HUAWEI

NetX2025
Target Network Technical White Paper

GUIDE to THE FUTURE

IDC ANALYZE THE FUTURE

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CONTENTS

Introduction

As a whole, society is soon ushering in a fully connected, intelligent world. At the same time, the ICT industry has entered a new cycle of development, accelerating digital transformation across a multitude of industries, such as finance, transportation, manufacturing, and governance.

Operator networks are strategically fundamental to sustainable development. As 5G, F5G, and other new network technologies continue to scale up, industry applications are expanding from 2C to 2B domains, changing the way of life and production while facilitating digital transformation services. Operators are in a unique position to provide high-quality connections through 5G and private lines and also boast abundant DC resources and reliable collaboration with government and industrial customers. This will enable them to fulfill diverse digital transformation requirements from government and industrial customers and develop comprehensive application ecosystems, while becoming more competitive against OTT vendors.

In addition, by utilizing excellent steering capabilities of network connections, they can expand the cooperation with OTT industry chains and leverage cloud-network synergy to encourage enterprises to migrate to cloud platforms, improving user experience, and although user experience relies on cloud, background networks are the key pillars that enable such an improvement. Therefore, in the future, differentiated E2E network connections will always be key to competition.

In collaboration with global operators, this white paper discusses the blueprint of the Target Network 2025, in order to facilitate industry-wide strategic thinking of business opportunities, cooperation, and technological evolution. It aims to help build a stable, reliable, and efficient target network architecture to foster future-oriented differentiated competitiveness, maximize network value, and sustain business success.

1

The Time to Initiate Target Network 2025

1-1 Three Driving Forces Behind Target Network 2025

1-1-1 Business Success

1.1.1.1 The Telecom Industry is Looking for the New Blue Ocean After the Population and the Traffic Dividends

Mobile networks are changing the world profoundly, digitalizing sharing, communication, shopping, entertainment, and lifestyle services, and contributing to the boom in the MBB industry. In the past 15 years, operators have experienced three successive phases of transformations: population dividend, traffic dividend, and data dividend. In phase one of population dividend, most operators achieved high-speed growth. But after entering the second phase, they stuck to the same development approaches, leading to a considerable decline in revenue despite increases in traffic volume. In the worst cases, some operators witnessed negative growth, resulting in a reduction in the number of operators worldwide.

1.1.1.2 Industry Digitalization Drives Operators to Capture 2B Opportunities

In July 2020, a large spinning mill in Shandong — an eastern Chinese province on the Yellow Sea — successfully constructed an automated production line measuring 35 km long in an effort to automate production and achieve unmanned visualized management for all procedures and working posts. 5G laser navigation AGVs were adopted to transport large and heavy cotton sliver cans without manual intervention. In addition, order progress monitoring, equipment status warning, quality out-of-gauge warning, environment monitoring, energy consumption tracking, one-click quality report generation, real-time quality data monitoring, real-time order tracking, and many other services were supported, and integrated data analysis was realized on all devices. All of this was achieved by leveraging the latest connection and computing capabilities. As a result, the number of workers in the digital production line is now 90% fewer, reducing labor intensity and costs, improving product quality, and further enhancing competitiveness in the textile industry.

The next decade will be another golden age for operator business development, after the era of program-controlled switches that created a boom in the fixed telephone market, the GSM era that led to considerable gains in mobile user bases, and the period of fixed broadband and 4G technologies. Now, full-industry digitalization, machine vision, IoT, and high-bandwidth terminals are giving rise to indefinite possibilities. With 5G development further accelerating, operators are provided with new opportunities to compete against OTT vendors in the digital enterprise business while innovating services and improving business performance.

1-1-2 Improving TCO Efficiency

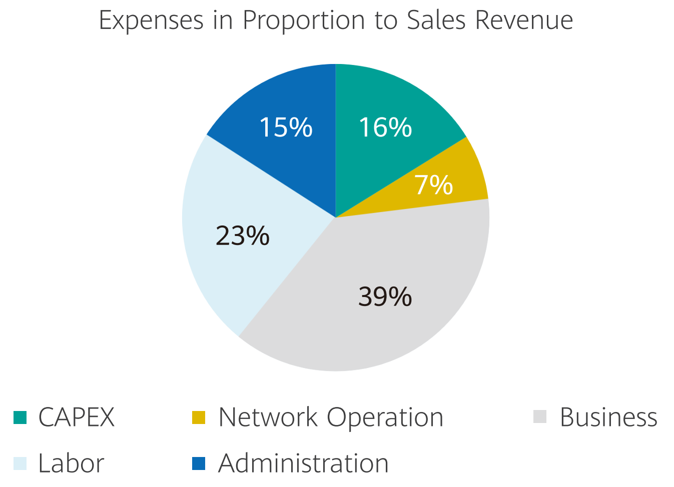
1.1.2.1 Budget Restriction Highlights the Necessity for Precise 5G Network Construction

Looking back on the development of 3G and 4G, there were strong demands in each phase. The population dividend was not over, and the ARPU was generally higher than it is now.

Looking ahead, given that 5G started before the investment on 4G was fully recouped and that the population dividend still exists, operators will be more cautious about investing. Starting strong is half the battle, and for operators to set themselves apart from competitors in the 5G era, target networks will be key. In the next five to ten years of 5G's life cycle, it is essential to make the best of limited investment to maximize the value of operator networks by precise planning, investment, and construction. This has become an imperative issue that requires operators to take immediate action.

1.1.2.2 Architecture Innovation is Essential to Reduce Costs and Improve Efficiency

The coexistence of 2G, 3G, and 4G networks in the past decade has led to a significant annual rise in OPEX for global operators, largely resulting from the structural issues of operator networks. The following is an example of operator in Europe in this regard.



This example shows that traditional operators are under great pressure, as OPEX accounts for over 50% of the total revenue and more than five times higher than CAPEX. It is generally accepted that a healthy investment has a 3:1 or lower ratio between OPEX and CAPEX.

The increasing complexity in networks, services, and O&M due to the concurrence of 2G, 3G, 4G, and 5G networks is certainly the primary cause of the challengingly high proportion of OPEX for operators all over the world. OPEX reduction has already become a common requirement in the industry and new technologies that noticeably improve network operation efficiency will be the crucial solutions operators can rely on. The CEO of a leading Internet company once said that "AI will bring revolutionary significance to our society and create even more profound impacts than fire and electricity."

"Looking ahead, putting wisdom at the forefront is the key to success." In addition to AI, other emerging technologies, such as big data, and digital twins, as well as new protocols and architectures, will inject new life into operator networks. We've noticed remarkable preparations from leading operators with plans to improve target network performance, efficiency, and business agility in the next five to ten years. We are also confident that architecture innovations will help the industry overcome the pressing network structural issues while optimizing the TCO for operators.

1-1-3 Technology Evolution

1.1.3.1 Network 2020 is the Starting Point for the Next Five Years

Cloud and its applications are just the prologue for the next round of the technological revolution. On-demand availability, always-on, self-help services, and elastic scalability are key features that meet the upcoming service requirements and robust open architecture distributed switching (ROADS) experience standards. As OTT development is largely driven by the cloud, migrating to the cloud is the first step operators must take. The public cloud provides operators with IaaS, PaaS, and SaaS capabilities, and the private cloud enables them to implement cloud BSS and OSS services to transform their management systems.

SDN makes networks more agile and enhances their real-time performance, helping implement self-help services, real-time service provisioning, and on-demand customization. SDN has been widely used in various fields, from WANs to data centers, VPNs, and private line service provisioning. Technologically, SDN has progressed significantly from forwarding-control plane separation to network automation. The previous five years has seen SDN play an important role in global operator networks to help improve O&M efficiency and reduce labor costs, freeing engineers from repetitive work.

NFV is another key technology facilitating the technological revolution. Virtualizing NE functions and migrating them to the cloud enable operators to scale up or down NEs on demand and keep them always online. Such elastic scaling has drawn broad attention from in and outside the industry.

Since 2014, global operators, led by AT&T, have been scrambling to transition to cloud, with AT&T setting the goal to operate 70% of its NEs on cloud by 2020. Other operators, such as Telefonica and Vodafone, have all set up cloud transition goals, clearly demonstrating the technological trend over the recent five years.

Though not being fully mature, SDN and NFV will architecturally lay an essential foundation for network development over the next five years.

1.1.3.2 5G, AI, Edge Computing, and Other Technologies Accelerate Digital Transformation

Throughout the industry, eye-catching new technologies are driving development. AI has inspired innovations in the communications and vertical industries, and the edge cloud has become a key focus. In addition, IoT is revitalized by 5G, AI, and edge computing. The integration of 5G with vertical industries is also becoming commonplace, with China Mobile for example, already launching the 5G+ strategy to advance their integration process. All these new trends indicate that an unprecedented industrial revolution is already on its way to take the industry to new heights.

Simply put, 5G deployment is accelerating to create business opportunities for industries. Synergizing 5G with AI, IoT, and edge and cloud computing will give rise to infinite possibilities; however, the resulting VR, AR, MR, V2X, digital twins, and holographic communication services will impose great pressure on incumbent networks, and adapting to these services will become a major challenge for global operators. This highlights the importance of Target Network 2025. 5G connections and applications will fully expand into all vertical industries to enable digitalization, presenting operators with both major challenges and, more importantly, huge opportunities over the next five years.

1-2 Target Network 2025 Planning: Service-Centric

Throughout the 2G, 3G, and 4G eras, target networks were planned with a key focus on voice and traffic, featuring simple service models and people-to-people communications. However, 5G will transform services in the next five to ten years, building on people-to-people communications to also include connections between things and scenario-based industry services. The target network 2025 should see operators focus on services, while treating the new changes in traffic directions, scenarios, and service capabilities as guidelines.

2C and 2H: Rich-media entertainment, VR shopping, and ultra-HD videos drive the rapid development of broadband for individuals and homes. 2D videos in HD, 4K, and 8K resolutions, are now expanding to the level of VR videos in 3D. Cloud VR and panoramic videos are also facilitating the development of gigabit broadband, requiring larger bandwidth: a 10-fold to 100-fold increase. The minimum bandwidth required for a panoramic 24K VR experience for example, is 870 Mbps. GSMA predicts that, by 2025, the total number of 5G users will reach 1.6 billion worldwide, with the Chinese market accounting for 40%. By then, the average network speed of global home broadband users will exceed 250 Mbps, and China will embrace more than 80 million users of gigabit broadband. The target network 2025 therefore needs to consider 5G and F5G coverage, structurally improve the TCO, support full-service evolution, and ultimately achieve ubiquitous gigabit connections.

2B: Throughout the 2G and 3G eras, operators' service types were relatively simple. Everyone was solely focused on occupying a slice of the rapidly booming and scaling market, preventing homogeneous competition. In the 4G era, the emergence of OTT services gradually blunted operators' influence on the industry chain. As a result, operators were trying to maintain their user bases against the backdrop of more severe channelization. In the 5G era, operators have shifted their focus from the 2C to 2B market to empower traditional industries. An expert organization in the field predicts that China's 5G industry will directly contribute to the output of CNY3.3 trillion in 2025. From a global perspective, operators' 2B services have included connections, computing, cloud, applications, and AI. Their service forms have also expanded to scenario-based solutions, featuring WAN connections, LAN connections, edge cloud, public cloud, and applications. Operators will inevitably provide new ICT services for enterprises on top of traditional connection services. It is estimated that by 2025, 2B services will become the main revenue source of global leading operators, accounting for more than 50% of the total. The target network 2025 therefore needs to fully consider precise coverage (indoor and outdoor), 5G slice deployment, edge cloud, and multi-cloud collaboration. When examining the scale of the project, the planning focus should shift from "large-scale construction, universal construction, and wide coverage" to "precise construction, scenario-based construction, and in-depth coverage." In addition, it is necessary to ensure the implementation of 5G applications, expand industry applications, and promote 5G network construction and planning, thereby achieving sustainable and high-quality development.

New technologies: Despite the uncertainty and complexity of 2B services in the future, technical innovation — learning and embracing new technologies — can effectively cope with these uncertainties. The target network 2025 needs to vitalize the next-generation information technologies, big data, cloud computing, IoT, and AI; add new driving forces to the intelligent world; and reduce uncertainty in the world economy.

Network flow direction: Operators' 2B services have significantly changed from traditional WAN connections to incorporating both WAN connections and enterprise/campus LAN connections. In addition, as MEC is deployed in enterprise or CO equipment rooms, 2B services are processed at MEC or enterprise private clouds. The traditional traffic model, in which traffic flow direction is north-south (access layer-transmission layer-DC), has now evolved to support omni-directional traffic flows. It is estimated that network traffic will increase by at least ten times in 2025, with east-west traffic reaching the same level as north-south traffic on operators' networks. Therefore, the target network 2025 must consider the planning and coverage of ubiquitous campus wireless connections, wired connections, MEC equipment rooms, and optical fiber resources.

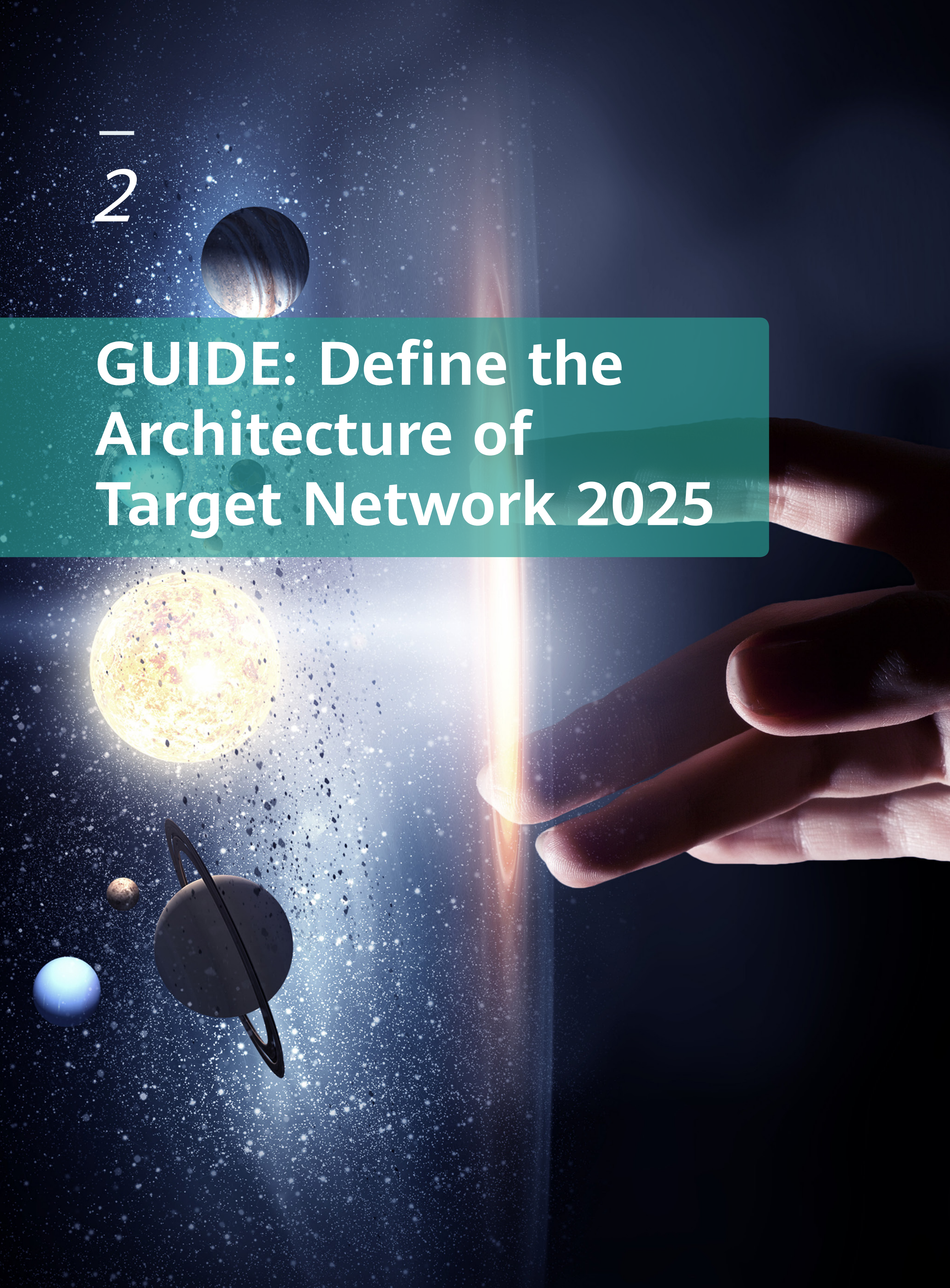
Network traffic: In the next five years, home HD video entertainment and large-scale commercial use of 5G will drive a traffic increase of more than ten times on operators' live networks. In terms of capacity, the target network 2025 planning must therefore ensure smooth or even slightly advanced evolution of the access network, MAN, and wireless bearer network. Based on the target network, operators should enhance the prediction accuracy and timeliness of service traffic growth, and promote network planning and construction in a step-by-step and focused manner.

Scenario-based requirements: With operators' service focus tilting towards the 2B market, the fragmented and scenario-based industry market diversifies the requirements of industries. Also, there is no unified product or solution for scaled replication in the same industry project. For example, network bandwidth requirements may vary in video upload when cameras of different vendors and different bit rates are used; high temperature, humid, explosive, and high-speed moving environments have higher requirements on network reliability and security; and machine vision in smart manufacturing factories requires the collaboration of 5G high uplink, cloud, and AI. These challenges pose higher requirements on operators' scenario-based solution capabilities. To address this, operators must prepare differentiated network capabilities for scenario-specific requirements through the target network 2025 in order to enable industry integration.

Service capabilities: The traditional offline 2C, 2H, and 2B service modes cannot meet the new requirements of enterprise ICT services by 2025. New service capabilities require minute-level service provisioning, visualized network SLA, flexible service customization, and an ultimate customer service experience — from subscription to utilization and payment. Simply put, high-quality services result in premium capabilities. Therefore, based on differentiated network capabilities, the target network 2025 planning should ensure higher accuracy, faster deployment, simpler O&M, and more efficient optimization through the digital operation system, achieving high-quality E2E network services.

