HUAWEI

Striding Towards
the Intelligent World
White Paper

All-Optical Network

Empowering Digital Transformation with Premium All-Optical Networks

Building a Fully Connected, Intelligent World

CONTENTS

Executive Summary

From 2025 to 2030, gigabit access will see a surge in popularity, with 10G access being put into large-scale commercial use. At the same time, enterprise cloudification and digital transformation will continue to advance. The intelligent era in which everything is connected is just around the corner, presenting unprecedented opportunities for fixed networks.

1. **The global rollout of optical fiber is expedited, and the construction of all-optical networks has become a consensus.** Global fixed network operators are accelerating the migration from copper cables to fibers. Meanwhile, a large number of mobile operators are building optical networks to improve market competitiveness by providing fixed-mobile convergence (FMC) services. In addition, more than 50 countries have outlined their own digital development visions and goals to provide policy support for fiber deployment. New technologies are making fibers easy to deploy and manage.

   According to Omdia's data and operators' service development trends, the global FTTH penetration rate will increase from 28% in 2020 to 40% in 2025, and reach 61% in 2030. The penetration rate of gigabit FTTH users will increase rapidly from 1% in 2020 to 26% in 2025, and reach 55% in 2030. At the same time, the developed market has shifted from gigabit packages to multi-gigabit packages. In the future, with the development and maturity of services such as XR and smart home, FTTH will usher in the 10G era.

2. **FTTR will usher in a new era of smart homes.** Home broadband services are shifting from HD video entertainment to immersive XR experience, online office, and all-in-one smart home. At the same time, residential buildings are developing towards green, digital, and smart homes. Against this backdrop, fibers will further extend to every room inside a residence. FTTR not only improves home service experience for users, but also presents operators with new revenue sources, increasing ARPU by 30%. The FTTR penetration rate is estimated to reach 8% in 2025 and 31% in 2030.

3. **The all-optical network is widely used in enterprise office and production to build a green and low-carbon office network and a reliable industrial Internet.** More and more enterprises are choosing all-optical campus networks for building next-generation green and simplified smart campus. All-optical campus provides campus networks with transmission media evolution, architecture innovation, and all-new O&M. An all-optical network carries all campus applications and has significant advantages in terms of bandwidth, deployment scope, O&M costs, and service life.

   The Industrial Internet is a vital infrastructure in the latest global industrial revolution. Countries hope to use the Industrial Internet to help machines run more efficiently, reduce energy consumption, and help enterprises reduce costs while achieving green and sustainable development. An industrial-grade optical network has advantages such as high reliability, simple architecture, multi-service bearing, and passive long-haul transmission. It can meet the network requirements of industrial scenarios in special environments, such as high bandwidth and low latency. This will improve O&M efficiency and support continuous evolution in the future.

4. **The optical transport network evolves to 100 Tbps per fiber and all-optical grooming.** Higher bandwidth is required by video-based content, online interaction, and cloudification of various industries, causing a surge in the Data Center Interconnect (DCI) traffic. At the same time, the network construction mode is becoming increasingly DC-centric, building a new cloud-edge synergy infrastructure. This implements flexible scheduling of distributed resources, high-speed interconnection of data across domains, and intelligent applications at the edge.

   As the foundation of all services, the optical transport network can further unleash the potential of fiber bandwidth by improving the single-wavelength rate and expanding the available spectrums of fibers, achieving "100 Tbps per fiber". The networking mode of "optical taking priority over electrical" reduces unnecessary processing of services at intermediate sites, realizes one-hop transmission of services, and reduces network energy consumption.

5. **Communication and sensing convergence, moving from the Internet of Everything to the Intelligence of Everything.** Fiber not only meets the requirements of enterprise communication, but is also able to sense things like vibration, temperature, and stress. This means that, combined with software algorithms, fibers can be used for high-precision environment detection in industrial fields. For example, optical cables can be buried along important pipelines to collect external vibration signals. The signals can then be used to accurately analyze and identify construction events and locations, implementing intrusion and damage risk warning within minutes as well as providing meter-level sensing precision and 99% accuracy. This prevents damage to important facilities such as underground oil and gas pipelines, cables, and municipal pipeline corridors during construction.

   The optical sensing technology can also be used in a wide range of scenarios such as fire and earthquake warning to explore new services and applications and maximize the value of fiber resources.

6. **All-optical networks are developing towards highly intelligent autonomous driving networks.** The number of connections, scale, and complexity of networks are increasing, calling for automated network O&M. Meanwhile, network capabilities and borders are expanding, requiring cross-domain collaboration and management. To improve user experience, networks need to support adaptive and agile deployment.

   Thanks to AI technologies, all-optical autonomous driving networks are made possible. Through continuous network architecture innovation driven by knowledge and data — as well as the collaboration of AI capabilities at the NE, network, and cloud layers — a "brain" is formed for all-optical networks to build an autonomous network featuring automation, self-healing, and self-optimization.

Trend 1

The Global Rollout of Optical Fiber is Expedited, and the Construction of All-Optical Networks has Become a Consensus

Trends

The COVID pandemic has changed the way we interact with application systems, with the likes of home office, live streaming and online learning becoming a daily norm. Considering this sharp increase in popularity and the development of new technologies such as 8K, AR/VR, and whole-house intelligence, higher demands are being placed on the network bandwidth. Users expect a smooth experience, while operators look forward to higher fixed broadband revenues. To ensure expectations are met on both sides, a fiber-in copper-out initiative is underway around the world, where FTTH is becoming the mainstream network construction solution for access networks. Global operators have made building intelligent optical access networks featuring simplified O&M a top priority, and aim to develop these in an efficient and economic manner.

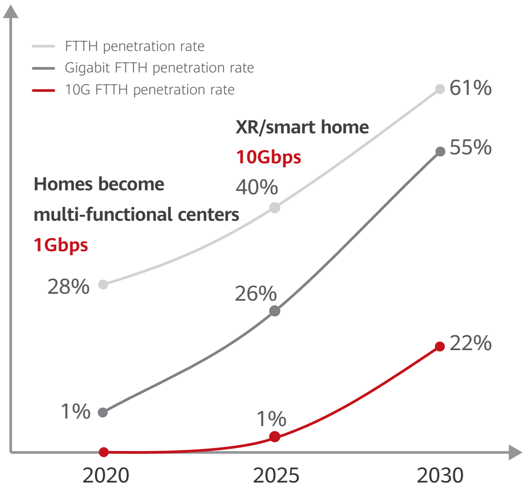
1. User Base and Turnover of Fiber Broadband Continues to Grow, Attracting Operators to Invest More

Fixed broadband is now the main revenue stream on operators' income statements, and global operators continue to benefit from its continued development.

Rapid increase in fixed broadband user base

According to Omdia's statistics, the global fixed broadband penetration rate has rapidly increased from 58% in 2020 to 66.4% in 2022. It is estimated that over the next five years, the fixed broadband penetration rate will increase by 10%, and the number of users will increase by

14.5%. This means that 200 million new users will be connected at a rate of 40 million per year. It is estimated the global FTTH penetration rate will increase from 28% in 2020 to 40% in 2025, and to 61% in 2030. From 2020 to 2030, the penetration rate of gigabit FTTH will increase from 1% to 55%, and 10G FTTH will increase from 0% to 22%. (Figure 1: Broadband Service Development Trend)



Source: Omdia, Huawei MI

Figure 1: Broadband Service Development Trend

More revenue attributed to FBB ARPU increase

In addition to an increase in the user base, the fixed broadband industry is also witnessing more premium service requirements. Gigabit is becoming mainstream on a global scale, and with packages being provided by operators in 72 countries and regions, the number of gigabit users is expected to grow by 35% annually in the coming years. Take China for example, by July 2022 the number of gigabit users exceeded 65.7 million, which was ten times that by the end of 2020. Gigabit packages also bring an ARPU increase to operators. Driven by the increase in the user base and premium service requirements, operators have experienced stable and rapid growth in the fixed broadband business over the past five years. According to Omdia's statistics, the growth rate of fixed broadband service revenue is higher than that of wireless service revenue in all the past five years put together. For example, in the first quarter of 2022, the growth rate of fixed broadband service revenue reached 8.5%, while that of wireless service revenue was 4.8%.

Fiber-in copper out gaining momentum

Traditional access media, such as copper lines and coaxial cables, have many restrictions. In contrast, optical cables consume less energy and meet the requirements of green and low-carbon operations. Fibers have an ultra-long service life of over 30 years, ultra-low latency of 5 μs per kilometer, and an ultra-high bandwidth that supports sustainable evolution, making FTTH the ideal solution for access network construction. According to estimates from Omdia, the number of FTTH users will continue to grow in the immediate future. By the year 2027, more VDSL and DOCSIS users will turn to optical broadband, increasing the proportion of optical broadband users from 62% in 2021 to 73%, whilst the market space for copper and coaxial cable solutions will be further reduced. (Figure 2: Broadband Access Mode Development Trend)

2. Many Governments Provide Preferential Policies and Fund Support for Fiber Broadband Construction

All-optical infrastructure has become the foundation for industrial development and the core strategy of many countries. For example, the European Union released the 2030 Digital Compass in 2021 and formulated the Digital Decade strategy, which specifies the vision of achieving gigabit connections for all households by 2030. Spain, France, Germany, the UK, and Italy have launched gigabit fiber network construction

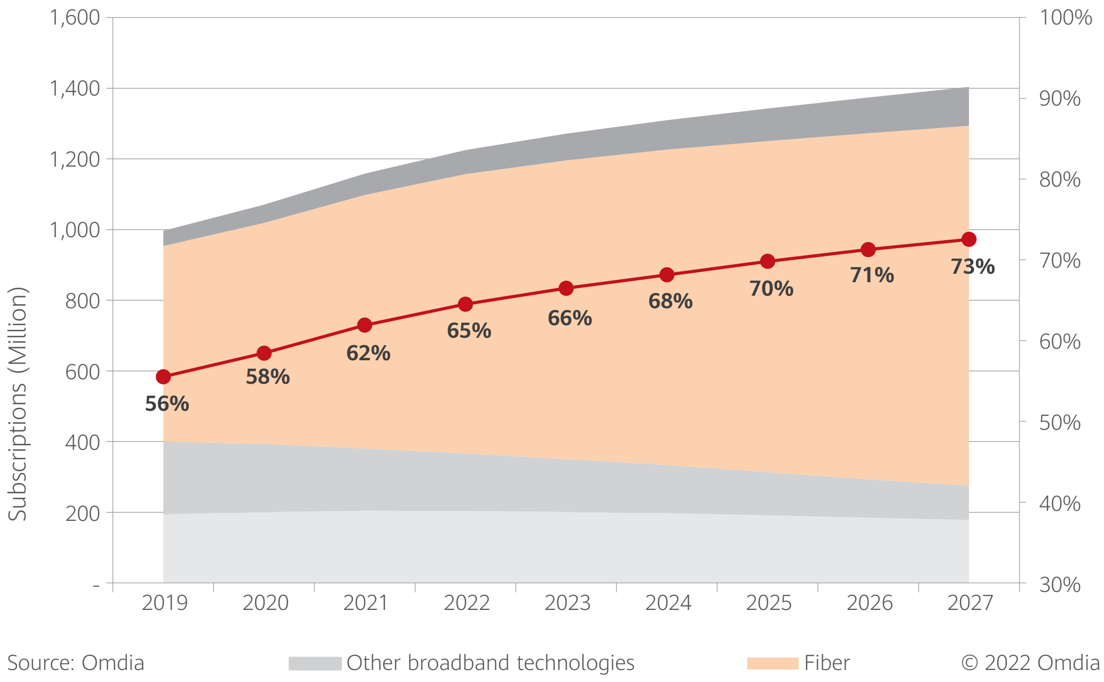


Figure 2: Broadband Access Mode Development Trend

plans to meet the strengthening broadband requirements. Gigabit all-optical networks have become the foundation for Europe's comprehensive digital transformation and carbon reduction. In China, F5G gigabit optical network construction has become a core national strategy. The Chinese government is enhancing investment and enriching application scenarios in 5G and gigabit all-optical networks, and has established goals of extending gigabit access to 100 cities by 2023 and 60 million users by 2025. In Thailand (Giga Thailand), Egypt (Decent Life), Cote d'Ivoire (NBP), and Malaysia (Jendela), broadband has become an infrastructure class equivalent to water, electricity, coal, and gas, sealing itself in the core national strategy. As Omdia, a well-known consulting firm, pointed out in its FDI fiber development index report released in 2022, national top-level planning and financial support play a direct role in promoting the development of the all-optical industry.(Figure 3: Fiber Development Index Comparison (2022 vs. 2020))

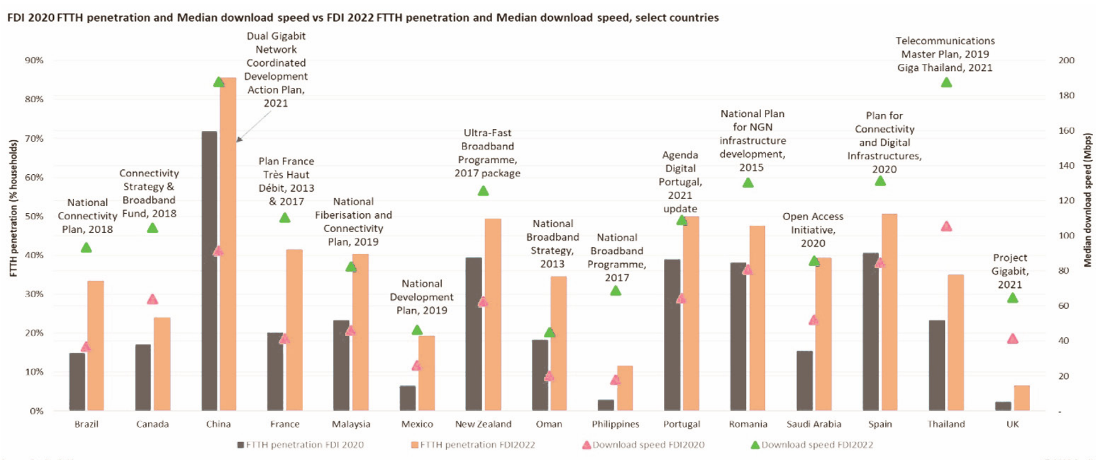


Figure 3: Fiber Development Index Comparison (2022 vs. 2020)

3. FTTH Network Construction Is Becoming More Economic and Efficient

The ODN accounts for 70% of the FTTH construction cost. However, as FTTH deployment gathers momentum, the cost of deploying optical access networks has decreased, with a 25% reduction in the global average from 2017 to 2020. In addition to the scale effect, new network construction models also play an important role in bringing down the ODN construction costs. For example, compared with underground cabling, aerial cabling reduces the cost per home pass (HP) by US$200, and reusing existing poles reduces the cost by another US$50 per HP. (Figure 4: Fiber Network Construction Cost Comparison (2020 vs. 2017))

In addition to lower costs, FTTH network construction efficiency is also rapidly improving. In traditional ODN construction, fiber pulling and splicing are labor-intensive and highly-skilled, which affects the efficiently of constructing the ODN. In recent years, the large-scale commercial use of QuickConnect ODNs has enabled operators to build networks much faster. Take Telmex Mexico in Latin America as an example. In 2021, the company only built 1.6 million HP lines, while in 2022, the company completed 3 million HP lines, which was attributed to the QuickConnect ODN solution.

