anatel, the Brazilian telecommunications regulatory body, approved the Structural Plan of Telecommunication Networks (PERT), which aims to coordinate public and private communications requirements to maximize the efficiency of communications networks. In 2018, India adopted the National Digital Communications Policy to define optical fiber communications as one of the top development priorities and promote smart city development through the use of optical fibers in public utilities and infrastructure. By 2022, India plans to connect about 60% of telecommunications towers with optical fibers and deploy 32,000 km of optical cables.

In China, to build urban optical networks, cities at all levels are planning and constructing integrated service access points, backbone, distribution, and terminal optical cables, and residential networks. From the core network to the backbone network, transport network, and finally the access network, optical networks have basically replaced the original copper networks. The goal of "All-Optical City 1.0" has been preliminarily achieved.

In addition to FTTH, optical access scenarios are also becoming diversified, including factories, buildings, and large enterprises. Thanks to the favorable policies, China is moving towards the goal of "All-optical City 2.0". Fiber to the factory will further improve the connectivity reliability in the industrial manufacturing field. Fiber to the building will promote the upgrade of a large number of private lines for small and medium enterprises. At the same time, OTN is also extending to large enterprises and campuses. High-quality OTN connections are used to support digital transformation of large enterprises and enable business application expansion.

In addition to all-optical access, an all-optical city needs to implement Optical to Electrical Connection (OEC), all-optical switching, and all-optical autonomous driving to fully leverage the capabilities of a city's all-optical infrastructure. If the communications network is compared to urban road transportation, OEC points are similar to urban traffic hubs. All-optical switching points are overpasses, and all-optical autonomous driving is the traffic management department. An end-to-end all-optical network can be formed only after all parts are upgraded. The network can be directly connected between any two OEC points or between any OEC point and the cloud, providing the highest-quality service experience.

Therefore, government departments need to systematically consider the strategy of All-Optical City 2.0 to lay a solid foundation for smart city construction. In addition, the construction of All-Optical City 2.0 depends on the joint efforts of upstream and downstream enterprises in the optical communications industry chain and cross-industry enterprises in emerging scenarios. This will help build high-quality all-optical networks, foster industry application innovations, and support high-quality development of the digital economy.

Summary:

Policies encourage operators to achieve new mileage

Initiatives, policy reforms, and investments, together with operators' positive response to construction using optical fibers, not only accelerates evolution to the optical information era, but also grows the upstream industry value chain. Chip, module, and optical fiber manufacturers will experience beneficial results as a greater range of optical fiber applications become available.

Continuous Capacity Expansion of Data Centers

Internet data centers (IDCs) provide basic Internet platform services and value-added network services for customers through features such as high-speed Internet access bandwidth, high-performance LAN, and secure and reliable equipment room environments.

Emerging scenarios fuel demand for data centers

As maturing 5G and fiber optic network technologies drive the development of the Internet of Everything (IoE), new scenarios with high-speed requirements are continuing to emerge. In these scenarios, mass terminals are connected and mass data is generated on a single node. As such, upgraded data centers are urgently required to cope with the exponentially increasing Internet data volumes.

Boosting data centers drive the growing demand for data center interconnect (DCI)

- **Data growth stimulates the increase of DCI bandwidth:** DCI bandwidth is a major part of data center CAPEX. Insufficient optical fiber resources cause traffic bottlenecks between data centers. To meet the requirements of low-latency, large-volume, and highly-reliable interconnection between servers and storage devices in multiple data centers, DCI needs to provide ultra-high bandwidth with low latency and high reliability, and must connect multiple data centers to form an ultra-large data center campus. However, as the traffic between some core availability zones is far greater than 20T, the bandwidth of a single pair of optical fibers is insufficient.
- **Data growth stimulates fiber upgrade:** Due to the shortage of DCI fiber resources, single-fiber capacity must be improved in order to enhance data transmission efficiency. Specifically, a wide spectrum, high modulation formats, and high baud rates can be used to increase single-fiber capacity.
- **Data growth stimulates WDM device upgrade:** Technologies such as coherent algorithms and high integration of electrical- and optical-layer boards are used to reduce WDM device costs and power consumption, thereby supporting data growth. The introduction of intelligent functions simplifies the O&M of WDM devices, making them more suitable for data center engineers with IT backgrounds.

Increasing DCI demand attracts investment in data center industrialization

Data center development in emerging scenarios is driving the growth of DCI demand, and this will eventually necessitate investment in data centers for industry implementation. As data centers develop towards distributed cloud-based DCs, traffic gradually changes from intra-DC to inter-DC. Consequently, the interconnection between DCs needs to be upgraded and reconstructed. The incremental market for data centers and the structural reconstruction market for traditional data centers are huge.