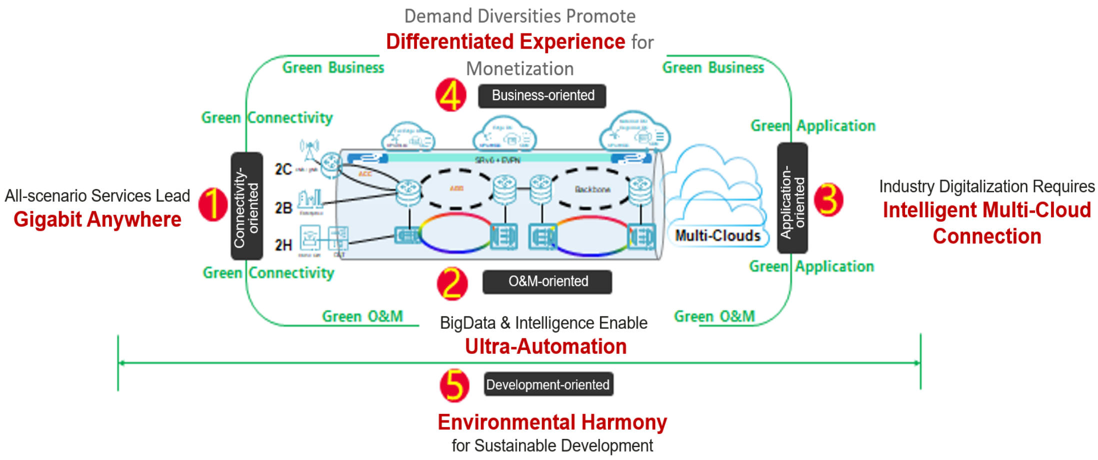
2

GUIDE: Define the Architecture of Target Network 2025



2-1 Five Characteristics of the Target Network 2025

Based on the preceding driving force analysis and methodology, we conclude that the operator target network 2025 should have the following characteristics:



2-1-1 Gigabit Anywhere

In its outlook on 2025, market research company, Omdia, points out that home broadband services with a download rate of less than 100 Mbps will have phased out. In that same period, the average download rate in leading countries is expected to exceed 500 Mbps. Even today, more than 300 service providers in leading countries and regions already provide a download rate of at least 1 Gbps. *1 Gbps per household will become the new normal and consumers will require more personalized services. (IDC White Paper, Sponsored by Huawei, CSP Network Transformation: The Journey to 2025, Doc #EUR147425621, February 2021)*

In addition, by 2025, Omdia predicts that there will be over 187 million gigabit broadband users worldwide. As VR and AR; the UHD evolution of UAVs, intelligence, and industrial cameras; and industrial manufacturing, outdoor inspection, and monitoring scenarios are future development trends, gigabit connectivity has clearly become a fundamental requirement.

In the 5G field, uplink capabilities, latency, and positioning are core to innovation. For example, in smart manufacturing scenarios, Super Uplink technology is introduced to achieve an uplink rate of at least 1 Gbps for HD video upload, and UTDOA and larger spectrum bandwidth are used to achieve submeter-level positioning, thereby improving the management efficiency of manufacturing campuses. In port scenarios, preallocation and mini-slot features are introduced to achieve a low latency of 20 ms, enabling automated remote control of cranes to replace over 90% of manual operations.

In intelligent IP networks, a three-layered intelligence architecture — comprising NE, network, and cloud — enables operators to comprehensively upgrade their WANs, implement multi-cloud and cloud-network synergy, and meet differentiated requirements, leading WANs into an intelligent full-service era.

Whereas in F5G intelligent all-optical networks, an all-optical bearer network solution is introduced to meet the multi-rate transmission requirements and significantly improve efficiency. A plug-and-play all-optical data center interconnection solution is also provided to support one-click service deployment, extending optical connections to the network edge and delivering an optimal service experience for each individual, home, and organization.

2-1-2 Ultra-Automation

The intelligentization of industries will inevitably increase the scale and complexity of networks. According to Internet reports, when new technologies — such as 5G — are introduced, the connection density will increase by 100 times and the number of parameter settings will increase by over 10,000, leading to more difficult O&M and management of connected networks. To tackle this problem, big data and intelligence must be introduced, transforming O&M from manual operations to ultra-automation, reducing decision-making complexity, and improving efficiency.

However, the ultra-automation implemented based on intelligence technologies not only automates simple and repeated tasks but also performs more intelligent adaptation based on differentiated services and experience. This streamlines multiple tasks to further unleash network productivity. The implementation of ultra-automation will enable the network to build self-X (self-service, self-delivery, and self-assurance) operation and O&M capabilities in its full lifecycle, providing users with zero-X (zero-wait, zero-touch, and zero-fault) experience.

Zero-wait: E2E automation is implemented from service intent to the release, delivery, and maintenance of network configurations. Breakpoints between different technical fields or layers on the network are bridged, helping enterprises or operators gain network service experience based on ever-changing service requirements.

Zero-touch: The complexity of network devices and the variability of consumers and enterprise customers in the digital economy make manual network management increasingly difficult. Especially in scenarios such as network optimization, the complexity of multi-parameter optimization has gone beyond human capabilities. The intelligence-enabled ultra-automation technology can gradually find the optimal solution based on evolving learning capabilities and perform self-adjustment based on analysis results. In addition, the complexity of the network is shielded by management and control units of the network. The upper-layer users or platforms of the network do not need to spend much time and energy on understanding technical details such as different device types, ports, and protocols.

Zero-fault: On a mesh network, a fault can be accurately detected or predicted by the network instantly or even before it occurs, and the fault can be avoided or rectified by the network itself. This rectification uses SLA adjustment to avoid the interruption of upper-layer services, which has no impact on user experience.

To support full-lifecycle closed-loop user experience and achieve zero-X experience, ultra-automation will be first applied to closed-loop autonomous management of a single domain and gradually expand to cross-layer or cross-domain closed-loop management.

2-1-3 Intelligent Multi-Cloud Connection

We forecast that the spend on public cloud infrastructure will surpass that on traditional IT infrastructure by 2022. Enterprises are also increasingly adopting new technologies to enable new business use cases. By 2024, 75% of enterprises will leverage modern architectures for most of their business workloads across multicloud environments. (IDC White Paper, Sponsored by Huawei, CSP Network Transformation: The Journey to 2025, Doc #EUR147425621, February 2021)

Multi-cloud has become the first choice for enterprise digitalization considering application attributes, supply security, reliability, and cost. The intelligent Clouds Connection feature of the target network will support enterprise demands for digital transformation on multiple clouds.

The multi-cloud aggregation network based on intelligent connection enables enterprises to implement multi-cloud for their frontline operations, and provide full e-commerce experience from subscription to fulfillment. On the access side, the intelligent network can maximize the utilization of bearer networks on existing 4G, 5G, and PON, while 5G private lines can be used to implement wide access coverage and fast service provisioning. On the metro aggregation network, cloud PE nodes are deployed in mainstream data centers to connect operator IDCs, telecom cloud data centers, and cloud service provider data centers, implementing multi-cloud connectivity between them. Meanwhile, the intelligent connection network uses technologies such as SDN and SRv6 to implement network-wide, cross-domain, low-latency, and self-service route selection, providing enterprises with SLA-guaranteed private network services.

The target network's multi-cloud consists of three clouds: edge MEC, sovereign cloud, and partner cloud. Edge MEC and partner cloud support inter-cloud collaboration and scheduling. At edge MEC, low-latency connection services and some computing services are provided for key applications, while more economical and powerful computing services will be provided on the partner cloud. In addition, the sovereign cloud will match the digital sovereignty requirements of each country and provide cloud services for key applications such as payment, logistics, and government affairs.

The intelligent multi-cloud connection will implement cloud-network synergy and convergence. Through the multi-cloud aggregation management platform, cloud and network resources can be operated and maintained in a unified manner, resulting in a system with integrated supply, operation, and services. The cloud management platform and network controller will open custom APIs for the multi-cloud aggregation management platform, implementing such capabilities as cloud-based network scheduling, network-based cloud scheduling, and cloud-based network migration to meet the multi-cloud requirements of enterprise users.

2-1-4 Differentiated Experience

In an intelligent future, the primary network connections are people-to-people and things-to-things.

The best-effort network service mode is capable of meeting the basic requirements of consumer entertainment services. However, if operators can provide a differentiated VIP experience, users will be willing to pay for such services. Consequently, a more effective monetization mode is formed.

In regard to industry services, a large number of application scenarios originate from production. However, such production scenarios vary greatly, with smart cities requiring large connection capabilities, smart factories demanding low latency, and cloud VR and other technologies necessitating high bandwidth. To meet such varying service requirements, differentiated experience assurance will become a mandatory option for the construction of these smart entities. For example, during peak hours at Shenzhen Airport in 2019, an average of 1.13 aircrafts either took off or landed each minute. In order to keep pace, the power system's reliability must reach 99.999%. For example, a single extra millisecond of latency in Wall Street's financial trading system could result in an economic loss of over US$1 million. To meet the requirements of complex industry application scenarios and high reliability, network connections must be oriented to different scenarios and industry applications in order to provide differentiated experience capabilities and maximize network value. As such, differentiated experience is an important feature of the future network architecture in 2025, and it is recommended that operators improve E2E experience solutions and continuously develop network capabilities through application, discovery, and resolution.

2-1-5 Environmental Harmony

According to statistics, over 120 countries around the world are legislating to achieve net zero carbon emissions by 2025, as environmental awareness and sustainability has become major factors in the context of enterprise's social and economic roles. As a result, operators are responsible for ensuring environment-friendly practices and lowering power consumption and promoting energy conservation, emission reduction, and circular economy development through product and technology innovations, and continuously driving the industry chain to build a society with low carbon emissions.

Look forward to 2025, the continuous growth of cloud, edge, and terminal data will lead to the traffic carried by operator networks increasing year on year, expanding the overall network scale. With the accelerated commercialization of global 5G networks, this trend is set to become even more noticeable. Consequently, operators must consider energy efficiency as well as data and cost efficiency while planning networks and designing services. According to the planning of the target network 2025, operators are advised to use new technologies at the following layers to improve energy efficiency and achieve environment-friendly connections, operations, business, and applications.

At the equipment level, certain outdated network equipment and technologies need to be upgraded to reduce the number of antennas, base stations, forwarding devices, and equipment rooms. Full-band antennas can be deployed to reduce space, power, and the number of sites, thereby significantly lowering the total energy consumption of the network. The intelligent shutdown technology can be utilized to enable sites to assist operators in making shutdown decisions with the help of intelligence.

In terms of site energy, it is recommended that modular, high-density power supplies, lithium batteries, and outdoor blade power systems with natural heat dissipation be used. In addition, solar energy can be connected to improve system efficiency and apply renewable energy.

At the network layer, E2E network slicing is deployed to implement multi-plane integrated bearing on a single network, and to accurately allocate network and computing resources to specific industries, enterprises, applications, and tasks. Once these tasks are complete, slice resources can be released immediately and put to use elsewhere, maximizing the network utilization per bit. Slicing deployment will provide on-demand virtual private networks for various industries, without the need to deploy excessive enterprise private networks, thereby avoiding unnecessary resource consumption.

When designing and constructing a large-scale data center, environment-friendly measures must be taken into account without compromising the balance between operation and electric power reliability. For example, recycling the waste heat generated by the data center can boost heat supplies, advanced air and water cooling technologies as well as sealed hot or cold aisles significantly reduce power consumption, modular construction is leveraged to increase capacity as required, and renewable energy resources such as solar and wind power replace conventional coal-generated alternatives.

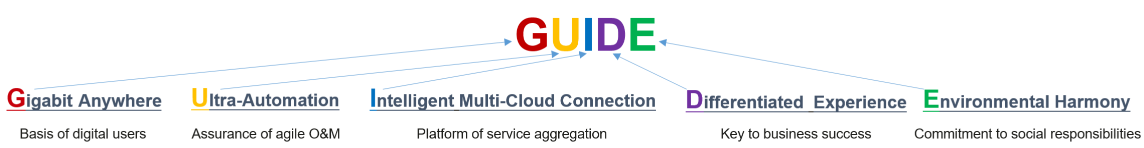
At the operation layer, the autonomous driving technology is used to implement intelligent and remote network O&M, improving the per capita efficiency and reducing repeated manual labor and travel requirements.

At the business level, operators are advised to develop ecosystems by optimizing data center construction, server deployment, and repeated application development through multi-cloud cooperation.

As we approach 2025, new technologies relating to improved energy efficiency will begin to emerge, enabling operators to further optimize energy management and reduce energy consumption at each level, leading to more energy-efficient networks.

2-2 GUIDE to the Target Network 2025

To summarize, the typical characteristics of the operator target network 2025 are defined as the GUIDE model.



The GUIDE model serves as an exploration of the target network 2025. In the 5G era, users, service scenarios, product and service modes are greatly changed. Conventional Internet service modes are unable to satisfy consumer and production requirements, and operators must urgently explore a new service development path. The GUIDE model is developed to help operators explore future network development, make plans, and better support conventional services in the 5G era. In addition, this model helps operators strengthen innovation and incubation in new service fields, and facilitates continuous exploration of new growth opportunities.

The GUIDE model also aims to better help operators solve structural problems through architecture-level innovation. In the 5G era, the service growth of operators will predominantly depend on 2B services. By planning and deploying network capabilities in advance, operators can take a leading position in terms of industry digitalization for 2025, and establish first-mover advantages in new service fields. Thanks to such advantages, as well as the 2B industry's forest effect, the market entrance threshold is high, and once operators have successfully tapped into the industry production system, it will be difficult to lose their position. In addition, due to the new requirements and upgrades of the industry production system, an internal cycle from requirements to product upgrades is formed, enabling operators to continuously build and strengthen industry capabilities and attributes. As such, these new fields require differentiated advantages during the initial stages in order to ensure competitiveness. By targeting these new requirements, GUIDE aims to innovate and plan the network architecture through the methodology of the target network, continuously explore the differentiated advantages and capabilities of operators in new service areas, and develop the selected industries into their own advantageous fields. This will be achieved by focusing on the industry's most powerful capabilities to help operators achieve leading, green, and sustainable development in new business domains.

3

Planning and Development of the Target Network 2025

3-1 Wireless Access

3-1-1 All-Services Requirements of Mobile Networks in 2025

5G does not just upgrade communications technologies. It also represents new businesses, ecosystems, and opportunities. Compared with 4G, 5G features more diversified services and more differentiated requirements.

It is estimated that by 2025, in the 2C field, all screens will be connected with mobile phones. This means that people, vehicles, and homes will be connected through mobile networks, and mobile phones will become personal data nodes. In the 2B field, 5G will enable a wide range of applications.

- Individual: The way people use mobile connections is changing, from interacting with mobile phones to expanding our perception of the world around us. With the advent of high-definition mobile phones and AR/VR, it is estimated that Internet and AR/VR users will reach 6.2 billion and 337 million, respectively, by 2025. In the next five years, the traffic on mobile networks will increase by five to ten fold.

- Home: Mobile phones will become inlets for information. Large-screen TVs are expected to regain domination of home entertainment, while mobile phones will replace DVDs and STBs. Mobile phones, large-screen TVs, computers, and tablets will collectively become the center of social information in our homes.

- Vehicle: Mobile phones will be connected to vehicles by default. Navigation will always be enabled to facilitate road direction and improve efficiency. Three-layer coordination of autonomous driving will be enabled, encompassing public and private networks and sensors. UAVs will enable Internet access in the air.

- Vertical industry: Vertical industries such as security, public transportation, electric power, manufacturing, coal, health, steel, education, airport, cement, oil and gas, and port will pose huge connection requirements.

3-1-2 All-Scenarios Requirements of Mobile Networks in 2025

Mobile networks will evolve from mere ground and indoor coverage to full-scenario coverage, including ground, indoor, underground (such as mines), low-altitude (such as UAVs), flight routes, and uninhabited areas (such as deserts, forests, and oceans). The connection of people requires a large-bandwidth network that provides continuous coverage to deliver next-generation experience and greatly reduce the cost per bit. The connection of things also requires a large-coverage network to support massive connections with IoT terminals. Industry connections are limited to local scenarios at the early stage, requiring flexible capabilities such as large uplink, low latency, and high-precision positioning.

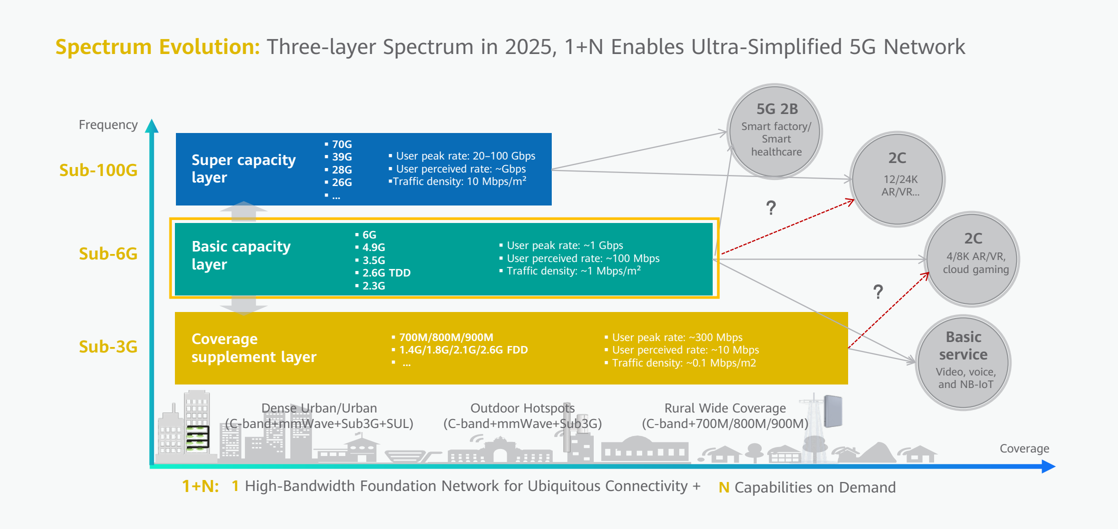
3-1-3 Mobile Network Evolution Towards 2025

To meet full-scenario coverage and full-service requirements in the future, mobile networks need to evolve in terms of spectrum, architecture, and site towards 2025.