Suggestions

Facing continuously evolving user requirements in bandwidth, Wi-Fi coverage, and premium experiences, operators can perform upgrades and iteration from network capability planning, network construction, and O&M. Existing OLTs can be upgraded to XG(S)PON OLTs. The concept of "thick coverage and short access" is required to realize the rapid construction of the network, promoting the fiber-in copper-out movement. Digital and QuickConnect technologies can be used to build ODNs efficiently and economically, and simplify ODN O&M.

1. Accelerate the evolution of 10G PON. As a result of COVID-19, more and more users are requiring gigabit or even 10G fixed broadband. Traditional GPON networks need to evolve to 10G PON or even 50G PON in the future. 50G PON is the only line rate that is standardized by ITU-T as the next-generation PON after 10G PON. It is estimated that 50G PON will be put into commercial use at the end of 2024 to provide users with ultra-high bandwidth and ultra-low latency services.

2. Accelerate fiber-in copper-out. Traditional

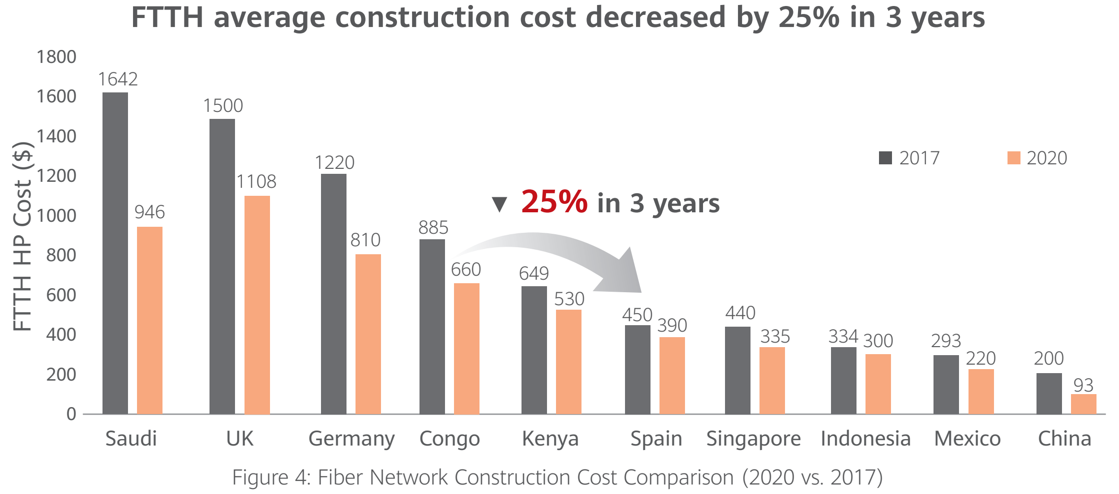


Figure 4: Fiber Network Construction Cost Comparison (2020 vs. 2017)

copper lines and coaxial cables face mounting challenges in new service support, network acceleration, experience assurance, O&M, and energy conservation. In contrast, fibers are designed for the future, as they can significantly improve bandwidth and user experience, owing to a mature business model and standardization.

3. Move sites closer to users, and build full-service access nodes with thick coverage and short access. The traditional CO-centric network construction mode has many difficulties, such as long fiber coverage distance, high optical power loss, complex ODN links, difficult right of way (ROW) acquisition, high network construction costs, and long time-to-market (TTM). To solve these difficulties, operators can move OLTs to mobile base stations to reuse existing site resources for rapid network construction. During network construction planning, 2B/2C/2H full-service access grids can be planned to significantly improve network construction efficiency, simplify O&M, and reduce costs.

4. Build ODNs using QuickConnect and digital technologies. Traditional ODN construction requires complex fiber pulling and splicing, which greatly hinders the efficiency of the FTTH rollout. QuickConnect ODN technology uses plug-and-play components to simplify ODN deployment and reduce skill barriers. In addition, construction work can be carried out in parallel, greatly improving efficiency. Digital ODN technology makes ODN networks visible and manageable by providing features such as automatic ODN topology restoration, port resource management with 100% accuracy, and automatic fault locating, greatly improving O&M efficiency and service quality while reducing the OPEX.

Huawei Solutions

Huawei's SingleFAN Pro solution provides all-scenario OLTs and digital ODNs, and offers planning and design, deployment tools, and intelligent O&M capabilities for operators to efficiently build networks. The solution helps operators build a unified ubiquitous gigabit access

network that supports the evolution to 10G. SingleFAN Pro contains the following solutions: (Figure 5: Intelligent Distributed Access Network)

1. FlexPON solution: FlexPON supports a smooth evolution from GPON to XG(S) PON. Operators can deploy OLT boards one at a time and install combo optical modules on demand. FlexPON is compatible with GPON, XG PON, and XGS PON terminals. In this aspect, the GPON ODN can be reused to roll out gigabit services without reconstruction to protect the operator's investment. In addition, Huawei OLTs can be directly upgraded to 50G PON by installing 50G PON boards to provide 10G bandwidth.

2. CO+AirPON hybrid network construction solution: This solution enables fast and cost-effective FTTH network construction and helps operators build premium networks from planning, construction, installation, and maintenance. The AirPON solution is applicable to all scenarios, such as fixed network construction by mobile operators, and copper-to-fiber conversion by MSOs and traditional operators. The uNB quick planning tool provides one-stop support for value identification and HLD/LLD, helping operators to achieve FTTH business success. In CO+X aggregation management, site OLTs are managed as virtual boards of CO OLTs, greatly reducing the number of managed NEs. Blade OLTs are plug-and-play, realizing integrated OLT installation and commissioning.

3. Digital QuickODN solution: The innovative QuickConnect and uneven optical splitting technologies simplify ODN construction using plug-and-play components, and shorten the fiber access terminal (FAT) installation time from 90 minutes to 15 minutes, and reduce manpower from four people to one person respectively. The image scanning and recognition technology enables digital management of the mapping between optical cables and closure ports, and automatic restoration of the ODN network topology. The innovative fiber iris technology transforms an ODN network from a passive network to an autonomous network, so that faults are automatically diagnosed and located in minutes at the meter level. The O&M efficiency is greatly improved, and the port resource usage statistics are 100% accurate, thus avoiding GPON port waste and unnecessary capacity expansion.

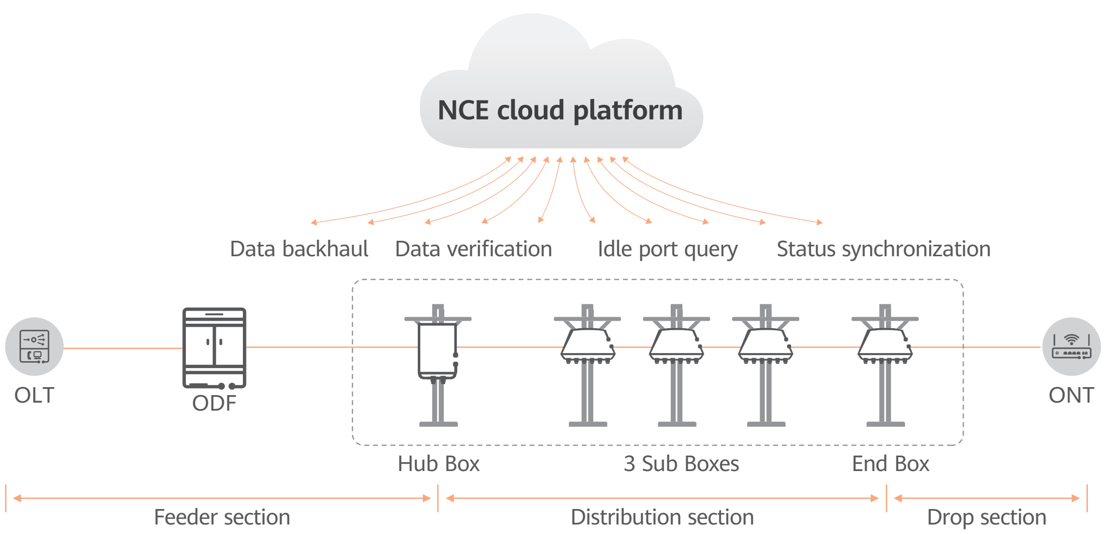


Figure 5: Intelligent Distributed Access Network

Trend 2

FTTR will Usher in a New Era of Smart Homes

Trends

Homes are becoming increasingly digital and smart, and with many people now working from home, it has created a growing demand for smooth, convenient, and efficient communication services. Various new services, such as online classes/offices, live broadcasts, 8K HD movies, in-depth entertainment (VR/cloud gaming), and all-in-one smart homes, are emerging rapidly. These services pose great challenges to network latency, bandwidth, and jitter. Smart home users are in urgent need of high-bandwidth, low-latency, and multi-connection networks. In the future, indoor broadband connections for homes will be ubiquitous. However, in current home broadband scenarios, users still experience many coverage blind spots. Even though users' homes are connected at the gigabit level, when users enter individual rooms, they are reduced to megabit-level connections. Many operators are now trying to figure out how to extend a network to reach every corner of a home, so as to provide users with premium smart home services. Drawing on the successful experience of FTTH, we know that point-to-multipoint (P2MP) fibers can be connected to homes and from there, into each room. Fibers can be combined with the latest Wi-Fi technology to form a brand-new Fiber to the Room (FTTR) all-optical home network. By connecting to the last 10 meters of the network, you can break the bottleneck of the home broadband experience and provide an all-optical base for future smart homes.

1. Smart Homes Require New Networks with Multiplying Capabilities

In the new era of gigabit networks, a premium service experience will become the focus of home broadband users. According to research and statistics on digital home scenarios, smart homes require several times higher broadband network capabilities than standard homes. For example, many broadband applications require high bandwidth, low latency, multi-connections, imperceptible roaming, green security, and intelligent O&M.

- **Ultra-high bandwidth:** Applications such as 8K/VR drive bandwidth growth. 8K 360-degree VR requires a bandwidth of over 1 Gbps. IPTV services are upgrading from 4K definition with a handover of one second to 8K definition with a handover of 500 ms. Bandwidth requirements have increased from 50 Mbps to over 150 Mbps. These figures show that gigabit-level bandwidth, reaching every corner of the home, is a rigid demand of smart homes.

- **Ultra-low latency:** The network latency required by online classes and offices has grown from 720p definition with a handover of 500 ms to 4K definition with a handover of 150 ms. Mobile games generally require a latency of less than 60 ms to guarantee a zero-lag experience. Strong-interaction Cloud VR with 20 ms latency will become a new service for more homes.

- **High-connection capacity:** The number of home IoT devices has increased rapidly. Various new IoT scenarios in areas such as lighting, security, and fitness and health are emerging. The number of smart IoT connections in a typical family of five is set to exceed 100. Good connectivity is a basic requirement for building smart homes.

- **Imperceptible roaming:** Wi-Fi roaming with a handover latency of 50 ms enables users to switch Wi-Fi signals quickly and accurately when they move between different floors or from one room to another, ensuring smooth and uninterrupted services.

- **Green security:** Enables highly reliable, secure, and trustworthy local home data storage and sharing. Provides security risk control, such as parental controls and addiction prevention functions, which are always the top concerns of parents.

- **Intelligent O&M:** Both home users and operators are concerned about home network experience reports, the health status of home network device connections, remote network recovery, network visualization, management, and maintenance. In addition, smart homes are moving towards ecosystem-based centralized control, which requires powerful local computing services.

To sum up, next-generation broadband needs to support the three digital centers of smart homes: a high-speed network connection center, a data storage center, and an intelligent computing center. Among them, the most urgent is building the "high-speed network connection center".

2. Increasing Conflict Between Insufficient Home Broadband Capabilities and New Smart Home Requirements

With continuous breakthroughs in IoT, cloud, and big data technologies, requirements for HD home videos, VR, smart homes, and smart applications are increasing, and new ecosystems such as the smart community are developing vigorously. Home networks that support Wi-Fi will further become the ecosystem foundation of home broadband services. However, home networks have the following problems:

- **Poor Wi-Fi experience:** Data shows that Wi-Fi-related complaints account for 60% of broadband complaints. The main causes of Wi-Fi-related complaints are old network cables, old ONTs, 2.4 GHz single-band routers, and networks using devices from multiple vendors with different specifications.

- **Difficult to fulfill the bandwidth subscription rate:** In copper cable, mesh, and power line communication (PLC) networking, the network speed is limited by the transmission rate of media. In addition, Wi-Fi signals having to penetrate walls decreases its speed significantly. As a result, although users subscribe to gigabit broadband, 90% of users are unable to enjoy the full subscription bandwidth. Indoor Wi-Fi connections are only dozens of megabits, which severely affects home users' experience in online courses, online offices, and in video entertainment.

- **Difficult home Wi-Fi coverage and poor roaming performance:** Many homes have complex partitions and Wi-Fi routers are usually placed in information boxes. As a result, Wi-Fi signals can cover only 50% to 80% of all areas. Frame freezing, disconnection, and reconnection often occur during hotspot handover.

These problems are not prominent when the bandwidth requirement is low. However, with the rapid development of new intelligent services, the impact of these problems on the network experience of home broadband users is increasing. FTTH needs to go further and provide a new generation of networking. With the maturity of 10G PON and Wi-Fi 6 technologies, fibers are further extended to rooms inside homes in the P2MP architecture, and each room has a Wi-Fi hotspot. This is an effective method to solve the problems being faced.

3. FTTR Will Become the Next-Generation Home Broadband Network Solution

The FTTR solution is mainly made up of four components: a high-performance master FTTR unit (MFU) connected to a 10G PON OLT, slave FTTR units (SFUs) deployed in each room, an optical distribution network (ODN) between the MFU and SFUs, and an intelligent network management platform.

The next-generation home network FTTR solution has the following features:

- **High bandwidth:** Compared to traditional 100 Mbps networking using routers, FTTR can provide connections with a bandwidth greater than 1000 Mbps.

- **Full coverage:** FTTR fibers deployed in the P2MP architecture connect to a Wi-Fi hotspot in each room, achieving whole-house coverage. In addition, distributed devices can provide stable connections for more than 100 user terminals. The MFU-SFU architecture supports access point handover with lower latency, realizing whole-house seamless roaming.

