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All-optical network facilitates the Carbon Shift.

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Contents

Executive Summary

The outbreak of the pandemic has led to an inevitable surge in the use of digital technologies and placed broadband networks as a key enabler for various digital applications in residential segment as well as enterprises, including teleconference, online education, 4K / 8K ultra-high-definition video, VR / AR games, cloud computing, etc. Meanwhile, the industry 4.0 is focusing on digitalizing manufacturing to improve operation. This will generate a large amount of data used by customer applications and for the operation and management of the network itself.

Facing the rapidly growing bandwidth demand and challenging network requirement of the new services, operators need to update their existing network infrastructure. Moreover, operators need to address various other challenges with their existing network, such as insufficient capacity to support future growth, large equipment footprints, high-power consumptions, and low operation and maintenance efficiency.

Fibre-powered broadband solution can help address these problems through providing high speed, low latency connections with high reliability and energy efficiency. Operators have focused on fibre networks to support the continuous increase in traffic.

According to IDATE, as of December 2021, there were 780 million FTTH/B subscribers worldwide and 1093 million FTTH/B home passed. FTTH promises connection speeds of up to 1Gb/s, 20 to 100 times faster than a typical cable modem or DSL connection. With the innovations of fibre technology, fibre connection will extend to everything everywhere, including rooms, enterprises, industry 4.0 and 5G backhaul, to build the all-optical network.

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

- Part 1 Introduces the climate change caused by global carbon emissions and the setting of carbon emission targets by countries around the world.
- Part 2 shows the carbon emission in the ICT industry and key factors affecting carbon emissions related to transmission networks operation. It also discusses the latest advancement in optical technology.
- Part 3 provides an overview of the current broadband market trends, covering data-heavy residential applications and digital transformations of enterprises.
- Part 4 discusses how an optical network based on an all-fibre infrastructure contributes to achieving sustainable development by reducing energy consumption in fixed networks, as well as by helping industries to reduce carbon emissions. The section also provides quantitative forecasts of CO_2 emissions reductions by 2030.
- Part 5 provides a perspective on current evolution in China on FTTR and vertical industries.
- Part 6 presents the document conclusions.

1. Global insights on carbon neutrality

1.1. Carbon emissions and global warming

Over the past 30 years, the world has witnessed a sharp increase in greenhouse gas emissions, with carbon emissions growing by a staggering 30%[1]. Global warming has risen to unprecedented levels, posing a significant threat to all life on Earth. The Intergovernmental Panel on Climate Change (IPCC) released a report titled *Climate Change Report 2021,* a document describing how humankind impact has had in accelerating climate change at record-breaking speeds. Taking targeted actions to limit and prevent global warming from becoming worse has never been more critical.

1.2. Carbon emission targets

To decrease the negative impacts of climate change, international organizations have launched climate change-related initiatives in numerous industries. The UN Secretary-General António Guterres said at the World Economic Forum: "Every country, city, financial institution and company should adopt plans for transitioning to net zero emissions by 2050 — and I encourage the main emitters to lead the way in taking decisive action now to get on the right path towards achieving this vision."

The United Nations Framework Convention on Climate Change (UNFCCC) adopted the landmark Paris Agreement, proposing to limit the rise in global average temperature to less than 2°C above pre-industrial levels, and strive to keep it within 1.5°C. More countries and organizations have responded to the UN's call to make commitments to achieve carbon neutrality. 195 countries have committed themselves to achieving net-zero carbon emissions by 2050. In addition, countries such as France and the United Kingdom have enacted laws to promote the achievement of carbon emission targets, and about 40 countries and more than 20 cities around the world have implemented carbon tax systems.

2. Carbon emissions in the optical industry

2.1. Distribution of carbon emissions in the ICT industry

After decades of development, the Information Communications Technology (ICT) industry now facilitates communication across the world, transforming the way people work and live, and promoting social and economic growth. It has become vital to the operations of nearly every sector, such as government, banking, power generation, and transportation, to drive society forward and usher in an era of digitalization. The deployment of networks in ICT is also increasing year on year, further expanding the positive impact of digitization. This requires network equipment deployment to increase. This adds the challenge of generating enough energy to power them all. ICT produces about 2%[2] of global carbon emissions, mainly from connected equipment, data centers, and transmission networks in the operation phase. The ICT industry has, however, found ways to enable the reduction of its carbon emissions, which is estimated to contribute much less in the future.

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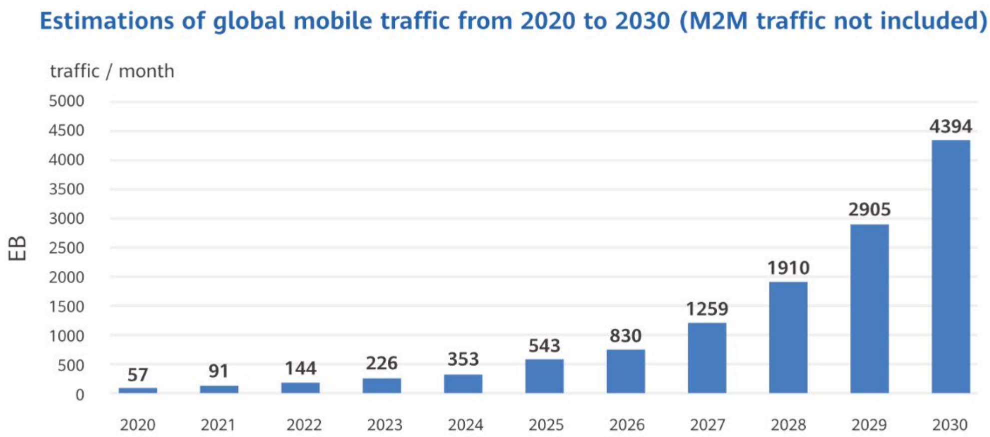
[1] IPCC, Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C

[2] Global e-Sustainability Initiative, Smarter 2030 report

Adopting the ICT solutions in essential sectors and services such as energy, transport, commerce, and construction reduces global carbon emissions by 15% while creating 15 million[3] green jobs, according to the *SMARTer 2030 Report,* released by Global Emissions Systems Inc (GeSI). The International Telecommunication Union (ITU) expects mobile communication network services to grow by 54% [3] annually. Balancing service growth and carbon emission reduction efforts has become a difficult but vital endeavor.

Figure 1 shows the estimated global mobile traffic growth. It is also expected that the fixed network traffic grows similarly, since the traffic growth is driven by new applications and services.

Figure 1: Estimations of global mobile traffic from 2020 to 2030 (M2M traffic not included)



Source: IDATE

Figure 2 shows the distribution of carbon emissions produced by network equipment.

Figure 2: Distribution of carbon emissions of network equipment

Source: IDATE

[3] GESI, *SMARTer 2030 Report*

More than 80% of network equipment carbon emissions are produced in the operation phase[4]. Therefore, an effective strategy for decreasing carbon emissions in the ICT industry is to improve network operation energy efficiency. That is adopting systematic innovations to improve the energy efficiency of telecommunications, from nodes to the whole network, to save energy, reduce emissions, and achieve green development. The most energy efficient solution is to deploy optical networks to the edge, to enable the green development of the industry.

2.2. Key factors affecting carbon emissions in ICT optical networks

2.2.1. Legacy copper access network

Even with the rapid development of telecom services, traditional copper line access technologies still exist in the access networks. Copper line technology has many problems, such as high construction costs and high maintenance costs. Bandwidth resources are limited, and users' requirements for high bandwidth cannot be met. It has become a bottleneck that restricts the development of new users and the provisioning of new services. In addition, copper lines consume a large amount of power. Therefore, it is urgent to upgrade and replace copper lines to the home to meet the increasing bandwidth requirements and build green access networks.

2.2.2. Legacy SDH/SONET: small capacity, large space, and high energy consumption

After decades of development, some traffic is still carried on SDH equipment. SDH network capacity and capabilities cannot be expanded to meet the deployment requirements of high-bandwidth and high-quality services. In addition, most SDH networks have been in service for more than 10 years, which is approaching the end of their lifecycle. The lack of spare parts makes maintenance difficult, and fault rates have increased significantly.