Spectrum evolution:

By 2025, mobile networks will have access to all spectrum below 100 GHz. To achieve this, Huawei has proposed the new three-layer network, involving sub-3 GHz, sub-6 GHz, and sub-100 GHz. Sub-6 GHz, including TDD 3.5 GHz, 4.9 GHz, and 2.6 GHz as well as 6 GHz in the future, will build the layer for basic capacity and universal coverage by using large bandwidth and Massive MIMO technologies. Sub-100 GHz and sub-3 GHz will be deployed based on service requirements. For example, mmWave can be introduced when a top-quality experience is required or at super hotspots. When high uplink bandwidth is required, sub-3 GHz can enhance uplink coverage and capacity. When wide coverage or deep indoor coverage is required, low frequency bands such as 700 MHz, 800 MHz, and 900 MHz can be used for enhancement. To sum up, future target networks will have "1+N" capabilities, that is, one large-bandwidth fundamental network to implement ubiquitous connectivity and N frequency bands on demand to meet the service requirements of 5G in diversified scenarios.

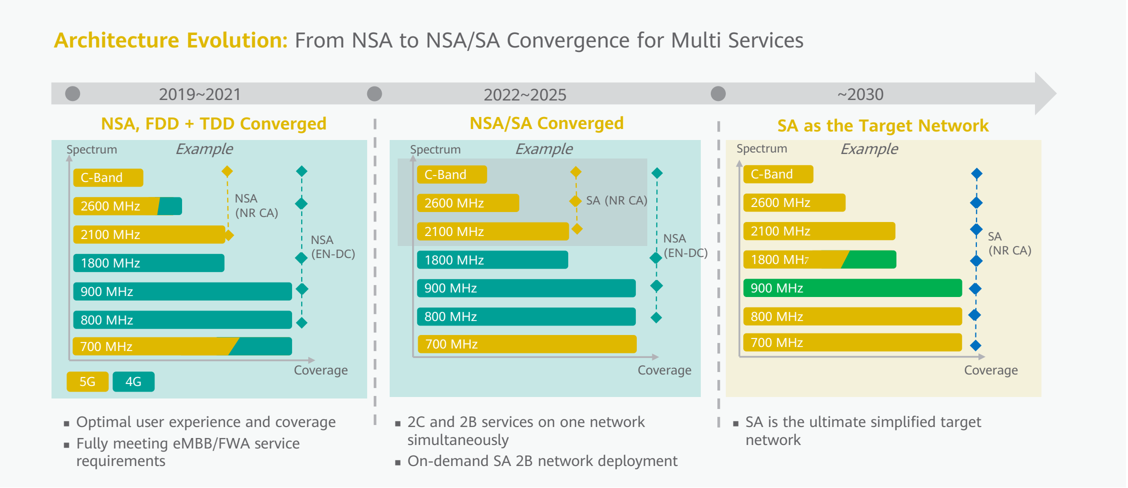
Take 5G smart manufacturing of China Mobile Guangdong as an example. Traditional production equipment cannot provide the expected efficiency of modern enterprises. Huawei's Southern Factory planned to apply 5G to improve the efficiency of production. One typical application is machine vision in mobile phone production workshops to inspect the shapes and integrity and detect defects on objects. This generates ultra-large concurrent traffic in the uplink, with uplink traffic density far exceeding 3 Gbps within a range of several thousands of square meters. Huawei overlaid 4.9 GHz on the basis of 2.6 GHz (and may add 2.3 GHz in the future), and uses D-MIMO to enable ultra-dense deployment of small cells.



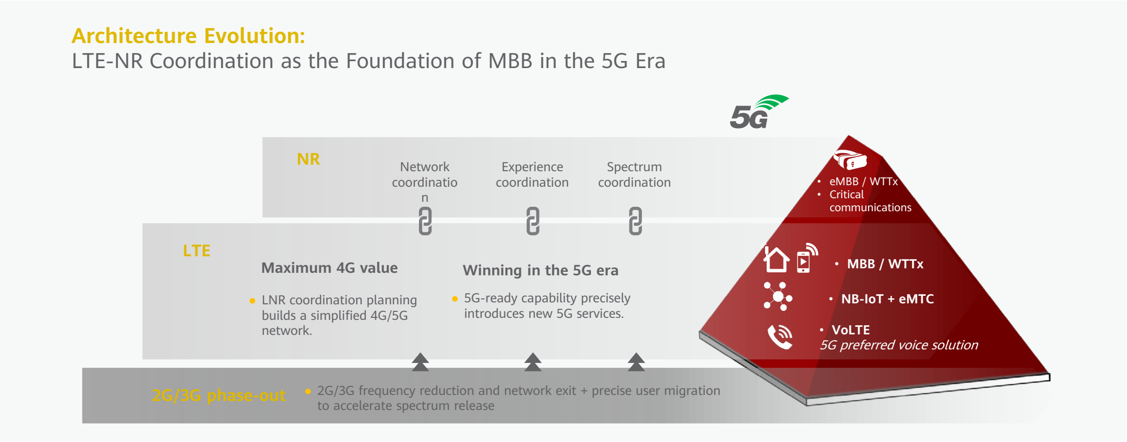
Architecture Evolution

The first step in evolving network architecture is to converge NSA and SA networks. Currently, most commercial 5G networks employ the NSA architecture, which delivers excellent user experience and coverage. This means that the global ecosystem is already set up to support the early deployment requirements of eMBB and FWA. The next step — introducing SA networks — depends on terminal maturity and the requirements of vertical industries. In 2020, China's three major operators began to deploy converged NSA and SA networks, which support both 2C and 2B services.

However, some commercial 5G terminals support only NSA networks. Therefore, Huawei anticipates that NSA and SA will coexist for a long time, and SA-only networks will become commonplace only after 2025. Once this happens, networks will become simplified, featuring double uplink throughput, lower latency, and prolonged battery life of terminals.



Another trend for wireless architecture is the coordination between LTE and NR. Even though the commercial use of 5G is growing quickly, GSMA predicts that LTE will continue to play an important role on the market. Therefore, operators around the world are turning to LTE-NR coordination, hoping to maximize network efficiency. LTE-NR coordination involves networks, experience, and spectrum. Looking ahead to 2025, this approach will maximize the value of 4G services and networks. In terms of services, it will support the development of a VoLTE foundation for 5G voice services, the evolution from NB-IoT to 5G IoT, and the provision of data and video services on par with 5G. In terms of networks, we can look forward to using FDD DSS to balance user experience between 4G and 5G, as well as facilitating 5G readiness through network modernization.



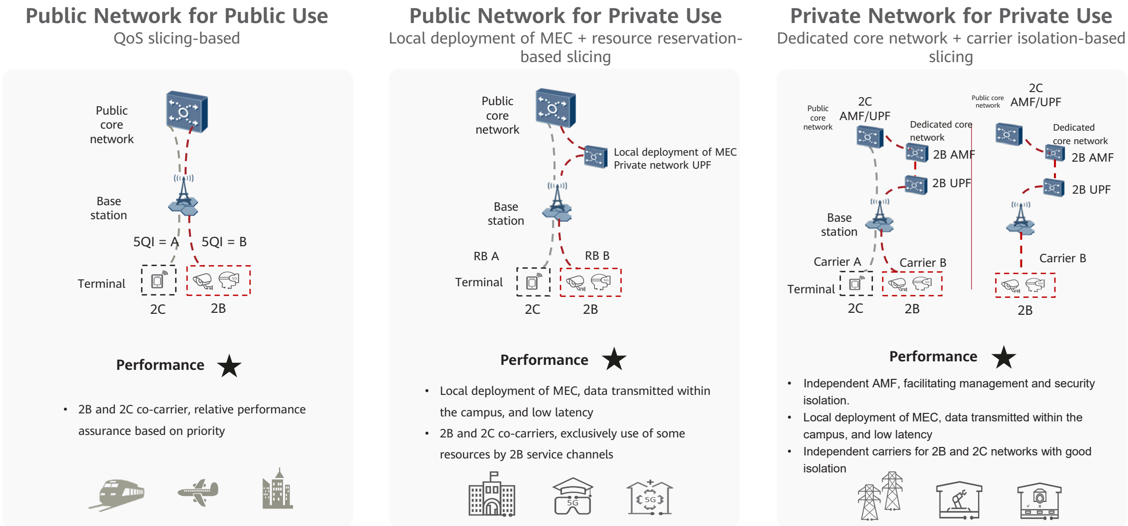
The third trend in wireless architecture is the collaboration between 2B and 2C. Depending on the specific applications, there are three possible models:

- Model 1: Using QoS slicing, 2B and 2C services share the network and carrier, offering performance assurance based on priorities. This model applies to high-speed railways, low-altitude coverage, and enterprise private networks.

- Model 2: This model uses the public network for private services. In this case, slicing offers resource reservation, and the MEC is deployed locally to ensure that data is transmitted within the campus as well as lower service latency. This model applies to 5G healthcare, smart policing, and enterprise private networks.

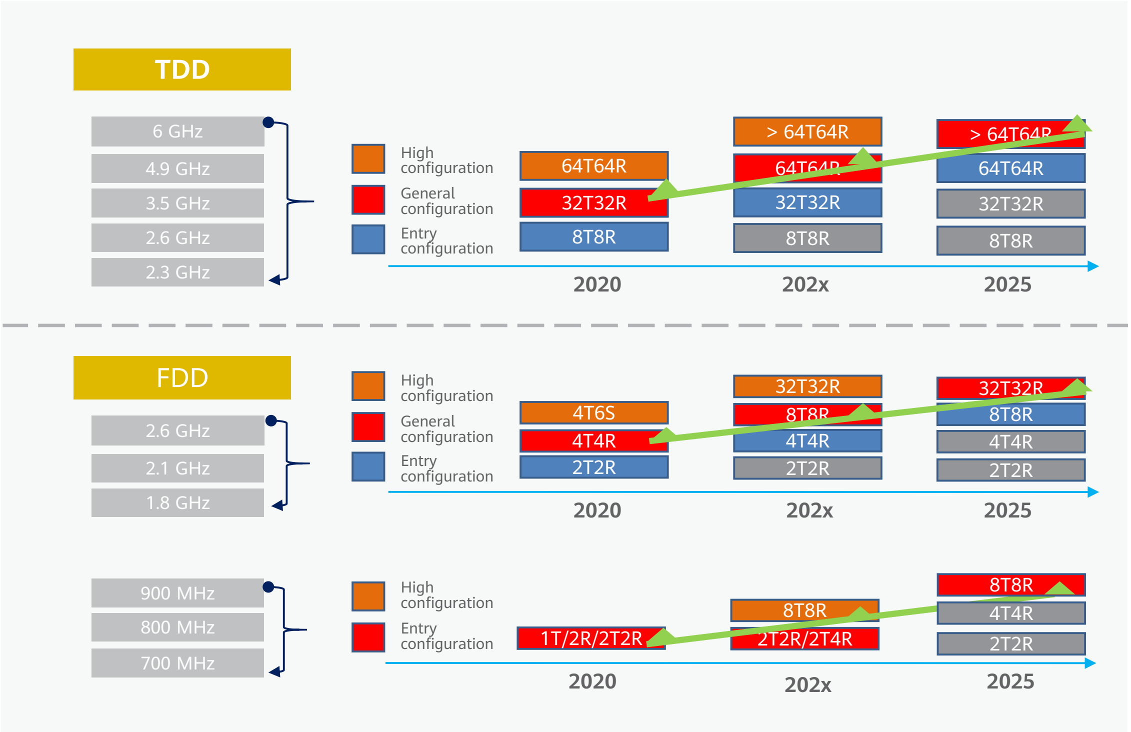
- Model 3: In this model, private networks are allocated for private use. They utilize exclusive wireless spectrum resources to meet specific requirements for scenarios such as smart grids, smart manufacturing, and smart coal mines.

Three 5G 2B Network Architectures for Scenario-based Service Requirements



Site Evolution

By 2025, Huawei anticipates five or even ten times more mobile traffic in most countries and regions. This begs the question — how can we reach the ultimate network capacity without having to add too many physical sites? The answer is to evolve existing sites to meet future capacity requirements. In this sense, we can expect low frequency bands (700 MHz, 800 MHz, and 900 MHz) to evolve to 4T4R, IF bands (1.8 GHz, 2.1 GHz, and 2.6 GHz) to evolve to 8T8R and even 32T32R, and C-band to evolve from 64T to higher-order Massive MIMO.



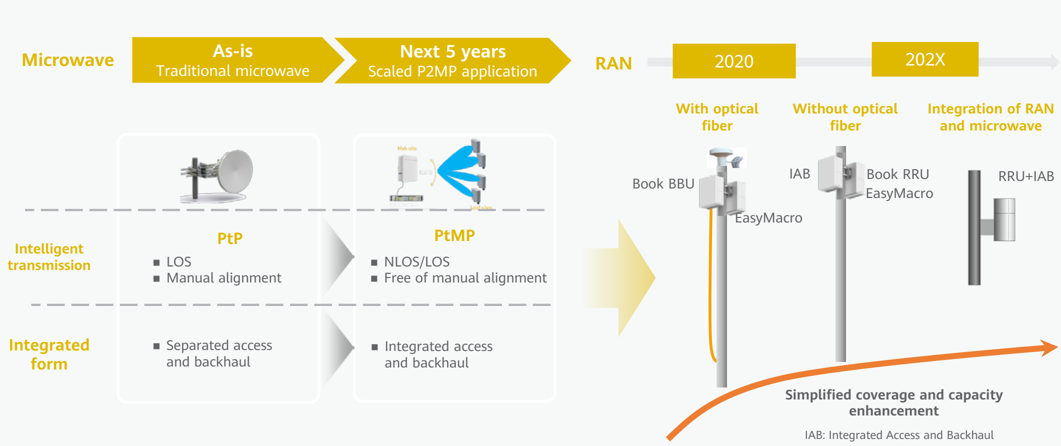
As ultimate capacity and simplified sites do not go against with each other for site evolution. This means that, in addition to expanding site capacity, it is also essential to improve engineering capabilities. For antennas, we will see one antenna connecting to all RRUs, supporting all of the passive antennas working in the sub-3 GHz band. As for RF modules, systems will be able to support low-frequency tri-band RRUs, IF tri-band RRUs, and dual-band FDD Massive MIMO.

If the antenna installation space is extremely limited, it is recommended that the sub-6 GHz all-in-one box be developed to support 32T or 64T Massive MIMO as well as include sub-3 GHz passive antennas. This will facilitate the deployment of 5G Massive MIMO on a single antenna.

Site Evolution: Simplified Macro Sites Optimize Engineering Capabilities and Improve Network Performance

In addition to the basic coverage provided by macro base stations, pole sites can be utilized to fill coverage holes, absorb hotspot traffic, or enhance uplink coverage in blind spots. Simplified pole sites are also one of the key directions for site evolution. Conventional microwave communication is PtP, but will evolve to PtMP in the future. In addition, IAB enables the convergence of wireless and microwave networks, so IAB pole sites are also slated to gain popularity in the industry. When there are no optical fibers, it is possible to use C-band or mmWave IAB to substantially increase backhaul performance, achieving "one pole, one site" and quickly strengthening coverage and capacity.

Site Evolution: Integrated RAN and Microwave，Achieves "One Pole for One Site"



Energy Evolution

When it comes to 5G, one of the biggest challenges in energy infrastructure will be to improve site capacity:

- High energy consumption: Fast 5G construction multiplies site energy consumption and electricity fees, eroding operators' profits (key pain point).
- Slow construction: It is difficult to obtain 5G sites and mains supply for fast 5G construction.
- High O&M costs: Conventional power and environment monitoring does not employ intelligent technologies, leading to lower operational efficiency and higher O&M costs.

To cope with these challenges, energy networks need to focus on the future, building simplified, intelligent, and green networks. This can be achieved through comprehensive digitalization, including innovation for key components and the application of intelligent control technologies.

Simplified evolution is possible with modular devices, high-density power supplies, and lithium batteries, and only requires a single cabinet. The power system supports multiple energy sources and voltage levels, for example, solar power and AC power supply (which may be required to upgrade sites due to MEC deployment). The high-density design enables one cabinet to house all of the site devices, reducing construction costs. In addition, an intelligent O&M system can be introduced to improve remote management and O&M efficiency.

If a site is difficult to acquire, it is possible to use outdoor blade power supplies and batteries capable of natural heat dissipation, saving engineering and rent costs. Natural heat dissipation ensures zero energy loss, improving energy efficiency and reducing OPEX thanks to a lower O&M workload.

To achieve green energy, we need to make systems more efficient and apply renewable energy:

1. Solar power: Huawei anticipates that 5G-based communication energy infrastructure will largely use solar energy. The efficiency of solar power generation can be boosted through intelligent PV and mains scheduling as well as photovoltaics power generation. Ultimately, this will accelerate the large-scale application of green energy.

2. From indoor to outdoor: Currently, many indoor sites require cooling systems, leading to high energy consumption. Reconstructing sites outdoors can significantly reduce energy consumption and related OPEX.

3. Rebuilding sites with low-efficiency power supply: Many sites still use a low-efficiency (below 90%) power supply in core facilitates. Substituting these with a high-efficiency (98%) power supply will reduce both energy loss and OPEX.

4. Application of renewable energy resources: Traditionally, sites that have low or no mains supply use two diesel generators to generate power and lead-acid batteries to store power. However, this system is inefficient. In this context, integrated power solutions can be introduced to integrate solar energy, high-performance cycle lithium batteries, and intelligent algorithms,

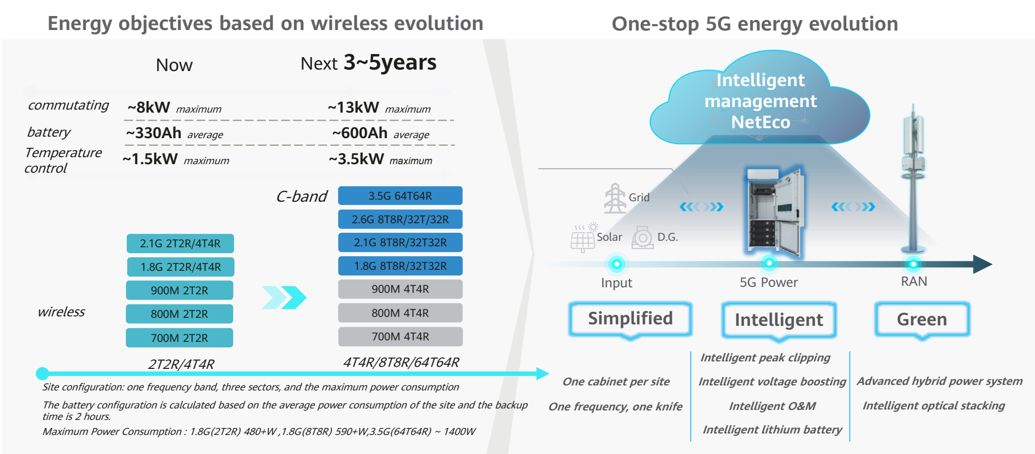
thereby improving system efficiency as well as reducing energy consumption and O&M costs.

