All-Optical ADN Solution White Paper

(**Autonomous Driving Network**)

HUAWEI

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Opportunities and Challenges Faced by All-Optical network

1.1 Opportunities

With the digital industry as the core, all-optical networks as the carrier, and digital technologies deeply integrated with the real economy, the digital economy has become a key driver of global GDP growth. According to analysis from the China Academy of Information and Communications Technology (CAICT), the global digital economy scale reached $32.6 trillion in 2020, accounting for 43.7% of the GDP. To date, more than 50 countries have unveiled their digital strategies to promote the digital transformation of industries, of which new cloud and network infrastructures are the basis.

In addition, with the accelerated cloudification of enterprises and rapid development of cloud-network integration, digital governance, and digital life applications, demand for all-optical network acceleration and quality improvement grows stronger, driving carriers to continuously consolidate all-optical networks in order to serve the digital transformation of various industries. In the B2B market, enterprise services are becoming more intensive and both video- and Internet-based. In the securities and futures industries, high-frequency transactions and ultra-low latency are required. In the healthcare industry, interconnection acceleration, cloud-based medical images, telemedicine, and teleconsultation are booming. In the enterprise field, digital transformation is accelerating, and enterprise interconnection and cloudification are fast becoming the norm. In the B2H home broadband market, with the popularization of strong-interaction and ultra-HD video services, as well as the rise of the stay-at-home economy and cloud life, families are transforming from traditional entertainment centers to both entertainment and production centers. Consequently, a high-quality all-optical network is required.

To achieve the "fiber to everything" vision, as well as the development of standardized all-optical networks, the European Telecommunications Standards Institute (ETSI) established the Fifth Generation Fixed Network (F5G) working group at the beginning of 2020, defined F5G (which is represented by technologies such as 200G/400G, next-generation OTN, 10G PON, and Wi-Fi 6), and clarified its three characteristics: enhanced fixed broadband (eFBB), full fiber connection (FFC), and guaranteed reliable experience (GRE). F5G all-optical networks use optical fibers as the transmission media and provide high-security, high-reliability, high-bandwidth, and low-latency super computing power and premium connection services to build an all-optical base for the digital economy. This approach serves to accelerate both the digital transformation of various industries as well as the development of the digital economy.

1.2 Challenges

A recent analysis by Ovum revealed that the telecom industry's revenue growth has never outperformed its operating expense (OPEX) growth throughout the past decade. As the network scale expands, OPEX rapidly increases, and the industry's structural contradiction becomes increasingly prominent.

As the cornerstone of communication networks, all-optical networks are used to carry a wide range of services. With the digital transformation of various industries and the intelligent connection of everything, the scale of optical networks is expanding and the quality requirements are increasing. As such, traditional O&M (primarily manual and machine-assisted) faces the following significant challenges:

Challenge 1: Long service provisioning periods and complex dynamic bandwidth adjustment

Traditionally, optical network planning and service configuration primarily depend on inefficient manual operations, which involve the following disadvantages:

First, resources are difficult to manage. Resource data is scattered across various systems, and resource changes require several days of manual checks. In addition, it is difficult to detect network resource bottlenecks in advance, and emergency capacity expansion is frequent, which greatly impacts user experience.

Second, service configuration is usually complex and service provisioning requires extended time frames. Private line services usually involve multiple sites, OTN optical/electrical layers, and multiple process nodes. In addition, manual checks of idle resources, manual route calculation, and manual service configuration are required. As a result, highly-skilled personnel are essential, errors often occur, and service provisioning can take several weeks.

Third, rapid and on-demand bandwidth adjustment is difficult. For example, network traffic increases sharply when e-commerce enterprises carry out large-scale promotion and marketing activities during the Double 11 or Black Friday shopping periods, necessitating a temporary increase of bandwidth. Another example is the regular reconciliation between the branches of a bank and its headquarters, as this involves the transmission of large amounts of data and also requires dynamic bandwidth adjustment. Consequently, carriers must be able to quickly and dynamically adjust bandwidth to meet customer requirements.

Finally, on-demand provisioning of differentiated SLAs is difficult, as is one-stop provisioning of optical and cloud networks in the context of cloud-network convergence.

Challenge 2: Manual passive O&M is inefficient and must be improved

Traditional optical network O&M is device-specific and is typically performed in man-machine interaction mode. With the rapid development of Internet+, 5G, 4K, and VR services, optical networks function as the primary bearer of bandwidth traffic and become increasingly complex.