2.2.3. Existing 10G/40G/100G WDM networks: high network proportion and high per-bit energy consumption

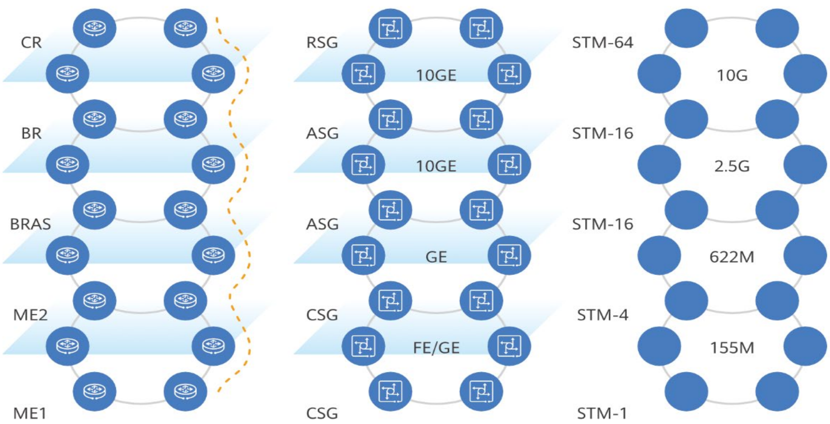
With the rapid growth of global data traffic year on year, traditional low-speed 10G/40G/100G WDM networks are bandwidth limited and cannot meet the access requirements of high-speed customer interfaces. With the mature development of beyond 100G technologies and the introduction of high-speed ports, 8-wavelength 200G lines can fully support the service capacity of the traditional 10G WDM 80-wavelength system, reducing per-bit energy consumption by 50%.

[4] IDATE analysis based on equipment manufacturers interviews

2.3. Multi-layer networking, hop-by-hop forwarding, and multi-platform stacking create high energy consumption.

Legacy networks use multi-layer aggregation and hop-by-hop forwarding, such as the Figure 3, which have Core Router (CR), Border Router (BR), Broadband Remote Access Server (BRAS), Aggregation Site Gateway (ASG), and Cell Site Gateway (CSG) layer. Most services undergo multiple Optical/Electrical (O/E) conversions when passing through multi-section paths. Flattening the networks can minimize unnecessary O/E conversions to reduce energy consumption. Energy consumption can be reduced by more than 50%, by introducing energy-saving method in the transmission domain. Figure 3 shows all the existing legacy network architectures.

Figure 3: Legacy network architectures

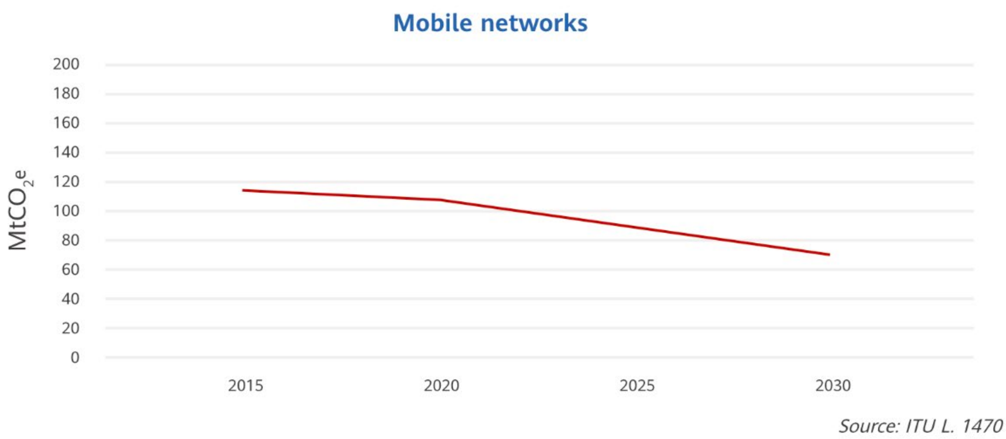


Source: IDATE

2.4. Carbon emission targets for the ICT communications network industry

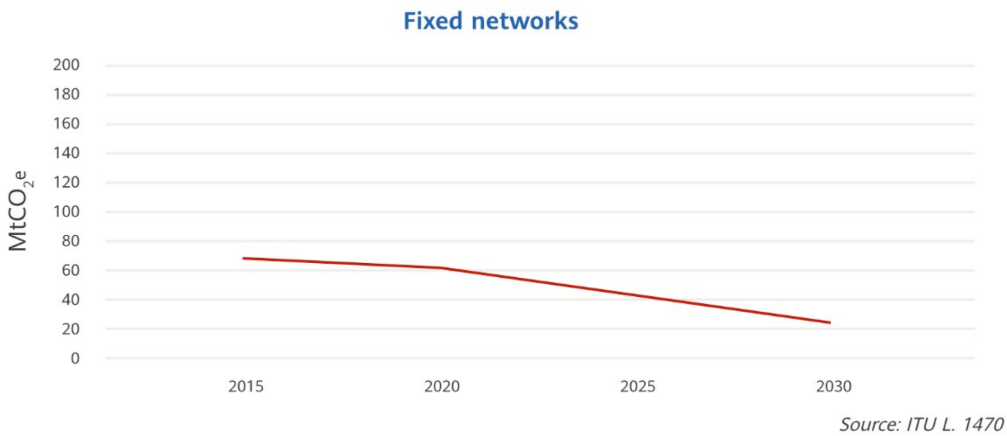
ITU worked with GSMA, GeSI, 29 major operators worldwide, and other organizations to develop carbon emission roadmaps and assessment methods for the ICT industry and its sub-domains. The result of the activity is an industry climate action plan, and the document “Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement” (ITU L.1470). Figures 4 and 5 show the carbon emission targets in ITU L.1470 for mobile networks and fixed networks. Some of these operators also joined the European Green Digital Alliance (EGDC), pledging to set carbon reduction targets by 2030 and to achieve carbon neutrality by 2040.

Figure 4: Carbon emission target of mobile networks



Source: ITU L.1470

Figure 5: Carbon emission target of fixed networks



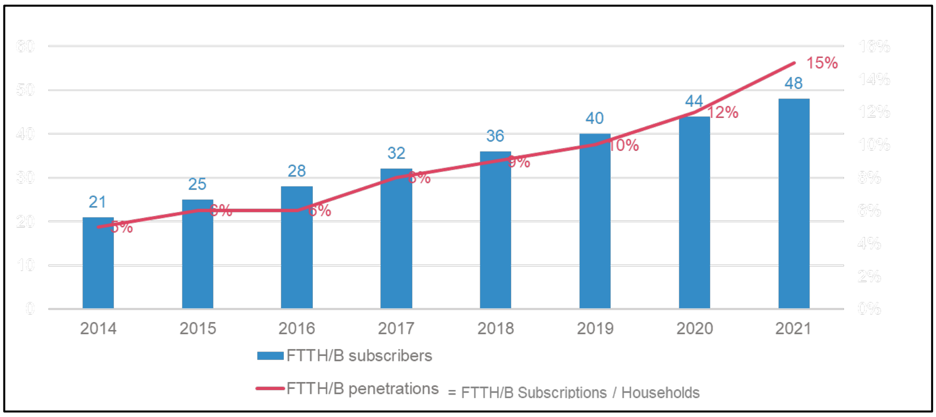
Source: ITU L. 1470

2.5 The evolution towards an all-optical network

Evolution of average EU network performance

Over the past decade, the European commission and its member countries supported the deployment of fibre networks and a full fibre strategy by allocating funds to speed up optical network deployment. In recent years, incumbent operators have started to announce their copper network switch-off dates and to implement the decommissioning of their legacy networks. Meanwhile, fibre optics deployment to homes in the European Union has tripled in the last five years, reaching 99 million subscribers and 118 million homes passed in 2021, according to FTTH Council Europe with data from IDATE (as shown in Figure 6).

Figure 6: Europe FTTH subscribers (million) and FTTH/B penetration rate (%)



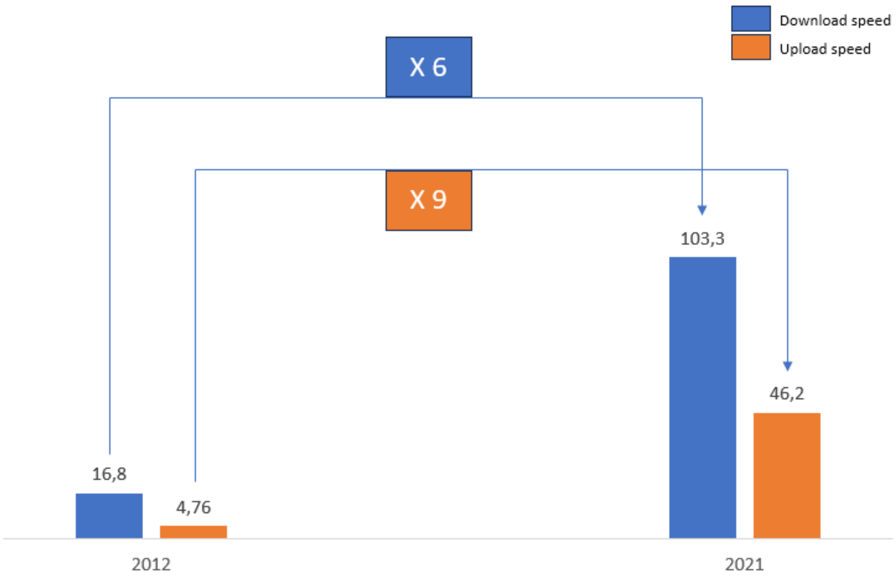
Source: IDATE

Figure 7 shows that the average Internet performance in Europe has improved dramatically over the past ten years. This speed is the actual speed measured at households by IDATE partners. The speed is highly dependent on local loop technology.