Summary:

Emerging scenarios pose higher requirements on data processing and cloud storage, and this is driving the sharply increasing demand for data centers. Additionally, the increasing shortage of data center resources encourages the construction of data center infrastructure, which in turn drives the demand for DCI and DCN. As a result, fantastic growth potential remains likely for data centers in the long term.

Iteration and Upgrade of Campus Networks

Traditional local area networks (LANs) are usually composed of Ethernet copper cables. However, as services such as ultra-HD video conferencing, cloud services, massive data exchange, and mobile office place higher demands on data traffic, bandwidth, and compatibility between signals and devices, the LAN network's multi-layer switching and concurrent service management structure now face key bottlenecks, such as insufficient bandwidth, difficult upgrade and capacity expansion, and complex cabling and maintenance of switches and routers. These challenges make it increasingly difficult to meet campus network requirements through traditional methods. As flattened networks, high bandwidth, low latency, and easy management are now all required, an urgent upgrade of campus network architecture has become necessary.

This industry climate has led to the development of passive optical LAN (POL), a new LAN networking solution based on passive optical network (PON) technology.

Based on the anti-interference and low loss features of the fiber network, and the OLT and ONU structures of the POL network, this new solution features the following benefits:

- **High bandwidth:** approximately 10 times that of traditional LAN networks
- **Easy management:** two-layer flattened network
- **Enhanced energy conservation:** ELV equipment room footprint reduced by 80%, while energy savings have increased by more than 30%
- **High security:** avoiding electromagnetic interference and leakage
- **Low cost:** O&M expenses are reduced by approximately 60%
- **Full-service support:** including Wi-Fi, voice, data, video, broadband, and security access control
- **Long distance:** 20 km coverage for multiple buildings
- **Easy deployment:** mature construction solution
- **Easy maintenance:** simple fault locating and rectification

As a result, the POL network will continue to accelerate the replacement of the LAN network and play a more significant role in the fiber optic network era's digital campus networks.

The massive advantages offered by the POL network attract users from various scenarios, such as campuses (smart or otherwise), business sites, enterprises, hotels, governments, factories, finance, and shopping malls. Meanwhile, Enel also uses POL technology to complete their LAN construction and to further their green concept. In a similar vein, Singapore's Changi Airport has chosen the POL solution for their video backhaul network construction, while Mexico's Temptation Cancun Resort and India's Taj Mahal Palace & Tower also utilize the solution to improve their network transmission capabilities. In China, the State Grid Corporation of China (SGCC), the Hilton Hotel in Qingdao, Fudan University, Beijing Jiaotong University, Southwest University, YOFC's Science and Technology Park, and The Macau Roosevelt have also completed POL network deployment, taking the lead in the digital upgrade and smart campus domains.

According to Transparency Market Research (TMR) analysis data, the global POL market (including active devices, passive devices, and deployment) will continue to grow at a compound annual growth rate (CAGR) of over 20% from 2016 to 2024, and is expected to exceed €89 billion by 2024 based on statistics from different regions, devices, and applications.

The rapid growth of POL is driven by the maturity of solutions and improved user perception, and the penetration rate increases rapidly. China's POL market has the most vigorous growth. It is estimated that the addressable market (AM) of China's POL will continue to grow at a compound annual growth rate (CAGR) of over 80% in the next five years, making it the most important part of the global POL market.

Initiated by Huawei, Nokia, Yangtze Optical Fiber and Cable, Digital China, and China Overseas Property Management, the Optical Network Alliance (ONA) was established in October 2019. ONA is now with more than 70 members, including vendors, design institutes, and integrators. With the aim of promoting the all-optical industry, major work includes industry standards fostering, member development, application promotion, talent cultivation, and marketing campaigns. For standard fostering, major progress includes the launch of the world's first POL engineering technical standard and a technical amendment of the China National Architectural Design Standard with POL.

Summary:

Enterprise campus LAN upgrades propel the POL market

Original copper line campus LANs cannot meet the network performance expectations of emerging downstream scenarios such as smart working and enterprise cloudification. Consequently, the enterprise campus LAN requires an urgent upgrade.

Compared with traditional LAN networks, POL networks involve lower costs and better network performance. Driven by upstream requirements, the POL market is ushering in a new round of development.

Gradual Upgrade of Industrial Optical Networks

Fiber optic network supports industrial all-optical networks

The industrial all-optical network implements machine-to-machine (M2M) and machine-to-server (M2S) interconnections based on modular applications of the communications network. In this way, communication is achieved between people, devices, and information systems.