First, optical fibers function as the communication media of optical networks. However, due to the passive physical characteristics of dumb resources, optical fiber resource information is inaccurate. For example, devices on passive optical networks (PONs) often to continue to occupy optical ports after being brought offline, and the ditch- or cable-sharing information between working and protection routes on OTNs is not completely accurate.

Second, the O&M response to optical network faults is slow, as are fault locating and maintenance. According to statistics, 90% of home broadband faults are reported through user complaints, and 90% of home visit time is devoted to fault locating, which requires more than 2 hours on average. On private line networks, service interruption, intermittent disconnection, and deterioration are the major causes of complaints from enterprise customers. As such, service quality monitoring, fault diagnosis, and source tracing functions need to be improved.

Challenge 3: Optical networks need to provide differentiated SLA experience

All-optical networks feature high bandwidth, low latency, high availability, and so on. With the increase of network traffic, increasingly fierce market competition, and requirements for differentiated service level agreements (SLAs) such as customer bandwidth, latency, and reliability, carriers need to provide more diversified services and various SLA fulfillment capabilities, while also improving network reliability, resource utilization, and operational efficiency. This all leads to higher requirements on the O&M and assurance capabilities of optical networks. Network hardware and software innovations are required to implement digital measurement of SLAs, service provisioning, and continuous monitoring and assurance during daily operations, providing users with differentiated products and innovative services. In this way, carriers can improve customer satisfaction, effectively cope with market competition, as well as achieve agile business monetization, quality improvement, and increased revenue as a result of enhanced network quality.

To address the preceding challenges, the industry has been actively exploring next-generation all-optical O&M solutions to reduce costs and improve efficiency across the entire process.

ADN Exploration and Practice

As early as 2011, the telecom industry attempted to improve ICT service and network agility, while reducing costs and complexity, through the use of SDN, NFV, and cloud technologies. However, SDN/NFV-based network automation remains unable to completely resolve the problems caused by large-scale deployment of different applications and the introduction of new network technologies. Autonomous driving network (ADN), in contrast, attempts to drive the telecom industry from digitalization to intelligence by applying multiple intelligent technologies and leveraging the advantages afforded by convergence. This will have a profound impact on methods of production and operation, as well as the skills and thought processes of personnel, across the entire telecom industry.

Today, the telecommunication management forum (TMF) version 3 of the AN white paper is available. According to this white paper, autonomous networks must use Intelligence, big data, and cloud computing technologies and adopt a simplified network architecture to provide innovative networks and ICT services with zero wait, zero touch, zero trouble and full autonomy for vertical industries and end users. Additionally, this white paper defines a three-layer four-closed-loop framework (shown in Figure 1) featuring single-domain autonomy and cross-domain collaboration and network autonomy levels (L0 to L5, shown in Figure 2), and clarifies the target architecture and implementation path for intelligent O&M transformation of communication networks, accelerating industry collaboration.

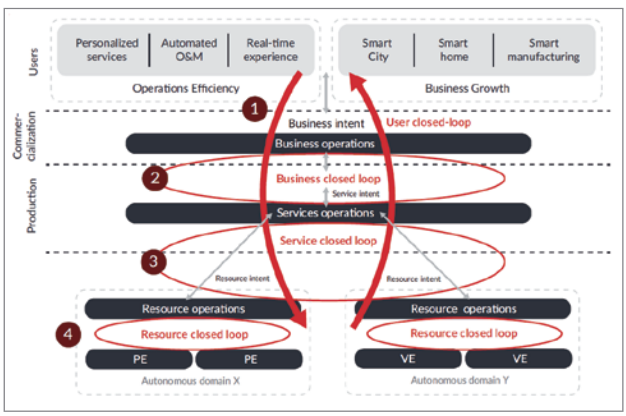

Figure 1 Autonomous network framework
(Source: TMF Forum, 2020)

Autonomous Levels	L0: Manual Operation & Maintenance	L1: Assisted Operation & Maintenance	L2 Partial Autonomous Networks	L3 Conditional Autonomous Networks	L4 High Autonomous Networks	L5 Full Autonomous Networks
Execution	P	P/S	S	S	S	S
Awareness	P	P/S	P/S	S	S	S
Analysis	P	P	P/S	P/S	S	S
Decision	P	P	P	P/S	S	S
Intent/ Experience	P	P	P	P	P/S	S
Applicability	N/A	Select scenarios				All scenarios
P People (manual) S System (autonomous)						