The average fixed line download speeds increased six-fold, from 16,8 Mb/s in 2012 to 103.3 Mb/s in June 2021, while upload speeds have increased by a factor of 9, from 4,76 Mb/s to 46.2 Mb/s. The average speed at the household's level is highly dependent on the local loop technology used. The progressive migration from DSL technology to FTTx technology is the key lever for a higher bandwidth availability and hence bandwidth consumption.

We must emphasize that upload speed increase has been by far the largest contributor to internet traffic increase. Cloud services, gaming services and other internet-based services are maintaining the pressure on upload speed. The digitalization of our societies, both from a residential and professional perspective, will probably speed up and progressively lead to a catch up of upload and download speed in the medium term.

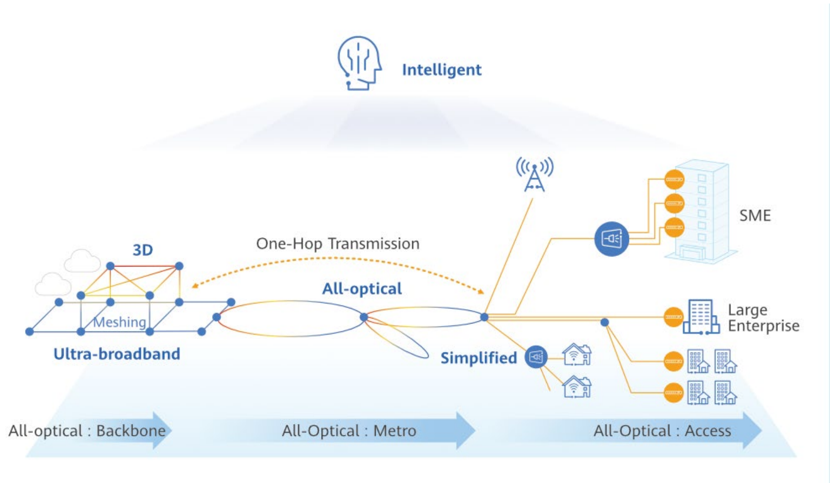
Figure 7: Evolution of European countries' average Internet speed (Mb/s)



Source: IDATE

The following all-optical network shows the end-to-end vision, including three domains: Backbone/core, Metro and Access.

Figure 8: All-optical network architecture



Source: IDATE

2.5.1 Future PON technologies moving beyond 10G PON for access network

During the last decade, the Passive Optical Network (PON) has been the key enabler of fixed network optical access worldwide. The PON system is an optical-fibre-based network architecture that can provide much higher bandwidth in the access network compared to traditional copper-based networks and allows for the connection by fibre optics of multiple users without the requirement to use active devices that need external power sources. PON can be used for different FTTx solutions, including Fibre To The Building (FTTB), Fibre To The Curb (FTTC), Fibre To The Home (FTTH) and Fibre To The Desk (FTTD).

The GPON standard was released in 2004 by the ITU-T, and the technology has been deployed since 2009. In 2012, the first phase of the XG(S)-PON standard was published and in 2016 operators have begun to launch 10G PON around the world, especially in Asia and the USA. In 2020, the IEEE standard organization has first approved 25G/50G EPON standard. The ITU-T, in 2018, began to develop 50G PON technology solutions and the standard was approved in September 2021.

Improved bandwidth powering the evolution of PON

The main driver for each PON technology upgrade has been bandwidth demand increase. New digital services, such as video services, gaming services, residential and professional cloud services, and new wireless technologies such as 5G or Wi-Fi6 require faster transport and symmetric bandwidth.

The first-generation GPON technology, gradually replacing the existing copper cable access technology, can provide 100 Mb/s service bandwidths to users. 10G PON is the start of the second generation and has overtaken GPON. 10G PON technology is lined up to overtake GPON as the dominant PON solution. Bandwidth per user (FTTH scenario) can go up to 1 Gb/s or higher. 50G PON has already been defined by ITU-T as new PON and was released in September 2021. It will provide flexible bandwidths to meet various service needs. For example, the bandwidth per user of the 50G PON technology (FTTH scenario) can go up to 10 Gb/s. Figure 9 shows a summary of the different PON technology characteristics.

Figure 9: Summary of PON technological characteristics

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

Source ： IDATE

2.5.2. Optical Metro network technologies

- **OTN to the network edge**

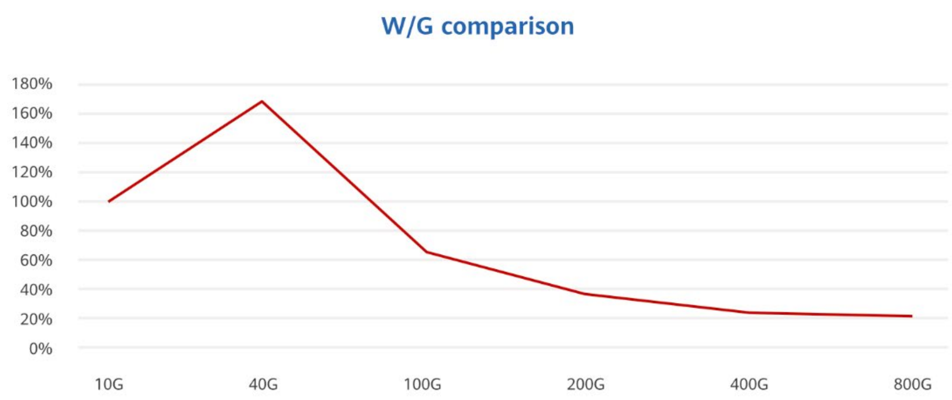
5G, local applications, and the number of connected IOT devices will drive network edge traffic growth in the next few years. According to IDC, *more than* half of new enterprise IT infrastructure *will* be at the *edge* by 2023. In addition, increasingly emerging applications have very strict performance requirements such as low delay. Operators are looking for better solutions to transfer data in the network edge in an efficiency way with limited environmental impacts.

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

The extension of OTN to network edges such as central offices, is very important to provide the premium experiences for connected home application with large bandwidth requirement, industry 4.0, and 5G xhaul. The innovations in OTN technologies enable flexible deployment, high integration, and smooth evolution for future generation of PON technologies. They allow operators to manage the challenges in the current networks, especially in the aggregation and access segments, such as lack of space and high-power consumption, and problematic support of future capacity growth.

Figure 10 shows the watts per gigabit power consumption per line port, compared against 10G. This analysis shows a reduction trend with the evolution of the new technologies. The energy consumed by the latest technology, namely starting with 100G, consume far less energy per gigabit than previous technologies. The growing trend of data consumption demonstrated before will beneficiate from the newest technologies that mitigate the energy consumption increase, hence the carbon impact.

Figure 10: Power consumption comparison and analysis of line ports (watt per gigabit, index 100 for 10G technology)



Source: IDATE

2.5.3. Innovations unlocking the Potential of Backbone Networks

- **400G/800G trends**

The demand for higher transmission capacity, lower per-bit transmission costs, and power consumption has always driven optical modules towards higher transmission rates. With the explosion of Internet traffic and new service requirements, the backbone network also needs to be upgraded to meet higher bandwidth requirements. Currently the backbone can handle traffic at 100G and 200G line rates. However, the increasing traffic growth will made 100G and 200G insufficient to meet bandwidth requirement. 400G is expected to replace 100G and 200G deployments soon.

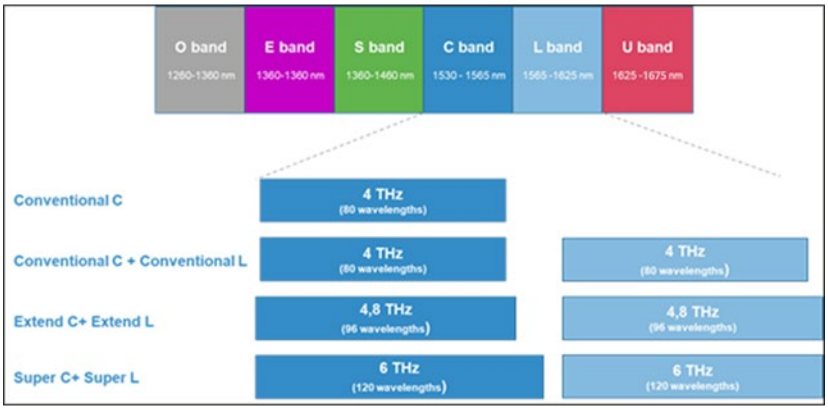
A shift towards 400G backbone is underway, which is driven by the following factors:

- Emerging applications and services: 400G backbone Internet will significantly improve bandwidth to support data-hungry applications such as high-definition video streaming, cloud computing, and big data analytics.