5. More efficient system collaboration: Joint scheduling across systems can increase system efficiency. For example, the AAU is associated with the power supply, and the site power supply is in turn associated with services. This assures on-demand power supply and offers the lowest energy consumption per traffic (ECT). Additionally, intelligent technology can be used to adjust system running parameters in real time (based on site temperature, humidity, energy status, and service status) for optimal system efficiency.

Ultimately, target energy networks should feature:

- Simplified deployment, O&M, and the evolution of 5G communication power
- Higher resource utilization and less reconstruction of peripheral facilities such as mains and cables
- Higher energy utilization and lower energy costs

One-stop Deployment for 5G Target Networks Meets Evolution in the Next 3-5 Years



By 2025, wireless networks with high bandwidth and wide coverage will have to be built to facilitate massive connections between people and things. At the same time, networks will need to offer differentiated capabilities in response to the needs of various industries. Therefore, it is a must to build a "1+N" simplified network that features efficient collaboration and in-depth convergence of NSA and SA, LTE and NR, as well as 2B and 2C. In this way, we can meet the full-scenario coverage and full-service provisioning requirements forecasted for 2025.

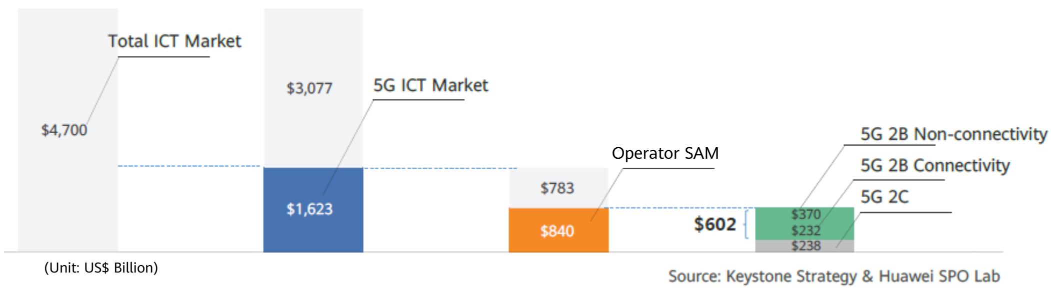
3-2 Core Network

5G brings unique advantages that will unleash the potential of various industries, becoming the key for industry digitization and the new driving force of the digital economy. According to the forecast by Keystone Strategy & Huawei SPO Lab, the global revenue from ICT-related industry digitalization will reach US$4.7 trillion by 2025, of which 5G alone will take up a market share of over US$1.6 trillion. Operators will tap into about half — US$840 billion — of this market share; and the 5G 2B market will be the major growth opportunity, accounting for about US$602 billion. A multitude of new 5G applications will emerge, due to the application of 5G — its large bandwidth, low latency, and massive connectivity — to the production processes in various industries. This will quickly highlight the value of networks, signaling unprecedented gains for the economy and society.

The core network is a key resource for operators, which allows them to learn about services, users, and network-wide resources. Its capabilities can be deployed at the edge (such as industry networks) through MEC. This means that its construction roadmap and solutions are particularly important.

Global ICT Investment Forecast for 2025

US$4.7 trillion ICT investment and 18% 5G SAM for operators in 2025



3-2-1 New Challenges for the Core Network

3.2.1.1 Network Reliability and Stability

Telecom and 5G services require existing IT DCs and infrastructure to offer higher reliability. The telecom cloud system consists of servers, storage, networks, and cloud operating systems. The numerous nodes create many potential fault risks. Therefore, reliability needs to be optimized to 99.999% through targeted solutions. Furthermore, some sensitive services may have even higher requirements on deterministic low latency, security, and reliability (99.9999%).

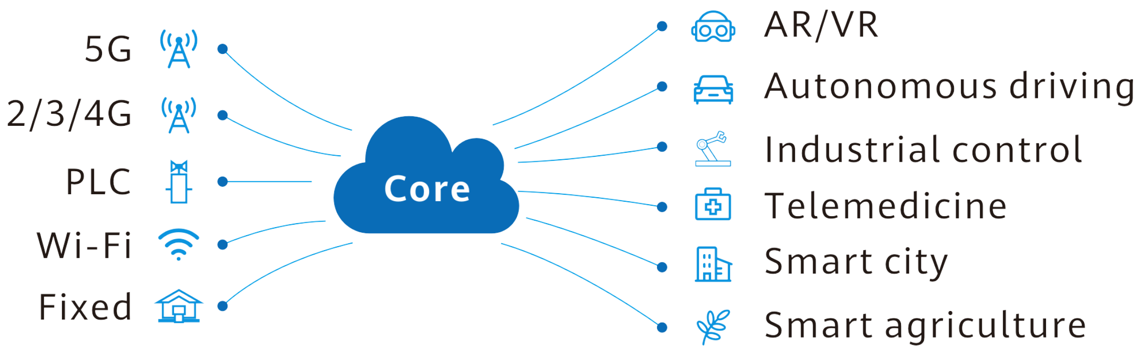
3.2.1.2 Network Cloudification Capability

Building networks that can automatically adapt to traffic changes, including flexible resource application and release, can considerably improve resource utilization and network flexibility. This makes cloud native essential for all solutions. With it and in contrast with traditional private lines, 5G mobile networks can be scheduled on demand as virtual private networks based on cloud-based microservices and flexible resource orchestration. In addition, cloud native provides technologies such as microservices and containers, which enable more reliable and flexible networks as well as more agile service deployment. On a conventional network, reliability largely depends on the exclusive use of hardware resources. However, in a fully cloud-based system, however, operators have multiple ways to define and dynamically adjust differentiated SLAs, such as HA isolation, VDC or VPC isolation, network slice isolation, and resource sharing.

Cloud-based infrastructure is also an important part of 5GDN. Normally, industries face complex deployment and have unique requirements for functions and performance. As such, they tend to use dedicated hardware and protocol stacks for their networks. However, this solution is not replicable or scalable, and is therefore costly. In response, 5GDN utilizes cloud-based infrastructure to support diverse deployment environments and upper-layer applications, achieving one 5G network for multiple purposes.

3.2.1.3 Full Service Convergence

5G networks will inevitably involve 2G, 3G, and 4G terminals and services. Therefore, the 5G core network must be fully converged to support all RATs. At the same time, some applications will heavily depend on voice and messaging services, requiring fully converged voice networks as well as efficient voice encoding and decoding capabilities.



3.2.1.4 Edge Computing and Industry Applications

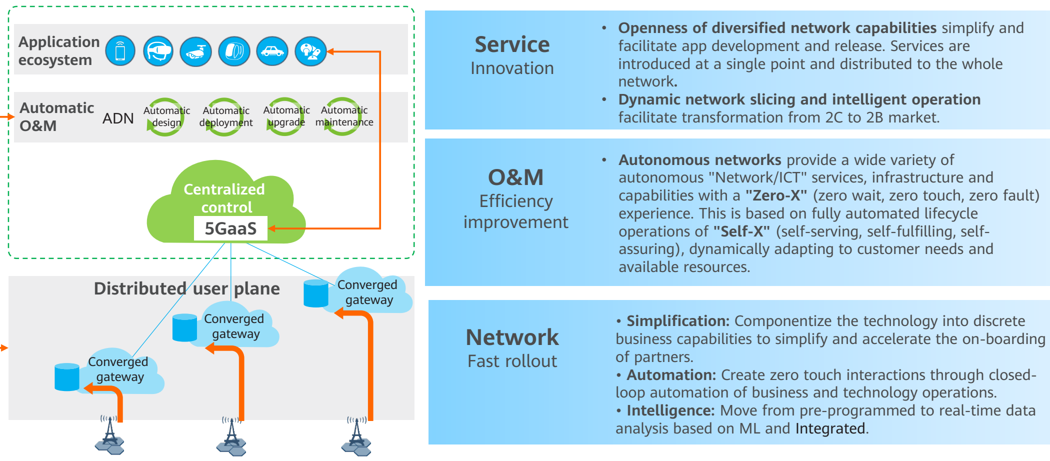
Different industries, and even different applications within an industry, have varied requirements for 5G connectivity. For instance, the industrial Internet and campus video surveillance focus more on the uplink bandwidth (eMBB) and camera deployment density (mMTC), while industrial control requires the connection control capability (URLLC) with deterministic latency. Another example is the difference in latency requirements between cloud gaming (less than 20 ms) and live event broadcasting (less than 800 ms, including video collection from cameras, editing, and playback).

Deterministic networks refer to network performance indicators, such as bandwidth, rate, jitter, latency, and availability, as well as security isolation requirements. Deterministic connectivity plays a vital role in specific production and life scenarios. For example, in smart healthcare, during pre-hospital emergencies, data upload requires an uplink bandwidth of at least 30 Mbps and a network latency of less than 50 ms. And when it comes to WAN deployment, operators' WANs are often reused to provide connectivity with different capabilities. In LAN deployment, WANs are also reused to lower costs. Plus, industries may consider building their own local/private 5G networks for security and isolation.

MEC is a bridge between network connectivity and industry applications. As such, it needs to both simplify the rollout, deployment, and management of third-party industry applications as well as facilitate the collaboration between 5G connectivity and industry applications, thereby enhancing user experience.

3.2.1.5 Full Automation and O&M

Network capabilities will become important resources and require automation. Network slicing is one of the key value-adds of the 5G core network. It requires the entire network to be highly automated in terms of deployment, provisioning, and O&M. Traditionally, operators use a process based on work orders, which prevents efficient service development. Instead, operators should use portals to allow 2B customers a higher degree of autonomy. This way, each industry customer will be able to customize and purchase the slices they require from an online store, and then manage the slice networks through one-click provisioning and remote O&M. For example, media companies will not need to route cables in advance to live broadcast major events. They will simply purchase slices for the specific time and location on the operator's website. They will then be able to conduct interviews and shoot video onsite, later efficiently transmitting video over the 5G network to the broadcasting system.



3-2-2 Key Features of the Future Core Network

3.2.2.1 Continuously Improvement in Reliability and Service Stability

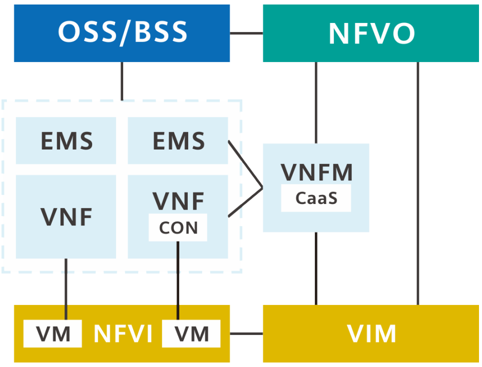
Telecom-level services pose higher requirements on the reliability of DCs because the NFV system has more service nodes than the traditional one, increasing potential fault points and risks. In response, IT design needs to build multi-level DR and backup systems for the VNF system.

- IT-level DR: A single DC supports hardware multipathing and multiple availability zones (AZs), improving the reliability of a single DC. Each AZ is equipped with independent power supply and network. When an AZ in a DC is faulty, services can be quickly switched to another AZ.

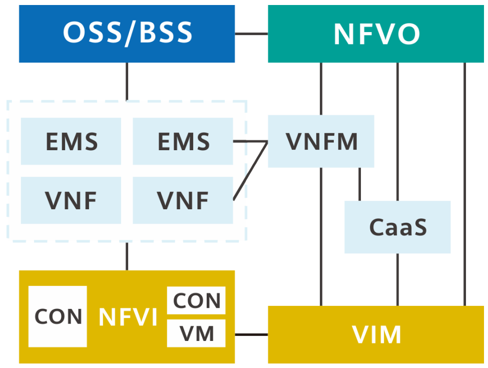
- NE-level DR: Multi-path architecture improves VNF reliability by coping with multi-point faults. The stateless design decouples status data from service processing. Even if multiple VMs in the system become faulty simultaneously, services can be quickly switched to the remaining VMs to cope with multi-server faults. In addition, A/B testing is performed to provide agile service release and reduce commercial risks on the live network.
- Network-level DR: Cross-DC NE pools are used to improve network reliability. When a VNF in a single DC is faulty, services can be quickly switched to a VNF in another DC, ensuring service availability. Services and multiple DCs are connected to reach telecom-level reliability.

3.2.2.2 Container and Elastic Network

The service-oriented architecture of the 5G core network is based on microservices, giving its services finer granularity. The container technology is a cloud-based NFV platform capability required for flexible service orchestration and on-demand function invoking. The current NFV technical standards are based on Hypervisor and predominantly support VM deployment. Therefore, the VM container solution can be used at the initial phase of 5G core network deployment. Considering the performance requirements of 5G core network VNFs, containers are generally embedded in the VNFs provided by vendors. As the Container as a Service (CaaS) function is embedded in the VNFM, the NFVO is unaware of containers. The advantage of this solution is that the existing ETSI NFV architecture can be directly used without reconstruction. Containers share the guest OS kernel of the VM to which they belong, and do not need to obtain the management permission of the host OS. In addition, VMs ensure resource isolation and security, which is ideal for large-scale and task-intensive networks such as the core network.



Once the container platform is running stably, it is necessary to expose the containers in the vendor's VNF. This allows operators to gradually standardize the container application framework and optimize the 5G core network microservice architecture solution. Based on the VM container solution, the independently deployed CaaS platform is also introduced to manage and schedule container resources as well as provide centralized container invoking interfaces for external systems. Based on the CaaS platform, the VNF consists of containers, performing resource management, orchestration, and scheduling on a per-container basis. Containers can be deployed in VM-based or bare-metal mode. This helps gradually change the lifecycle MANO unit from VM to container, achieving low performance loss, fast startup, as well as the agile development and deployment of containers.



The evolution of the 5G core network will continue to break the boundaries of NEs, deconstruct network functions into services, and perform scheduling, orchestration, and resource configuration based on services. At the virtualization resource layer, software-based open interfaces can be provided to organize various network services, building a centralized NFV application ecosystem. In the future, infrastructure will resemble cloud architecture, where the CaaS platform will manage container services, the IaaS platform will provide VM or bare-metal resources for the CaaS, and both of them will connect to the universal cloud architecture. CaaS standards are quickly maturing. This will facilitate agile development and deployment, enabling the quick response to frequent service iteration and changes. It will also allow systems to draw on the advantages of mature IT solutions to promote in-depth ICT convergence, thereby contributing the growth of various industries.

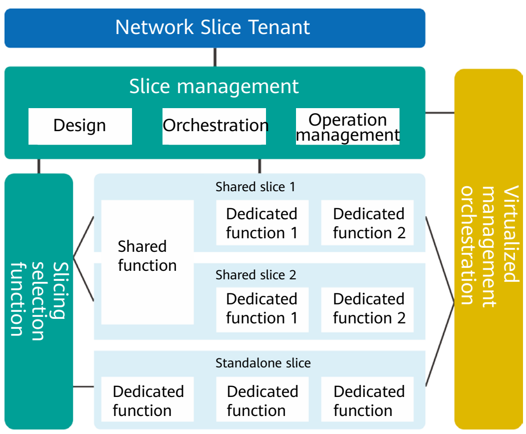
3.2.2.3 Slice Deployment and Flexibility

Network slicing requires key operation capabilities, including on-demand design, automatic deployment, SLA assurance, intelligent analysis and prediction, security isolation, and tenant management and control, to guide vertical industries to select slices for application innovation and new operation modes.

The initial phase of slice operation includes the construction of multi-vendor management and network functions virtualization orchestrator (NFVO). The cloud platform can first roll out 5G core network sub-slices based on tenants' key requirements to implement fast deployment of network services (NSs) and service configuration and activation. Layered SLA indicators and cross-layer root cause locating can also be used to ensure O&M. With the gradual improvement of cloud platform slice O&M functions and enhanced architecture standards oriented to vertical industries, tenants have clearer requirements on networking, the architecture, and resource usage during slice operation. As such, an information infrastructure operation mode with network slicing as the unit will be formed, fully utilizing the agile services provided by the 5G core network and cloud-based NFV platform.

A slice is essentially a logical private network provided by operators for tenants, with customized networks, computing, and storage resource nodes deployed on it. A complete slice may contain network functions both provided by operators and customized by tenants. Therefore, information must be integrated, extracted, and centrally presented from different layers and network domains to help tenants view, manage, control, and orchestrate slices. Based on the traditional operator view, the tenant O&M view needs to be provided for O&M personnel to enable secondary customization of the operator O&M service-level, network-level, NE-level, and user terminal views, including key service KPIs, terminal access information, package configuration, and notification of key events (such as success rates, faults, quotas, and fees).

A network slice constitutes an E2E logical network, and one or more network services are flexibly provided based on slice requirements. Therefore, interface openness is also critical for slices. As shown in the following figure, interface openness is related to requirements, management, deployment, and orchestration.