Figure 2 Six levels of autonomous networks (Source: TMF Forum, 2020)

According to a TMF survey result, 88% of carriers plan to deploy ANs on a large scale within the next 10 years. In addition, some leading operators are actively exploring and practicing ANs based on their service strategy requirements. China Mobile, for example, maintains communication networks featuring large numbers of customers, a wide variety of service types, and massive network scale. Based on the TMF AN framework and hierarchical system, China Mobile, in collaboration with partners such as Huawei, released an AN white paper in July 2021, planned the digital intelligence transformation of network O&M, and enhanced the construction of automation and intelligent capabilities, as well as set an overall objective for achieving L4 network O&M autonomy by 2025. This white paper not only defines clear objectives, ideas, and an internal practice framework, but also proposes scenario-based autonomy grading standards for the O&M process. The carrier organizes the scoring of capability levels and the identification of weaknesses among provincial branches, enhances and accelerates system construction and standard guidance, and proactively carries out innovation pilots and commercial use of automatic and intelligent applications to improve the network O&M autonomy level through step-by-step iteration. China Unicom established a "three-in-one" AN promotion methodology based on hierarchical evaluation, product R&D, and enablement for standards compliance. This carrier has partially completed the defining of AN architecture and grading standards, and has initiated pilot iteration in wireless access scenarios. Vodafone group has also defined AN architecture and plans to define its grading standards by referring to those of the TMF. Vodafone has also begun to pilot use cases in certain subnets.

Huawei All-Optical ADN Solution

3.1 Vision

From the All Cloud strategy to the ADN strategy, Huawei continuously collaborates with industry standards organizations, carriers, and the industry as a whole to explore new network architectures, O&M modes, and business models. It is committed to becoming an explorer, innovator, and leader of future networks and is dedicated to promoting intelligent upgrade and network autonomy of the telecom industry. By referring to the target architecture of TMF AN, Huawei released the ADN Solution White Paper in May 2020 (as shown in Figure 3), which elaborates on the ADN strategy. In this context, Huawei aims to conduct further research on the impact of intelligent technologies on future network architectures, O&M modes, and business models by integrating multiple intelligent technologies, such as SDN, NFV, cloud, big data, Intelligence, and the knowledge graph. Huawei will leverage architectural innovation to solve the structural TCO problems of telecom networks, achieve network automation, self-healing, and self-optimization, and enable new services capable of delivering optimal customer experience and implementing efficient O&M and resource utilization. This approach will drive the intelligent upgrade of the telecom industry, while also promoting its healthy and sustainable development.

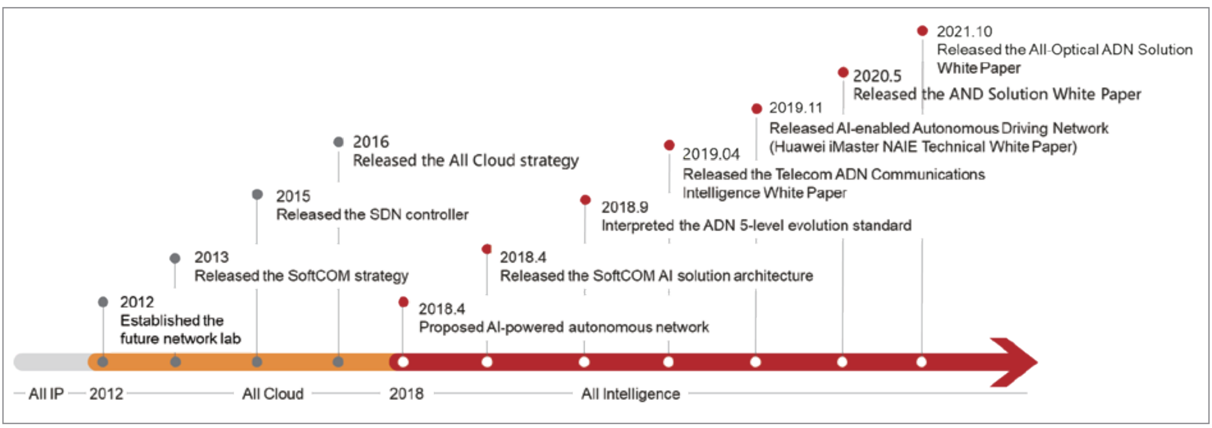

Figure 3 Huawei's ADN exploration process

Huawei's all-optical ADN is a scenario-specific solution that implements the ADN strategy in the all-optical network field. In this solution, Intelligence is introduced at the NE, network, and service layers to build automated, self-healing, and self-optimized O&M capabilities, and enable the digitalization of optical cable infrastructures. The vision driving this solution involves building an efficient, secure, and green all-optical ADN capable of full-lifecycle automatic operation and intelligent O&M. Such a network is expected to serve as the foundation of all-profession autonomous driving, and provide home broadband (HBB) and industry subscribers with zero wait, zero touch, zero trouble experiences in premium HBB and private line services, thereby supporting the high-quality development of enterprises and HBB.