- Cloud computing: with the massive adoption of cloud computing technologies, and cloud-based service with demand for increasing bandwidth capacity and low latency, 400G is essential to provide high speed connections between data centers as well as data centers and users.
- 5G network and edge computing: edge computing is a crucial part of 5G to bring cloud capability closer to the end users. The extension of 400G fibre connection to edge nodes provides the foundation to support 5G service demand, such as autonomous vehicles, VR/AR and 4K video streaming.
- **C+L band**

Recent advancements in C+L band technologies have the potential to greatly expand the transmission capacity and speed of optical backbone networks. Compared to the conventional C+L band, covering the wavelength range of 1530-1625 nm, the super C+L band extends this range to 1450-1700 nm, which can support 240 wavelengths, offering a larger wavelength range (see Figure 11).

Figure 11: Different wavelengths of fibre optical communication band



Source: IDATE

The integration of C+L band capabilities into one ROADM is a recent advancement in optical technology that provides enhanced capacity and more flexible management of optical signals. This can also enable network operators to manage and route C+L band optical signals more efficiently.

2.5.4. All-optical network extension to fibre to everything

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

The all-optical network has been successfully deployed and put into practice on backbone networks as an infrastructure network. At the same time, the OTN network is constantly moving closer to the metro and Optical Line Termination (OLT) sites. The OTN technology enables a single fibre network to carry multiple services, maximizing the utilization of fibre resources and achieving green and low-carbon networks.

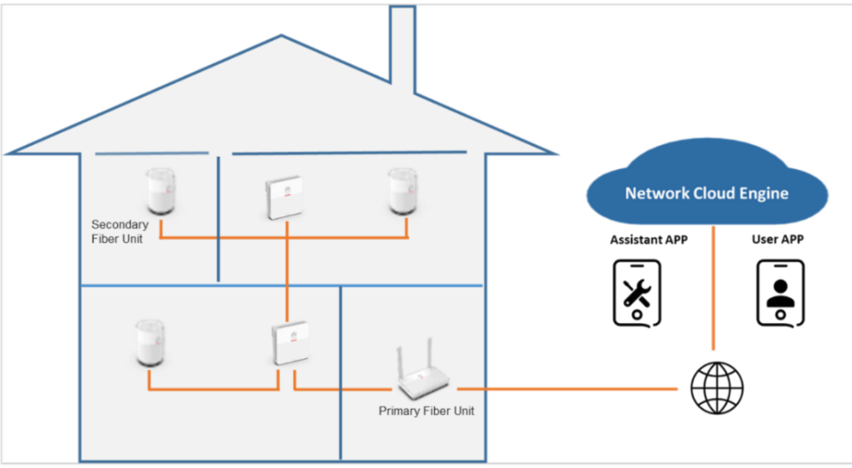
All-optical switching is constantly moving closer to the metro core, metro aggregation, and network edge sites. The target network features all-optical, ultra-broadband, 3D, mesh, simplicity, and intelligence, thereby meeting the requirements of various industries for high bandwidth, low latency, and low carbon emissions in the 5G and cloud era.

2.5.5. Fibre-to-the-Room offers a high-speed full fibre connection for a variety of new home applications.

The home Broadband is moving from entertainment centric to multifunctional centric. High speed broadband is a major prerequisite for enjoyment of high quality entertainment and for access to companies' resources through the cloud and supports a variety of smart home devices.

FTTR is the next step in the evolution of FTTH solutions. In the FTTR architecture (see Figure 12 for the overall architecture), a Primary ONU (P-ONU) is connected via optical fibre to multiple Edge ONU (E-ONU) placed in different locations. Both the P-ONU and E-ONU can provide Wi-Fi 6 access, enabling gigabit speed access in every part of the house. Mobile apps are used for monitoring, maintenance, and management of the entire network. The P-ONU is located between the Optical Line Terminal (OLT) and the E-ONU at the local end and serves as the main control center of the home network, enabling unified management and configuration of all the E-ONUs.

Figure 12: FTTR architecture



Source: IDATE (Primary and Secondary Fibre Unit are equivalent to P-ONU and E-ONU in the F5G architecture)

Compared to traditional FTTH technology, FTTR shows various advantages:

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

Easy installation and greener solution: fibre is easy to deploy in-house because of the lightweight and small diameter of optical fibre cable. On average, it takes only 20 minutes to complete a Wi-Fi access point deployment (shown by a southern American operator). Additionally, FTTR is also a “greener” solution, reducing energy consumption by 30% compared to cable connection, enabled by the low loss of optical fibre.

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

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

2.5.6. All-optical networks accelerate the digital transformation of SMEs

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

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

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

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

3. Current broadband market status

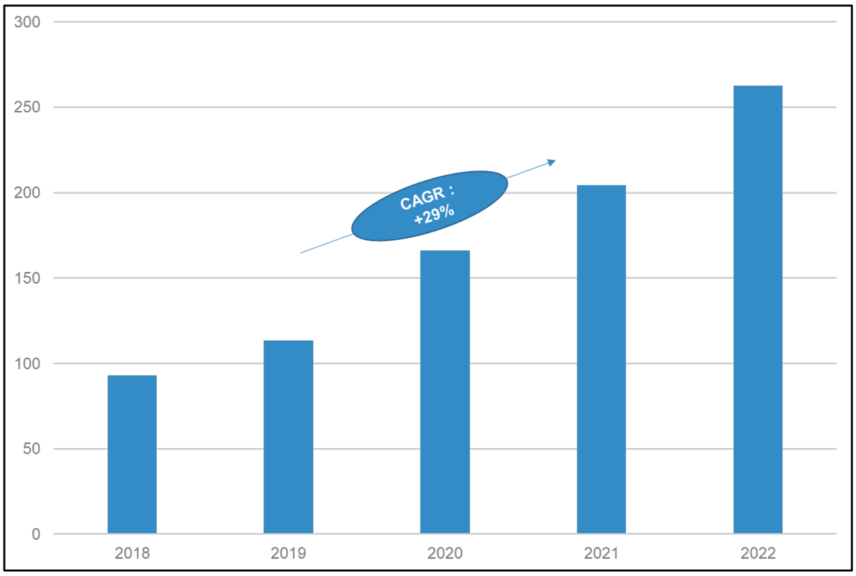
3.1. Increase of residential gigabit broadband demand through new data-heavy applications

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

Since the outbreak of Covid-19, home broadband has experienced a surge in Internet traffic. Figure 13 shows that the average Internet traffic reached 262 Terabytes per second in 2022, increasing at a CAGR of 29%. The average traffic growth increased from 22% from 2018-2019 (before Covid-19) to 30% from 2021 - 2022 (post Covid-19), while peak traffic growth went from 20% to 28% over the same period. Traffic growth can be attributed to a variety of Internet video services, such as video conferencing, online education, and telemedicine. At one of the biggest Internet Exchange Points in Frankfurt, video conference traffic increased 120% and online and cloud gaming increased 30%.

Extrapolating a 29% Compound Annual Growth Rate (CAGR) would mean that in 2030 we can expect to have around 2 Petabytes of global Internet traffic.

Figure 13: Global International Internet Traffic (Tb per second)



Source: Telegeography

The quality of experience of broadband networks has become more critical than ever. Although superfast broadband entertainment is sufficient for most household needs, the demand for services that use a lot of data, such as online video streaming, continues to increase even after the pandemic. COVID-19 has further highlighted the need for widely available and reliable digital connectivity. The pandemic fueled the necessity of home office, home-schooling, and home entertainment which will continue to drive the need not just for higher speeds, but also for lower latency and increased data volume consumption driven by increased use of video calls, cloud services, and media.

High-speed broadband is a major prerequisite for the enjoyment of high-quality entertainment content, access to company' resources via the cloud access, and supporting a variety of smart home devices. High-quality entertainment content such as 4K/8K, online gaming, and VR/AR are gaining popularity at home.

Adding upstream capacity will be increasingly important as people use more high-bandwidth two-way communications-like video conferencing and upload more and more video to the cloud. Customers expect higher bandwidth to ensure smooth Internet access at any time. At the same time, the emergence of new services requires higher peak bandwidth and lower latency. Network interaction during busy times leads to congestion, which results in higher latency and jitter.

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

Businesses and vertical industries are increasingly requiring ultra-reliable low-latency networks to keep them competitive and support future growth. From digital marketing to improved collaboration, high speed Internet is the starting point for Small and Medium Enterprises (SMEs) to embrace digital transformation. For vertical industries, industry 4.0 requires higher-speed, higher-quality network connectivity to accelerate enterprise digital transformation.