- **Low latency:** Wi-Fi 6 FTTR units are deployed in each room and connected through fibers, greatly reducing interference scenarios and achieving a latency less than 20 ms.

- **High reliability:** Fibers are corrosion-resistant and have a service life of up to 30 years. In addition, the SFUs form a protection relationship. Even if an SFU is faulty, user terminals can automatically connect to other normal SFUs.

- **Easy deployment:** Fibers are extended to each room with passive optical network components and connections. Transparent micro optical cables with low friction are easily routed through pipes. The deployment is simple and the cables are neat.

- **Easy O&M:** The home network management system needs to support visualization of the home network topology and faults, and implement differentiated optimization based on user scenarios.

FTTR can solve the experience problems of existing home networks, and meet the requirements of new smart home services on premium home networks.

4. FTTR Will Help Operators Change from Bandwidth Monetization to Experience Monetization and Promote the Development of Digital Homes

Traditional home broadband faces problems such as traffic increasing without revenue increasing and slow average revenue per user (ARPU) growth. FTTR is an effective way to solve these problems. FTTR helps operators transform from bandwidth monetization to experience monetization and upgrade services in the following four aspects:

- **Package upgrade:** Based on the FTTR for Home network solution, operators can release premium gigabit or higher broadband packages to greatly increase the ARPU and resolve the business dilemma of traffic increasing without revenue increasing.

- **Experience upgrade:** Based on FTTR, full-home gigabit Wi-Fi connections can be achieved. Users can enjoy digital home services such as online classes/offices, live broadcast, 4K/8K HD movies, entertainment (VR/cloud gaming), and smart home appliances.

- **Service upgrade:** Operators can provide complete network deployment services for home users. In addition, networks and user experience are visible on mobile apps.

- **Ecosystem upgrade:** Based on the FTTR distributed deployment capability, a data service platform can be built to achieve the prosperity of the data operation ecosystem, thereby improving user loyalty and increasing value-added benefits.

Suggestions

To shift from bandwidth monetization to experience monetization, telecom operators and related industry chains need to continuously improve the digital home experience of home broadband users and ensure that users can enjoy high-speed and convenient gigabit network services.

1. Standards first: Fibers are the mainstream medium for high-speed connections in the future. To improve FTTR deployment efficiency in residential and building areas, it is recommended that the government, communication management organizations, and housing and construction management organizations jointly release cabling standards for deploying fiber networks during the construction phase of new residences and buildings. In addition, they need to release the FTTR construction and acceptance criteria for interior decoration and reconstruction scenarios.

2. Wide deployment: Thanks to technical advantages such as FTTR network-wide management and control, plug-and-play, and collaborative scheduling, operators can quickly deploy high-quality home networks for home users. In addition, we need to promote FTTR from multiple dimensions, such as business models, construction and experience acceptance criteria, and policy support.

3. Continuous development: Based on FTTR, we need to start the industry definition and ecosystem construction of next-generation home broadband, and provide full coverage and high-speed network experience for home users. In addition, we need to provide secure, reliable, and easy-to-share data storage services, building a computing platform for homes and smart communities.

Huawei Solutions

Huawei takes the lead in launching the industry-leading OptiXstar series products for the FTTR for Home solution, including Wi-Fi 6 series MFUs and SFUs such as HN8000, V100+K600, and K100, innovative power over fiber (PoF) cables, digital ODN capabilities, and end-to-end (E2E) intelligent management and control services. Huawei introduces the industry's brand-new centralized Wi-Fi access network (C-WAN) architecture in which the MFU functions as the brain to centrally manage and coordinate air interface resources. Wi-Fi hotspots work in an orderly and efficient manner, improving the performance of the entire network.(Figure 6: Huawei FTTR for Home Solution)

Huawei FTTR for Home solution has the following advantages:

1. Ultra-gigabit: The innovative network processor architecture design supports 100% offloading processing and acceleration engine for Wi-Fi 6. In addition, the SmartRadio technology for intelligent scheduling of air interface resources effectively reduces interference, increases the signal-to-noise ratio (SNR) by 5 dB, and increases the rate to 2 Gbps.

2. Zero frame freezing: Intelligently identify important broadband applications, such as live broadcasts, video conferences, online courses, and e-sports, and enables dedicated channels for VIP applications. This reduces Wi-Fi latency by more than 60% and ensures zero frame freezing.

3. Seamless roaming: With the unique seamless roaming coordinated network (SRCN) technology, the FTTR system provides one roaming policy per terminal. The network can be switched quickly and accurately with a roaming latency of less than 20 ms, ensuring smooth video and conference services.

4. High concurrency Compared with the industry solution, the Huawei FTTR for Home solution supports four times more concurrent terminals on the entire network by using the unique intelligent conflict optimization and frequency band adjustment algorithms. A maximum of 128 concurrent terminals can work stably and at a high speed.

5. Green: Super flexible and transparent fibers are used as networking media, which are easy to deploy and do not affect a home's interior decorating style. They are corrosion-resistant, cost-effective, and environmentally friendly. The service life of these fibers is up to 30 years. They can work with Huawei MFUs and SFUs to save 20% of emissions. On average, one set of devices saves 240 kWh electricity per year. In addition, the first PoF solution for home scenarios is designed, which does not require strong-current cabling during construction.

6. Full management: iMaster NCE makes home networks visible, manageable, and maintainable. Users can use a mobile app to learn about the Wi-Fi network status in real time, perform one-click detection and remote recovery, and ensure healthy Internet access. This feature enables operators to identify poor network quality and implement precision marketing.

7. Elegant appearance: Various types of SFUs support flexible installation and adaptation in multiple scenarios, including desktop, wall-mounted, and panel-mounted SFUs. Scalable fiber socket units (FSUs) are used and space for coiling drop cables is reserved, allowing indoor cabling to achieve a more elegant appearance.

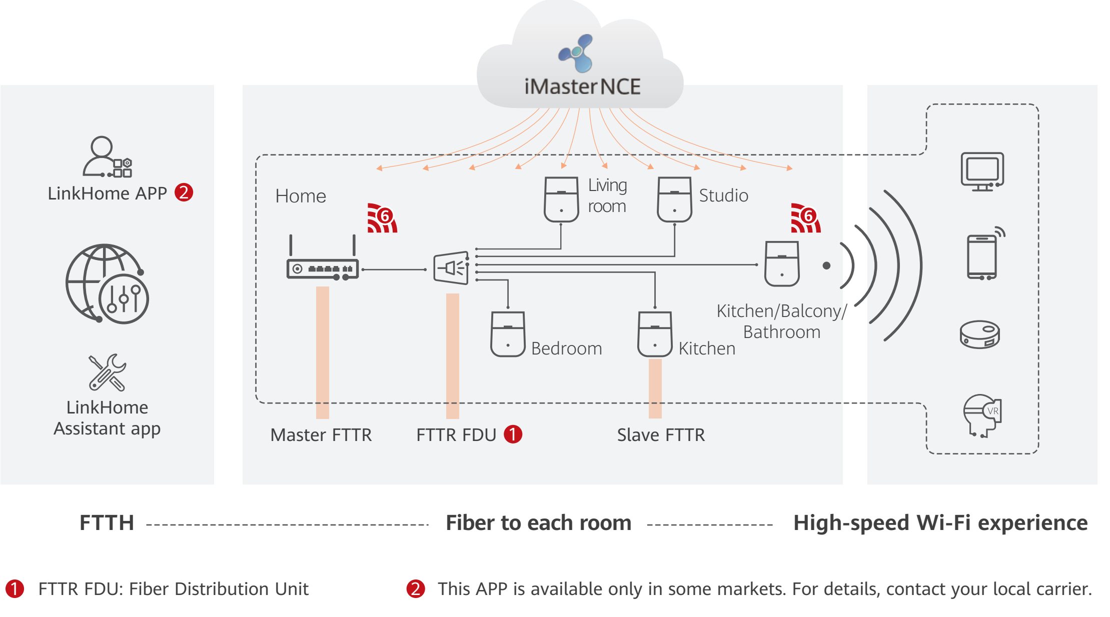


Figure 6: Huawei FTTR for Home Solution

Trend 3

Fibers Help Enterprises Build Green, Low-Carbon Campus Networks and Reliable Industrial Internet

Campus Networks

Trends

From governments to enterprises and from industries to individuals, digital transformation is on the rise around the world. We see surges in popularity for smart cities, smart campuses, smart transportation, smart power supply, smart policing, smart firefighting, smart environment protection, and smart manufacturing, bringing brand-new experience to production and people's life and creating new value for society.

Smart campus is the foothold of an intelligent society, and a new concept and model for developing the digital economy.

1. Service Cloudification

According to the Global Optical Communications Industry White Paper released by Ernst & Young, a large number of small- and medium-sized enterprises (SMEs) are in urgent need of cloudification. According to the estimation based on the market scale of enterprise cloudification in Germany, the compound annual growth rate (CAGR) of cloudification will reach 12% from 2020 to 2025. Evidently, more and more enterprises are using cloud services. This results in various services and application servers being centrally deployed in data center equipment rooms or on public or private clouds. Campus network traffic is mainly composed of north-south traffic instead of east-west traffic. As such, there is a need for network that adapts to north-south traffic, has a simple architecture, and supports fast deployment.

2. Ubiquitous Connectivity

In the future, smart campus networks will collect status and service data through connections at the perception layer, aggregate the data to the digital platform, and converge data and services on the platform for further analysis and decision-making. Therefore, ubiquitous connectivity at the perception layer is the basis for in-depth convergence of status and service data in smart campuses. This is why ubiquitous connectivity technologies are crucial to building smart campuses.

3. Simplified O&M

The construction and management of traditional industrial parks lack integration with science and technologies. This leads to problems such as information and data silos in campus management. Such issues are further exacerbated as the network scale increases, with configuration management and maintenance of devices becoming more and more burdensome. As such, the existing campus network architecture needs to be changed and optimized to implement multi-network convergence and unified management, as well as simplify O&M. This will help improve precise operation and informatization management level of campuses, promoting scientific and technological innovation in smart industrial campuses.

4. Green and Low Carbon

In 2022, China's Ministry of Industry and Information Technology (MIIT) and six other departments jointly issued the Action Plan for the Green and Low-Carbon Development of the Information and Communications Technology Industry (2022-2025). According to the plan, by 2025, the comprehensive energy consumption per unit of information flows should be further reduced by 20%. In the future, smart campuses will be green and highly efficient physical spaces, reducing energy consumption and carbon emissions. To achieve this, construction of campus networks needs to: use environmentally friendly solutions that reduce energy consumption; accelerate the upgrade and replacement of old, energy-intensive network devices; accelerate the green reconstruction of core equipment rooms, as well as aggregation and access equipment rooms; accelerate the deployment of green communication media optical cables and fibers in the entire campus.

Suggestions

Focusing on service cloudification, ubiquitous connectivity, simplified O&M, and green and low-carbon networks in campuses, enterprises can accelerate the transformation and upgrade to FTTO all-optical networks. The FTTO campus networks have the following characteristics:

1. Simplified architecture: The P2MP network architecture is simplified to two layers: the aggregation and access layers. This reduces the number of active aggregation nodes and enables one-hop cloud access, providing better network experience assurance.

2. All-optical connections: Fibers continuously move closer to users, and one fiber carries multiple services, achieving fiber to the room and fiber to the desktop. Both wired and wireless connection modes are used to connect the management system, data system, and production system in campuses. This solution enables on-demand, seamless, secure, and plug-and-play connections to ONUs in campuses, in addition to providing network experience assurance such as high bandwidth and low latency.

3. Intelligent O&M: Device running status is monitored and comprehensively detected in real time to improve device running efficiency. Statistics on device running data are collected and big data analysis is performed to diagnose device faults, evaluate device health, and adjust maintenance policies in real time to prolong device service life. Provide a real-time online, on-demand, intelligent, and premium-experience device maintenance mode to quickly handle device fault alarms, reduce device fault response duration, and improve management efficiency.

4. Energy conservation and emission reduction: Passive devices replace active devices, eliminating the need for ELV equipment rooms. The P2MP architecture improves port bandwidth usage and reduces energy consumption per traffic unit. Multi-network convergence reduces the number of NEs. Renewable fibers that have an ultra-long service life are used as transmission media.

Huawei Campus Network Solution

Huawei FTTO solution is widely used in education, healthcare, hotel, and enterprise office scenarios. The following are the networking diagram and some innovations of Huawei FTTO solution.(Figure 7: Huawei FTTO Solution)

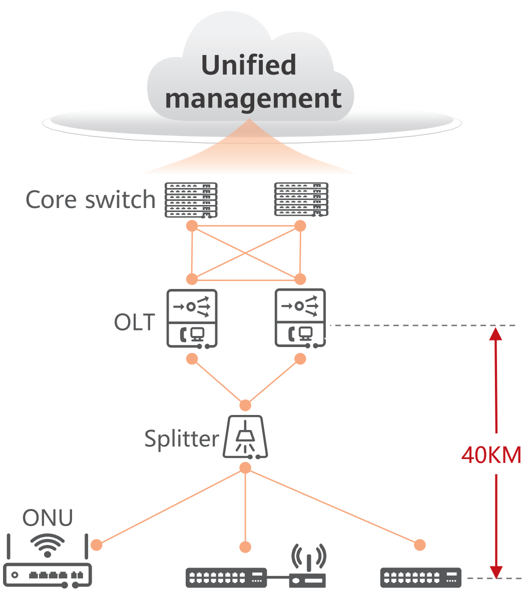


Figure 7: Huawei FTTO Solution

- With an advanced and reliable architecture, the industry's first OLT with a distributed architecture provides 200G or 400G slot bandwidth and separates forwarding and control services. In addition, the OLT supports smooth evolution of PON technology, protecting customers' investment. Both its control boards and service boards supporting in-service software upgrade (ISSU).
- Digital ODN and end-to-end (E2E) fiber pre-connections support outdoor aerial and duct scenarios, as well as indoor MDU scenarios, achieving efficient network construction. The industry's first AI+optical iris technology visualizes the entire network topology.
- Dedicate networks (D-NETs) (hard slicing network): D-NETs are isolated using hard pipes. VLANs and MAC addresses of slices can be repeatedly planned. The minimum slicing granularity supports ONU user-side ports. One network carries multiple services, reducing network construction costs.
- The industry's first 20G PON ONU supports two XGS-PON high-bandwidth ports, four 10GE downstream ports, PoE++, and full-rate access of four Wi-Fi 6 APs.
- ONUs of various types meet the requirements of various scenarios. ONUs require no configuration and support plug-and-play, while services are available immediately after ONUs are replaced.
- Power over fiber (PoF) cables support 800 m power supply, transmitting power and optical signals over the same cable. ONUs can be installed anywhere, irrespective of power supply availability.
- The industry's first Class D+ XGS-PON optical module with a high optical power budget of 38 dB.
- The F5G small all-optical solution focuses on small and micro campus scenarios with less than 100 information points, providing ultimate experience, simplified deployment, and intelligent O&M.