3.2 System Architecture

Long-term exploration is required to achieve L5 ADN on all-optical networks for the ultimate goal of self-evolution and self-optimization. Such a target depends on a series of theoretical and technical breakthroughs, such as network self-cognition and knowledge and experience extraction. Considering the maturity of current technologies, it is recommended that L4 ADN become the phased target of future all-optical ADN architectures, and that newly matured technologies, tools, and methods, such as Intelligence and the knowledge graph, be introduced to reconstruct and optimize network devices, O&M systems, and business operations in an all-round manner.

From a technical perspective, it is anticipated that the L4 all-optical ADN architecture will have the following basic features:

Feature 1: Network and expert knowledge is digitalized, transforming from passive manual O&M to predictive intelligent O&M.

Feature 2: Simplified all-optical network infrastructure and intelligent optical NEs are emerging.

Feature 3: Hierarchical single-domain autonomy and cross-domain collaboration drive all-optical networks to real-time closed-loop management.

Feature 4: Unified cloud-based AI training, knowledge management, and O&M design studio support the iterative evolution of all-optical networks.

Based on the design concept and basic features, the architecture of Huawei's all-optical ADN solution is defined as follows (Figure 4):

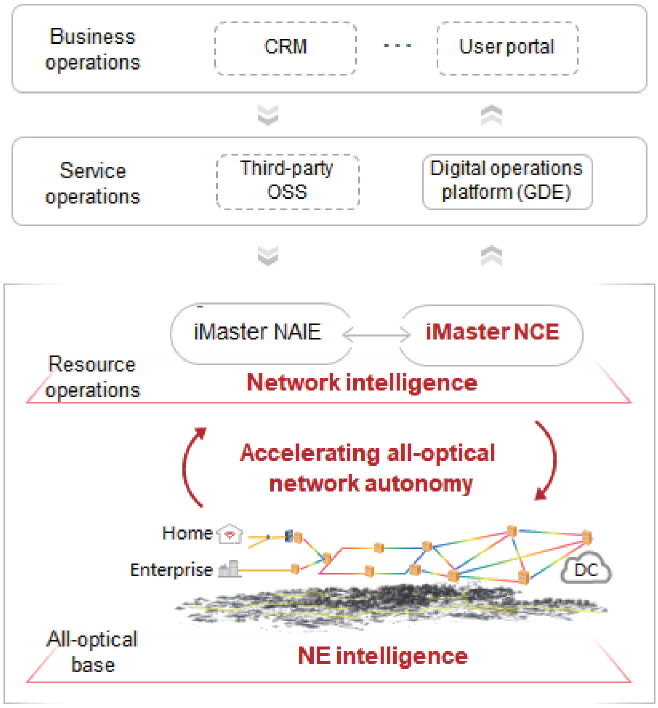

Figure 4 Architecture of Huawei's all-optical ADN solution

Simplified All-Optical Network Infrastructure

The simplified all-optical network infrastructure fundamentally guarantees an intelligent ADN with hierarchical autonomy. Specifically, the simplified network architecture, protocols, devices, sites, and deployment solutions address the complexity caused by ultra-high bandwidth and premium connections, improving efficiency and customer experience throughout the network lifecycle. Meanwhile, additional real-time sensing components and intelligent inference capabilities are introduced to network devices, making them smarter. In this way, the digital sensing capability of resources, services, and surrounding environments is enhanced, and edge intelligence capabilities such as sensing analysis and decision execution are provided at the data source.