With the rapid development of optical communications, China has gained a leading edge in optical connection technologies. Under the current approach of new infrastructure construction, the leading optical connection technologies can be used in the industrial field. The cross-domain convergence will promote the digitalization, networking, and intelligence of China's industrial networks and industrial control fields.

Compared with traditional industrial Ethernet, the industrial optical network delivers stronger anti-electromagnetic interference capabilities and provides higher bandwidth, higher reliability, microsecond-level low latency, and highly concurrent topology for flexible deployment. It simplifies industrial equipment and production line architecture and facilitates collaboration through digital model communication. It enables force sensing/tactile computing and supports high level language programming to achieve highly flexible manufacturing.

The industrial all-optical network empowers traditional industries, particularly those in manufacturing, energy, and transportation scenarios. Given the continuous iteration and upgrade of communications networks, real-time monitoring and industrial data communication of high-speed M2M/M2S networks can be implemented in the fiber optic network era. In addition, these optical connections are reliable in real time and transparent in the upstream direction, allowing industries to support multiple protocol suites using a unified data model. This will create an open and secure ecosystem to facilitate world-wide interworking, reduce manufacturing cost, and boost productivity.

Figure 18

	Industrial Ethernet	Industrial Optical Network
Immunity to interference	Weak	Strong
Latency	<100 ms	<10 μs
Bandwidth	100 Mbps	10 Gbps
Energy consumption	High	Low

Source: Expert Interviews, Desk Research, EY Analysis

Summary:

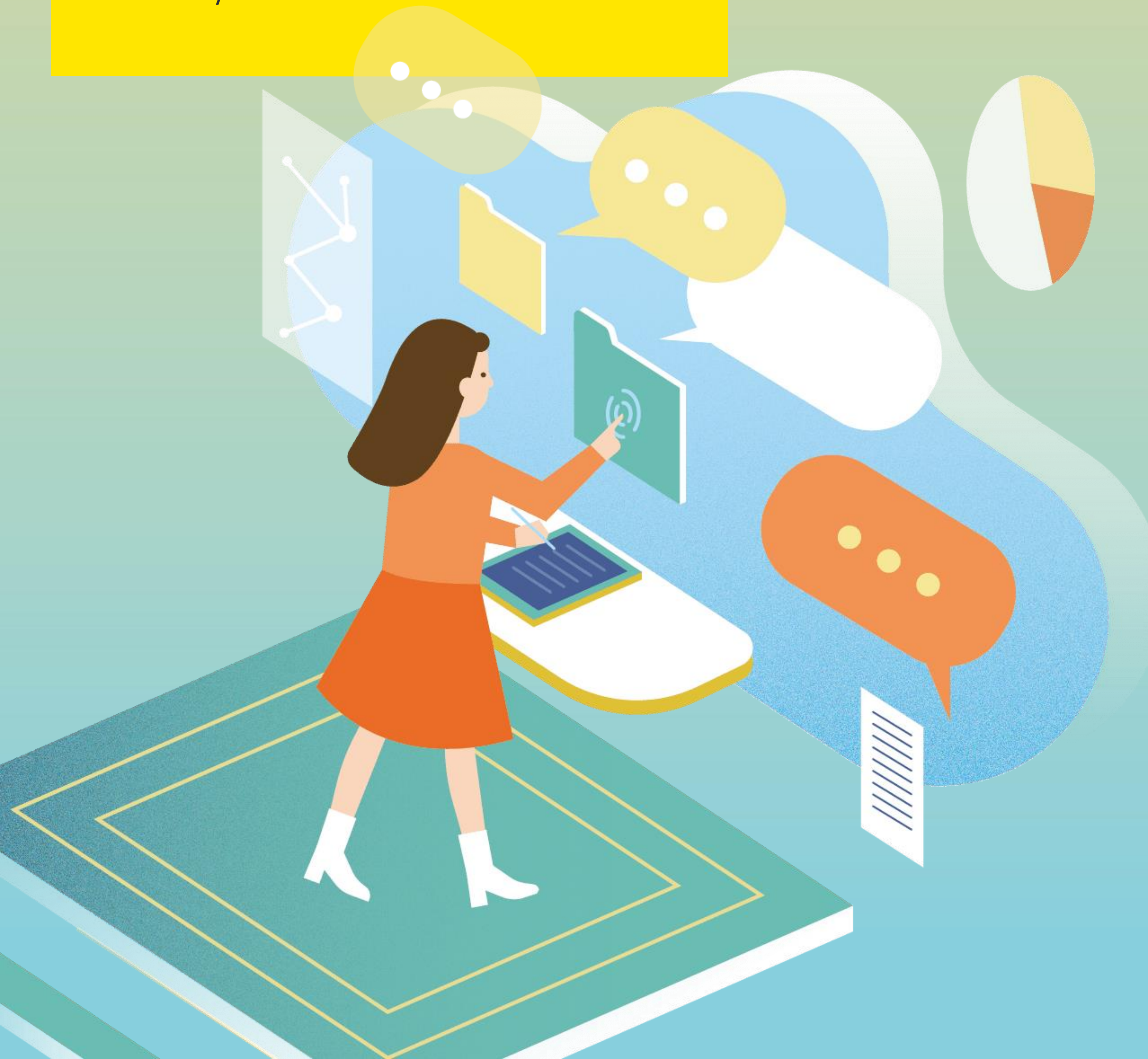
Robust development of infrastructure scenarios boosts upstream industry chain demand