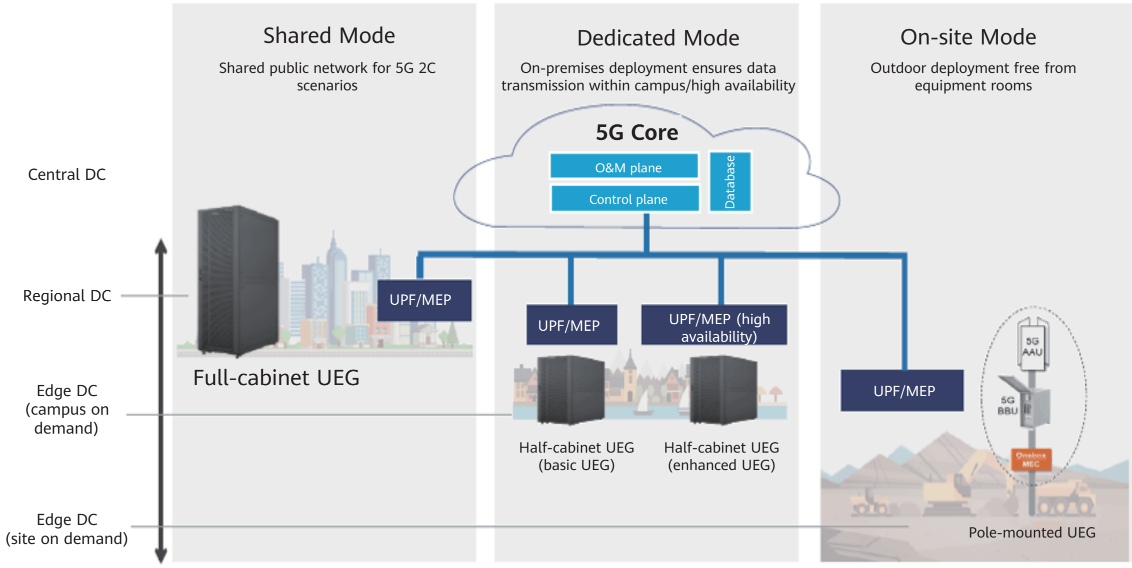
3.2.2.4 Diverse MEC and Automatic Deployment

Industry applications pose high requirements on data security and self-management. Industry customers require an independent 5G network that includes a RAN, bearer network, and a core network. A subscriber uses a dedicated card to access the network, and service authentication is performed locally. In this case, services on the private network are separate from the public network. This mode of deployment is applicable to specific services such as industrial Internet.

In addition, some services require exclusive resources and construction costs to be balanced. For example, data needs to be transmitted within campus. Therefore, most campuses use the partial sharing mode to deploy independent core network user planes, while their RANs, bearer networks, and core network control planes share resources with the public network.

In this case, MEC is the optimal choice to help operators improve subscriber loyalty. The deployment position of MEC depends on the network mode (sharing/exclusive) and service's requirements on latency. City-level MEC is equipped with the best equipment rooms. In some 2C scenarios with low requirements on latency, such as HD and VR videos, full-cabinet UEG is recommended on the user planes of 5G public networks. In an enterprise campus, MEC is deployed to ensure that data is transmitted within the campus and meet the latency requirements of services such as industrial visual inspection and industrial control. Equipment rooms vary with campuses. As such, the MEC deployment mode needs to be aligned with that of IT devices.

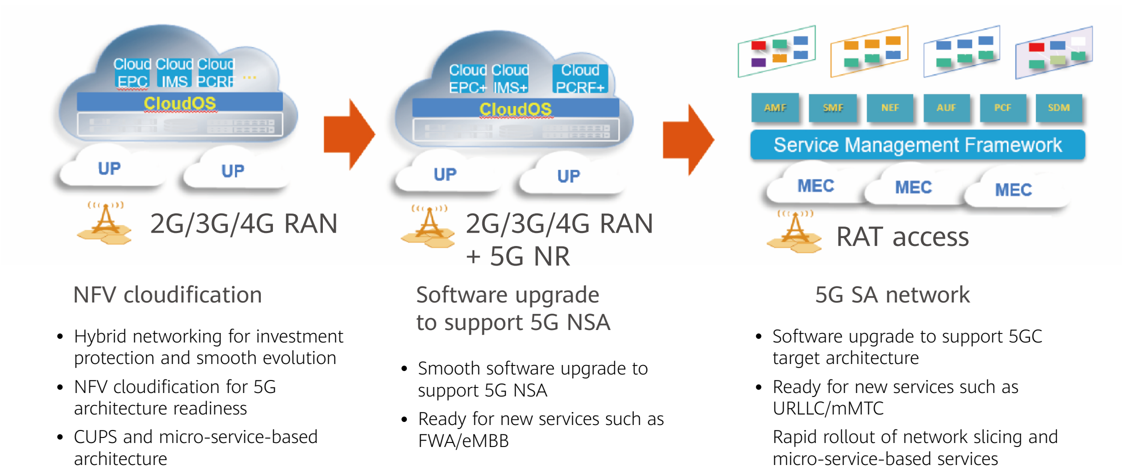
Onsite UEG is deployed at the extreme edge, which is applicable to services that have strict requirements on latency and deployment conditions. For example, the lightweight pole-mounted UEG, which is free from cables or air conditioners, can be directly and easily installed on the pole of a base station in emergency communications and live broadcasts of sports events. All of these models support pre-installation, fast deployment, lightweight deployment, remote centralized O&M, and resource redundancy and high reliability solutions.



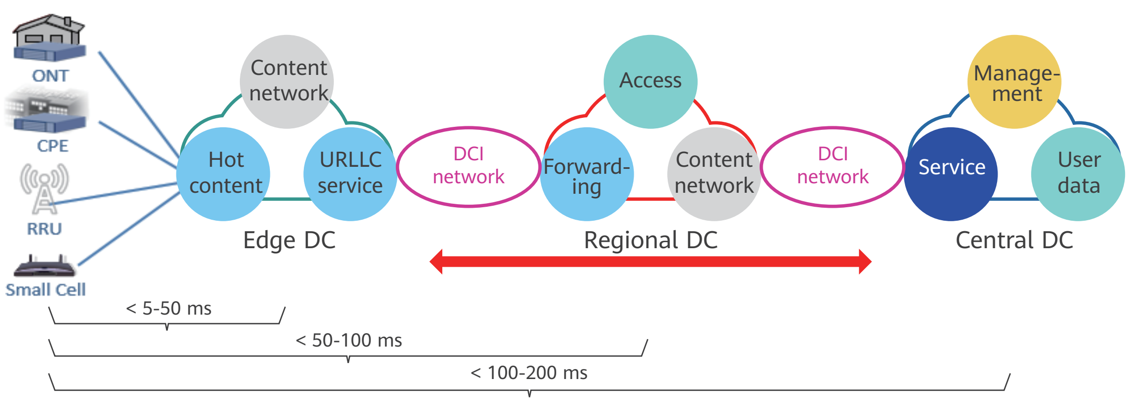
The massive and high-density deployment and flexibility of edge services will inevitably lead to a drastic increase in the network OPEX. Automatic operations such as remote O&M and one-click deployment should be performed to reduce the need for manual intervention. In this way, plug-and-play is achieved in MEC edge applications, and the network can automatically adjust based on service requirements. In addition, hierarchical O&M at the central and edge layers enables operators to centrally manage the edge network and cloud infrastructure and enterprises only to locally manage their applications, simplifying edge O&M.

3-2-3 Core Network Planning and Deployment

Core network construction must be carried out in order to gradually complete cloudification and transform network architectures. Operators currently implement construction through the following steps. First, cloud-based reconstruction is strengthened, and software is upgraded to support 5G NSA and SA networks. Moreover, new functions and features such as 5G FWA, eMBB, URLLC, and mMTC are gradually adopted in actual applications.



In terms of architecture and site selection, latency requirements vary with different services, according to 3GPP and ETSI. The following figure shows the relationship between NE types and DC deployment.

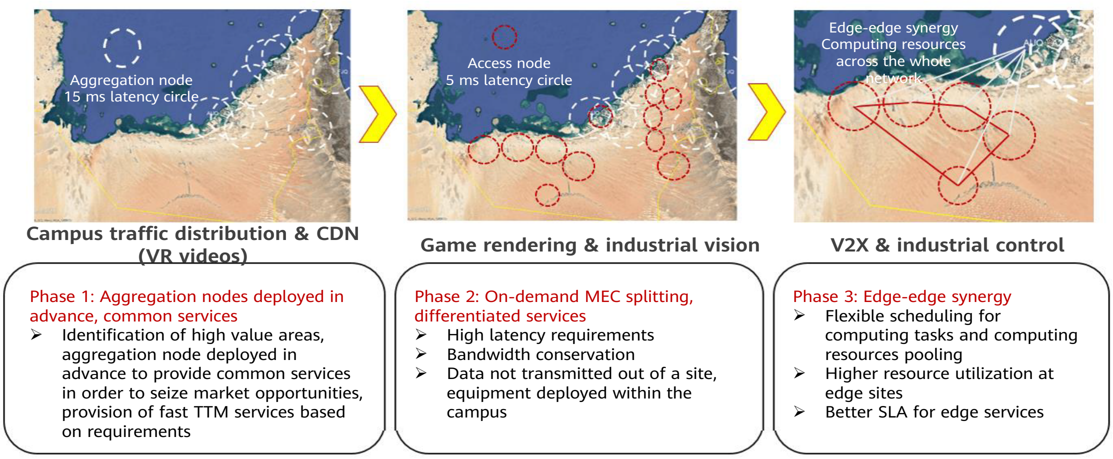


- Central DC: Management and registration NEs are used to manage user registration, which have low requirements on latency (100 ms to 200 ms).

- Regional DC: Forwarding and access NEs process MBB traffic with the latency of 50 ms to 100 ms.

- Edge DC: With flexible deployment, latency requirements range from 5 to 50 ms. As low-latency services further increase, edge DC will be the focus of network development to meet the coverage requirements of high-value areas.

On top of that, both accessibility and mobility need to be ensured for new MEC services. The following figure shows the deployment of edge DCs to meet service requirements in 2025.



3-3 Fixed Network

To gain a competitive edge in the rapidly developing and increasingly fierce telecom industry, operators need to innovate services and develop bearer networks with greater intelligence, simpler architecture, and a more flexible and scalable networking mode. Moreover, the competitive pressure from multi-service bearer networks means it is imperative that we adopt a unified access mode with optimal per-bit cost.

In addition, with the emergence of new service applications, especially high-speed, large-capacity, and low-latency service applications such as 4K and AR/VR, new technical requirements are raised for bearer networks. In general, future bearer networks have the following characteristics:

- Fast and efficient access and transmission of multiple services, such as 2C (base station backhaul services), 2B (enterprise services), and 2H (home broadband services)

- SLA requirements vary with different services. An efficient bearer network requires large bandwidth, low latency, and low packet loss to deliver optimal 4K/AR/VR video service experience.

- The simplified IP+optical network architecture supports high-speed, high-bandwidth, and long-distance transmission with agile, flexible, multi-granularity, and multi-SLA service bearing capabilities, ensuring high reliability.

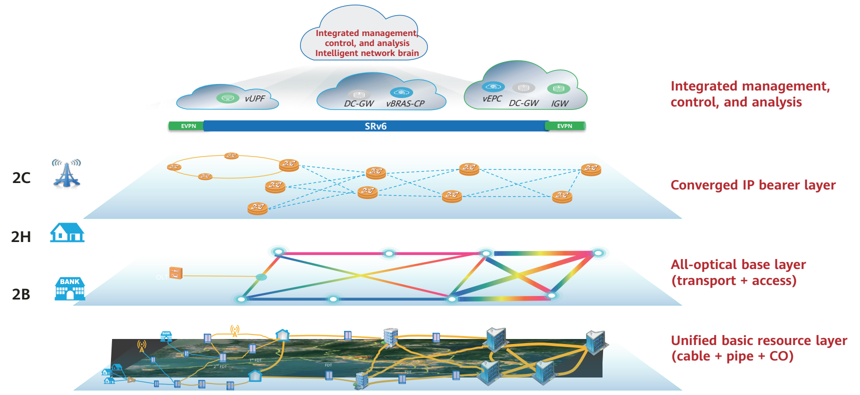
- The unified basic resource layer, including central offices (COs), pipes, optical cables, and fiber distribution points, realizes integrated access of 2B/2C/2H services and supports the efficient networking structure of IP+optical equipment networks.

- Cloud DCs are interconnected and hierarchically deployed at the edge for fast access to the cloud and better cloud experience.
- A unified intelligent center will be a must for the future bearer network to implement SDN-based service provisioning, management, control, and O&M.

3-3-1 Target Architecture of the Bearer Network

The following figure shows the target bearer network architecture in the 5G and cloud era based on the preceding characteristics of future bearer networks and the successful experience of most leading carriers worldwide.

Future-oriented target bearer network architecture

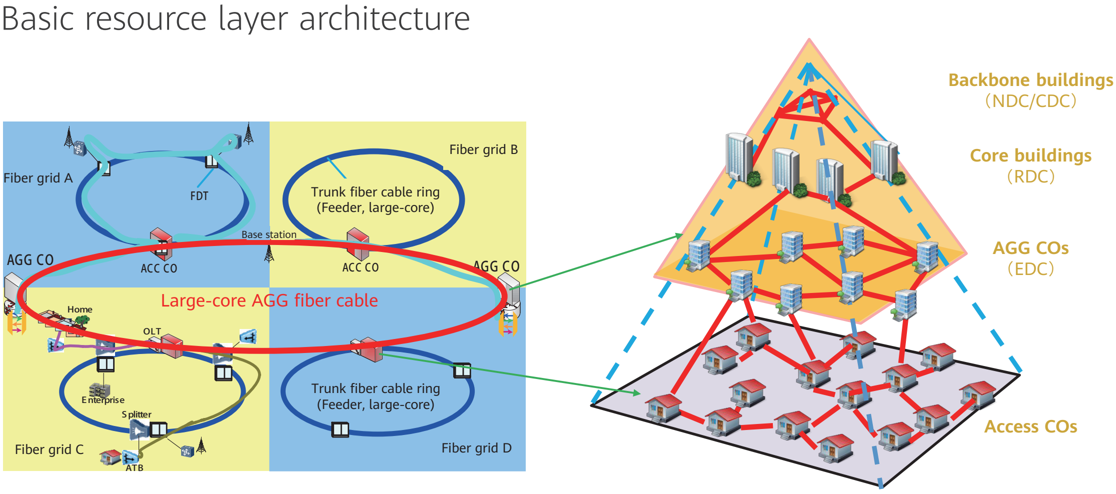


The architecture consists of the unified basic resource layer, all-optical base layer, converged IP bearer layer, and integrated management/control/analysis layer.

3.3.1.1 Unified Basic Resource Layer

The unified basic resource layer is composed of backbone optical cables, backbone and metro equipment rooms, metro optical networks, and integrated service access areas. It provides unified basic resources for the optical network layer. To achieve this, core backbone equipment rooms should be deployed with consideration towards the footprint, power supply, load bearing, routing of outgoing optical cables, and service security backup. Furthermore, backbone optical cables must be laid out in ring topologies, and meshed between key service nodes (such as P nodes). A mesh structure is recommended for the optical cable network at the metro core layer, and ring topology is the main configuration for the metro aggregation layer, alongside mesh topology, which is also used. At the access layer, the integrated access area of base station, enterprise, and home broadband services should be designed from the perspective of CO equipment rooms, pipes, and optical cables. In this way, flexible, fast, efficient, and scalable service access can be provided to achieve optimal TCO.

Basic resource layer architecture



(a) Full Service Fiber Grid (b) Unified Fundamental Resource

While a large number of subscribers access the network, the cost of equipment on the CO side and the user side accounts for only a small proportion of the TCO, while the cost of infrastructure networks, such as CO, pipes, and optical fibers, continues to take up a larger percentage of the TCO. One example is home broadband services. With the development of 4K/AR/VR videos and their requirement for high-bandwidth and high-quality networking, we are in urgent need of PON-based FTTH access. The optical distribution network (ODN) lies at the end of the optical network covered by FTTH. The ODN takes up over 80% of the investment in scenarios where ROW is hard to obtain or the OSP is costly.

On top of this, the FMC network needs to access the basic resource network for integrated construction.

- Full-Service Fiber Grid, can meet the access requirements of base station, enterprise private lines, and home broadband services. An urban area can be divided into multiple areas based on the administrative and geographical division, road network structure, and customer distribution, for independent service access and convergence. Each integrated service access area should include one or two ACC COs, one trunk fiber cable ring, and several FDTs.

- ACC CO, also called multi-service node. Generally, OLTs, IP RANs, and OTNs are deployed to provide access and convergence for home broadband and enterprise services. In principle, one or two access equipment rooms should be set for each integrated service access area.

- Trunk Fiber Cable Ring, lies between a service aggregation node and an FAT. It is used for the centralized deployment of optical cables on public routes between a service aggregation node and physical access nodes, saving pipe resources and reducing construction costs.

- Fiber distribution point, refers to an passive optical network node that provides fiber core grooming and fiber distribution functions and is deployed on an optical cable route to achieve fast and convenient access of customer services. In general, the fiber distribution terminal (FDT) is used outdoors, and the optical distribution frame (ODF) is used indoors. The fiber distribution point should be placed close to the target user distribution center and oriented to specific coverage objects.

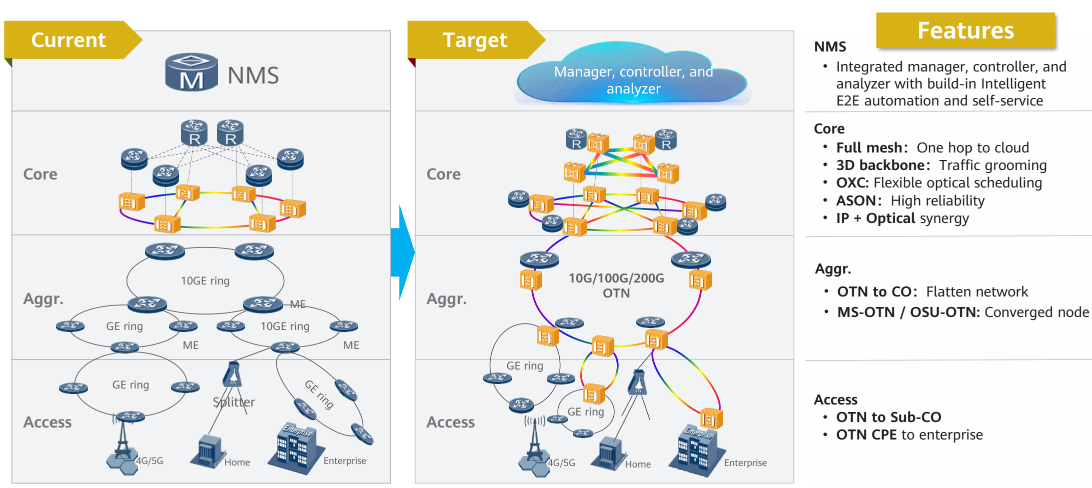
- The essence of the Full-Service Fiber Grid to consider the grid-based planning, construction and management of basic resource network. The size of a fiber grid depends on the user density of 2B, 2C, and 2H services in the area, ensuring optimal cable cost for each user. The multi-service node, namely the ACC CO, converges multiple services on the network. The trunk fiber cable rings and FDTs extend the sharing and construction of optical cable resources for multi-service access. The end coverage fiber cables are then connected flexibly and expanded efficiently based on real-world situations to minimize service provisioning time and ensure investments are made effective.