Intelligent management and control system (iMaster NCE)

iMaster NCE (NCE for short) integrates three modules, the network manager, controller, and analyzer. By injecting knowledge and AI models, NCE automatically translates upper-layer services and application intents into network behavior to implement single-domain autonomy and closed-loop management, thereby guaranteeing the SLAs of network connections and functions. The network management and control unit associates discrete network resources, services, and status data through digital modeling to produce a complete intra-domain digital HD map, implementing integrated network data collection, awareness, decision-making, and control. In addition, new AI models and network O&M knowledge are continuously injected from the cloud to steadily strengthen and expand the local AI model library and network knowledge base, enabling the local intelligent awareness and decision-making capabilities to be continuously optimized and enhanced.

Intelligent Service Platform (GDE)

The intelligent service platform provides cloud services for O&M processes, knowledge assets, and the programmable O&M design framework. Oriented towards streamlined O&M processes and flexible service orchestration, it helps carriers quickly develop new service models, O&M processes, and service applications in iteration mode based on its network characteristics, while also promoting service agility and O&M skill enhancement.

Network AI Platform (iMaster NAIE)

The network AI platform provides an intelligent platform and cloud services in the network field. As the basic platform for network intelligent design and development, it continuously trains AI models and extracts knowledge based on the network data uploaded to the cloud, generating new AI models and network knowledge. These AI models and network knowledge can then be injected into the network infrastructure, network management and control unit, and multi-domain intelligent O&M unit to create an intelligent and easy-to-use network. The network AI platform also acts as a sharing center for carrier intelligence assets. In this regard, it manages AI models and network knowledge developed and trained by carriers during planning, construction, maintenance, and optimization, which can then be shared and reused to minimize repeated development and training. The network AI platform provides basic services and capabilities such as AI training, data services, a network knowledge base, and an AI marketplace on the cloud.

3.3 Key Capabilities

The all-optical ADN solution with NCE at its core introduces cloud, big data, and intelligent technologies to address the three key challenges in all-optical networks. It adopts three-layer intelligent architecture innovation and continuous iterative practices, and focuses on full-lifecycle automation use cases, such as resource information visualization of optical cable networks, automatic configuration of optical private lines, high-quality optical private line experience, differentiated HBB services, and potential HBB subscriber recommendation. As such, the solution enables agile business monetization, upgrades O&M modes, and transforms from passive fault handling to proactive and predictive maintenance.

3.3.1 Visualizing Resource Information of Optical Cable Networks

Optical cable networks, the dumb resources of optical networks, can traditionally only be managed only through manual monitoring and updating via resource management systems, which leads to issues such as inaccurate resource data. In the all-optical ADN solution, visualizing the resource information of optical cable networks and intelligently sensing dumb resources are important cornerstones. Two key issues need to be resolved in terms of sensing dumb resource awareness: how to implement optical distribution networks (ODN) digitalization, and how to identify ditch- and cable-sharing risks of working and protection routes on OTNs.

Digital ODNs: With the rapid development of optical access networks, ODNs now connect thousands of households and various industries as an expanding fiber network. The ODN construction environment is complex, encompassing poles, streets, corridors, and even sewers. It also represents one of the optical access network's investment priorities. As optical splitters and optical fibers are passive devices that do not require a power supply, ODNs become dumb resources that cannot respond to the management system. Consequently, it is difficult to manage ODNs in real time.

The digital ODN solution has been designed with these challenges in mind, and offers the following two objectives:

First, reduce network construction costs, including fiber upgrade from onsite welding to E2E pre-connection.

Second, improve the level of digitalization. By introducing next-generation hardware technology for optical feature detection, the recording of ODN topology data can be upgraded from manual to automatic, resolving issues such as inefficient and error-prone manual maintenance, and realizing automatic data update and efficient O&M.

Identification of cable-sharing risks on OTNs: Route-sharing risks on OTNs lead to numerous major accidents every year. However, as effective monitoring methods for such accidents are not available during actual operations, it is necessary to use optical network probes and intelligence to analyze optical fiber feature data and data changes, such as Rayleigh scattering, Brillouin scattering, Raman scattering, and SOP optical polarization changes, in order to accurately identify the cable-sharing status of protection links on OTNs. By effectively identifying cable-sharing risks, rectifying services in advance, and eliminating potential accidents, major network security accidents caused by route-sharing risks can be avoided.

3.3.2 Automatic Configuration of Optical Private Lines

Given the acceleration of digital transformation across a wide range of industries, rapid service provisioning, bandwidth on demand (BoD), and customer self-service have all become standard features. To address these changes, NCE focuses on the following:

Agile service provisioning: NCE provides one-stop and E2E OTN private line service provisioning to address the challenges presented by multiple sites, multiple optical/electrical layers of OTNs, and manual resource checks. After the O&M personnel set certain required information such as the source and sink sites and service profiles, private line services can be automatically and quickly provisioned, greatly shortening the time to market (TTM).