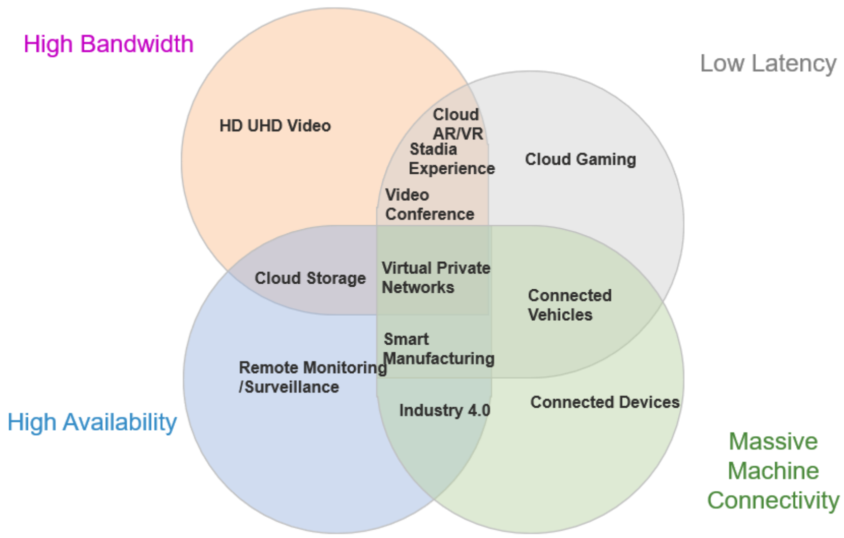
High-speed connectivity is the prerequisite for embracing the digital transition and effective adoption of digital technologies is the future of companies. The pandemic accelerated the rate of digitalization of SMEs. Business needs to leverage various digital tools, such as, cloud computing, e-commerce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

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

Furthermore, high-speed networks enable SMEs to generate more revenue. Many SMEs are building their own website or mobile application platforms to engage in e-commerce, increase their brand recognition and boost their revenues. These sophisticated digital platforms require *high-speed Internet access for optimal customer experience.* To meet and to anticipate *increasing demand*, network capacity needs to be upgraded to meet the potential traffic growth.

For vertical industries, high speed Internet lays the foundation for the fourth industry revolutions. Smart manufacturing and Industry 4.0 require cloud-based services and connectivity. Enhanced digital services require differentiated network capabilities. High-speed broadband connectivity can result in more efficient business processes and promote innovation, including the introduction of new products and services, as well as innovative business models. Moreover, high-speed connectivity with low latency will facilitate long-distance collaboration through collaboration tools, and it is essential for remote control of some industry specific devices. See Figure 14 for a summary of application requirements along various dimensions.

Figure 14: Enhanced digital services require high quality network



Source: Earlswood Marketing

4. Green all-Optical network

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

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

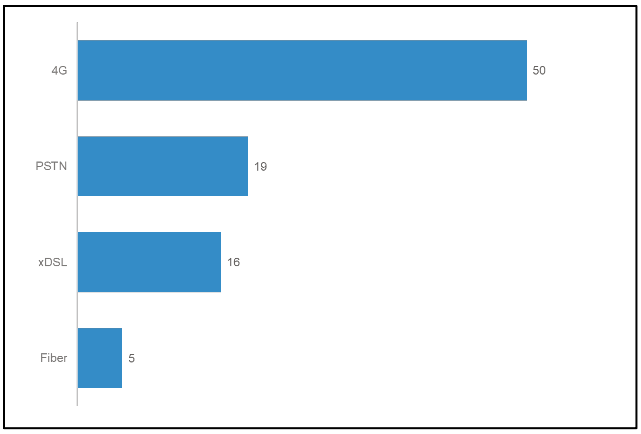
Fibre is a future-proof medium that provides the high-performance demanded from different scenarios and 5G uses cases. An optical network is a sustainable infrastructure, which provides not only faster, more secure, and more reliable connection, but also promotes passive infrastructure to improve energy consumption and make an eco-friendly recycling raw material. Fibre is a more sustainable material and has a longer lifecycle. Intelligent operations and maintenance also contribute to carbon reduction.

Compared to traditional copper cable, optical network delivers network connection in an energy- efficient way. Fibre consumes 3 times less energy than xDSL, while Internet speed is generally 10 times faster (see Figure 15 for the comparison of different technologies with regards to energy consumption).

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

The following figures comes from an ARCEP (French Telecom Regulatory Authority) study. It calculates the kWh per line consumed by access technology. It clearly demonstrates how fibre networks consume significantly less energy than any other fixed or mobile access technology.

Figure 15: Comparison of different network technologies yearly energy consumption in kWh per line (Based on 7GB monthly data consumption per line)



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

All-optical networks contribute to achieve green agenda.

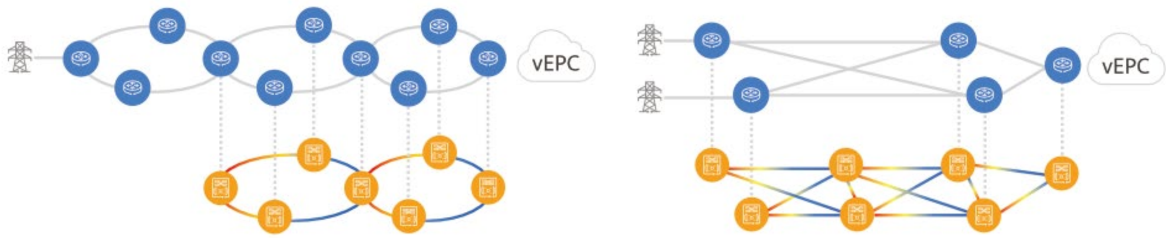
Compared to conventional network architecture, all-optical networks provide significant energy efficiency improvements in three areas:

All-optical connectivity: All-optical networks provide better high transmission efficiency. Analysis show that all-optical networks emit 88% less greenhouse gas emissions per Gigabit than legacy technologies. The all-optical network reduces the energy consumption to 1 Watt (for every 300 meters) compared to 3.5 Watts for the copper network (for every 100 meters) in the data transmission service[5].

For instance, as copper switch-off is a growing trend among operators around the world, the transition from copper networks to fibre-based networks will enable operators to achieve energy efficiency targets and save energy-related costs. Additionally, all-optical networks use passive optical components to replace electrically powered components, enabling to save energy consumption tenfold. In residential scenarios, optical fibre extended to each room can be used to replace copper cable, reducing energy consumption by up to 75% and support immersive digital experience in the home. In enterprises and vertical industries scenarios, all-optical network is the most energy efficient solution, which extends fibre connection to the office and the factories providing high speed and low latency connections to benefit the digitalization, while reducing energy consumption of the network. In Mobile backhaul scenarios, fibre is also the most convenient technology for backhaul infrastructures in terms of energy consumption[6].

Simplified network architectures: Legacy optical networks use the ring architecture that features multi-layer aggregation and hop-by-hop forwarding using electrical NEs, resulting in low efficiency in long-haul transmission. The simplified network architecture implements one-hop transmission at the electrical layer, greatly improving transmission efficiency and reducing network power consumption, as well as simplifying network maintenance. All operators now agree that simplifying the network architectures is paramount (see Figure 16).

Figure 16: Simplifying the network architecture (Legacy Network to New Network)

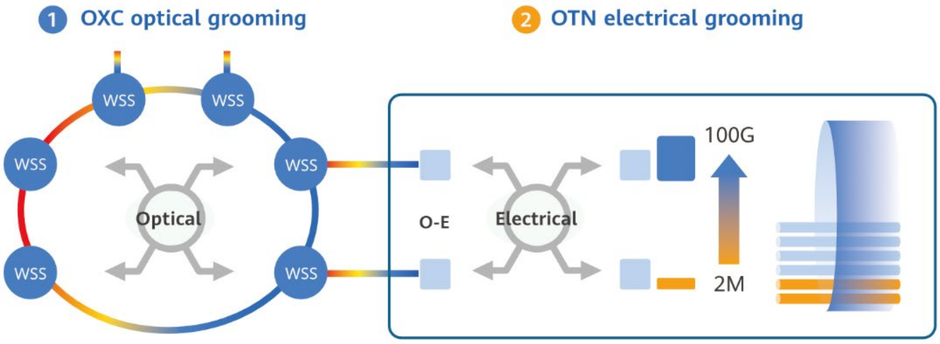


vEPC: Virtual Evolved Packet Core

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

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

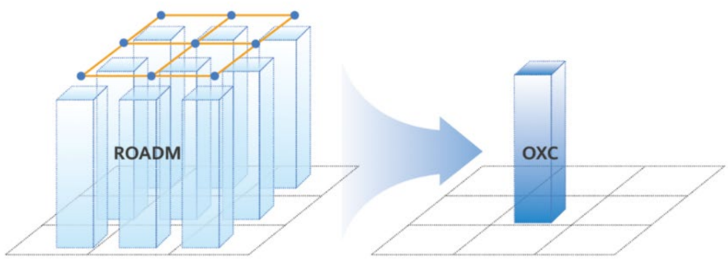
Figure 17: OXC and OTN grooming



Source: IDATE

Using Wavelength Selective Switch (WSS) technology (see Figure 17, number 1) is recommended to build a full-mesh all-optical switching network and simplify the network. All nodes implement one-hop connection through the optical layer, reducing the number of electrical regeneration nodes. By deploying electrical nodes only at the source, sink, and key intermediate nodes, network power consumption is minimized in scenarios such as full-granularity services and conflicting wavelengths (see Figure 17, number 2).