Deployment of full-service fiber grids can be carried out in high-value areas first (that is, densely populated urban areas, developed towns, industrial campuses, and commercial buildings). For common metro, suburban, and rural areas, the deployment can be carried out and expanded step by step according to the service progress (penetration rate).

3.3.1.2 All-Optical Base Layer

Transport Target Network

The transport target network consists of backbone and metro OTNs. It builds an efficient transport layer between backbone and metro COs, featuring high speed (single-wavelength: 200 Gbps to 1 Tbps), large capacity (SuperC: 120 wavelengths), long distance, and flexible mesh grooming. The OTN can be deployed to a network layer (AGG, ACC, or SubCo) in accordance with the deployment pace of DCs at the edge and vBNG/vCPE. OTN access is an optimal choice for large-granularity enterprise services and wholesale services. Furthermore, SDN should be enabled to ensure service provisioning, management, TE, as well as protection and restoration for optical networks. At the metro aggregation layer or an upper layer, the optical network should be planned together with the IP network to ensure efficient and high-quality service transportation.



Core layer: OTN DCI is constructed on a full-mesh physical topology to support one-hop connection between cloud DCs. The 3D backbone is constructed on hotspot core nodes, and all-optical cross-connect (OXC) is used to implement efficient and flexible service scheduling of optical-layer wavelength channels. Furthermore, 99.999% reliability and fast protection switching at the optical layer are implemented based on ASON 2.0.

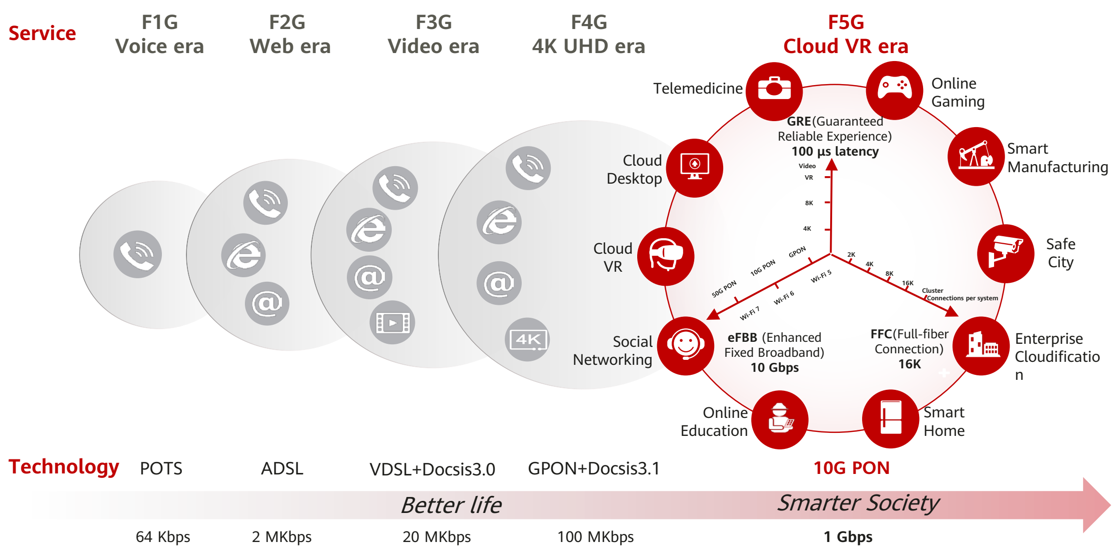
Aggregation layer: OTN is gradually moved to the CO equipment room according to the service volume to build a flattened network structure, enabling cloud DCs to move to a hierarchical location on the edge, and southbound and northbound services to expand flexibly. In addition, MS-OTN and OSU-OTN are used to form a converged enterprise access and bearer network featuring multi-switching mode, flexible multi-granularity, and high-SLA.

Access layer: With the development of comprehensive services, the OTN is gradually moved to the ACC CO (multi-service node/ Sub-CO) to implement unified bearing of 2B/2C/2H services in the full-service fiber grid. The OTN CPE is used to meet the access requirements of high-level enterprise customers.

F5G-Oriented Next-Generation Access Network

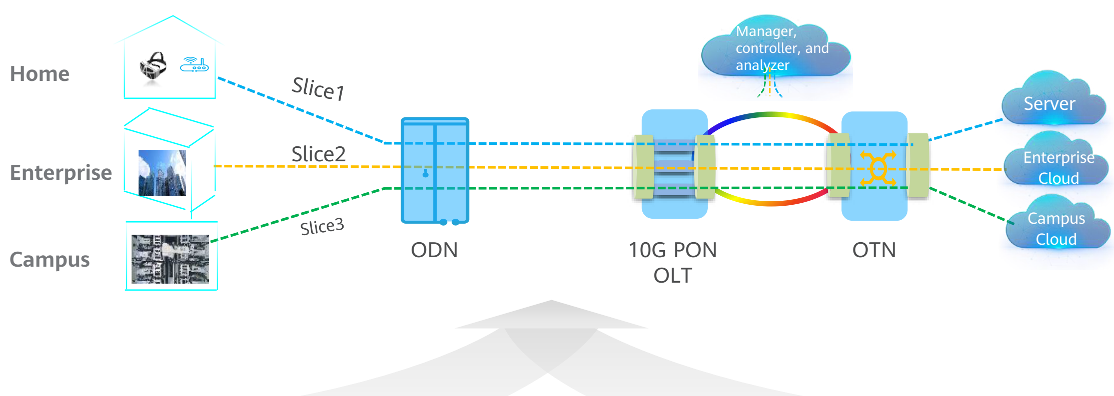
Rapid development and iteration of network technologies create a large number of new products and applications in the network industry. Recently, rapid advances in technologies such as GPON, WDM, and OTN, as well as the explosive growth of 4K/8K UHD videos and cloud VR/AR content and applications indicate that the access network has entered a F5G gigabit era.

F5G evolution



F5G all-optical networks feature large bandwidth, low latency, and high reliability. They include gigabit broadband access networks based on 10G PON as well as Wi-Fi 6 and optical transmission and switching networks based on 200G/400G single carrier.

Fixed access target network architecture



New services

- 2H: Cloud VR + gaming broadband
- 2B: Enterprise cloud migration + video upload
- 2C: All-optical campus + industrial automation

New capabilities

- 10G PON + slicing + built-in Intelligent Digital ODN + E2E pre-connection
- Wi-Fi 6 + omnidirectional antenna + FTTR

New experience

- Intelligent + big data for intelligent O&M
- Wi-Fi visualization and optimization
- Accurate identification of PON optical path faults

The features of the fixed access target network are as follows:

- The network provides integrated bearer network for 2H, 2B, and 2C services, such as 4K/8K TV, cloud VR, commercial broadband, enterprise cloudification, video upload, all-optical campus, and industrial PON (industrial automation). Moreover, it delivers high SLA and efficient deployment.
- 10G PON-ready OLT platform supports large-scale coverage of class D.
- In terms of 2H services, Fiber to the Room (FTTR), Wi-Fi 6, dual-band and omnidirectional antennas are adopted to provide high-quality coverage and experience at home.
- E2E network slicing support service-level scheduling and SLA assurance.
- Digital ODN and pre-connection capabilities are available throughout, making passive resources visible, manageable, and controllable, shortening TTM and simplifying deployment.

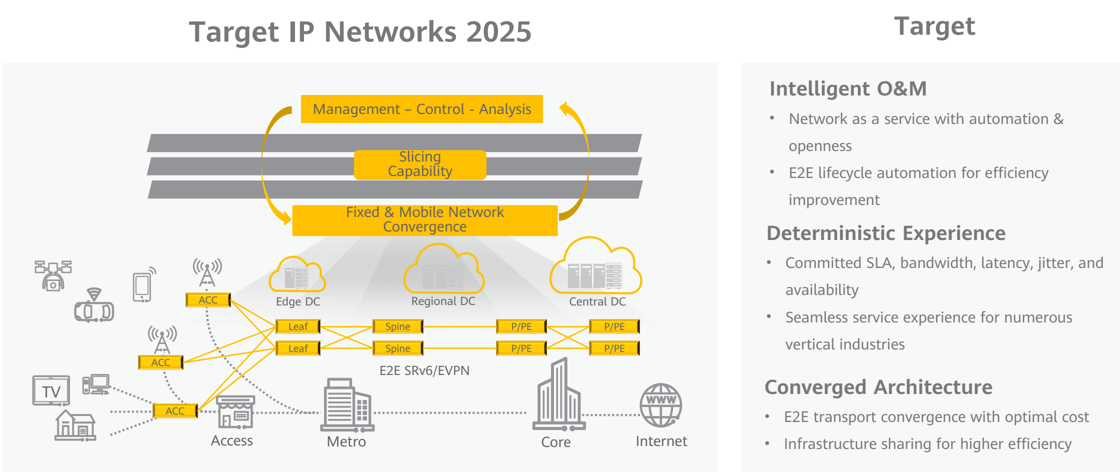
Intelligent O&M supports Wi-Fi visualization and optimization, as well as the precise identification of PON faults.

3.3.1.3 Converged IP Bearer Layer

Intelligent IP Bearer Network

The IP bearer layer uses an E2E Layer 3 seamless architecture based on E2E SRv6 and EVPN to provide clear, simplified, and flexible access and transmission of multiple services. It adopts FlexE to isolate resources to match different service scenarios. The RAN layer uses 10GE, 50GE, or 100GE IP networking, and supports 2G, 3G, 4G, and 5G on one bearer network and smooth evolution. At the aggregation, core, and backbone layers, 100GE, 200GE, or 400GE networking can be applied. At the protocol layer, the unified underlay and overlay architectures of SRv6 or EVPN can be used to implement VPNs in various scenarios.

Target IP bearer network architecture



The future-oriented IP network 2025 has the following features:

- 5G- and cloud-based integrated bearer network ensures efficient MBB backhaul and hierarchical distributed cloud DCs, and provides integrated access and bearing capabilities for 2C, 2B, and 2H services.

- E2E soft and hard slicing based on FlexE and EVPN implements SLA-based security isolation of various services, meeting the backhaul requirements in 2C, 2B, and 2H scenarios.

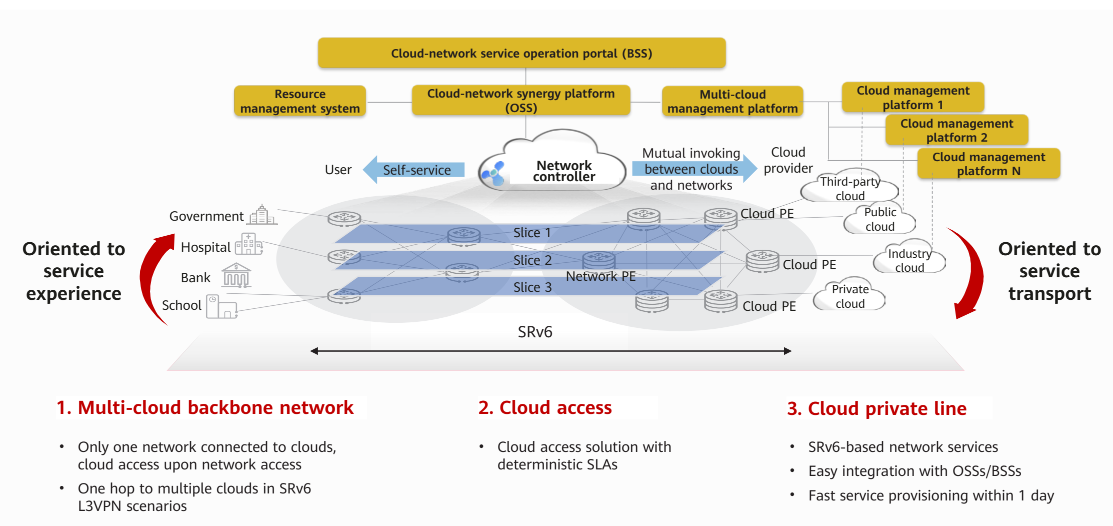
- sRv6 and EVPN simplify Layer 2 protocols to build an E2E unified overlay-underlay combined architecture for quickly building efficient direct circuits.

- iFIT enables segment-by-segment, E2E detection of network KPIs, such as packet loss and latency, as well as real-time detection of link status changes, effectively ensuring deterministic service experience of the network.

Intelligent Cloud-Network

The intelligent cloud-network solution achieves automated and intelligent cloud-network O&M based on intelligent IP networks. It supports quick network adjustment upon cloud changes and provides service network capabilities featuring cloud-network-security integration.

Overall technical architecture of the intelligent cloud-network



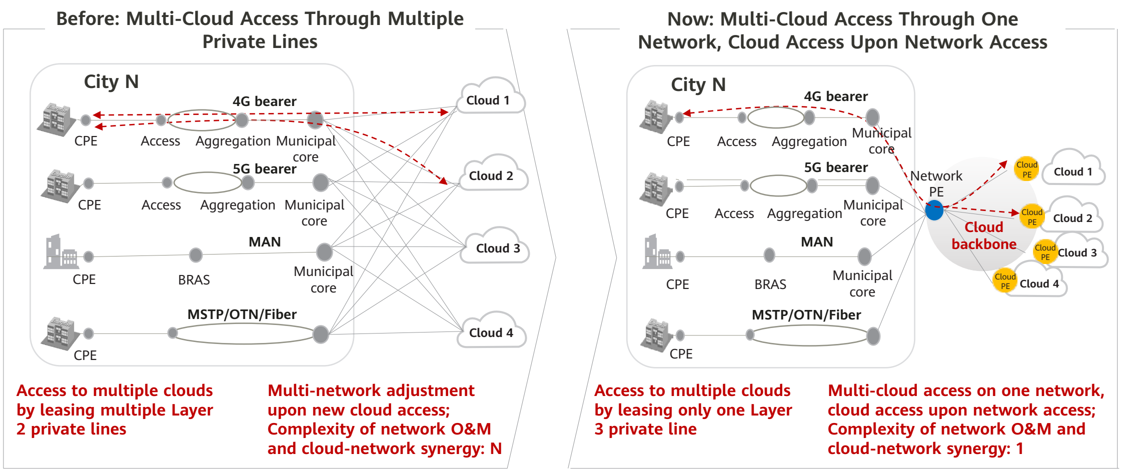
Cloud Backbone Network

Given the popularity of multi-cloud and hybrid-cloud deployments, flexible access to and scheduling of applications both on and across different clouds has become a major demand for enterprises. As such, bearer networks are required to provide on-demand cloud connections and agile cloud interoperability to enable dynamic and on-demand resource provisioning on clouds.

The traditional solution of Layer 2 point-to-point private lines is no longer suitable for a number of reasons. First, enterprises have to rent multiple cloud private lines based on where each cloud is deployed. Second, enterprises must manually switch between cloud applications or build internal networks to schedule the access to different applications. All of this ends up compromising service agility and multi-cloud access experience, and adds to the complexity of cloud-network orchestration.

The lack of a fully connected cloud backbone network is also a significant issue. When multiple networks require access to multiple clouds and a new cloud data center needs to be created, each network and cloud needs to be connected. This translates into complex connections, segment-by-segment deployment, and extended service TTM.

Technical solution of a cloud backbone network



The intelligent cloud-network solution, in contrast, delivers interconnection of multiple clouds and networks through the use of a cloud backbone network. Cloud-network connections are pre-deployed, achieving simultaneous cloud and network access, while SRv6 L3VPN technology enables flexible access to multiple clouds over a single connection, in addition to agile service provisioning.

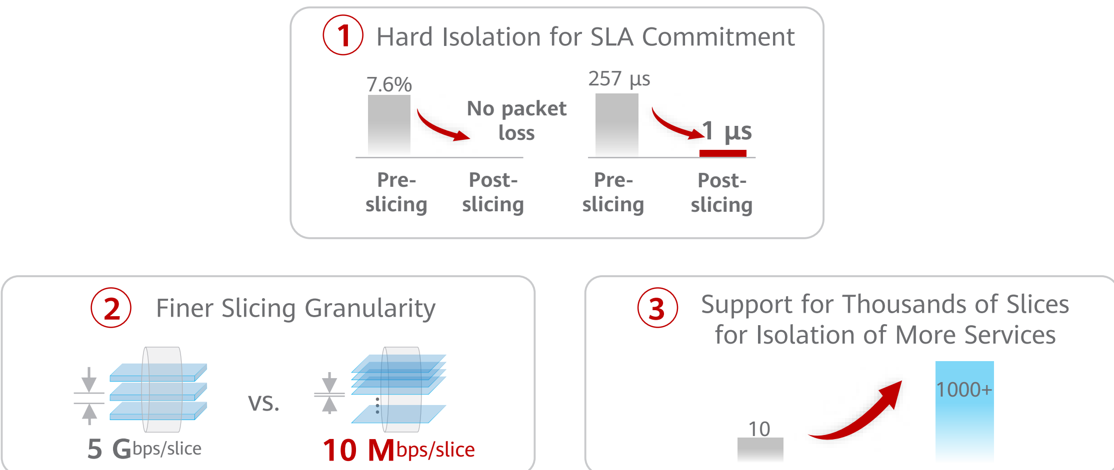
- Intelligent cloud backbone network: Cloud PEs are deployed on clouds and pre-connected to clouds through the cloud-network orchestrator, reducing the resource planning and deployment time required to set up cloud and network connections. Meanwhile, network PEs implement unified access of multiple networks, aggregating the cloud private lines of different networks and access modes to achieve simultaneous cloud and network access as well as multi-cloud reachability. SRv6 BSID technology enables the pre-deployment of SLA-guaranteed cloud service paths between cloud and network PEs. As such, qualified service paths can be pre-deployed on the cloud backbone network based on service requirements (for example, bandwidth and latency) and then provided as network services using SRv6 BSIDs. As a result, the service paths can be flexibly invoked by a network controller through standard interfaces to provide connections for applications.