Industrial Internet

Trends

The Industrial Internet is an important infrastructure for this latest industrial revolution that's taking place around the world. Governments around the world have formulated and released related policies: Germany's Industry 4.0, the U.S. Industrial Internet, and China's Made in China 2025. Countries hope to use the Industrial Internet to improve machine running efficiency, reduce energy consumption, and help enterprises reduce costs and achieve green, secure, and sustainable development. Networks form the connection layer of the industrial Internet. As such, they face new challenges and need to meet new requirements with the development of the industrial Internet.

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1. Industrial Internet Security and Network Connection Security Become More Important

Network connection is seen as underpinning the industrial Internet, making network security increasingly important. The network security of the industrial Internet includes the security of internal networks of factories that carry industrial intelligent production and applications, as well as the security of external networks. With the development of the industrial Internet, the internal network of a factory becomes IP-based and wireless and covers a large area, while the networking mode becomes flexible. For the external network of a factory, the information network is gradually integrated with the control network, the enterprise private network is gradually integrated with the Internet, and products and services are increasingly Internet-based. These trends mean that network security issues on the traditional Internet start to spread to the industrial Internet. Specifically, industrial interconnection protocols change from proprietary protocols to Ethernet or IP-based protocols, leaving networks more vulnerable to attacks. Some existing industrial Ethernet switches (usually non-management switches) are unable to defend against increasingly sophisticated DDoS attacks. Meanwhile, factory network interconnection, production, and operation gradually change from static to dynamic, posing enormous challenges to security policies. To address these challenges, highly reliable communication technologies are required to implement network isolation for converged services, encrypted transmission of network data, access authentication of network devices, and highly reliable network protection in extreme cases.

2. Industrial Internet Factories Shift Towards Unstaffed and Least-Staffed, Leading to Longer Network Connection Distance and Requiring Higher Bandwidth

The industrial Internet factories in the future will move towards being unstaffed or least-staffed. In scenarios such as coal mining areas, as well as explosion-proof areas of chemical campuses, ports, large logistics campuses, airports, and large construction sites, frontline miners, tower crane drivers, and container truck drivers are the core of production lines. However, this presents a series of issues for enterprises. For example, working environments are complex, safety accidents frequently occur, production efficiency is low, labor costs are high, and recruitment is difficult. There is an imbalance between the working environments as well as salaries, and requirements for efficiency and low-cost. As such, enterprises urgently need new information and communications technologies (ICTs) to implement ultra-long distance, low latency, and ultra-high bandwidth transmission of data such as videos. This can help enterprises realize remote, unstaffed, or least-staffed operations in factories.

3. As the Basis of Industrial Interconnection, the IoT Connects Countless Terminals and Requires Diversified Connection Capabilities

According to Gartner's 2021 Hype Cycle, IoT will be one of the core technologies that reshape lifestyles. It is the basis for Internet-based and digital industries and provides huge volumes of data for industry digitization. From 2023 to 2025, home appliances will be networked on a large scale. And from 2026 to 2030, IoT will see wide use thanks to the support of technologies such as AI, cloud computing, edge computing, and big data. Its application scenarios and business models will be gradually enriched.

Reliable network connections are fundamental for large-scale application of IoT. In addition, devices connecting networks need to provide various port types, such as RJ45, RS485, RS232, DIDO, Wi-Fi, ZigBee, LoRa, and BLE ports. The combination of fiber networks and ONUs will pave the way for large-scale application of IoT in the next decade. While fiber networks feature low latency, high bandwidth, ultra-long-distance transmission, high reliability, and energy saving, ONUs provide various ports.

Suggestions

To meet the network connection requirements of the industrial Internet, such as security and reliability, ultra-high bandwidth, ultra-long distance, and Internet of Everything (IoE), enterprises can accelerate the transformation and upgrade to fiber to the machine (FTTM) networks in their internal production and operation environments. In enterprise cross-campus, Data Center Interconnect (DCI), and private line service scenarios, it is recommended that optical transmission be used to build reliable private networks for enterprise communication.

The FTTM solution is a future-oriented and sustainable network solution based on fiber connections. It has a green and simplified architecture, and offers stability, reliability, and easy capacity expansion. With these advantages, it can help enterprises quickly roll out new production lines, ensure stabled operations, and improve quality and efficiency. These benefits are further explained below:

- Green and **simplified**: Unlike copper cables, fibers can exceed 100 meters and require no intermediate aggregation layer, simplifying cabling. In addition, large split ratios reduce the overall cabling costs by 50% and the energy consumption of the entire network by 40%.

- **Secure and reliable:** Fibers are not affected by electromagnetic interference and prevent unauthorized access to production data and control services. In addition, devices provide strong anti-DoS and full-link protection capabilities, implementing fast switchover upon faults. Fiber links also support AES128 encryption. In addition, the FTTM network can realize hard isolation of various services, eliminating interference among services.

- **Easy capacity expansion:** After the production line network is deployed, services can still be adjusted as required. The FTTM solution provides network port reservation and plug-and-play ONUs to help quickly roll out new services.

Optical transmission networks are recommended for enterprise communication on private networks to cope with service security and supply security challenges, as well as meet future service development requirements. Optical transmission networks can carry real-time production services and IP data at the same time. The networks use fibers as the media and technologies such as single-fiber multi-wavelength aggregation and single-wavelength high bandwidth to maximize the usage of fiber resources. The optical transmission networks have the following features:

- Wide coverage of port types, supporting ubiquitous connections of various services

- Flexible bandwidth expansion and bandwidth slice management, greatly improving bandwidth usage

- E2E hard pipe isolation, improving service transmission security

- Simplified network architecture and management, and one-hop cloud or site access

- Intelligent O&M, realizing network-wide visualization and management

Huawei Solution

Huawei FTTM solution provides various types of industrial ONUs, including intrinsically safe ONUs, DIN rail-mounted ONUs, junction box (86 mm) ONUs, and SFP ONUs. These ONUs work with PoF cables to meet requirements for fast installation and deployment in various scenarios. They also support 802.1X authentication to ensure secure device access. In terms of security and reliability, Huawei FTTM solution provides Type B and Type C protection as well as switching within 50 ms. This ensures that services are quickly switched to the standby link when the active link is interrupted, protecting services. For long-distance transmission, Huawei launches Class D optical modules, achieving a transmission distance between an OLT and ONU of up to 40 km.(Figure 8: Huawei FTTM Typical Networking)

Huawei FTTM solution applies to various industries. In intelligent coal mines, for example, Huawei's first FTTM ring network is secure, reliable, and easy to maintain, and provides ultra-high bandwidth for underground communication through innovations. These innovations include the two-layer network architecture, industrial ring network protection, and pre-connected optical components, and bring four benefits to coal mine communication: electrical safety, service security, construction safety, and maintenance security. Due to the introduction of optical ring passive (ORP), a large number of passive optical transmission nodes replace active devices, reducing the number of explosion-proof nodes by about 40%. This ensures electrical safety and reduces the investment in explosion-proof devices. The innovative industrial optical ring (IOR) protocol improves service reliability by protecting against multi-point failures. Pre-connection is an innovative optical component technology that avoids underground fiber splicing, reduces security risks, and improves construction efficiency. The intelligent diagnosis

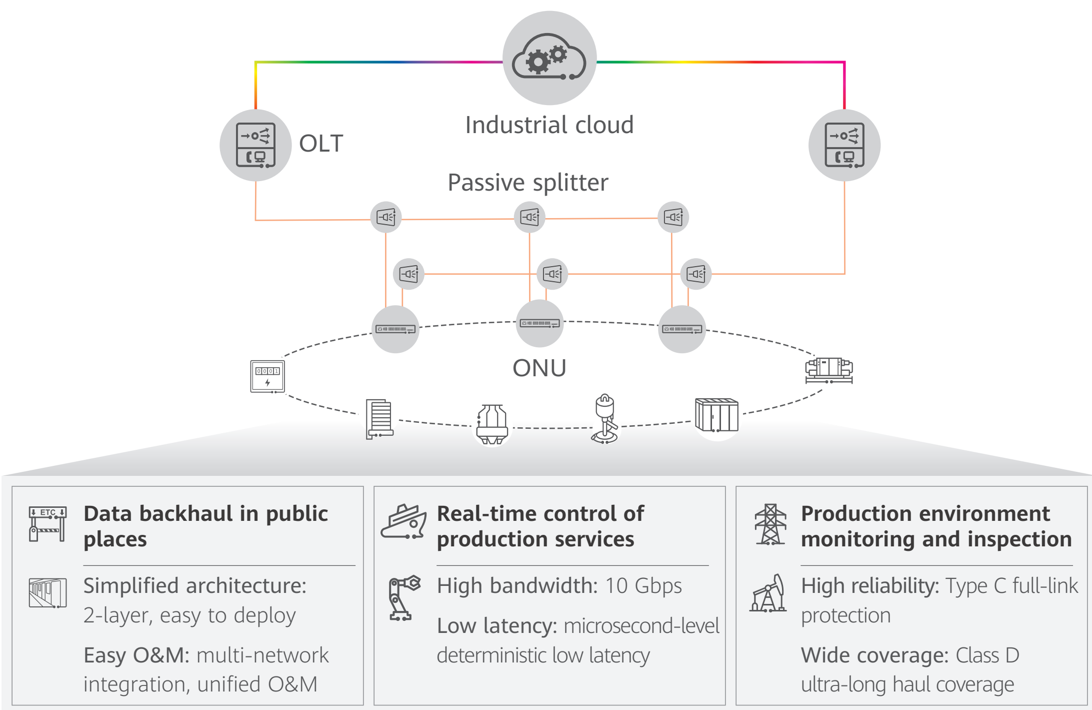


Figure 8: Huawei FTTM Typical Networking

function locates faults with an accuracy of meters, reducing the underground operation time by about 90%.

Transmission networks use a native hard pipe (NHP) technology based on the time division multiplexing (TDM) technology. Transmission networks gone through carrier communication, PCM/PDH, SDH, and OTN technologies, and now arrive at the fifth generation of communication technology: optical service unit (OSU) technology. The OSU technology combines the advantages of SDH and OTN technologies. Specifically, in addition to an ultra-high bandwidth over 100 Gbps, it provides service access capabilities ranging from 10 Mbps to 100 Gbps. This is why OSU technology is the first choice for SDH network upgrade.

Huawei's transmission network solution also applies to various industries. In the intelligent power grid, for example, the NHP all-optical network integrates the OSU technology into the backbone network, power transmission and transformation networks, substation campus network, and distribution network. In this way, the NHP all-optical network flexibly carries services at each layer. After the NHP backbone network is integrated with the OSU technology, the OTN backbone network can be further deployed at substation campuses. NHP all-optical power transmission and transformation communication networks carry various services, including industrial control services, such as teleprotection, security and stability, and scheduling automation. These services feature low bandwidth, high reliability, low latency, and high latency certainty. Based on the characteristics of electric power services, the NHP all-optical substations and power distribution communication network uses OSU over PON to reconstruct the traditional PON technology. The PON/ODN network architecture is used to implement OSU P2MP access of substation campuses. The following figure shows the NHP all-optical network architecture.(Figure 9: NHP All-Optical Network Architecture for Power Grid)

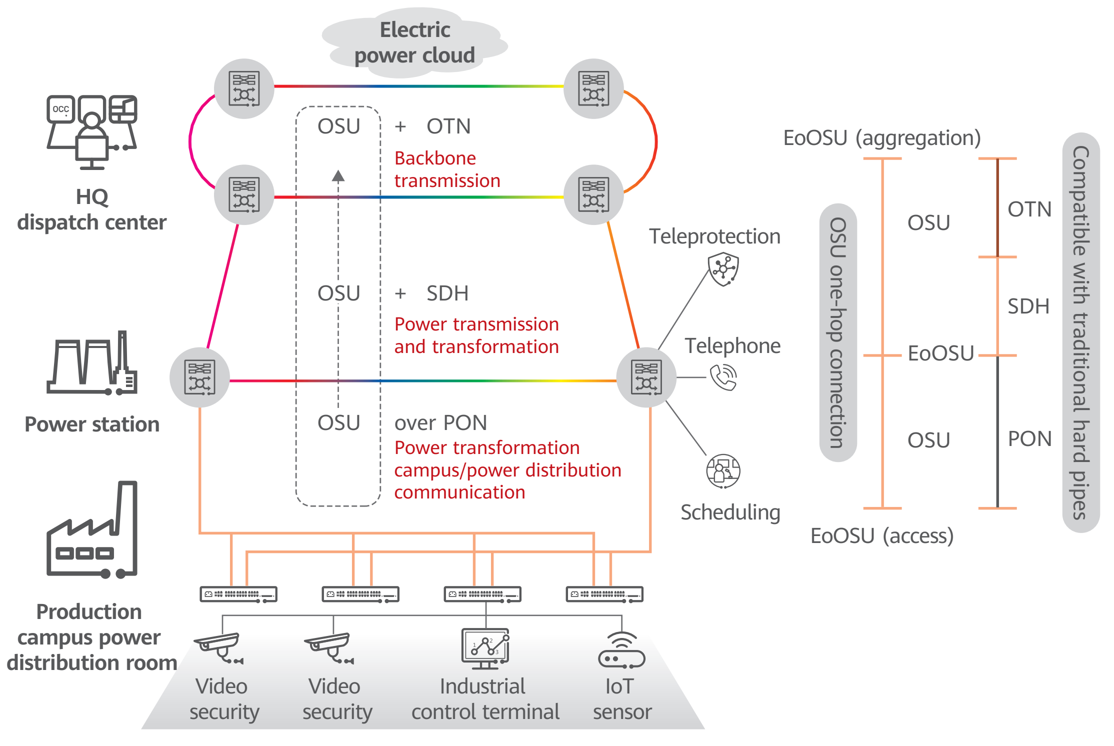


Figure 9: NHP All-Optical Network Architecture for Power Grid

Trend 4

Evolution of Optical Transport Networks to 100 Tbps per Fiber and All-Optical Grooming

Trends

1. Video-based content and online interaction continuously increase network traffic.

The information society is evolving towards an intelligent society, with video content becoming an increasingly important information carrier. The same can be said for the development of video services, which are rapidly transitioning towards ultra HD (such as 4K and 8K), real-time interaction, immersive, and AR/VR services. However, with the development of video services, the requirements for network bandwidth increase exponentially, and the requirements for latency and jitter are also elevated. For example, 8K ultra-HD videos require a bandwidth of higher than 100 Mbps and a latency of lower than 20 ms. Strong-interaction XR services require a latency of lower than 5 ms.