In addition, to meet subscriber requirements for dynamic bandwidth adjustment, the BoD feature supports numerous flexible bandwidth adjustment policies, including one-off adjustment, permanent adjustment, periodic adjustment, and scheduled provisioning.

Latency assurance: The traditional O&M system is not capable of accurate and automatic latency measurement, so E2E latency requires manual estimation based on intra-site latency and link latency (fiber distance and fiber loss). Such a system involves high cost and low accuracy and lack latency monitoring and assurance measures. NCE provides full-lifecycle management and assurance capabilities to enable visible, manageable, and guaranteed latency, helping carriers provide private line services with differentiated latencies and accelerating monetization of latency sales.

Supported by the real-time latency measurement technology of physical boards based on the G.709 standard, NCE's latency map feature provides a network-level latency map with microsecond-level precision. Like Google Maps, NCE automatically provides latency-based route navigation to support flexible sales by latency.

In the sales phase, latency-based path computation is automatically performed and services are provisioned based on the latency committed in the contract.

In the after-sales phase, the system monitors service latency in real time and automatically provides warnings in the case of latency threshold crossing, helping identify and eliminate potential default risks in advance.

OTN CPE plug and play (PnP): OTN CPEs need to be installed on the enterprise customer side to provision private line services. Traditionally, CPE deployment is complex and relies primarily on manual operations, involving multiple site visits for installation, software commissioning, and acceptance. CPE commissioning requires remote collaboration between the network operations center (NOC) and site engineers. This mode is inefficient and error-prone, requiring 3 to 5 days to complete deployment. To reduce site visits and avoid coupling between site engineers and the NOC, NCE and device development teams collaborate to launch the innovative CPE PnP solution. After O&M engineers perform a few preconfigurations (for example, loading a preconfigured profile) on NCE, site engineers install CPEs onsite which are then powered on for fiber connections. In this way, CPE management channels are automatically enabled, discovered, and managed by the NMS. As no onsite configuration, software commissioning, or personnel cooperation is required, the CPE deployment and service provisioning duration is reduced by 80%.

Network as a service and fully open optical network capabilities: After surveying a large number of private line subscribers, the Next-Generation Optical Transport Network Forum (NGOF) converts industry customer requirements into network KPIs, and releases a five-star indicator system for premium private lines. This system defines the quality of enterprise private lines across five dimensions: high availability, guaranteed bandwidth, low latency and jitter, service agility, and online self-management. For a five-star premium private line, the agile dimension requires scheduled online provisioning and minute-level provisioning capabilities for online services, and the online self-management dimension requires visibility and hitless adjustment of key private line indicators. This demonstrates the importance of automatic and self-service private line services.

With NCE as the core, the all-optical ADN solution provides extensive northbound interfaces such as ACTN APIs, and fully opens up service-oriented capabilities such as network resources, topology, alarms, performance, and configuration. In addition, the experience gained through integrating more than 10 OSS partners and 40 projects helps carriers implement automatic and self-service optical private line service provisioning. Consequently, the average service provisioning time is shortened from months to days or even minutes in some cases.

China Mobile Tianjin's "DoubleS-OTN Enterprise Private Network" project is an ideal example, as NCE is integrated with OSS/BSS to streamline the entire private line services, implement automatic private line service provisioning, and launch the Enterprise Customers app. Through the app, subscribers can reserve optical private line services, view real-time provisioning progress, perform self-service bandwidth acceleration, view service performance indicators, report faults, and view troubleshooting progress.

3.3.3 High QoE of Optical Private Lines

The all-optical ADN solution incorporates intelligence into NEs, networks, and clouds. This solution not only prevents repeated and complex manual computing, but also significantly improves the prevention and prediction capabilities of all-optical networks by virtue of big data-based intelligent analysis, significantly enhancing O&M efficiency and achieving proactive and predictive O&M:

At the NE intelligence layer, various built-in optical probes, such as the optical digital signal processor (oDSP), optical time domain reflectometer (OTDR), and optical frequency domain reflectometer (OFDR), are used to detect all-optical network performance data in digital and real-time way. In addition, built-in lightweight intelligent inference modules are used for efficient edge intelligent analysis and inference.