- One-hop cloud access with SRv6 L3VPN: SRv6 reverses the traditional mode of multi-segment splicing when cloud private lines span different domains, facilitating cross-domain access between various networks and implementing one-hop access to clouds. Layer 3 technologies such as L3VPN and EVPN L3VPN are leveraged to support cloud private lines and inter-cloud connections, with Layer 3 network routing capabilities used to implement one-point access to enterprise sites and flexible access to any cloud resource pool. In addition, SRv6 Policy provides differentiated SLA capabilities and selects paths based on various SLA requirements (such as bandwidth and latency) to deliver differentiated SLA assurance for numerous cloud applications.

Cloud Access Network

In order to ensure differentiated competitiveness in the cloud era, industries have high service experience and isolation requirements. In this regard, operators can use network slicing to provide the required resources for various services, thereby delivering a differentiated service quality. A unified cloud access network can provide fine-grained, multi-layer, accurate, fast, and stable network slicing solutions capable of ensuring cloud-network service experience.

Highlights of the network slicing solution



- Hard slice isolation for SLA commitment

Network slicing requires exclusive resources to be reserved for different services on the forwarding plane of network devices. On the IP bearer network, one physical port is split into different FlexE interfaces or sub-interfaces to guarantee deterministic latency and bandwidth for high-value services based on IP statistical multiplexing. The SLA of slice-carried services remains guaranteed, regardless of a burst of other services.

- Fine-grained slicing

While FlexE is capable of 5 Gbps slicing, this granularity is unable to match the bandwidth model of enterprise private lines. Instead, the innovative FlexE sub-interface technology can deliver a minimum slicing granularity of 10 Mbps, which is easily capable of providing SLA assurance for any-bandwidth private line services.

- Thousands of slices for isolation of more services

Despite the many slicing control plane solutions, exclusive control plane resources must be allocated to slicing interfaces regardless of whether slicing is implemented based on affinity attributes, multi-topology, or Flex-Algo. These resources could be different IP addresses, multiple IGP neighbor relationships, and specific segment IDs for individual slicing interfaces. Traditional solutions heavily consume control plane resources, limiting the slice scale and application scenarios.

3.3.1.4 Integrated Management/Control/Analysis Layer

With the continuous advancement of the Internet and the advent of the cloud era, new business models are emerging, and enterprises are favoring on-cloud operations and digitalization. As a necessary facilitator of digital transformation in various industries, the telecom industry faces massive business opportunities as well as additional challenges.

Cloud enablement results in both great flexibility and uncertainty regarding the application of services, but a significant gap remains between operators' infrastructure networks and various applications.

- A large number of legacy networks coexist with new SDN and NFV networks, causing severe resource isolation which makes it difficult and costly to adapt to new services. Enterprise private lines, in particular, face such challenges as extended service TTM, slow customer responses, and rigid data plans.

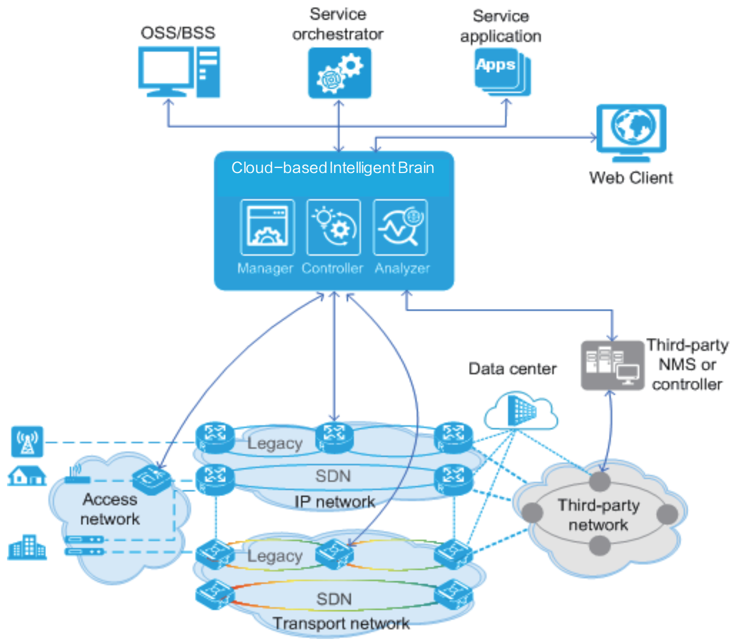
- As enterprises migrate applications to clouds and new services develop (such as telecom cloud), the traffic passing through operators' networks becomes more dynamic and unpredictable. In this context, traditional network planning and optimization solutions are insufficient, placing SLA assurance at risk.

- The growing network scale and complexity only lead to more complex O&M. Operators urgently require deployment automation measures to reduce O&M skill requirements and effectively control OPEX in the long term.

An intelligent mediation layer or, more specifically, a new management, control, and maintenance system must be set up between service applications and infrastructure networks. The system must be able to abstract network resources and capabilities, automatically schedule them in a centralized manner, and allow application developers to conveniently apply and flexibly assemble various network capabilities in order to continuously and quickly innovate services and applications.

Intelligent network brain diagram

As illustrated in the figure, the future-oriented cloud-based intelligent brain integrates three functional modules: network management, service control, and network analysis. Consequently, it can implement core functions such as network resource pooling, network connection automation and self-optimization, and O&M automation.



Management and control based on the cloud network:

- Downwards, the cloud-based intelligent brain manages and controls IP, transport, and access devices, supports unified management and control of SDN and legacy networks, and implements automation of single-domain, multi-domain, and multi-layer services.

- Upwards, the cloud-based intelligent brain opens capabilities to support interconnection and integration with OSSs, BSSs, and service orchestrators, thereby achieving quick customization of the application layer.

- The cloud-based intelligent brain connects to a third-party management and control system to implement multi-vendor service orchestration and automation.

Cloud-based intelligent network analysis:

- The cloud-based intelligent brain collects and analyzes real-time network status and parameters and automatically generates service policies based on big data to implement proactive maintenance and closed-loop optimization.
- The cloud-based intelligent brain utilizes and machine learning to build an intelligent network that can automatically generate dynamic policies.

In summary, the future cloud-based intelligent network brain will centrally deploy the management, control, and intelligent analysis planes based on the cloud architecture (public or private cloud). These three planes will respectively implement: real-time management and monitoring of network-wide devices; intelligent control, distribution, and optimization of service routes; analysis and prediction of network status, faults, and alarms based on big data and intelligent algorithms to realize intelligent service provisioning and proactive O&M.

3-4 ADN(Autonomous Driving Network)

3-4-1 Definition and Reference Architecture of ADN

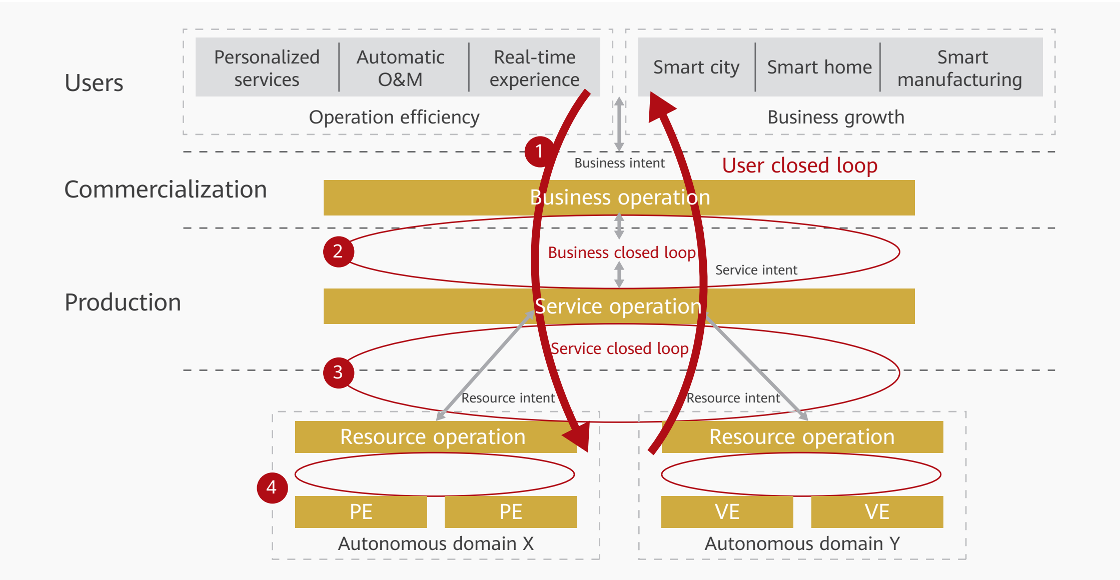
3.4.1.1 Definition

The autonomous driving network (ADN) is a telecom network system and service with capabilities of self-serving, self-fulfilling, and self-assuring. Relying on key technologies such as single-domain autonomy, multi-domain collaboration, and simplified infrastructure, intent-driven autonomous networks can implement full-lifecycle automation and intelligence of O&M and provide users with the optimal ICT service experience with zero wait, zero touch, and zero fault.

3.4.1.2 Reference Architecture

The TeleManagement Forum (TM Forum) collaborated with its 22 members, including British Telecom, China Mobile, China Unicom, Orange France, Vodafone, Huawei, Ericsson, and Nokia, to release the Autonomous Driving Network White Paper 2.0. The following figure depicts the blueprint for operators' digital transformation with a three-layer framework and four closed loops featuring single-domain autonomy and cross-domain collaboration. This also provides top-level architecture reference for multi-party practice and cooperation, enhancing efficient cooperation of industries.

TM Forum's ADN target architecture



ADN aims to deliver vertical industry users and customers with full-automatic innovative networks and ICT services featuring zero wait, zero touch, and zero fault. In addition, ADN needs to provide self-serving, self-fulfilling, and self-assuring telecom network infrastructure for internal users in planning, market, operation, and management departments. The ADN utilizes a simplified architecture that features autonomous domains and automatic services and network operation to achieve closed-loop control of digital services, optimal user experience, full-lifecycle operation automation and autonomy, as well as maximized resource efficiency. Currently, TM Forum is working with its members to build the ADN framework, which is composed of three layers and four closed loops. The three layers refer to common operation capabilities that support all scenarios and service requirements

Resource operation layer: It provides network resources and automated capabilities for a single autonomous domain.

Service operation layer: It provides IT services and network planning, design, rollout, provisioning, assurance, optimization, and operation for multiple autonomous domains.

Business operation layer: It provides AND services and operation capabilities for customers, ecosystems, and partners.

Four closed loops enable full-lifecycle interaction between layers.

User closed loop: The interaction between the three layers above and three closed loops supports user services. The three layers interact with each other through intent-driven simplified APIs.

Business closed loop: It implements the interaction between business and service operation. Traditional isolated services need to be developed into an ecosystem featuring on-demand, automatic, and collaborative services, enabling a closed loop of customers, services, and ecosystem operation. This usually requires multiple service providers worldwide to collaborate through business interfaces.

Service closed loop: It empowers the interaction between services, networks, and IT resource operation. The traditional project-centered customization operation mode needs to be upgraded to the data and knowledge-driven platform based on full-lifecycle automatic service operation. One key is to change the way of thinking from "construction and operation" to "design and operation." Additionally, it is essential to recognize the value of the knowledge as a service (KaaS) operation mode, which pushes specific knowledge to people on an appropriate occasion through desktops, laptops, or any mobile devices. In this context, automatic operation plays a key role in improving production efficiency and service agility.

Resource closed loop: It enables the interaction between networks based on autonomous domains and IT resource operation. The siloed NE layer needs to be integrated and transformed to ADN domain closed loops using the simplified network architecture. Abstraction helps reduce the network complexity, facilitating cross-domain autonomous collaboration and laying a foundation for the closed loop of network operation and collaborative production.

In addition, TM Forum further defines the high-level criteria of ADN L1 to L5, providing high-level references for the progressive development of the industry.

Five-level definition of TM Forum ADN

Autonomous Levels	L0: Manual operation & maintenance	L1: Assisted operation & maintenance	L2: Partial Autonomous Networks	L3: Conditional Autonomous Networks	L4: High Autonomous Networks	L4: Full Autonomous Networks
AN services (Zero X)	N/A	Individual AN case	Individual AN case	Select AN case	Select AN services	Any AN services
Execution	P	P/S	S	S	S	S
Awareness	P	P	P/S	S	S	S
Analysis/ Decision	P	P	P	P/S	S	S
Intent/ Experience	P	P	P	P	P/S	S

P: People S: System

- **L0: Manual O&M:** The system provides auxiliary monitoring capabilities. All dynamic tasks are executed manually.
- **L1 – Assisted O&M:** The system executes subtasks repeatedly based on pre-configurations to improve the execution efficiency.
- **L2 – Partial ADN:** The system implements closed-loop O&M for certain units in the system based on the intelligent model and specific external environment.
- **L3 - Conditional ADN:** Building on the capabilities of L2, the system senses environment changes in real time, and performs self-optimization and adjustment to implement intent-driven closed-loop management.
- **L4 – High ADN:** Extending the capabilities of L3, the system analyzes and makes decisions in a more complex multi-domain environment, and implements service- and customer-oriented predictive or proactive closed-loop autonomy.
- **L5 – Full ADN:** This layer is the ultimate goal of telecom network evolution. It has closed-loop autonomy in all scenarios across multiple services and domains within a full lifecycle

3-4-2 Autonomous Driving Network Features

Long-term exploration is required to achieve L5 ADN on telecom networks for the ultimate goal of self-evolution and self-optimization, and currently commercial use is uncertain. The achievement of the ultimate goal depends on a series of theoretical and technical breakthroughs, such as network self-cognition and knowledge and experience extraction. In consideration of the maturity of current technologies, it is recommended that L4 ADN be set as the phased target of future 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, the L4 ADN architecture has the following basic features

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

Most operator networks are manually operated and maintained by experts. If a network problem occurs, experts use OSSs, EMSs, or auxiliaries to perform manual analysis, decision-making, and closed-loop management. In the future, this will no longer be viable due to massive connections, increasing network scale, and on-demand cloud service provisioning. The following capabilities need to be improved:

- Predictive network problem awareness: Based on in-depth analysis of large volumes of network data, O&M personnel will proactively analyze network status, predict network faults and problems, and promptly provide RCA results. This helps resolve problems before customers complain.
- Autonomous network decision-making: Under certain conditions, for example, under the supervision of O&M personnel, the network will make

decisions independently for specific networking and service scenarios. This will greatly speed up the network's response to complex and uncertain problems and improve network efficiency.

- Automated network execution: Automated processes should replace inefficient and repetitive manual operations. O&M personnel operations will change from "in the Loop" to "on the Loop", and will focus more on process and rule management and design.

The digitalization of networks and expertise is the key to improving these capabilities.

Network digitalization: It is a prerequisite for network automation. With the digitalization, data can be collected to facilitate network status awareness and analytics as well as intelligent training and inference. This data could relate to network resources and services as well as real-time dynamics such as running status, faults, and logs. Though the resources and services of telecom networks have been undergoing digitalization in the past three decades, 5G evolution and intelligence make it imperative to expand and refurbish the incumbent digitalization models in order to accommodate new network services and scenarios. This involves incorporating the capability of describing the network history, current status, and future from the time and space dimensions, as well as increasing the availability and ensuring real-time performance of data during hierarchical perception and decision-making at the network and device layers.

Expertise digitalization: A magnitude of expert knowledge and experience, typically management rules and troubleshooting methods, have been created by operators and network device vendors after years of network O&M, but they are present in various intellectual assets, such as O&M manuals or specifications. These knowledge needs to be pooled into computers to build a centralized knowledge base that computers can comprehend and use. With the extra help of intelligence, computers can significantly automate network analytics, decision-making, and loop closure. Already some practices have proved effective, with methods and technologies such as knowledge graph applied on telecom networks to achieve intelligent identification of faults and loop closure for troubleshooting.

Intelligence is still in the infancy, and it takes time to mature and be commercially ready. At present, for telecom networks, intelligence improves the intelligent perception of networks or provides the most suitable solutions to improve the efficiency and quality of expert decision-making (L2/L3). However, advancements in basic theories and technologies such as network cognition capability and knowledge extraction will give intelligence more room in self-optimization and adjustment in specific network domains to achieve conditional closed-loop autonomy (L3) or predictive and proactive closed-loop autonomy (L4) for multiple networks. Efficient autonomous decision-making will phase out manual input.

(2). Simplified network infrastructure and intelligent NEs

Network infrastructure is becoming simplified. For one thing, networks and devices are simplified in four aspects:

- Lightweight equipment: Devices are going integrated, blade-shaped, high-density, and modular.

- Elastic implementation: Sites are operated on clouds, deployments are automated, connections and installations are factory-finished, and heterogeneous architectures are mutually compatible.
- Normalized protocol: Protocols are simplified and gradually unified.
- Agile architecture: Decoupled and flat architectures, multi-network integration, and resource pooling are being favored.

For another, network elements also need intelligent and digital capabilities, and more sensing components will be introduced to enhance the perception of resources, services, and ambient environments. The perception will be real-time and multi-dimensional, from service flows, resources, and topology status to O&M events and energy consumption. Additionally, network elements will come with intelligence and inference units. Higher-level intelligence of network elements will enable devices to be intelligent, supporting self-sensing, decision-making, and closed-loop management.

(3). Hierarchical single-domain autonomy and cross-domain collaboration to enable online and real-time network closed-loop

As telecom networks develop, new device configuration parameters, as well as service and scenario complexity, increase significantly. Technologies as well as software and hardware versions from multiple vendors coexist on networks. Network architecture becomes even more complex and dispersed. This has considerably driven up network O&M costs and complexity. In this context, network O&M faces two major challenges.