According to Omdia's prediction, the compound annual growth rate (CAGR) of traffic of different services on the network will exceed 40% from 2018 to 2024, and video services will account for nearly 80% of total traffic. The bearer network must have a higher transmission bandwidth to ensure a stable user experience.

2. Various industries accelerate cloudification, and data center interconnect (DCI) traffic increases rapidly.

The digital economy has exploded in recent years with more and more enterprises upgrading their IT systems as digital transformation gathers pace. According to Gartner's prediction, more than 85% of global enterprise applications will be migrated to the cloud by 2025.

DCI is an important infrastructure for industrial digitalization. The traffic volume and quantity of global DCs are increasing, and according to data from Equinix, the CAGR of DCI traffic will reach 51% from 2018 to 2022. This will drive DCs to develop from 100G to a higher rate, higher bandwidth, and lower latency. The arrival of 400G is just around the corner.

Omdia predicts that 400G development will enter an acceleration phase from 2023. Around 2024, the market scale of 400G will be equivalent to that of 100G/200G. By 2025, the 400G market scale will surpass that of 100G/200G.(Figure 10: Global 100G/200G/400G/600G/800G Coherent Optical Module Forecast)

3. Cloud-edge-device synergy diverts traffic directions.

In traditional DCs, services are deployed on one or more physical machines in a centralized manner. The overall traffic of DCs is mainly "north-south", and the "east-west" traffic in comparison is light. With the advent of the Internet of Everything (IoE), computing requirements increase exponentially, which has a great impact on the traffic model of DCs. For example, search and parallel computing services require a large number of servers to form a cluster system for collaborative work. As a result, the traffic between servers becomes heavy. In addition, DCs are encouraged to migrate towards the edge, and cloud-cloud synergy, edge-cloud synergy, and edge-edge synergy are implemented to form a collaborative computing system that integrates the cloud, edge, and device. In this case, network traffic also changes direction from "north-south" to "north-south + east-west".

The reconstruction of the DC-centric network advances the evolution of a network architecture to full-mesh interconnection and three-dimensional networking, and builds a new infrastructure featuring cloud-edge-device synergy. This will form an important structure to implement flexible scheduling of distributed resources, high-speed interconnection for all-domain data, and penetration of intelligent applications to the edge.

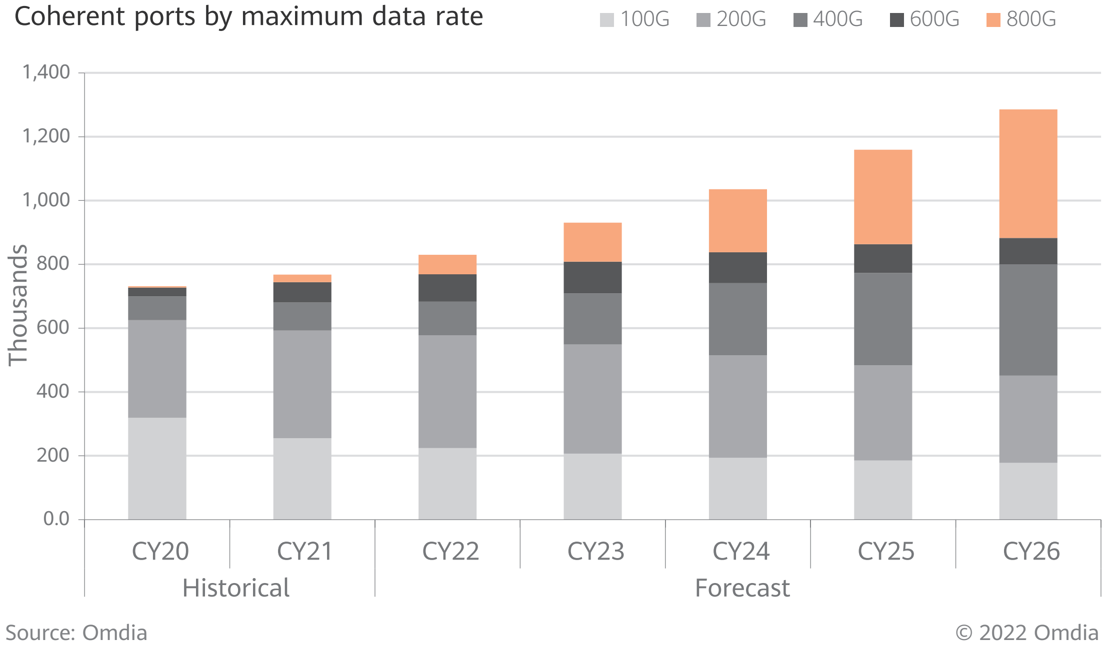


Figure 10: Global 100G/200G/400G/600G/800G Coherent Optical Module Forecast

Recommendations

1. Promote the evolution of optical transport to 100 Tbps per fiber to meet the requirements of a continuous increase in traffic.

There are two important paths for improving the capacity of OTN/WDM optical transport systems: A. Improve the single-wavelength rate, for example, from 10G to 40G, to 100G, to 200G, to 400G, and then to 800G. B. Expand available spectrum resources, for example, from C band to extended C band, to Super C band, and then to Super C+L band.

A.Continuously improve the single-wavelength rate to evolve from single-wavelength 100G/200G to 400G.

Generally, more subcarriers, higher baud rates, and higher-order modulation formats can be used to improve the transmission rate. Compared with the dual-carrier 400G solution, the single-carrier 400G solution reduces the number of line ports by half, thereby reducing costs and simplifying O&M. In conclusion, the single-carrier 400G solution is a better choice for service bearing. The higher-order modulation format can multiply the rate, but has poor anti-noise capability and short transmission distance. 400G 16QAM at a 100 GHz channel spacing supports a transmission distance of about 1500 km, meeting the requirements in metro short-distance application scenarios. A higher baud rate can increase the rate without affecting the transmission distance. The 400G system has the same transmission performance as the 100G/200G system without changing the current network infrastructure. To meet the requirements of ultra-long haul transmission scenarios such as backbone networks, the 400G QPSK modulation format with a baud rate of 130 GB+ must be used.

B.Expand the range of available spectrum resources of optical fibers to double from 6 THz to 12 THz.

Theoretically, the spectrum range available for optical transmission can be extended to 1260~1675 nm, covering the O, E, S, C, and L bands respectively. Currently, the extended C band is the most commonly used band in the optical communications industry, and the available spectrum range is 4.8 THz. Over the

past two years, some operators have also started to deploy Super C band on a large scale, and the available spectrum resources are 6 THz, 25% higher than those of the extended C band. The L band is second only to C band, and it can further double the available spectrum resources of optical communication. The Super C+L band optical transport system is constructed to achieve a total of 48 Tbps transmission capability, which is 120 400G wavelengths. In the future, single-wavelength 800G can further increase the transmission capability to 100 Tbps per fiber.

2. Promote all-optical cross-connect OXC deployment from the core to the edge to meet efficient device-edge-cloud synergy and flexible grooming requirements.

ROADM transforms traditional point-to-point links into flexible and groomable optical networks. It is a highly commercial and mature optical switching technology. All-optical cross-connect OXC provides more innovative and flexible all-optical switching and grooming. Compared with traditional ROADM optical switching based on discrete boards and inter-board fiber connections, OXC uses an all-optical backplane to achieve zero fiber connections, effectively preventing incorrect manual fiber connection operations. One cabinet is used to replace multiple traditional cabinets, reducing equipment room footprint and power consumption, building an all-optical switching resource pool, and implementing low-latency and non-blocking grooming.

Based on the cloud-network convergence and cloud-edge synergy trends, OXC optical switching and grooming are preferred to replace electrical-layer forwarding. The advantages of all-optical networks are fully utilized to build "digital overpasses" for optical wavelength grooming, so that different optical signals can be groomed in any direction. It is recommended that many-degree OXC be introduced to the backbone and metro core layers, low-cost and few-degree OXC be introduced to the metro aggregation and access layers, and E2E OXC be used to build an all-optical base that features simplified architecture, ultra-high capacity, low latency, high flexibility and reliability, and energy saving to achieve efficient device-edge-cloud synergy.

Solution

Huawei Green All-Optical Network connects to enterprises and homes downwards and connects to cloud and computing power upwards, supporting fixed-mobile convergence (FMC) for operators and digital development in various industries.(Figure 11: Networking Diagram of Green All-Optical Network)

This solution consists of four innovations:

1. Metro Alps-WDM solution efficiently shares and flexibly allocates resources on demand to reduce network construction costs.

On a traditional metro network, there are a large number of WDM rings between COs and aggregation sites, but only a small number of wavelengths are used on each ring. As a result, wavelength resource utilization is low and network construction costs are high. Most metro networks mainly use FOADM sites, and

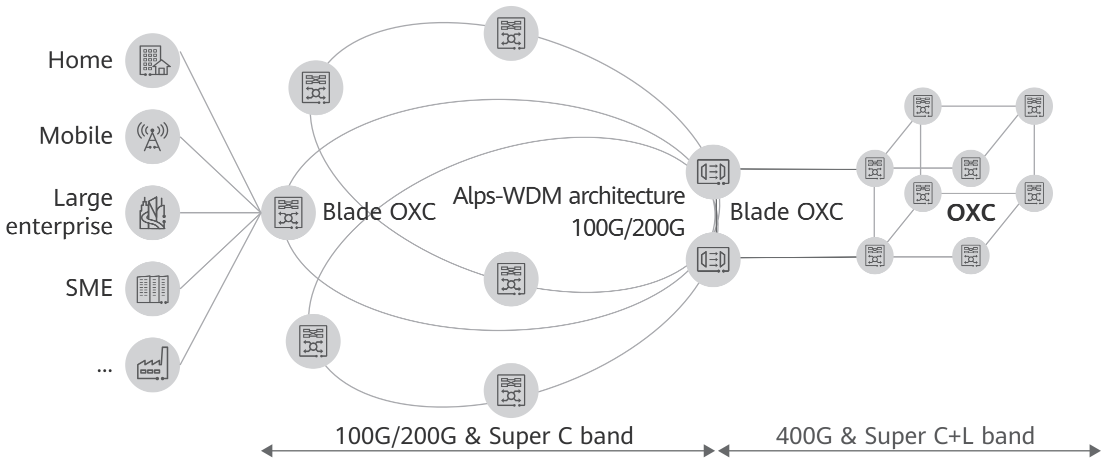


Figure 11: Networking Diagram of Green All-Optical Network

therefore service grooming is inflexible. The innovative Alps-WDM solution implements evolution from FOADM networking to OXC/Blade OXC networking and E2E all-optical one-hop connection, thereby reducing network latency. In addition, a bandwidth resource pool is constructed between COs and aggregation sites to efficiently share wavelength resources. Each CO dynamically obtains required resources on demand to reduce per-bit network construction costs. This solution also supports automatic planning and allocation of wavelength resources to improve O&M efficiency and reduce OPEX.

2. A series of 400G solutions meet the requirements for multiple scenarios and high bandwidth.

Huawei Coherent 3.0 solution uses an advanced GSC-FEC algorithm, faster-than-Nyquist (FTN) algorithm, highly-integrated optical component coherent optical subassembly (COSA), and optoelectronic packaging technologies to continuously improve performance and reduce power consumption, and provides a series of 400G solutions.

Low-power-consumption and short-distance 400G s16QAM: supports single-wavelength 400G with a 100 GHz channel spacing over a transmission distance of around 3000 km.

High-performance and long-distance 400G QPSK: supports single-wavelength 400G with a 150 GHz channel spacing. The transmission capability of 400G is equivalent to that of 100G/200G, meeting the requirements of long-haul backbone application scenarios.

3. Continuous and smooth capacity expansion from Super C band to Super C+L band is achieved.

Huawei has made continuous breakthroughs in hardware design, algorithms, chips, lasers, receivers, amplifiers, and other system components to achieve Super C+L band communication. For example, a new doped EDFA is used to expand the L-band spectrum. In the system engineering design, the stimulated Raman scattering (SRS) effect is overcome when channels are added or deleted, achieving stable Super C+L band performance.

Huawei's innovative optical amplifier board provides two independent pluggable optical amplifier modules, which correspond to Super

C band and L band respectively. In the initial phase, capacity is low, and therefore only Super C-band OAs are required. In the future, L-band components can be added to implement on-demand deployment and reduce network construction costs.

4. All-optical cross-connect OXC builds an "overpass" in the information world.

Huawei OXC devices use new technologies, such as the high-precision automatic fiber printing machine based on 3D lattice algorithms, optical digital AI label, and 2D liquid crystal on silicon (LCOS). Through miniaturized and integrated components and intelligent management, Huawei OXC device implements an "all-optical 3D-mesh grooming network" using a backplane with the same size as an A4 piece of paper, greatly simplifying optical grooming scenarios and achieving non-blocking, flexible grooming of optical signals in 32 degrees.

Huawei provides the industry's only full series of end-to-end OXC products that can be put into large-scale commercial use. These OXC products include frame-shaped OXC devices, P32 and P32C, that are applicable to backbone and metro core nodes, 20- and 9-degree OXC devices oriented to metro core and aggregation nodes, and 9- and 4-degree blade OXC devices oriented to metro and access nodes. Blade OXC is highly integrated and cost-effective. Compared with traditional separated solutions in the industry, blade OXC reduces the device footprint by 80% and the power consumption by 20%.

Trend 5

Communication and Sensing Convergence, Moving from the Internet of Everything to the Intelligence of Everything, Constructing an All-Optical Sensing World

Trends

1. Digital sensing achieves the Intelligence of Everything, making social production and life more intelligent

The progressive development of both digital and intelligent technologies has revolutionized the 21st century, offering breakthroughs in the evolution of the Internet of Things (IoT), Big Data, and sensing technologies, moving humanity away from the Internet of Everything towards the Intelligence of Everything.

2. Communication and sensing convergence constructs an all-optical world, facilitating secure and efficient production

Fiber optic sensing has been applied across multiple industries and constitutes a major component of optical sensing. Optical fibers not only transmit signals, but also sense vibration, temperature, and strain. Communication and sensing convergence is an inevitable trend. Digital sensing enables the Intelligence of Everything, and optical sensing facilitates a secure and efficient manufacturing, and evolution towards automation and intelligence.

Production security: For example, security protection for long-distance oil and gas pipelines brings about high manual inspection costs and unpredictable emergencies. If pipelines suffer structural damages, not only huge economic losses will be incurred, but also a large number of enterprises and residents' energy and gas supplies will be shut down, leading to environmental damage and even casualties, as well as adverse social impacts. To prevent such risks, the fiber optic sensing function is applied to oil and gas pipelines for the early detection of anomalies. The fiber core of the accompanying optical cable in the oil and gas pipeline is reused. Based on the fiber's vibration detection ability, pipeline intrusion events are continuously monitored, construction activities such as mechanical excavation and manual excavation are identified, and threat warnings are generated. This effectively reduces pipeline damage accidents, improves inspection efficiency and quality, and reduces manpower, which allows minimal staff or even unstaffed scenarios for pipeline inspection.