Thanks to the ongoing support of policies, the deployment of optical networks, the construction and continuous capacity expansion of data centers, and the upgrade of campus POL networks and industrial all-optical networks have all been carried out on a large scale. As construction is gradually improved, the value of infrastructure construction investments in high-demand scenarios is further emphasized.

Optical communication manufacturers will embrace a new round of development peaks when construction projects are advancing and optical communication devices are applied on a large scale.

Chapter 3

Global Optical Communications Industry Outlook

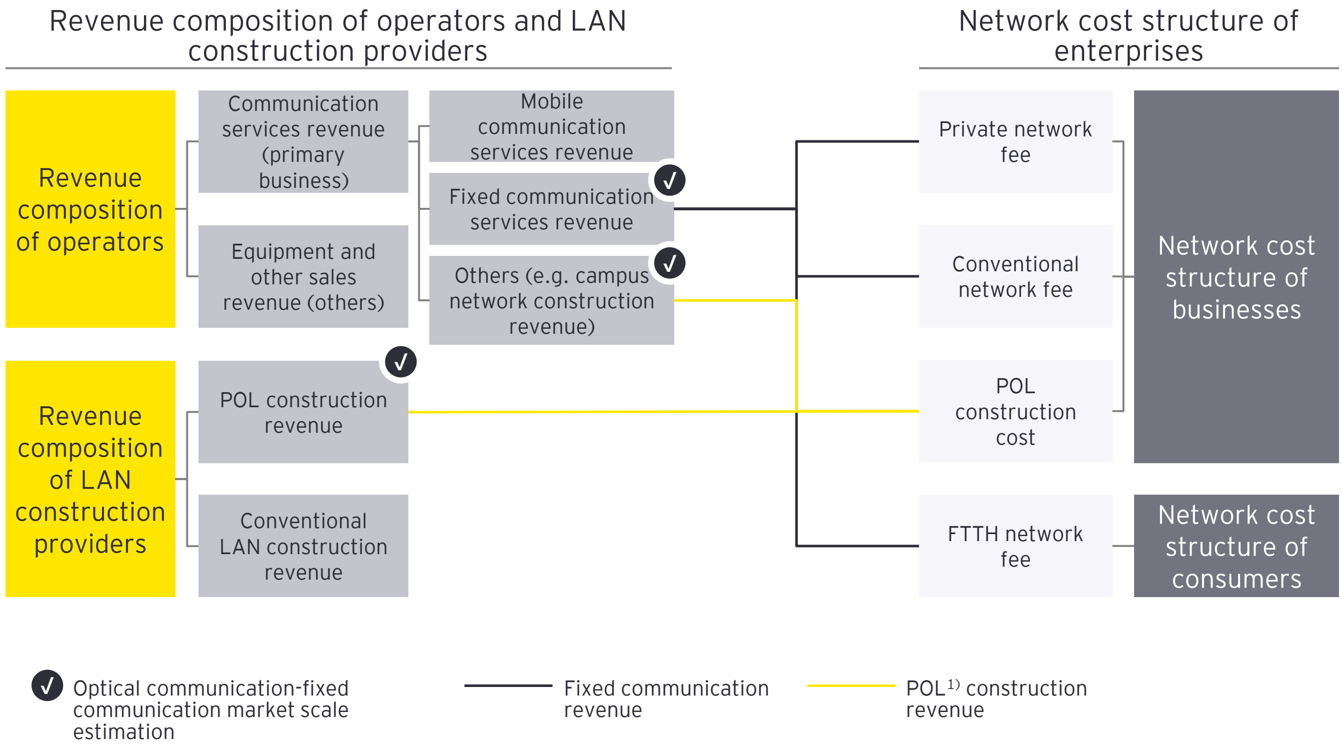


The optical communications industry has ushered in a historic development opportunity, with favorable policies and markets propelling the development of optical communications. fiber optic network, the foundation of the Internet of Everything, forms the solid base of intelligence for digital economies, empowering numerous industry verticals, and driving a market of hundreds of billions.