At the network intelligence layer, NCE collects and intelligently analyzes optical network data over a long period of time, compresses massive alarms, and revitalizes dumb fiber resources to detect the subhealth status of optical fibers and channels in real time. In this way, more than 90% of gradual fiber faults can be predicted in advance.

Optical network health assurance: Optical fibers are the transmission media of all-optical networks, and the quality of network services depends on fiber performance. The key to improving the all-optical network quality is to reduce fiber faults. Fiber faults include sudden and gradual faults. Gradual faults (including bent fibers, loose fiber connectors, aged fibers, damaged fiber cores, poor fiber quality, and deteriorated drop fibers) account for 20% to 50% of all faults. As dumb resources are passive, troubleshooting is often driven by complaints, and field engineers need to troubleshoot the faults onsite segment by segment, which is costly, inefficient, and time-consuming.

For gradual change characteristics of fiber performance deterioration faults, optical performance indicators such as the optical power, optical attenuation, and bit error rate (BER) are detected in real time on the device side, and short-period edge inference and analysis are performed, after which, the results are reported to NCE. NCE performs long-period big data collection and intelligent analysis, automatically displays the health status of network-wide fibers and OCh channels, and predicts the risk level and occurrence time (hours/-days/weeks/months) of faults in advance based on the predictive deterioration trend. For potential faults, the built-in OTDR automatically locates the faults and provides handling suggestions. In addition, when optical line faults are rectified by means of fiber cutover, NCE automatically compares and analyzes the optical line quality before and after the cutover to prevent repeated site visits in case of poor quality after the cutover.

China Unicom Jiangsu uses the optical network health assurance solution to proactively identify optical performance deterioration risks in advance, reducing the fault locating time by 83%. The fiber core attenuation inspection is automatic and the inspection time is reduced from weeks to minutes. Passive processing is changed to proactive predictive protection, reducing fiber faults by 30%.

Fault incident management: A large amount of manual effort is required to handle a massive number of alarms and repeated work orders. Complex network structure and diverse alarm types require personnel to be highly skilled in performing root cause and service impact analysis, which is time-consuming. NCE's fault incident management can be used for 3-level fault compression and intelligent algorithm analysis. With this feature, the suspected root cause alarms of faults are automatically identified within 5 minutes, which provides useful support for the O&M objective — only one work order for one fault. This process is implemented as follows:

First, perform noise reduction filtering on the massive number of alarms on the live network. That is, automatically identify and mark invalid alarms such as repeatedly reported alarms, maintenance mode alarms, and intermittent alarms, greatly reducing the total number of alarms.

Then, intelligently aggregate alarms based on correlation rules. For example, associate and aggregate the alarms based on the topology association, context association, and fault occurrence time association of the objects where the alarms are located, and generate associated incident events.

Finally, use intelligent algorithms to identify the root causes of an incident and between incidents, identify the fault scenarios, and analyze impacts on services to find out the suspected root cause alarm that causes the incident, and generate a fault ticket.

3.3.4 Differentiated Home Broadband Services

As living standards improve, people demand in-depth and diversified network experience in addition to high bandwidth.

In the era of IoE, massive devices need to access the network, and each device may carry multiple services. These devices and services belong to different industries and have different characteristics, posing different requirements on network security, latency, reliability, and bandwidth. Consider the following:

· Smart cities and smart homes require a large number of device connections and frequent transmission of small data packets.

· Entertainment services such as HD video, AR, and VR require high-bandwidth network connections.

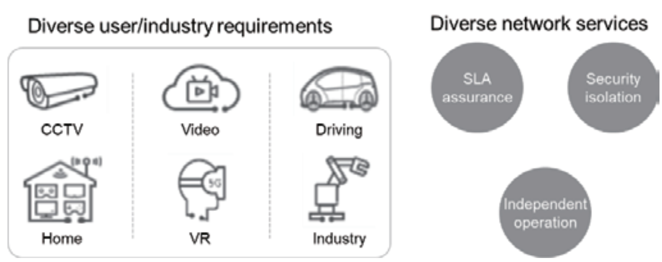

Figure 5 Diverse network service requirements

A single network or unified policy cannot satisfy the requirements of emerging services and new scenarios. However, it is not feasible to build independent networks for each service scenario due to high cost and long time. Currently, two key requirements must be met:

· Differentiated service assurance: In multi-service home broadband scenarios, multiple applications (such as applications for online courses, online games, live broadcast, online shopping, and online chat) may be connected to one home terminal at the same time. These services have different network assurance requirements and priorities. Carriers need to provide different assurance for different services.