Perimeter security: Frequent incursions of railway and airport perimeters bring about major disruptions and losses to property, personal safety, and the safe operations of the area. Vegetation, animals, pedestrians, vehicles, wind, rain, snow, fog, and other complex weather and environments challenge the reliability, adaptability, and stability of perimeter protection systems. Perimeter protection is transforming from the traditional physical/manual kind to a more sophisticated type of technical protection. Due to its easy deployment and cost-effectiveness, the vibration optical cable is suitable for detecting various types of intrusions along long-distance fences, such as irregular and sheltered fences. Therefore, it is regarded as one of the most important technical protection measures for railway and airport perimeters.

City security: For example, gas leaks and explosion accidents frequently occur in urban pipeline corridors, endangering people's lives. A traditional sensor has a short service life and requires complex maintenance. Whereas, an optical sensor has advantages such as passive components, intrinsic security, high precision, and full-time and all-fiber segment monitoring, establishing a general trend in the technical protection for preventing intrusions and damage monitoring for urban pipeline corridors.

Suggestions

Long-distance coverage, precise positioning, and passive components of fiber optic sensing facilitates production, perimeter, and city security

Leverage the advantages of all-optical sensing, and focus on four aspects: ultra-long-distance comprehensive sensing, precise positioning, high security and reliability, and simplified deployment and O&M. Subsequently, this transforms the system from manual to technical defense, enabling the evolution of production, perimeter and city security.

1. Build a comprehensive sensing network

Optical fibers are used as sensing media to implement the real-time sensing of multi-dimensional information such as vibration, temperature, and strain in over an ultra-long range. This significantly reduces the dependency of traditional sensing technologies on infrastructure, such as the power supply and network, and builds a sensing data foundation for an intelligent world.

2. Achieve the ultimate and most precise sensing experience

Distributed fiber optic sensing technology can sense physical quantities at all points of an optical fiber. The spatial sampling density can be set to achieve ultra-long-distance sensing and ultra-high positioning accuracy at the 1 m level. This technology also senses multi-dimensional data such as vibration, temperature, and strain, and achieves identification accuracy beyond 99% with the help of intelligent identification algorithms, which in turn brings an unparallel user experience.

3. Ensure high security and reliability

The all-optical sensing technology is intrinsically secure. Optical signals are free from electromagnetic interference and can be reliably sensed in strong electromagnetic environments. In addition, this technology produces no external electromagnetic interference and is not restricted in electromagnetic sensitive environments. In fact, the service life of an optical fiber is over 20 years, meeting the stringent requirements of various industries for both the security and reliability of technical solutions.

4. Provide simplified deployment and O&M

Communication optical cables can be reused. Only one optical fiber and one device are required to implement sensing coverage of the entire segment, facilitating power supply and data backhaul. The network structure is a linear connection, allowing optical fiber faults to be easily visible and quick to locate. The entire system can be brought online quickly and is easy to operate and maintain, reducing the customers investment in system deployment and O&M.

Huawei's Innovative Solutions

Solution 1: All-optical sensing-based pipe inspection solution

In 2021, Huawei officially launched the Sensing OptiX Oil&Gas Pipeline Inspection Solution. This solution uses communication optical cables laid in the same trench as buried pipelines to sense vibrations along the pipeline, and uses intelligent analysis algorithms to implement real-time risk warning and precise positioning of hazards such as third-party construction, drilling holes, and oil theft.(Figure 12: Sensing OptiX Oil & Gas Pipeline Inspection Solution)

This solution includes DAS devices and sensing algorithm servers deployed at stations or BVSs. The maximum distance between two sites is 100 km. The centralized management platform deployed in the command and dispatch center can interconnect with other platforms such as GIS, video surveillance, drones, and pipeline inspection systems to form a complete, integrated solution in the production process. This ultimately eliminates pipeline security risks in a closed-loop manner.

Key technology 1: Enhanced oDSP

This solution focuses on precise warnings. At the optical system and hardware layers, the enhanced oDSP algorithm is used to eliminate monitoring blind spots and improve the signal-to-noise ratio (SNR). The effective collection rate of sound wave signals is greater than 99.9%, providing sufficient and reliable information input for data analysis and ensuring zero false negatives.

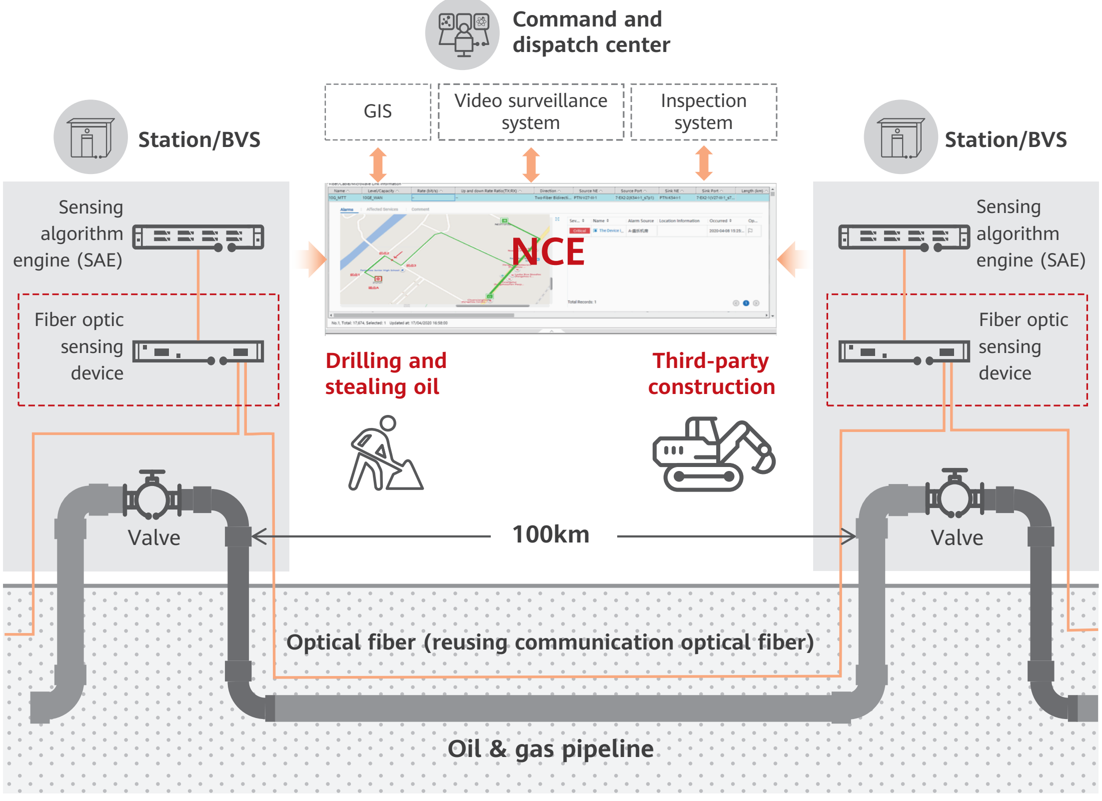


Figure 12: Sensing OptiX Oil & Gas Pipeline Inspection Solution

Key technology 2: 32-dimensional vibration waveform analysis algorithm

Based on the characteristics of sound wave signals, the voiceprint-based identification algorithm and noise reduction and voice enhancement technology are used to filter out background interference and enhance weak signals such as signals generated by manual mining. The preprocessed data is classified using the multi-dimensional voiceprint analysis algorithm based on deep learning technology to eliminate non-threat interference signals, and report threat events with an accuracy of over 97%.

Key technology 3: Online self-learning algorithm

The sensing algorithm also supports self-learning and self-optimization. Local samples can be learned online and algorithm models can be quickly adjusted to adapt to new environments and scenarios.

Based on the preceding three key technologies, the solution achieves precise warnings for pipeline security, significantly reducing repeated inspections and costs, and improving efficiency.

The key components of the solution include the EF3000 device, SAE engine, and NCE centralized management platform. EF3000, namely the DAS device, collects Rayleigh backscattering light and completes quantitative measurement of sound wave signals. The SAE engine analyzes and processes voiceprint data to accurately identify threats and filter out interference. The NCE centralized management platform can manage multiple DAS devices at the same time, display alarms in multiple presentation modes and report notifications, and provide standard northbound interfaces (NBIs) to interconnect with other systems.

In terms of optical technologies, this solution reuses three decades of technical accumulation and industry chain experience, including optical components, channel algorithms and coherent technologies, to ensure optimal precision, performance, and reliability. In terms of sensing algorithms, the solution utilizes Huawei's technical advantages in noise reduction and voice enhancement and artificial intelligence to build an intelligent sensing algorithm based on the fiber optic sensing technology base, achieving accurate data analysis results and providing an unprecedented user experience.

This solution has been successfully applied to multiple oil and gas pipelines in and out of China. The application covers complex environments, including farmlands, mountainous areas, highways, railways, and factories. No matter what the terrain is, the fiber optic sensing system can adapt to various topographies, effectively filter out background interference, and detect third-party construction behaviors along the pipeline in a timely manner. During a simulation test, when a customer simulated drilling holes with minor pressure, the system can still sense and accurately locate potential threats, thereby winning our customers' recognition.

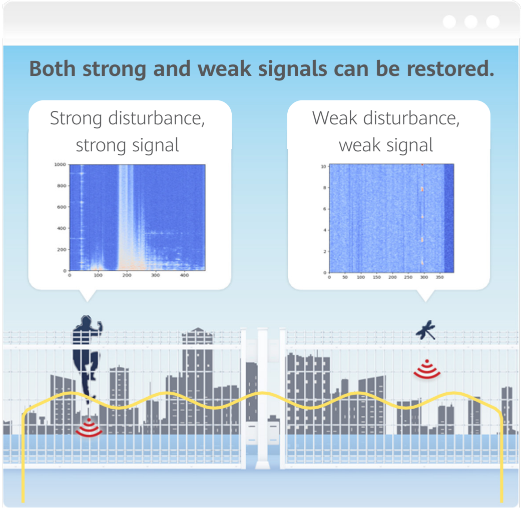
Solution 2: All-optical sensing-based perimeter Inspection solution

In addition to oil and gas pipeline warning scenarios, Huawei also applies the DAS technology to perimeter protection of sensitive areas, such as large campuses, airports, and railways. The multiple benefits of this solution include long-distance coverage, effective warnings, and fast deployment of fiber optic sensing technologies to detect intrusion behaviors such as illegal climbing and fence damage in a timely manner. (Figure 13: Sensing OptiX Perimeter Inspection Solution)

The sensing OptiX perimeter inspection solution is similar to that of the oil & gas pipeline inspection solution. The main differences in an all-optical sensing-based perimeter inspection solution are: (1) Optical cables are deployed on fences. (2) The SAE sensing algorithm adapts to perimeter intrusion behaviors based on global environment features, and eliminates interference from nature such as wind, rain, and small animals, implementing zero false negatives, anti-interference, and is able to continuously adapt. (3) The solution can flexibly work with the intelligent image identification feature of a video surveillance system to double check warnings, further improving customer experience.

Key technology 1: Enhanced oDSP, all-optical coherent noise suppression, and large dynamic range of vibration monitoring

This solution uses Huawei's unique low-noise coherent reception system and high-performance oDSP algorithm to detect weak signals as a result of minor fiber stretching.



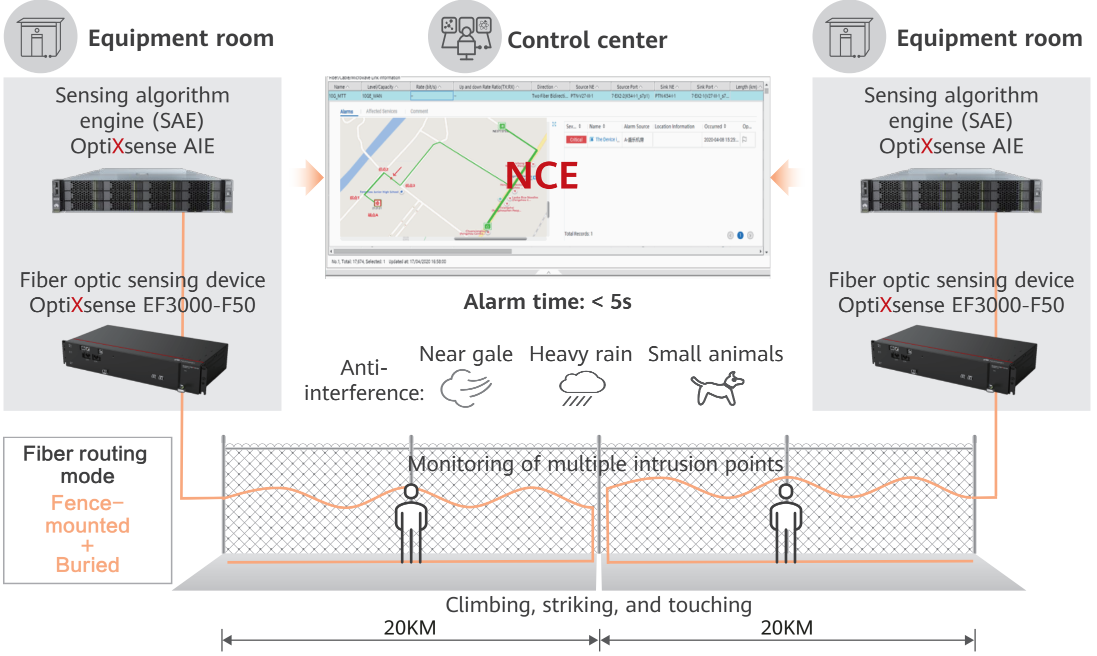
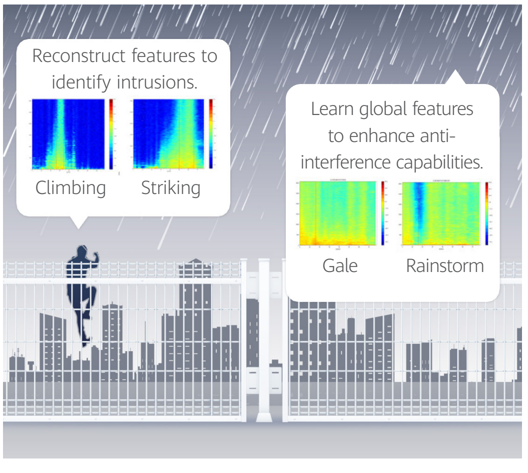


Figure 13: Sensing OptiX Perimeter Inspection Solution

The minimum detectable strain is 0.25 nε. With Huawei's unique precise sampling technology featuring ultra-high-resolution and large-scale linear detection technology, both strong and weak signals can be restored, and the dynamic vibration signal range is greater than 50 dB.