Global Optical Communications Market Scale Estimation

In this white paper, the estimation covers the fixed network revenue of operators and the POL revenue of LAN construction providers. It involves the cost of customers, such as bandwidth fee of users and private network, conventional network, and POL construction cost of enterprises, as shown in the following figure.

Figure 19: Application scenario - specific market scale estimation of optical communications market



Note: 1) POL: Passive Optical LAN

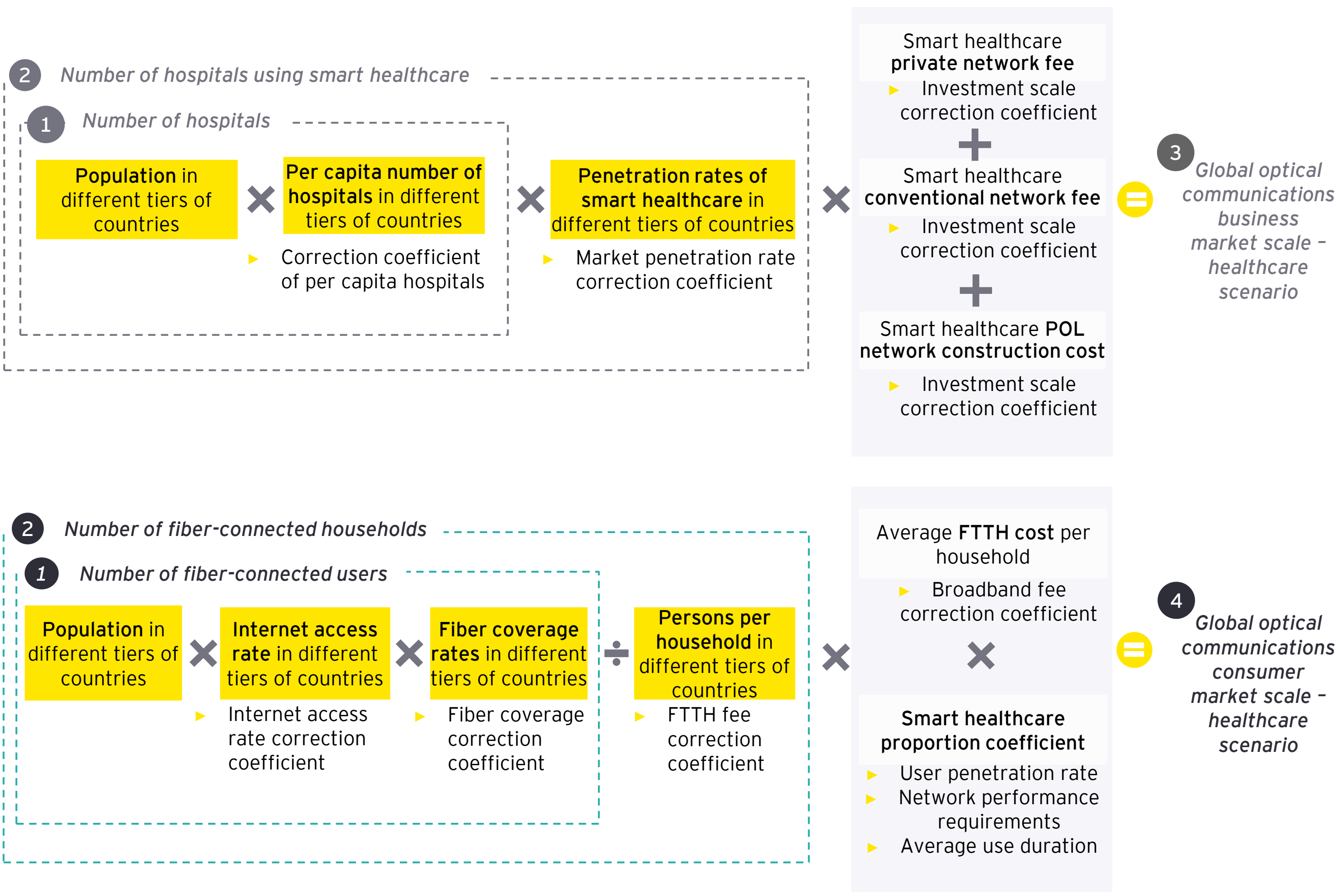
Source: EY Analysis

Core Calculation Logic and Scenario Example

The market scale can be estimated based on the research of business and consumer markets and the average data of typical countries, including developed, developing, and underdeveloped countries.

Take the smart healthcare scenario as an example. The business and consumer market scale can be estimated based on data such as network access rate, fiber coverage rate, fiber to the home (FTTH) network fee, user penetration rate, network performance requirements, average use duration, per capita number of hospitals, market penetration rate, and communication device investment cost in countries, as shown in the following figure.