Figure 18: Comparison between traditional ROADM and OXC

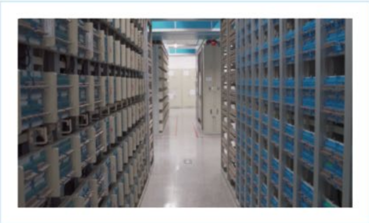


Source: IDATE

In an all-optical switching network, the traditional ROADM switching technology has many shortfalls, such as many sub racks, complex cable connections, and difficult maintenance. An Optical Cross-Connect (OXC) is a more flexible with an all-optical cross-connection grooming mode. Unlike traditional ROADM based on separate boards, OXC's optical backplane implements full-mesh interconnection, integrates many optical fibres on a single optical backplane, and supports high integration of service boards. One slot corresponds to one direction. OXC uses integrated interconnections to build an all-optical switching resource pool, achieving highly integrated, fibre-free, and all-optical cross-connections, in turn significantly improving the efficiency of switching large-granularity services. Using the latest OXC technology to replace the traditional ROADM can reduce the equipment room footprint by up to 90% and the power consumption by up to 60%.

Upgrading network technologies: SDH equipment based on electrical switching have been used on optical networks for many years, using OTN to modernize SDH network, greatly reduces equipment room footprint, and saves valuable optical fibre resources for operators. (see Figure 19).

Figure 19: Upgrading network technologies from SDH to OTN



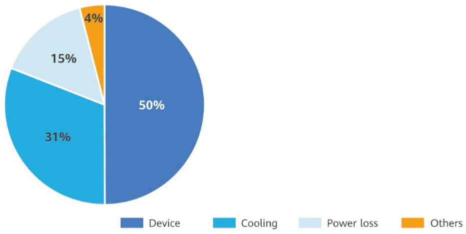
Source: IDATE

As a next-generation network technology, OTN achieves higher integration, greatly reduces equipment room footprint, and saves valuable optical fibre resources for operators. All-optical technologies achieve lower latency, higher bandwidth, higher reliability, and lower power consumption. Replacing traditional SDH technologies with fgOTN technologies can minimize network power consumption and reduce operators' power expenditure. The effective service integration ratio is 10:1 and the board integration ratio is 8:1, while the total power consumption is reduced by more than 40%. Note that replacing SDH with packet-based technologies like circuit emulation (CES) has still the problem of hop by hop and therefore non-deterministic network behaviour and larger energy usage due to the hop-by-hop O-E-O conversion needed.

For example, Orange replaced legacy SDH equipment with OTN equipment for 150 NEs at 110 sites, reducing the total power consumption by 67%, equipment room footprint by 58%, and maintenance costs by 62%.

Equipment-based power saving strategy: The power consumption of a sites (see Figure 20) consists of two parts: one is the power consumption of auxiliary devices, such as the air conditioner and power supply in the equipment room; the other is the power consumption of main equipment, such as electrical-layer equipment and optical-layer equipment. For a typical site where the Power Usage Effectiveness (PUE) is 2.0, the main equipment account for about half of power consumption, and auxiliary equipment account for the other half. The power saving of auxiliary equipment focuses on the application of advanced power supply, heat dissipation, and air conditioner energy saving technologies, thereby maximizing the site energy efficiency and reduce the PUE.

Figure 20: Power consumption of sites



Source: IDATE

With the continuous evolution of hardware techniques and materials, as well as the application of new technologies, hardware will be advanced every two to three years, and its power consumption will decrease significantly for the same specifications. The power saving of main node equipment focuses on the equipment architecture, key components (such as optical modules and chips), and heat dissipation.

Equipment architecture optimization: The equipment architecture greatly affects power consumption. As such, simplifying the equipment architecture greatly reduces the power consumption of the equipment. By improving the board integration and simplifying the cross-connect system, functional units can be reduced to simplify the equipment architecture.

Optical module innovation: High-performance algorithms, innovative materials, and innovative techniques are introduced to continuously improve the transmission performance of optical modules and improve energy efficiency. For client-side optical modules, new encapsulation technologies such as Co-Packaged Optics (CPO) and On-Board Optics (OBO) can be introduced to continuously improve integration, reduce power consumption by reducing the device electrical interface power, and save space.

Highly integrated chips: The power consumption of a single chip is reduced through continuous evolution of chip techniques and algorithms. Multi-functional modules are integrated to reduce internal conversions and the total power consumption of the chip. The scheduling mode of intra-chip resources is optimized to support service volume-based resource core scheduling by independent power-off control as well as frequency control over intra-chip resource cores.

Efficient heat dissipation: Under normal working conditions, the power consumption of optical modules increases at higher temperatures. Efficient heat dissipation technologies, such as heat pipes and bionic teeth, enable the modules to work at a relatively low temperature to reduce power consumption.

Equipment air duct structure requirements: To adapt to the evolution of Data Centre’s (DC) transformation, air-cooling equipment requires a front-to-back airflow configuration. The thermal management of the data center adopts cold-hot isolation, aligning with the front-to-back airflow design to enhance the heat dissipation efficiency of the equipment racks.

Smaller-granularity slicing: The fgOTN technology enables a single channel to transmit more services, improving channel utilization and service bearing efficiency. This improves device energy efficiency, reduces single-bit power consumption, and saves power.

Site-based power saving strategy (see Figure 21): The use of non-functional equipment like air conditioners can be reduced through site architecture innovations, such as DC-based equipment deployment, isolation of cold and hot air channels, and liquid cooling. Currently, a traditional equipment room uses Vertical UnderFloor (VUF) air distribution, Vertical OverHead (VOH) air distribution, or horizontal air distribution. Due to the mixing of cold and hot air, the heat dissipation effect is poor, and the PUE ranges from 1.8 to 2.0. After DC-based equipment is introduced to reconstruct the equipment room to have separate cold and hot channels, the PUE of the equipment room is reduced to 1.4–1.6, greatly reducing power consumption.

Figure 21: Site-based green and power saving strategy

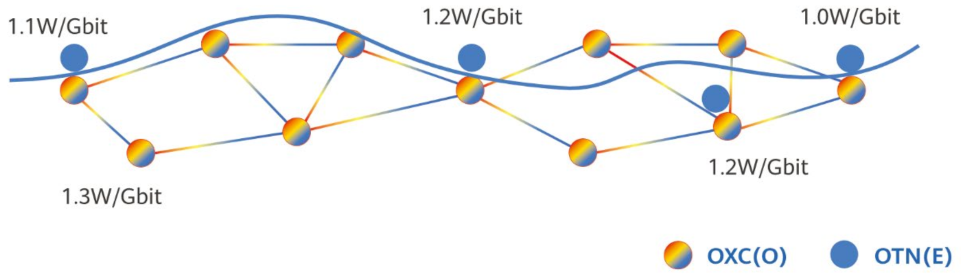
Mainstream Application Equipment Room	Transmission Equipment Room	DC Equipment Room	IT Equipment Room
Cooling mode	Vertical underfloor (VUF) air distribution, vertical overhead (VOH) air distribution, and horizontal air distribution	Isolation of hot and cold air channels, cold air pool, and smart module	Equipment room–level liquid cooling
Heat dissipation capacity	5–12 kW	10–20 kW	30–60 kW
Deployment complexity	Pipes are routed to the air conditioner area in the equipment room. Devices are easy to maintain.	Pipes are routed to the in-row air conditioner area. Devices are easy to maintain.	Pipes are routed to devices. Devices are periodically maintained.
PUE	PUE: 1.8-2.0	PUE: 1.4-1.6 (1.2 in western China)	PUE: 1.1-1.3

Source: IDATE

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

A visualized and manageable network-wide power consumption system, which is the foundation for building a greener network with visualized and manageable power consumption, is not supported by traditional networks. Without this capability, it is difficult to comprehensively understand the power consumption of these networks, identify low-efficiency links in a timely and accurate manner, and perform targeted optimization by replacing equipment and rerouting traffic. As a result, network power consumption remains constantly high. As such, operators need to determine how to effectively monitor, analyze, and manage network power consumption. Figure 22 shows an all-optical network with a visualized power consumption control system, operators can do the network planning with visualized and manageable power consumption system.