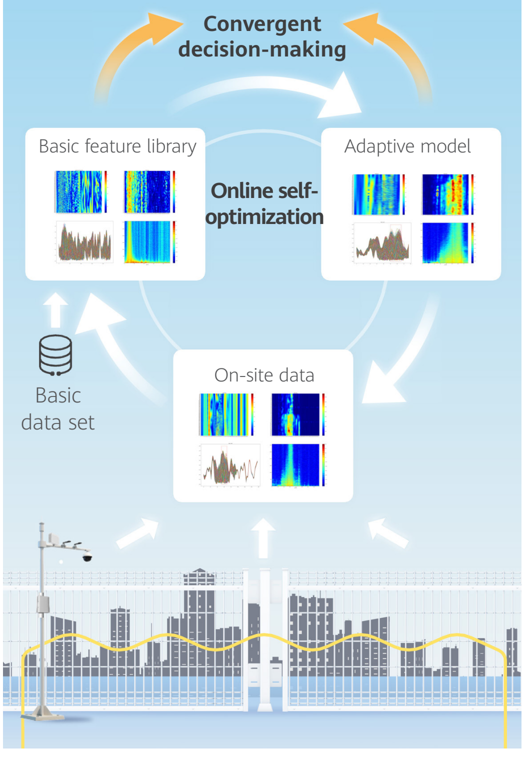
Key technology 2: IDF-AD extracts key intrusion features through feature reconstruction, generates alarms based on the judgment mechanism, and improves the alarm accuracy by 90%.

This solution identifies detailed differences between intrusion behaviors and interference behaviors based on the detailed features of the adversarial model, extracts global environment features based on the global features of the environment sensing network, integrates environment features with detailed features, and then distinguishes intrusion signals from interference signals by using the judgment mechanism. The alarm accuracy is improved by 90%. The false positive rate of the common single-event detection algorithm is 10x/km/day. While IDF-AD can reduce that to 1x/km/day.



Key Technology 3: FDTS adapts to environmental changes and user habits to continuously improve accuracy

After the solution is deployed, the system automatically collects on-site data, marks on-site events, and optimizes and learns data through online self-optimization algorithms; The system can also work with other sensing techniques, adjusts models online based on reliable on-site data samples, and generates adaptive models; The system dynamically selects convergence policies based on basic models and on-site adaptive models, improving model library iteration efficiency by 30 times. (The iteration period of the traditional model library is 30 days, and the FDTS supports iteration within one day.) This allows the system to adapt to specific environments and continuously improve the accuracy based on specific scenarios.



Trend 6

All-Optical Networks Move Towards Highly Intelligent ADN

Trends

1. Digital and Intelligent Transformation of Networks Reduces Costs, Improves Efficiency, and Becomes the Basis of Enterprise Survival

Global information and communications technologies (ICTs) are entering an era of change in technical architecture. Enterprise digital transformation is evolving from information management based on traditional IT architectures to intelligent operations based on cloud architectures. Accelerating innovation has become the core of digital transformation. Finding business breakthroughs and innovations to achieve sustainable development is the top priority of enterprises. Top global operators have formulated digital-first enterprise strategies. Here are some examples. China Mobile will promote intelligent transformation of network O&M and achieve high Autonomous Networks by 2025. MTN released its Ambition 2025 strategy and also plans to achieve high Autonomous Networks by 2025. According to a report released by IDC, by 2024, 51% of the global IT budget will come from digital innovation or transformation, and 70% of the IT budget in China will come from digital innovation or transformation. Digital transformation has become a strategic consensus among world-leading enterprises, and the reason why it is required has changed from cost reduction and efficiency improvement to enterprise survival.

2. From "Static" Manual Configuration to "Adaptive" Agile Deployment, Providing Premium Experience Assurance

As more and more key services of enterprises need to be quickly adjusted in a short period of time, frequent changes challenge the limit of manual network O&M. This requires networks to flexibly implement intelligent awareness and autonomous changes from traditional static policies to dynamic policies. Sensitive services, such as services in emergency command centers and financial institutions, require low latency and guaranteed bandwidth. Real-time application services, such as video conferencing and online training, require real-time network response and quick service provisioning. The surge of cloud access traffic and inter-cloud DC access traffic requires high-bandwidth connections.

3. 100x Increase in "Connection+Scale" of Optical Networks Drives Network Automation Evolution

Connectivity has become a factor of productivity when it comes to the digital progress of enterprises. To meet the service requirements for larger capacity, higher bandwidth, and lower latency, optical networks have gradually changed from the basic transport networks to business support networks, and the connection and network capabilities are continuously expanded.

Connectivity capability expansion: On the one hand, with the development of Internet of Everything (IoE), there is still room for increasing the number of connection nodes. On the other hand, the connection service scenarios, connected objects, and connection services are becoming more and more complex, posing higher requirements on connectivity. Reliable and secure connectivity requires not only continuous bandwidth improvement, but also intelligent identification of service scenarios.

Network capability expansion: Network boundaries are expanding. During the digital transformation of enterprises, a large number of offline applications are going online. An application service usually needs to traverse multiple networks, such as enterprise campus networks, WANs, and data center networks. In addition, differentiated experience requirements demand that multi-domain networks be coordinated and managed in a unified manner. Networks are being flexibly expanded from single-domain management to multi-domain convergence and collaboration, and from segment-based connections to multi-segment connections. In this way, differentiated and optimal quality services can be provided for end users.

4. Full-Stack "AI+X" Technologies of Optical Networks Enable the Evolution of All-Optical Capabilities to ADN

Full-stack AI is introduced to all-optical networks to drive continuous innovation of network architecture through knowledge and data, and build a self-fulfilling, self-healing, and self-optimizing autonomous network. Capability collaboration at the NE, network, and cloud layers enables intelligent O&M and operations of all-optical networks.

NE+AI: AI is introduced to NEs, which are upgraded to digital and intelligent devices. In this way, each NE and the entire network accurately perceive and process data, and perform inference execution. In addition, service policies are adjusted based on service intents to ensure service experience.

Network+AI: AI is used to reinvent management and control. By building a digital twin of a network through an intelligent management and control system, the network can be controlled dynamically and managed in a closed-loop manner. Key enablers include automatic deployment, pre-event simulation, post-event verification, prevention and prediction, and proactive optimization. The converged intelligent management and control system detects network status in real time. Based on user intents, the system automatically provides network connections, rectifies network faults, and optimizes network performance.

Cloud+AI: Network AI training and model services are provided on the cloud. The software systems and AI models on devices and networks are continuously upgraded to obtain more autonomous capabilities.

Recommendations

Focusing on Optimal Service Experience, Agile Network Operations, and Intelligent Network O&M to Accelerate the Transformation and Upgrade to All-Optical ADN

1. Optimal quality experience: The intelligent all-optical grooming feature provides the ultrafast self-healing function to meet service SLA commitments, enable optical networks to transform from basic pipe capability providers to all-optical service providers, and build E2E ultra-broadband and low-latency all-optical networks. Integrated all-optical access simplifies network layers and provides scenario-based broadband connection quality check capabilities and optimization suggestions, implementing precise fault locating for massive optical terminal networks and improving user experience.

2. Agile network operations: With upgrades to devices, networks, and services, agile all-optical networks provide user- and application-centric operation capabilities to implement agile optical connections, high bandwidth, low latency, and on-demand automatic service provisioning based on service intents (seconds-level TTM).

3. Intelligent and simplified O&M: Network resource usage is improved through intelligent technologies, implementing refined network management based on existing optical fibers, equipment rooms, and manpower, passive resource visualization, and full-lifecycle planning, provisioning, and O&M. Eventually, automatic network O&M can be realized.

4. Co-construction and sharing: To implement ADN, industry partners need to jointly promote the target ADN architecture, unified hierarchical model, and technical implementation paths in order to reach industry consensus, build a shared blueprint, and define unified standards.

Solution

Huawei's all-optical ADN solution consists of IntelligentFAN and IntelligentOTN. With the iMaster NCE intelligent management and control system at its core, the solution introduces AI at the NE, network, and service layers to build intelligent, secure, and efficient all-optical networks. In addition, the solution provides home and enterprise network subscribers with zero-touch, zero-wait, and zero-trouble premium home broadband (HBB) and private line service experience, and promotes digital transformation of various industries.

1. IntelligentFAN — All-Optical Access ADN Solution

Huawei's all-optical access ADN solution for all-optical networks (comprising FTTR, digital ODN, as well as smart ONT and OLT) contains the core components of the iMaster NCE intelligent management and control system. Through digital modeling of all-optical networks and introduction of cloudification, big data, and AI technologies, full-lifecycle intelligent O&M is provided. This helps meet requirements of differentiated application scenarios and high-quality broadband experience. Against this backdrop, single-domain autonomy of all-optical access networks can be achieved.(Figure 14: All-Optical Access ADN Solution)

1)Intelligent quality experience: User experience visualization and proactive collaborative optimization of PON and Wi-Fi, ensuring optimal user experience.

2)Intelligent passive resource management: Real-time visualization of passive ODN resources, including topology connections, optical component usage status, and optical power budget.

3)Intelligent and simplified O&M: Proactive identification of user experience problems, network fault demarcation by segment, and accurate locating of fault root causes.

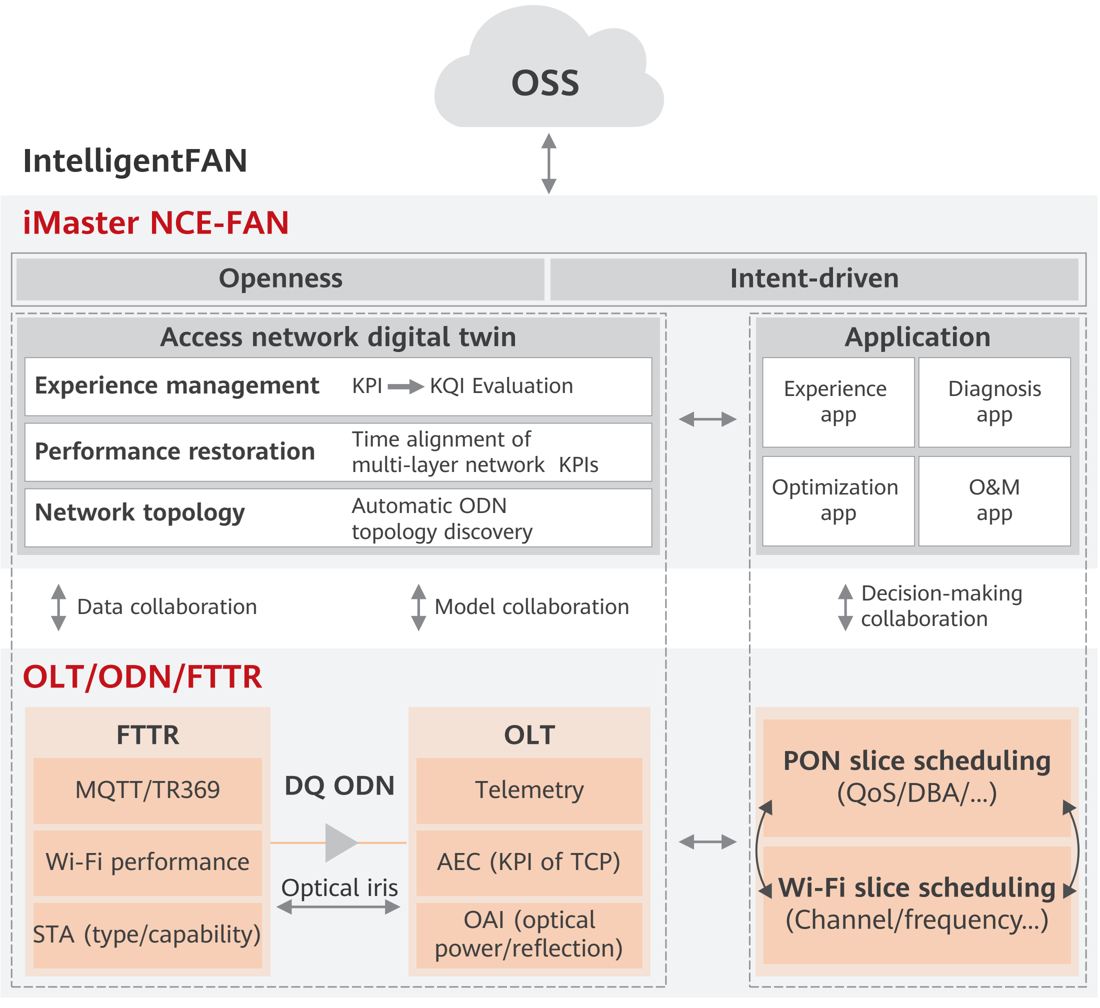


Figure 14: All-Optical Access ADN Solution

Key Use Cases

1)Identification of poor-QoE subscribers and bottleneck locating: Seconds-level collection of network KPIs and seconds-level awareness and measurement of service port–level KPIs help identify poor-QoE subscribers in real time and accurately locate network bottlenecks, supporting proactive O&M of user experience.

2)Accurate identification of potential HBB subscribers: Modeling for network data facilitates the identification of network value labels in four dimensions: terminal capability, home networking, network capability, and service feature. In this way, potential gigabit, FTTR, and scenario-based subscribers can be identified.

3)One-stop FTTR acceptance: The FTTR field service app can be used to perform automatic acceptance for more than 10 types of broadband KPIs in six dimensions (including networking, rate, latency, and roaming), and automatically generate acceptance reports to eliminate further home visits.

4)FTTR Wi-Fi rate analysis: The multi-dimensional FTTR speed test awareness function (which supports the proactive speed test and remote on-demand dialing test) can sense the Wi-Fi speed in real time and locate faults.

5)FTTR service experience assurance: Through proactive PON+Wi-Fi collaboration, service deterioration can be identified in real time based on service port KPI awareness, the network status data collected when faults occur can be viewed, and faults of high-value applications can be quickly located.

6)Visualized ODN resource management: Image identification technologies used in apps and optical iris technologies allow users to view and manage ODN resources and topologies, and provide accurate resource information.

7)Remote ODN acceptance and accurate fault locating: By comparing the data of the ODN topology model with that of the typical fault model, remote and automatic acceptance of ODN connection quality is implemented, and optical line faults can be accurately located to within a few meters.

8)FTTR subscriber self-management: Subscribers can manage FTTR networks using an app, which provides functions such as network status visualization, quick diagnosis and self-service troubleshooting, parental control, and other value-added scenario-based functions.

9)Quick FTTR fault diagnosis: Based on the network running status, faults can be quickly demarcated and located in the STA, Wi-Fi router, ONT, ODN, OLT, and bearer network dimensions, and rectified.