Figure 20: Global optical communications - transport and access networks market scale calculation - smart healthcare scenario example



Source: EY Analysis

Size Calculation of the Global Optical Communications Industry Driven by Different Emerging Scenarios

In general, the revenue of the optical communications downstream market is expected to reach €175 billion in 2020 and maintain a high growth rate at around 18%. The revenue growth rate of the business market is slightly higher than that of the consumer market as it benefits from downstream emerging scenarios, campus optical network upgrade, data center and edge computing.

In the business optical communications market, downstream revenue mainly derives from expenses related to the construction of private networks, traditional networks, and POL networks. The overall growth rate of POL will be the fastest, jumping from €39 billion in 2020 to €115 billion in 2025. The rapid growth of POL is driven by the maturity of solutions and improved user perception, and the penetration rate increases rapidly. China's POL market has the most vigorous growth. It is estimated that the addressable market of China's POL will continue to grow at a compound annual growth rate (CAGR) of over 80% in the next five years, making it the most important part of the global POL market.

Figure 21: Downstream revenue of business/consumer market (€ Bn)

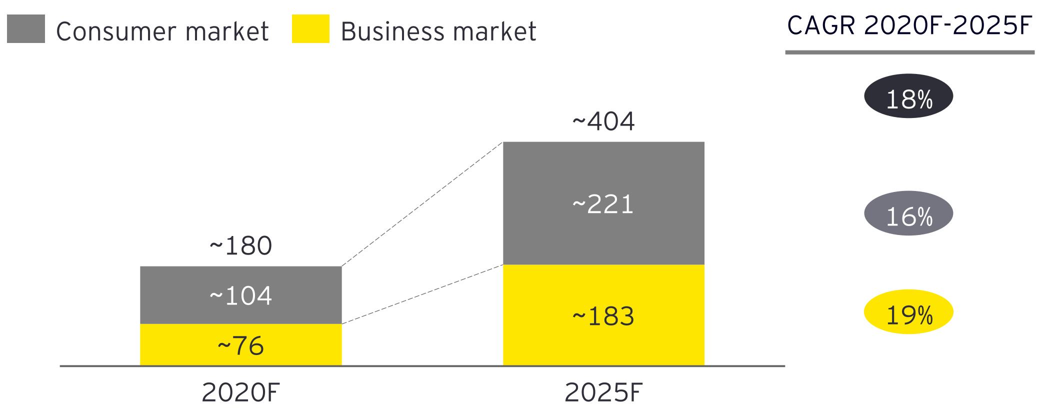
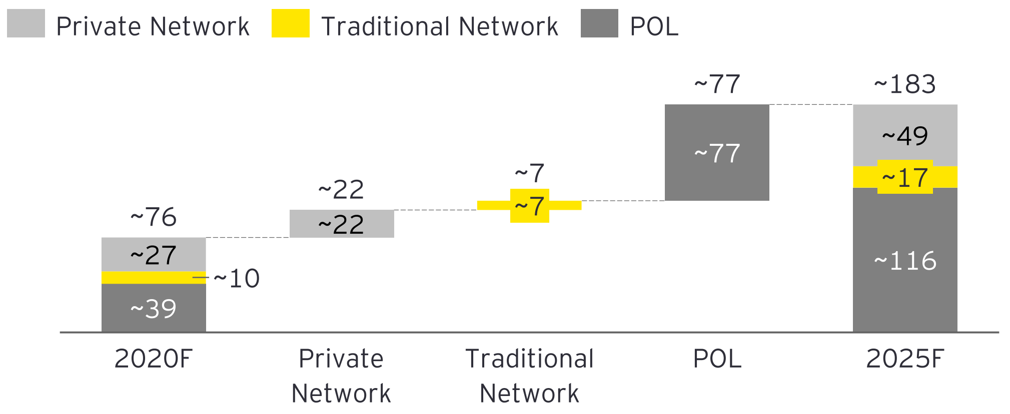