Figure 22: Route planning achieves power saving strategy

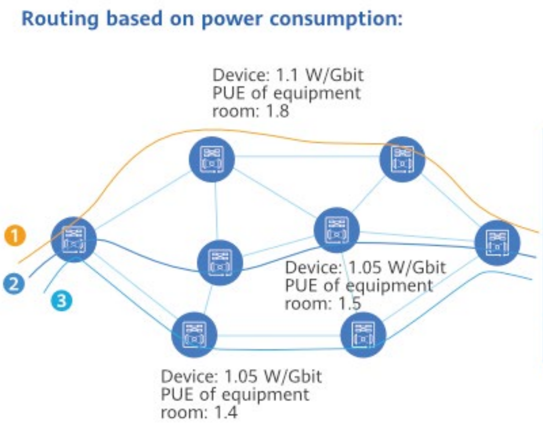


Source: IDATE

Based on the management and control system, the optical network can dynamically monitor the power consumption of the entire network and identify power-hungry and inefficient links in a timely manner, providing a basis for continuous power consumption optimization. The network energy efficiency is evaluated based on multiple factors, such as protection/recovery, transmission distance, and scalability, providing a comprehensive comparison of links (see Figure 23).

Service provisioning based on power consumption visibility: Network power consumption is not the same as service power consumption. When choosing a service provisioning path, a traditional network considers only information such as the number of nodes, latency, and bandwidth utilization on this path. Service provisioning is affected by factors such as the distance, number of nodes passing through, and technology used. Choosing different service provisioning paths will bring different power consumption results. Therefore, power consumption of each service provisioning path can be introduced for choosing an optimal path. For example, the power consumption of a path can be calculated by accumulating the power consumption (in W/Gbit) of all the equipment nodes along the path.

Figure 23: Routing based on power consumption



Available Path	Power Consumption (W)
1 Path 1	230
2 Path 2	200
3 Path 3	180

Source: IDATE

Service management based on visualized power consumption minimizes the service power consumption. When a new service is provisioned, the optimal service path can be selected based on the power consumption. When an old service is maintained, the optimal service path can be adjusted based on the power consumption to optimize E2E service power consumption and overall network power consumption.

4.2. Energy efficiency monitoring

Reduction in energy consumption is a key issue in future 6G transport networks. The optimization of energy consumption can be approached in different directions. In a first direction, multi-layer (packet/optical) traffic engineering can be used to assign energy-efficient paths instead of the traditional maximum capacity-oriented optimization. Optical bypass can be evaluated as an energy-efficient technique to achieve considerable power savings over per-hop optical-electronic-optical 3R regeneration performed in the packet layer. The multi-layer traffic engineering strategy can be applied for daily traffic variations. A second direction can consider a detailed power consumption model of the network to deploy power-aware algorithms which selectively switch off optical/IP network links under low utilization scenarios supporting energy efficiency. The target is to reduce the total energy consumption, while maintaining a low blocking probability under dynamic traffic.

To this end, it is essential to establish a unified perspective on energy consumption across Edge/Cloud DataCentre (DC), IP, and Optical networks to comprehensively grasp network operations. By gaining insights into the energy utilization of each device and service, you can optimize network efficiency effectively to facilitate this, it is required an energy monitoring system to systematically track and analyse energy consumption in three distinct networks: Edge/Cloud DC, IP, and Optical. This helps to gain insights into how much energy various devices, operations, and services are consuming. The energy monitoring system shall consist of three layers: probing, storage, and visualization as shown in figure 24.

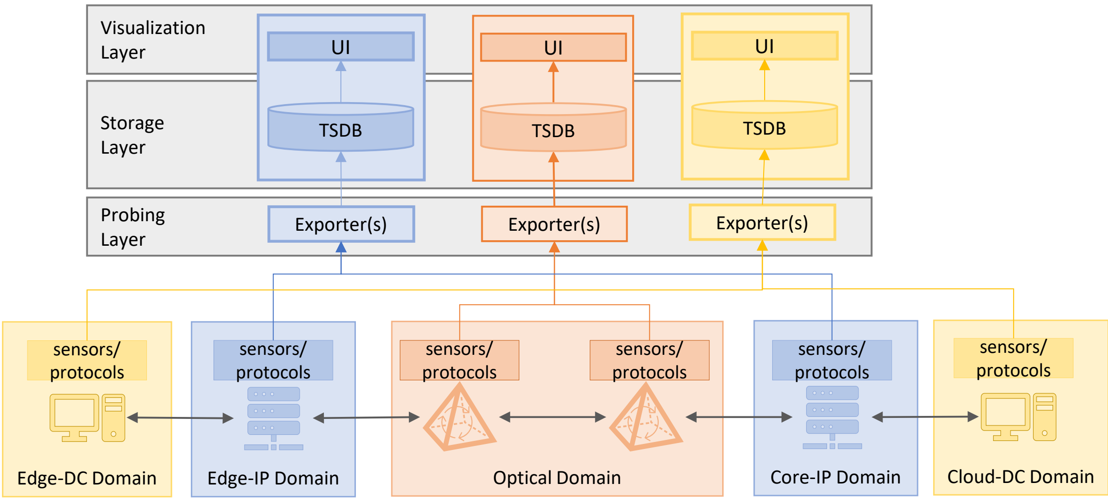
The probing layer records energy consumption metrics by communicating with devices and services. Depending on the devices and services being monitored, this layer may use a variety of technologies and protocols. This could include communication protocols specific to energy monitoring devices, including ACPI, and other monitoring tools. Here, an appropriate probing frequency should be defined for the specific needs of the network. There are many popular exporters available to meet the specified requirements. For Edge/Cloud DC networks, you can use an exporter like Scaphandre or any other exporter that can extract energy-related metrics. For IP network domains a protocol such as SNMP or NETCONF can be used to extract the energy consumption, but this information is very different between different router vendors. An alternative is the use of Openconfig, which with the platform model shows different values and can organize the energy data according to the type of router (card-based or monolithic). For optical networks, a physical sensor can be deployed on each device to measure energy consumption.

Energy consumption data are stored in the storage layer for analysis and future reference. These data are crucial for identifying trends, optimizing energy usage, and making informed decisions. These data can be stored in a variety of databases, file systems, and cloud storage services, such as Prometheus, Mimir, Amazon S3, and Google Cloud Storage. The storage layer should be able to store large amounts of data and provide fast access for analysis. While selecting a database for storage, importance should be given to scalability, speed and performance.

The visualization layer provides an interface for viewing real-time energy consumption data. It allows users to visualize the energy usage across different devices and services. This layer can be implemented using a variety of tools and technologies, such as Grafana, Kibana, and Power BI. The visualization layer should allow users to easily view and analyse the energy consumption data, identify trends, and drill down into specific devices or services. The visualization layer should also allow users to set alerts and notifications based on energy consumption thresholds. This can help users to identify and address potential problems before they cause outages or other interruptions.

By taking these factors into account, you can design an energy monitoring module that meets the specific needs of your network and provides you with the information you need to understand and manage your energy consumption.

Figure 24: The energy monitoring system



Source: CTTC

4.3. Fibre is empowering all industries to reduce carbon emission.

The impact of fibre network on CO2 abatement goes beyond the telecoms industry. Full fibre connection can benefit a wide range of vertical industries to reduce CO2 emission. From smart homes to larger settings like optical smart campuses (such as airports, hotels, university campuses, etc.) as well as smart grids and factory floors. A long list has been identified, the various industries should consider it for reducing energy and carbon footprint. Full fibre network will promote large-scale intelligent upgrading of business and public service, optimizing utility production energy consumption of different industries, especially for manufacturing, energy, transport and agriculture sector, which are the largest source of (direct) CO2 emission.

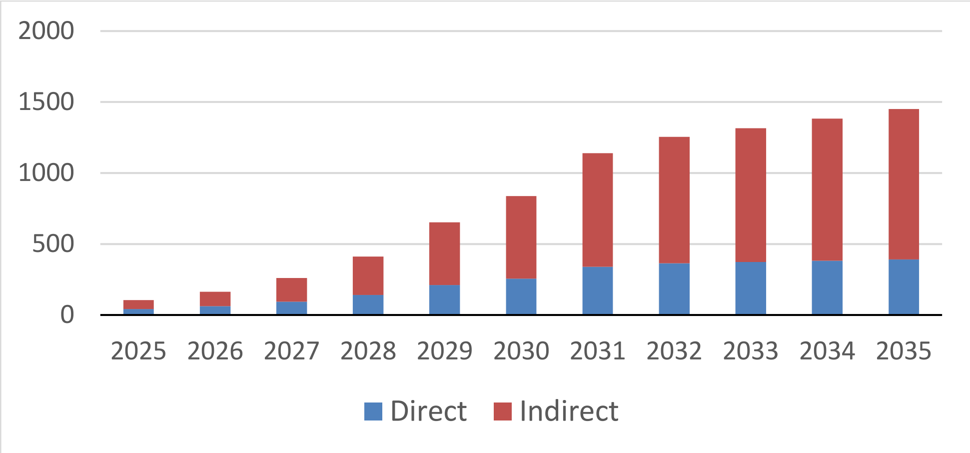
- **Manufacturing:** An all-optical network will empower smart factories by enabling communication with users and with machines, automated processes, and mechanisms to facilitate real-time communication between the factory and the market to support dynamic adaptation and maximize efficiency, to reduce human intervention and to improve energy efficiency.