· Multi-tenant independent operation: In enterprise network scenarios, if an independent hardware infrastructure network is provided for each tenant, the cost of carriers' investment is high and the device utilization is low. Multiple tenants can share physical network resources to reduce investment and improve device utilization.

Differentiated home broadband services based on SLAs: Based on the software defined networking (SDN) technology, Huawei divides one hardware infrastructure network into multiple independent virtual networks, which can be flexibly combined and allocated with resources on demand to meet different service requirements. If the live network cannot meet new service requirements, carriers can create a new virtual network without affecting the live network, and dynamically define different bearing capacities based on different service SLA objectives to meet different user service requirements in different scenarios. In this way, new services can be quickly provisioned.

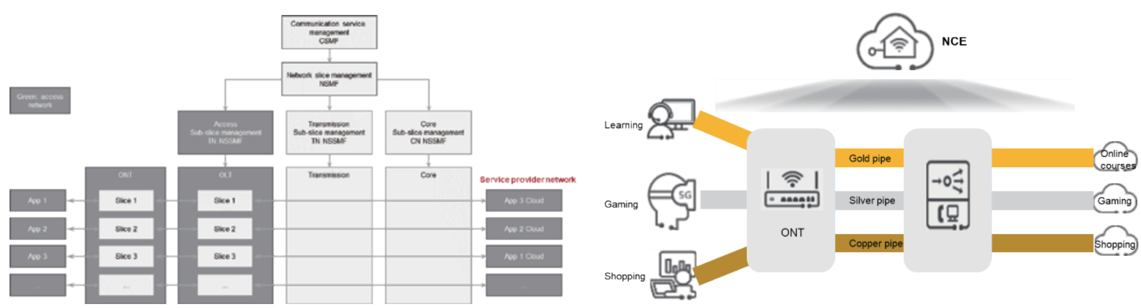

Figure 6 Technologies for dynamic, differentiated services based on SLAs

Home Wi-Fi experience assurance: Home Wi-Fi is becoming a top demand for home network users. Statistics show that home Wi-Fi network traffic accounts for more than 70% of carriers' traffic. However, after the bandwidth is accelerated (such as to 100 Mbit/s or 1000 Mbit/s), there is no corresponding improvement in user experience. The bottleneck is the home network on the user side. In addition, high-quality and high-speed Wi-Fi, on which HD video services and increasing mobile terminals depend, has become the ground zero of user complaints. The main Wi-Fi quality issues include low rate, poor coverage, strong interference, quality invisible to carriers, and difficulties in fault locating and troubleshooting. Therefore, toprovide differentiated home broadband services based on SLAs, the home Wi-Fi experience must be guaranteed.

According to a user video report from Conviva (a company dedicated to online video optimization and analytics), when video freezes, about 1/3 of video users immediately stop watching, and 84% of video users stop watching within 1 minute. In light of home Wi-Fi network coverage and quality problems that concern users, carrier-grade home Wi-Fi networks need to use dual-band Wi-Fi home gateways as the cornerstone and fully utilize indoor optical fibers as Wi-Fi extension media for implementing intelligent Wi-Fi coverage. The gateways function as the control center to implement seamless Wi-Fi roaming and channel adjustment for the entire home network. In addition, the Wi-Fi air interface dynamic scheduling technology is used to intelligently schedule Wi-Fi air interfaces resources according to service priorities and dynamic bandwidth requirements based on application experience awareness. In this way, home Wi-Fi networks can be easily managed, maintained, and adjusted, and a guaranteed home Wi-Fi experience can be delivered. In addition, systematic KQIs and KPIs need to be provided to measure end user experience of home Wi-Fi networks (with home gateways as the cornerstone) and objectively quantify end user experience in terms of online video latency, web page loading time, online gaming response time, and so on.

3.4 Outlook

The passive simulation characteristics and networking complexity of all-optical networks means that a fully autonomous all-optical ADN requires long-term efforts. Huawei looks forward to working with carriers, standards organizations, research institutes, and ecosystem partners to continuously explore and practice key technologies and innovative applications in all-optical network planning, construction, maintenance, optimization, and operation. In this way, Huawei supports agile innovation of all-optical network services, delivers zero wait, zero touch, zero trouble and full autonomy experiences, and accelerates the digital and intelligent transformation of various industries to bring high-quality all-optical digital lifestyles and all-optical digital production to every home and enterprise, while also stimulating the high-quality development of the digital economy.