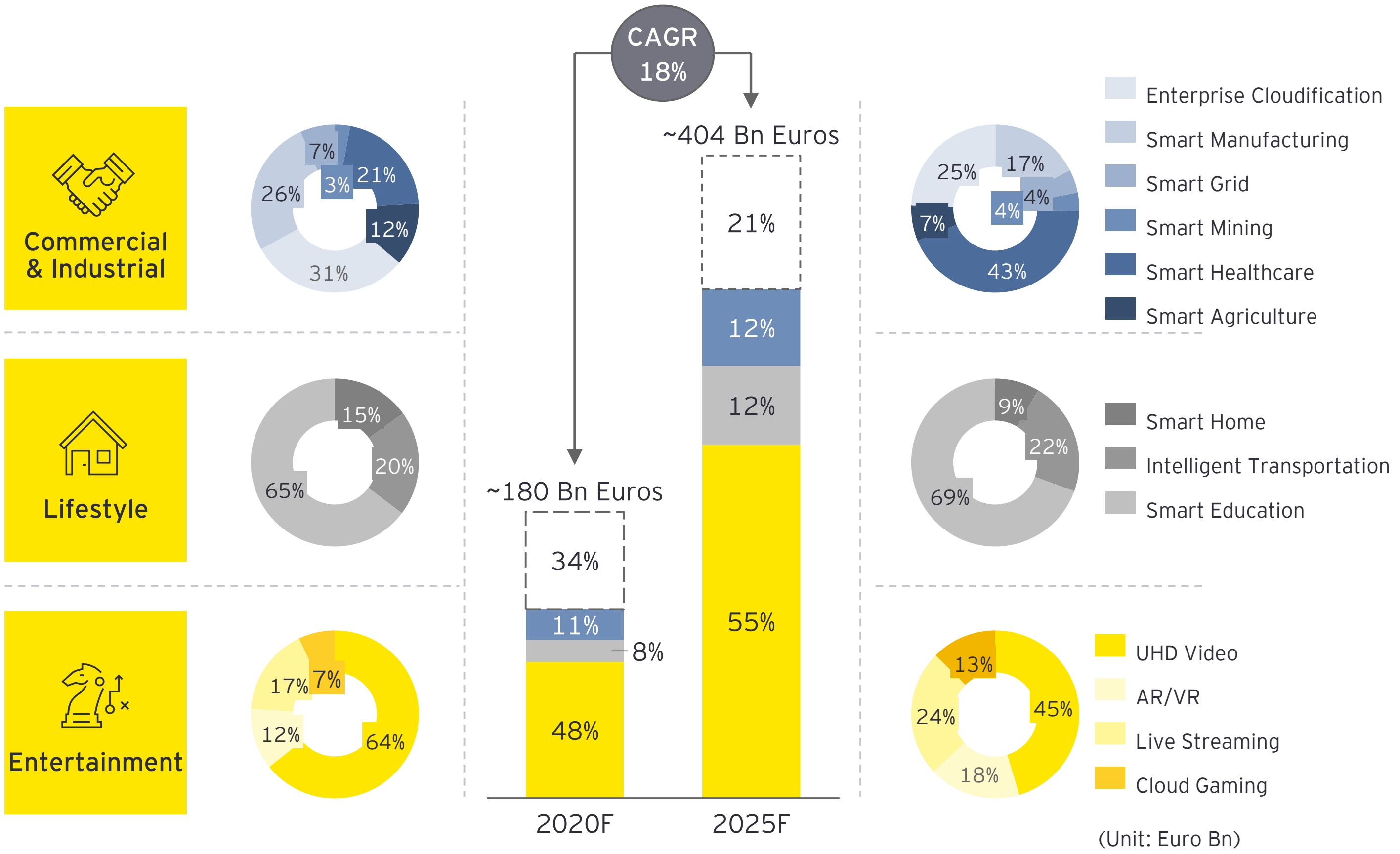
Figure 22: Downstream revenue of business market (€ Bn)



Source: Transparency Market Research, EY Analysis

Furthermore, emerging scenarios are playing a more important role in driving the consumer optical communications market. In 2020, increasing overall downstream revenue for optical communications is mainly driven by four emerging scenarios. Entertainment is the most significant driving force, and will account for 55% of the total revenue in 2025, up from 48% in 2020. Entertainment is driven by user requirements, with a rapid growth rate, of which ultra-HD videos account for the largest proportion. Despite this, the overall growth rate of VR/AR, live broadcasting, and cloud gaming is faster, while the growth of life and business scenarios is mainly affected by policies. Smart education and smart healthcare have higher growth rates than other scenarios.

Figure 23: Emerging scenarios drive the global fixed network optical communications market size



Source: EY Analysis

From the perspective of development levels, tier-3 countries have contributed greatly to the growth of downstream revenue for optical communications. The growth rate of tier-2 countries is slightly higher than that of tier-1 and tier-3 countries.