- **Energy:** An all-optical network promises low latency and high-speed connectivity to meet latency-sensitive smart grid application demands. The data on electricity consumption and usage can be transmitted in real-time to all network operators to optimize the production and distribution of electricity, to save energy, to reduce losses, and to improve grid reliability.
- **Transport:** An all-optical networks can interconnect different cities' traffic network infrastructure to facilitate real-time communications between a wide variety of remote field devices and traffic control centres. Using video transmission to monitor intersections helps reduce traffic congestion, improve traffic management, and lower carbon emissions.
- **Agriculture:** Fibre optics expand the Internet connectivity to farms, which enables Internet of Things (IoT) technology to refine and automate the farming processes. This process can significantly improve operating costs and reduce waste. Moreover, full fibre connectivity with higher speeds and lower latencies allows surveillance cameras and sensors to effectively capture the farming environment, and then transmit the collected data to IoT backhaul devices for intelligent analysis, thereby reducing investment costs and saving energy.
- **Data centres:** Data centres are strategic resources and digital infrastructure for the future economic and social development. As data centres are rapidly developing, energy-saving and low-carbon development of data centres is a major concern. Optical networks support high bandwidth, low latency, and high security. For example, China's east-data-west-computing project enables data centres to be deployed in Western China, where abundant natural resources help to keep PUE below 1.2. The all-optical network provides the most favourable approach for this project. Google uses submarine cable WDM systems to interconnect data centres, allowing them to build data centres in places where green energy is abundant or the external environment is conducive to energy saving. For example, Google data centres in Finland can achieve a PUE of 1.06[7]
- According to IDATE forecasts, fibre deployment commits to 30% carbon emission reductions by 2030 (from a 2021 baseline) across industries.

IDATE has been conducting a survey with more than 50 world-class industrial companies in sectors ranging from telecom to logistics, car manufacturing, energy production, food and beverage and pharmaceuticals. Based on these interviews and understanding of their carbon footprint reduction strategies, IDATE has modelled the level of carbon saved by sector and how these savings would occur in time. Consideration has also been given to the direct impact of the fibre deployment (i.e. direct energy savings) and indirect impact of fibre deployment such supply-chain optimization, industrial process improvements, real-time energy management systems and circular economy practices (i.e. waste reduction).

[7] Source: Google data on its datacenters efficiency, https://www.google.com/about/datacenters/efficiency/

Figure 25: Worldwide fibre Deployment cumulated CO2 savings due to fibre deployment (CO2 M Ton)



Source: IDATE

5. Emerging best practice

Case study of successful gigabit broadband deployment experience in China.

China is among the most advanced countries in terms of the deployment of all optical networks. China has the world's largest optical network and the largest number of net additions of FTTH broadband subscribers. According to IDATE, China has 920 million FTTH ports and 479 million FTTH/B subscriptions as of December 2022. Additionally, China is one of the leading countries in the global performance ranking.

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

The all-optical network solution has been applied across various scenarios, covering home, business and a broad range of industries.

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

The FTTR market in China is booming.

After its launch in September 2021, FTTR quickly attracted the attention of many Chinese operators, showing a strong growth trend. By December 2022, 87 provincial operators publicized FTTR commercial packages, with 2 million subscribers. According to the experience in China, customers show the trend to purchase an FTTR package with one or two FTTR E-ONU, with over 80% of the total FTTR subscribers. Furthermore, 20 other operators around the world have also launched pilot programs of FTTR solution.

To meet the application requirements of various industries, Chinese telecom vendors launched F5G related all-optical Network products, which can create more than 40 deployment scenarios covering more than 10 different application areas such as energy, transportation, mining, communications, construction, education, healthcare, and manufacturing.

Vertical Industry Applications of All-optical Networks solution in China

An all-optical network can support a broad range of digital applications across different vertical sectors. Below are some examples of all-optical networks applications in China.

In small businesses and enterprises scenarios, an FTTR solution needs to deliver Internet access speed up to 1 gigabit. The services of interest include cloud computing, e-commerce, and videoconference collaboration tools.

In the education sector, all-optical networks have been deployed in schools and universities to meet the educational needs (e.g., for online learning) and various other digital applications. An all-optical network provides up to 10 Gb/s connections to support various digital applications as well as digital interactions and collaborations tools. For instance, Shenzhen University has deployed an all-optical network over its campus to support various activities, including online learning, accessing online research databases, and conducting research. In another example, the deployment of an all-optical network in a Chinese college reduced energy consumption by 30%, reducing carbon emission and energy costs.

In the healthcare sector, an all-optical network is the backbone for various smart hospital applications. All-optical networks promise to deliver high-capacity, low latency, high reliability, supporting many connected devices which provides a comprehensive digital access service, including teleconsultation, remote patient monitoring, HD virtual consultations and sharing of medical record information. For example, Shen Zhen hospital upgraded its network to an all-optical one to allow sharing of patient records, saving around 9 million sheets of paper and 200,000 films (equivalent to more than 4 million Yuan) per year; in addition, an all-optical network allows real-time imaging, documents, and data transfers for video-based medical consultations. Using the new all-optical network architecture, 1,000 medical images can be read-in per second.

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

In the automotive sector, the deployment of an all-optical network in a Chinese car manufacturer's new factory provides high-speed and reliable connection for different applications, including production line automation, real-time data analytics and quality control. In addition, an all-optical network used instead of the traditional copper network in the same new factory has resulted in reducing cabling costs by 50% and energy consumption by 40%.

In the energy sector, Chuzhou Smart Factory of Dongfang Risheng has deployed an all-optical industrial solution to update their product inspection system. The solution helps the company to support the transmission of large amounts of data and improves the network tolerance to failures and degradations, but also reduces the energy consumption. For example, the inspection system generates terabytes of data per day. Moreover, networks have the capability to achieve fault recovery within 50 milliseconds, thus ensuring uninterrupted production. The all-optical network has improved the energy efficiency by 40%, reducing the energy consumption and related costs.

6. Conclusion

The onset of the pandemic has led to an inevitable surge in the use of digital technologies and placed broadband networks as a key enabler for various digital applications in homes and businesses, including teleconferencing, online education, 4K / 8K ultra-high-definition video, VR / AR gaming, cloud computing, etc.

Meanwhile, Industry 4.0, which focuses on digitizing manufacturing to improve operations, is generating vast amounts of data for decision-making and other operations such as predictive maintenance.

According to IDATE, by December 2023 there will be 887 million FTTH/B subscribers worldwide and 1 200 million FTTH/B homes connected. FTTH promises connection speeds of up to 1000 Mb/s, 20 to 100 times faster than a conventional cable modem or DSL connection. With innovations in fibre technology, the fibre connection will extend to everything, everywhere, including premises and businesses.

With rapidly growing demand for bandwidth and stringent network requirements for new services such as 4k or HD video, operators need to update their existing network infrastructure to meet customers' service requirements.

In addition, operators face various challenges with their existing network, such as insufficient capacity to support future growth, equipment congestion and high energy consumption.

Global GreenHouse Gas (GHG) emissions have risen dramatically over the last three decades and are of major concern for our society. Fibre-powered broadband solutions can help address these issues by providing high-speed, low-latency connections with high reliability and energy efficiency. More and more operators are focusing on fibre-optic networks to cope with the continuing increase in traffic.

The telecom industry has been pointed out as one of the drivers of carbon emission increase, but an attentive analysis demonstrates that a smart use of telecom networks, with state-of-the-art network technologies, allows a net carbon emission that tends to zero.

The impact of fibre networks in CO_2 abatement goes beyond the telecom industry. Full fibre connection can benefit a wide range of vertical industries to reduce CO_2 emission. From smart homes to larger settings like optical smart campuses (let it be airports, hotels, university campuses, etc.) as well as smart grids and factory floors.

In conclusion, we can say that there is no contradictory injunction between the changing needs of consumers and the need for telecoms operators to reduce their carbon footprint: Deploying cutting-edge fibre optic technologies can help achieve both objectives. In fact, on the one hand, it provides the capacity required for the networks to meet emerging needs (industry 4.0, teleworking, etc.); on the other, it reduces carbon emissions by using technologies that consume less energy and last longer.

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