2. IntelligentOTN — All-Optical Transport ADN Solution

Huawei's all-optical transport ADN solution for all-optical networks (such as OXC and OTN) contains the core components of the iMaster NCE intelligent management and control system. Through digital modeling of all-optical networks and introduction of cloudification, big data, and AI technologies, a green, intelligent, highly-reliable, and efficient all-optical base is built, providing a premium private line service experience to customers.(Figure 15: All-Optical Transport ADN Solution)

1)Intelligent all-optical networking: Intelligent and adaptive optical route calculation enables an all-optical transport network with high

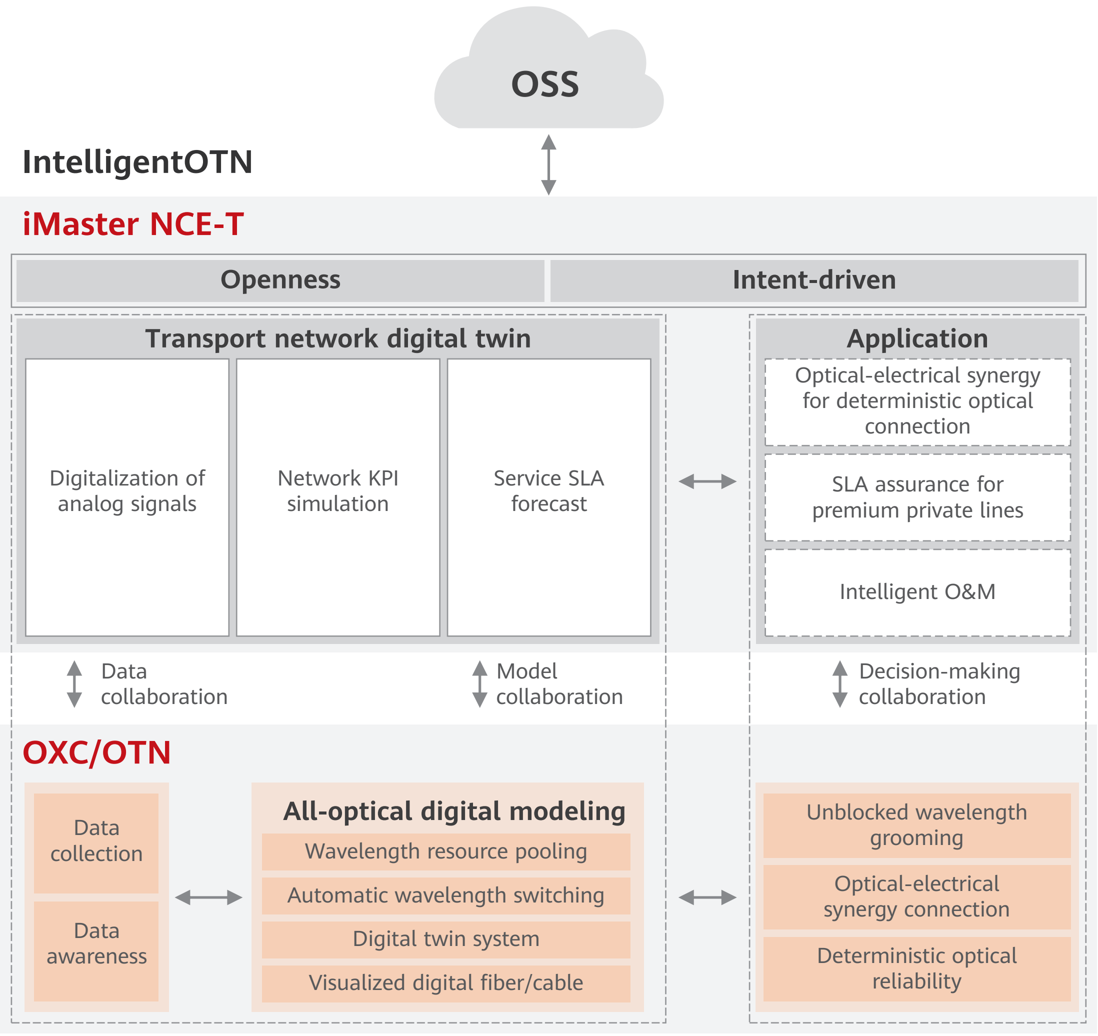


Figure 15: All-Optical Transport ADN Solution

performance, low latency, high reliability, and optimal energy efficiency.

2)Intelligent quality experience: Intelligent optical grooming provides deterministic protection and fast self-healing, ensuring SLA assurance.

3)Intelligent and simplified O&M: Based on visualization of dumb resources, services are automatically planned, designed, and configured throughout the lifecycle, achieving seconds-level TTM.

Key Use Cases

1)Optical network resource assurance: Implements unified visualization, analysis and forecast, online check, and capacity expansion planning for network resources, realizing zero-wait time for resources and shortening the service TTM.

2)Availability assurance: Automatically evaluates and analyzes availability of fibers and services, identifies potential risks and bottlenecks to availability on the live network, and provides optimization suggestions to improve availability.

3)Latency map: A microseconds-level, real-time, and dynamic network-level latency map

is provided, facilitating the mapping of network resources and marketing of private line services with differentiated SLAs.

4)Agile service provisioning: Support is available for automatic service provisioning in multiple service scenarios. Network capabilities are opened through standard ACTN APIs, and integration with the OSSs/BSSs is simplified, implementing automatic provisioning of private line services and improving the self-service level.

5)Optical network health assurance: Implements visualized and predictable fiber and OCh health status and fault locating, and transforms O&M from passive mode to the proactive mode, detecting potential faults and reducing service interruptions.

6)Intelligent incident management: Three-level intelligent alarm compression (alarm compression, alarm aggregation, and root cause analysis) greatly improves troubleshooting efficiency, shortens the duration of fault detection, diagnosis, and recovery, and enables "one ticket for one fault".

7)Intelligent identification of optical fibers in the same cable: Automatically identifies risks of working and protection fibers in the same cable. In this way, services can be rectified to eliminate potential accidents.

Prospect

Towards F5.5G, Ushering in a New Era of Fiber to Everywhere

Trend

Over the past 20 years, fixed networks have greatly improved our quality of life by meeting basic connection requirements and supporting high-bandwidth services such as 4K HD video. In the digital era, fixed network technologies undergo major advancements, culminating in the emergence of F5G. In 2020, European Telecommunications Standards Institute (ETSI) officially released the Fifth-Generation Fixed Network (F5G) to propose the industry vision of "Fiber to Everywhere" and define three main technical features: enhanced fixed broadband (eFBB), full-fiber connection (FFC), and guaranteed reliable experience (GRE). This has paved the way for the rapid development for global fixed broadband (FBB).

Our demands for connectivity and experience are increasing by the day. In particular, as new applications such as VR, AR, and holographic projection emerge, F5G is applied to more industries such as electric power and high-precision manufacturing. But with so many different service scenarios emerging, network requirements are highly varied, driving the development of the F5G technology. From 2025 to 2030, gigabit access will see significant uptake, with 10G access set to be put into large-scale commercial use. At the same time, enterprise cloudification and digital transformation will advance, and green and low carbon will become the direction of future development. And with the advent of the intelligent era in which everything is connected, fixed networks are facing unprecedented challenges and opportunities. Against this backdrop, all-optical networks have become an indispensable foundation for digital transformation in an intelligent society.

Faced with these new changes and opportunities, Huawei builds on the F5G released by ETSI to propose F5.5G by introducing three F5G capabilities (eFBB, FFC, and GRE) and adding three features (GAO, RRL, and OSV).(Figure 16: F5.5G Six Main Features)

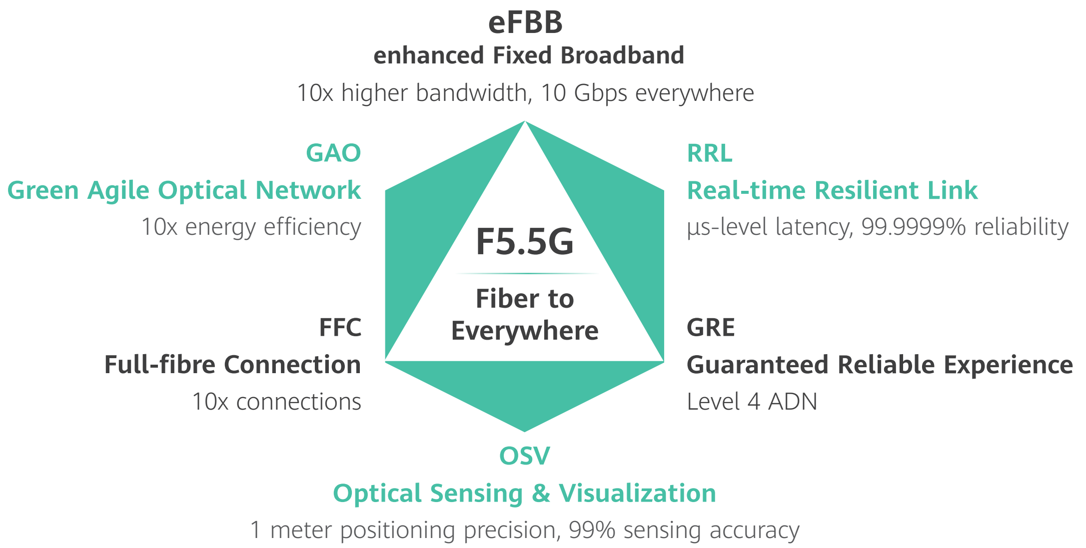


Figure 16: F5.5G Six Main Features

Enhanced fixed broadband (eFBB): Next-generation technologies, such as 50G PON, Wi-Fi 7, and 800G, are used to elevate user bandwidth experience from 1 Gbps to 10 Gbps everywhere, improving bandwidth 10-fold.

Full-fiber connection (FFC): Low-power consumption Wi-Fi technologies are used to cover more intelligent networking scenarios such as sockets, curtains, and thermostats. What's more, small and modular optical terminals are embedded in industrial devices, enabling more devices to benefit from high-speed and secure connections while increasing the number of connections 10-fold.

Guaranteed reliable experience (GRE): Autonomous driving network is upgraded from Level 3 to Level 4. By optimizing user traffic and Wi-Fi coverage algorithms, home broadband networks can advance from diagnosing fault diagnosis to implementing self-optimization. In addition, the transmission capacity map technology transforms private line services from resource provisioning within minutes to automatic path computation and scheduling within seconds, achieving fully automated home broadband and private line experience.

Green agile optical network (GAO): With the development of industry digitization, network capacity requirements will increase by orders of magnitude in the next few years, and service applications will become more diverse. In the face of these changes, the network architecture and technologies must be upgraded to meet the requirements of agile and fast service provisioning as well as the strategic requirements of green and low-carbon operations. Against this backdrop, the all-optical network architecture is upgraded to improve site energy efficiency 10-fold and achieve green and sustainable development. For example, the power consumption of a large hub optical/electrical transport site is more than 20,000 W, and about 337 W per Tbps. If the all-optical OXC technology is used to optimize the optical spectral efficiency and port usage, the power consumption per Tbps per site can be reduced to less than 32 W.

Real-time resilient link (RRL): In the telecom field, we often use 50 ms protection switching and 99.99% reliability as a benchmark. But in reality, when F5G is applied in some industry digitization scenarios, such numbers may not pass muster.

With the acceleration of industrial digitization and intelligent upgrade, as well as the large-scale development of applications such as ultra-HD video backhaul (such as machine vision) and remote motion control, connections need to deliver 20 μs latency, 20 ns jitter, zero packet loss, and 99.9999% high-reliability.

For example, in a power grid system, different services need to be strictly isolated, and the share of power generated by new energy is increasing. The supervisory control and data acquisition (SCADA) dispatching frequency needs to be increased by 10 times to ensure stable power supply. This requires 99.9999% network availability and less than 30 seconds of down-time per year. To meet such requirements of power grids, we can use the lossless multi-path solution and capabilities such as synchronization, caching, and multi-system automatically switched optical networks (ASONs).

In a highly automated precision manufacturing factory, the production IT network requires millisecond-level deterministic latency, while the production OT network requires even lower latency. For example, the latency from the factory control system to industrial robots needs to be within 20 μs. The high-density timeslot technology changes the traditional time division multiplexing (TDM) mode of PON networks. Specifically, by reducing the timeslot interval to 4 μs, the transmission latency can be reduced to several microseconds and the end-to-end jitter can be less than 20 ns.

These performance improvements enable fiber networks to truly extend to core industrial manufacturing systems and accelerate industry digital transformation.

Optical sensing and visualization (OSV): This feature focuses on integrating communication and sensing using fibers as well as digital operation capabilities, and exploring new application scenarios. Operators, electric power companies, and transportation systems around the world have laid innumerable fibers. As fibers further extend to terminals, managing and maintaining vast amounts of dumb optical cable resources becomes increasingly complex. Digital technologies are required to accurately locate optical cables and cable faults. For example, technologies such as ODN topology and optical power visualization, co-cable co-trench detection, and meter-level optical path fault diagnosis are integrated with software algorithms to build a digital optical cable network that features real-time visualization, precise sensing, and efficient self-healing.

Our research shows that fibers can be used not only for communication, but also for accurately sensing the external environment — such as detecting vibration, stress, and even temperature — using the Rayleigh scattering, Brillouin scattering, and Raman scattering effects. This capability can be used to discover all-new application scenarios. We have already applied this to oil and gas pipelines. By deploying optical sensing and monitoring units, we can use algorithms to locate construction activities and landslides to the nearest few meters based on the vibration changes of the surrounding environment of the pipelines. The event identification accuracy reaches 99%. In the future, the positioning accuracy can be further improved to about 1 m. With this feature combined with visualized management, intelligent unattended inspection of oil and gas pipelines will be achieved.

In the future, these optical sensing technologies can be widely used in more scenarios such as fire and earthquake warning, gas and water quality detection, and digital operation of fiber networks. Indeed, optical sensing technology is an important dimension for the future development of F5G.

F5.5G will bring four changes to the industry: (1)

Replace gigabit experience with 10G experience everywhere. (2) Provide real-time and reliable connections from carrier class to industrial class, reduce latency to microseconds, and improve availability to 99.9999%, enabling industry digital transformation. (3) Replace electrical devices with optical devices, upgrade the all-optical network architecture, and improve energy efficiency 10-fold, enabling green and sustainable development. (4) Advance from optical communication to optical sensing and achieve environment monitoring with an accuracy of 1 meter, presenting new scenarios and applications beyond connectivity.

In the future, the digital revolution will bring opportunities for homes, enterprises, and industry, and new service requirements will promote the wide application of all-optical networks in various industries. The prosperity of fixed networks depends on the cooperation of the entire industry chain and unification of standards. Huawei is looking forward to working with industry partners to set the path for F5.5G under the framework of standards organizations such as ETSI and International Telecommunication Union (ITU), promote technology maturity, and enrich F5.5G application scenarios.

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