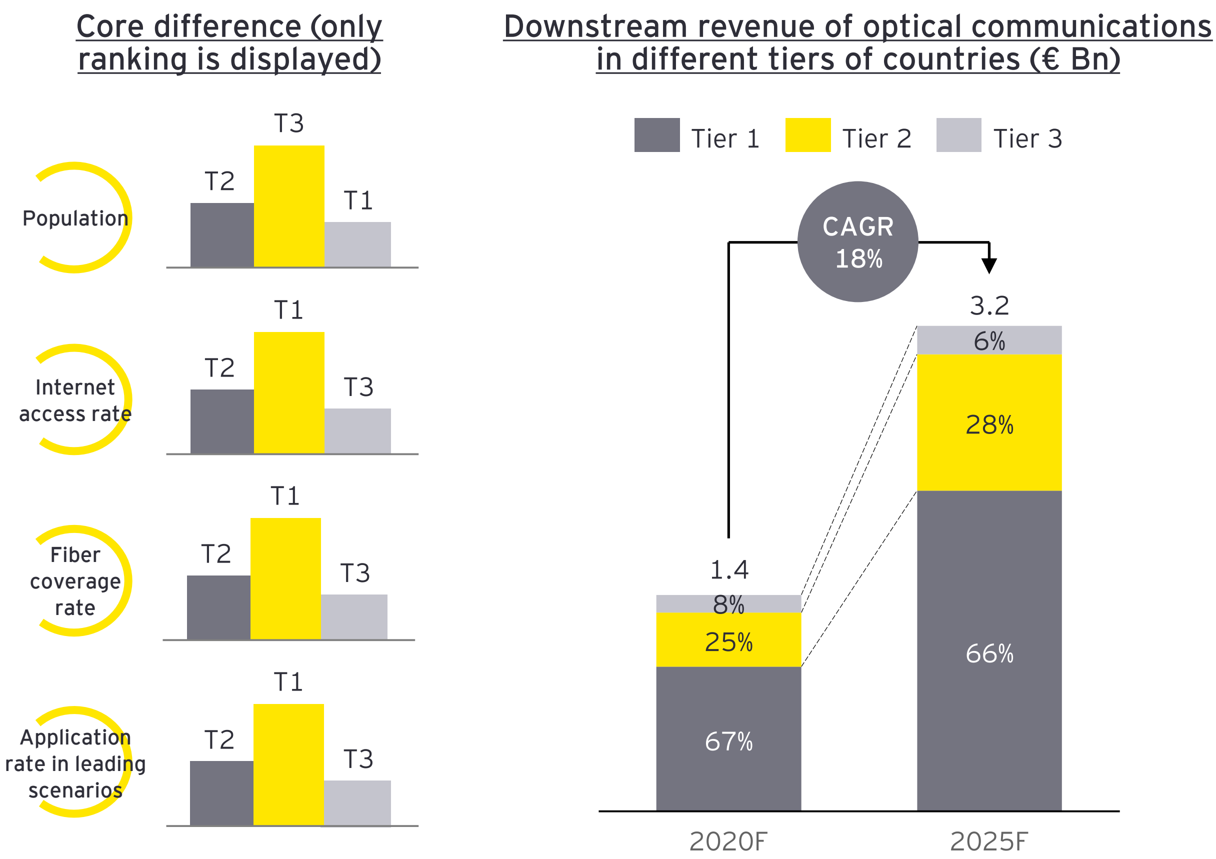
Tier-1 countries refer to countries with a per capita GDP that is greater than $12500. There are 55 such countries in total. For example, in South Korea, 97% of people have Internet access and 76% of households have optical fiber access, ranking top in Internet and fiber access. Tier-2 countries refer to countries whose per capita GDP is between $4000 and $12500. There are 50 such countries, including Brazil, which is one of the BRICS countries and the world's seventh largest economy with a strong industrial foundation. Meanwhile, there are 70 tier-3 countries with a per capita GDP lower than $4000. For example, Kenya is a highly industrialized country in Africa, and despite having a weak economy, it has huge development potential.

Summary:

COVID-19 has accelerated the demand for emerging scenarios in an effort to maintain social distancing in a number of different situations. This means there is a greater demand for remote services, such as distance education and telecommuting.

This has already resulted in the explosive growth of new services, including smart healthcare, smart education, and smart manufacturing. Likewise, growing demands for these services are pushing the service growth of operators.

Figure 24: Downstream revenue of optical communications in different tiers of countries (€ Bn)



Source: Oxford Economics, FTTH Council, EY Analysis

Conclusion

Over history, the development of human civilization correlates with the progress of science and technology. Now, we are entering a new era of transformation driven by informatization and digitalization.

Optical networks form the basic foundation of this transformation and helps build a smart ecosystem where all things are connected, and are indispensable for our entertainment, work, and life. Optical networks are reaching every household and business.

EY | Assurance | Tax | Strategy and Transactions | Consulting

APAC no. 03011098
ED None.

ey.com/china

Follow us on WeChat
Scan the QR code and stay up to date with the latest EY news.