I. Splitting ultra-large, complex networks into multiple autonomous domains and implementing autonomous closed-loop through single-domain autonomy and cross-domain orchestration: An autonomous domain is a group of intelligent network infrastructure combined with network management and control systems. It is divided by operators based on service features, network technologies, and maintenance modes. Each domain autonomously completes a full closed-loop consisting of data collection, analysis, control, and optimization, and provides intent APIs to simplify operations and shield internal implementation and differences. A single-domain autonomous network runs as an independent system and has a high autonomy. By sensing its own status and the dynamic changes in external users, applications, O&M processes, and environments, it provides the most suitable networking options, configuration models, and policies to enable proactive or preventive optimization, making it possible to realize online real-time closed-loops on networks.

II. Flexible design and orchestration platform oriented to both service production and O&M processes for operators to replace stereotyped, passive, and manual operations with intelligentOps — data-driven intelligent O&M. First, open programmability is foundational for network autonomous domains to focus on abstracting network technologies and provide scenario-specific intent APIs to decouple services from network resources. As a result, flexible definition, global orchestration, and data training can be distinctive depending on service scenarios, networking solutions, and O&M processes and knowledge, helping continuously reconstruct and optimize O&M processes. Second, after years of network O&M, operators and equipment vendors have accumulated abundant management rules, troubleshooting methods, and expert knowledge, which are present in various intellectual assets, such as manuals and specifications. Such scattered knowledge oriented to humans must be pooled into computers to form centralized knowledge libraries that can be perceived and exploited by machines. Assisted by the machines, O&M engineers can maximize their value by acting as new roles, such as network strategists, orchestration engineers, data analysts, and will continue to make a real difference in intent design, exception handling, and decision-making. Therefore, it will be essential to provide these new O&M personnel with Design Studio platform and programmable framework that will enable them to agilely perform intelligent O&M in no code, low code, and pro code modes.

(4). Unified platform for cloud intelligent training, knowledge management, and O&M, supporting iterative evolution of telecom networks

In the future, operator networks will establish collaborative intelligent capabilities at the cloud, network, and NE layers. Cloud intelligence is a unified and centralized intelligent design and development platform. It functions as an agile development tool for operators to continuously perform intelligent training and knowledge extraction, and it also enables digitalization of network and expert knowledge. In addition, cloud intelligence, functioning as a "knowledge center" and "library", provides critical capabilities of knowledge release and sharing for operators to reduce repeated development and training processes. Network intelligence is the key part to implement network intelligence. It offers online intelligent inference and local knowledge base support oriented to hierarchical network autonomy. NE intelligence focuses on real-time collection and filtering of network data and implements real-time local data processing. In a word, the unified platform for cloud intelligent training, knowledge management, and O&M supports continuous dynamic iterations and intelligent upgrades of telecom networks.

Consistent intelligent specifications, including intelligent model specifications/knowledge specifications/inference process specifications, are the first necessity required to ensure efficient collaborative intelligence capabilities at the cloud, network, and NE layers. The consistency helps in reasonable circulation and sharing of intelligent models and knowledge. The second necessity involves the unique capabilities of the three-layer intelligent architecture for an operator network, considering the subnet- or domain-specific O&M and frequent service changes. The unique capabilities are as follows:

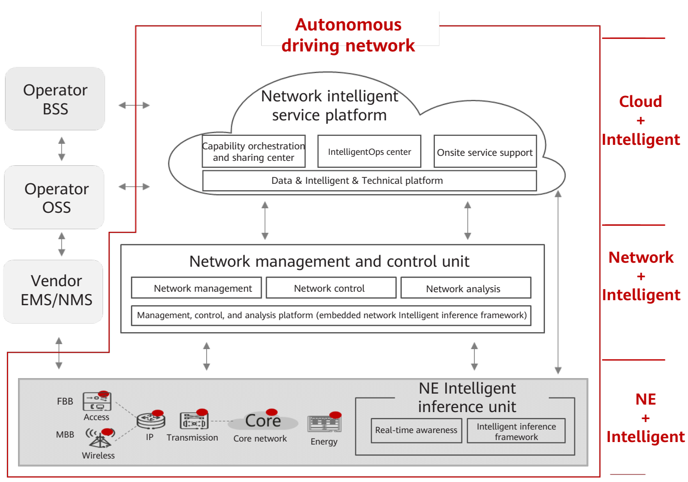
I. Intelligent model generalization and site adaptability: The operator's subnets may vary in service types, networking modes, and O&M rules, resulting in diversified network data distribution. Therefore, there may be difficulties in generalization and site adaptability when an intelligent model trained based on a subnet is applied to other subnets. To address this challenge, the intelligent inference components are required to provide relatively comprehensive capabilities of intelligent model generalization and local re-optimization.

II. Continuous evolution of intelligent models: Change or upgrade of operator networks and services may require synchronous update/upgrade of intelligent models and network knowledge. This requires collaboration between cloud intelligence, network intelligence, and NE intelligence to support continuous evolution and upgrade of intelligent models and network knowledge. In the case of network fault diagnosis using intelligence, if the alarm definition relationship in the new device version changes greatly or if batteries are added to the networked site, then the fault propagation relationship may change. In this case, the clustering algorithm and fault propagation rules of the intelligent model may require an upgrade.

Intelligence will be everywhere throughout the entire lifecycle (including reconstruction and evolution) of the E2E network in the future-oriented transformation of the autonomous driving network. A combination of network digitization plus expert knowledge digitization, infrastructures with a streamlined architecture, and hierarchical network autonomy is the core and basis for the ambitious transformation.

In conclusion, a clear, well-recognized target architecture that can be referenced by the industry is required for telecom networks to guide the production practices, achieving the L4 goal of the autonomous driving network. The recommended typical target architecture is outlined in the following figure.

Target architecture of the operator's autonomous driving network



Based on the target architecture, operators can systematically evaluate and sort out their existing architecture containing the OSS, integrated NMS, vendor NMS/controller as well as network equipment in a top-down manner, and then work out a feasible evolution roadmap that meets their requirements.

3-4-3 Grading Evaluation of ADN

The evolution of autonomous driving network (ADN) from L0 to L5 lasts for 10 years. It is critical to clearly understand the ADN status. In addition, operators face two major challenges in promoting network automation, intelligent innovation, and transformation:

- There are many pilots of intelligence-based network innovations. However, it is difficult to measure the value and overall benefits.
- Due to the lack of unified standards and theories and implementation methods that can measure intelligence-based network innovations, it is difficult to replicate good innovations.

To tackle these two challenges, the ADN grading standards and evaluation systems need to be established. O&M working scenarios are sorted out to identify key scenarios and weak points, thereby developing unified, objective, and quantifiable efficiency evaluation indicators. In addition, the network intelligence and automation levels are graded to provide guidance for intelligent O&M transformation and improve the O&M level.

3-4-4 Evolution Path of ADN

Achieving AND is a long and strenuous process. We recommend that the transition be first made from single-point autonomous systems to single-domain, then cross-domain, and then finally global autonomous systems. This way, innovative technologies such as intelligence and digital twin are gradually introduced to the device layer, network layer, cloud full stack, and operation system, and quickly promoted in the principle of "priorities are given to single-domain systems and value scenarios are for cross-domain systems". The goal is to achieve ultra-automated networks in the next five to ten years, with the focus on improving energy efficiency, network performance, operation efficiency, and user experience to help operators reap the benefits of network improvement.

Energy efficiency

Saving as much energy as possible across devices, sites, and even the entire network is a major challenge. Due to deteriorating network KPIs and complex dynamic network adjustments, conventional energy saving methods have not been efficiently executed. The intelligent power saving model is one approach to address this issue, streamlining the network load, power distribution, and temperature control systems to implement 24/7 dynamic and intelligent joint adjustment without KPI deterioration. This enables maximized matching between the energy consumption curve and the network responsibility curve to minimize energy consumption, with the target of zero bits and zero Watts.

Network performance

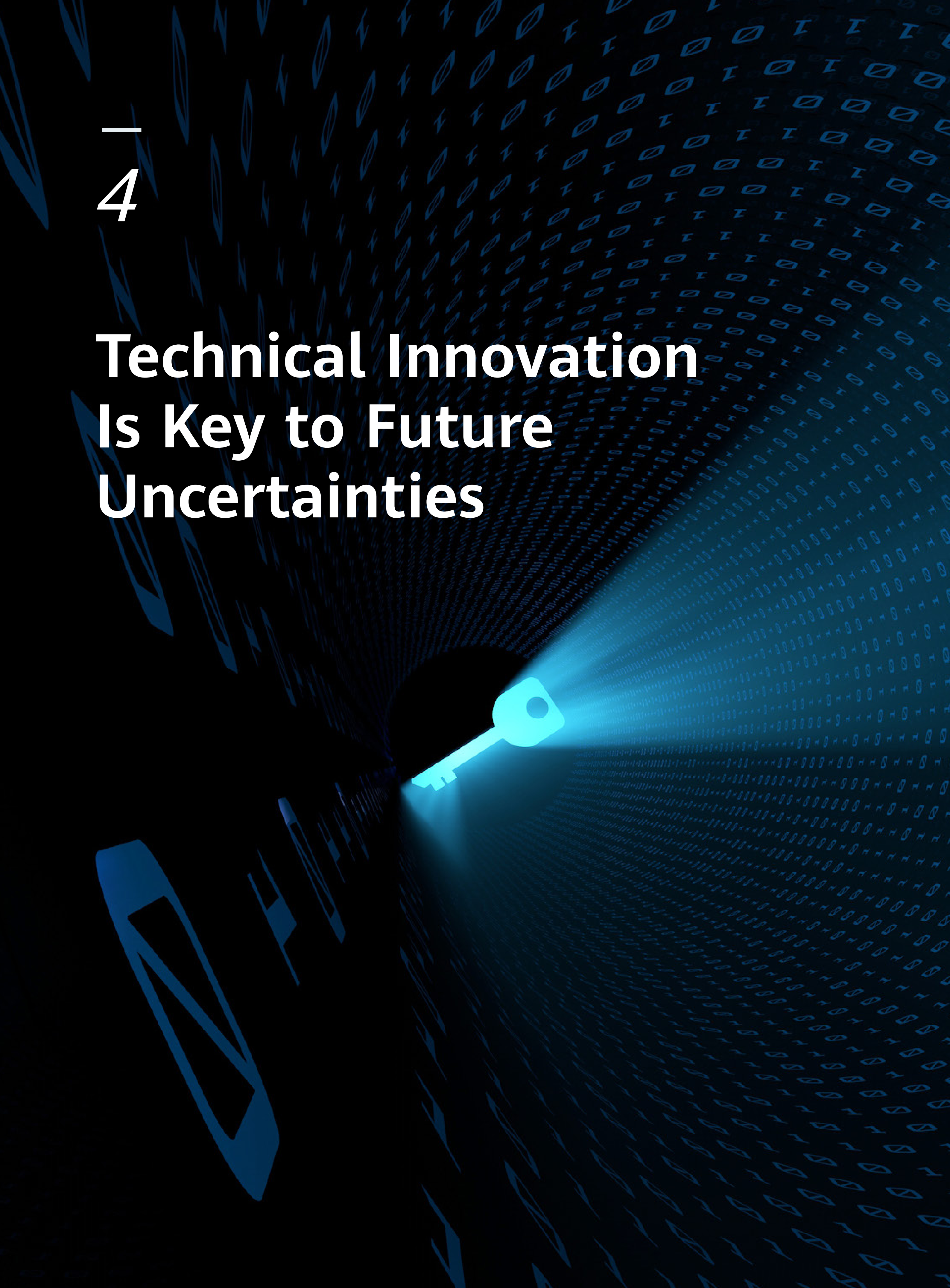
Evolving from product innovation to systematic network innovation, intelligent model training is performed with multiple parameters and big data across multiple domains, and the embedded intelligent inference module is used to achieve real-time inference, decision making, and resource scheduling on a 24/7 basis. This eliminates the bottleneck of available system resources, significantly improves the network performance, and maximizes the network value. Furthermore, performance optimization is conducted through multiple radio parameters, reducing the number of low-rate cells by over 80% and delivering ultimate 5G performance. The intelligent fabric network of intelligent lossless data centers ensures zero packet loss, low latency, and high throughput, improving IOPS by over 50% and providing more powerful and faster cloud services.

Operation efficiency

Whether you notice it or not, society is on the edge of full intelligentization. By 2025, the intelligence adoption rate of global enterprises will reach 86%, and as the digital bottom-layer platform, the telecom industry is at the center of transformation. As a result, operators are facing structural challenges in terms of efficiency and costs, where the OPEX of telecom equipment is approximately three times that of CAPEX, putting heavy burdens on operators. In terms of network resources, once a network is deployed, traffic flows accordingly, resource utilization may be improper, and it is difficult to manually analyze and adjust network-wide traffic. While it would take several weeks to manually analyze data, the application of intelligent slashes this time down to just several minutes. This helps operators break through the rigid network operation mode, deeply explore network potentials, and improve operation efficiency and comprehensive resource utilization. In addition, overall operation costs are reduced and service processing duration are slashed, as well as the incidence of manual operation errors.

User experience

The combination of network configurations alongside traffic scheduling technologies ensures an optimal user experience and indicates a fundamental change in network design. This new design is oriented to user experience, driving the network from top to bottom and adapting it according to service requirements. A clear transition has taken place, from network operations based on network indicators to network operations based on service experience indicators, in turn increasing operator revenues. For example, intelligence enhanced learning is used to optimize MIMO performance and provide different parameter combinations for cells, improving the average user rate by over 50%. The intelligent algorithm is also used to predict abnormalities that adversely affect user experience, perform maintenance in advance, detect network quality and faults before they are perceived by users, and proactively optimize user experience.



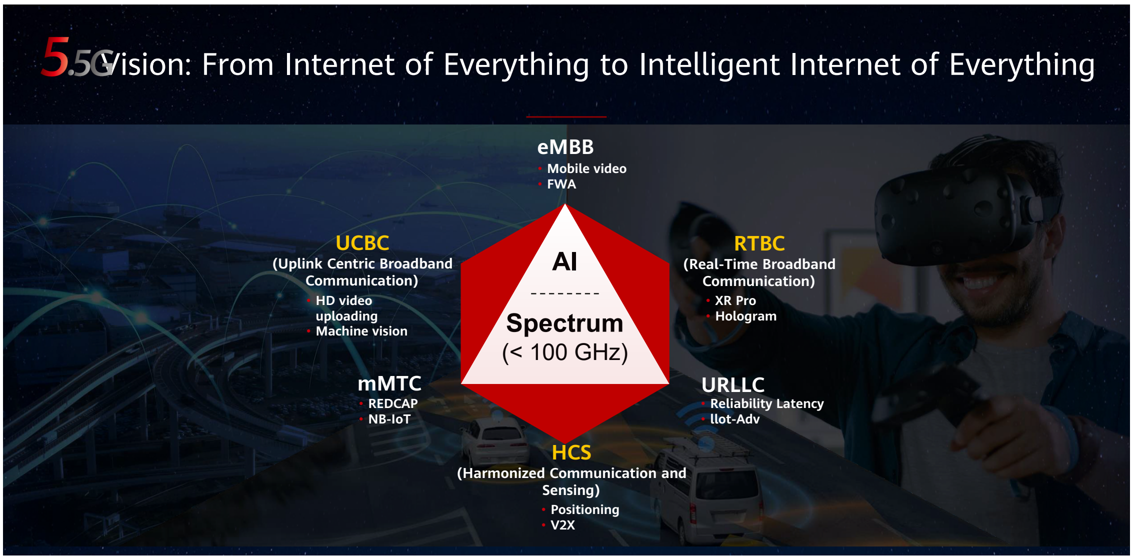
4

Technical Innovation Is Key to Future Uncertainties

4-1 5.5G: Enhancement and Expansion of 5G

Building on years of experience in the wireless communications industry, Huawei has proposed its vision for 5.5G. The vision will shape the development and evolution of the 5G industry, inject more vitality into 5G, and create new value for social progress and industry upgrade. As such, 5.5G is as much an industry vision as an enhancement and expansion of 5G.

The enhancements are for the three ITU-defined scenarios: eMBB, mMTC, and URLLC. Typically, REDCAP is introduced to diversify terminal types in order to better support broadband IoT in mMTC scenarios, and reliability-based latency is introduced to meet the connection requirements of smart manufacturing in URLLC scenarios (for example, remote motion control). The expansion aims to satisfy the increasing requirements of new applications, as the three scenarios defined by 5G can no longer effectively accommodate more diversified IoT settings. For example, in terms of industrial IoT applications which require massive connectivity and high uplink bandwidth, Huawei proposed the addition of a scenario between eMBB and mMTC — namely UCBC — which focuses on building uplink capabilities. As for other types of applications which require ultra-broadband, low latency, and high reliability, Huawei proposed a new scenario between eMBB and URLLC — namely RTBC — which focuses on building real-time broadband interaction capabilities. Lastly, regarding the pan-capability set which includes vehicle-road synergy in the V2X sector, and which requires both communication and perception capabilities, Huawei proposed a new HCS scenario which focuses on building communication and perception convergence capabilities.



In essence, 5.5G aims to evolve from the Internet of everything to the intelligent Internet of everything, and is expected to create entirely new value as a result.

- **UCBC will accelerate the intelligent upgrade of industries.** UCBC delivers ultra-broadband uplink experience. Relying on 5G capabilities, it will enable a 10-fold increase in uplink bandwidth. This is a perfect fit for manufacturers who need to upload videos in machine vision and massive broadband IoT, accelerating their intelligent upgrade. UCBC also significantly improves user experience of mobile phones in indoor areas requiring intensive coverage. Through multi-band uplink aggregation and uplink massive antenna array technologies, the uplink capacity and user experience in these scenarios can also witness a considerable improvement.

- **RTBC will deliver an immersive, true-to-life experience.** RTBC delivers large bandwidth and low interaction latency. It aims to provide a 10-fold increase in bandwidth at a specified latency, thereby creating an immersive experience for physical-virtual interactions such as XR Pro and holographs. It leverages typical carriers to quickly expand network capabilities, and the E2E cross-layer XR experience mechanism to build real-time interaction capabilities featuring large bandwidth.

- **HCS will facilitate the development of autonomous driving.** HCS predominantly enables V2X and UAV scenarios, which place autonomous driving as a key requirement. These scenarios need wireless cellular networks with both communications and perception capabilities. On the basis of 5G capabilities, UCBC will enable a 5-fold increase in uplink bandwidth. This is a perfect fit for manufacturers who need to upload videos in machine vision and massive broadband IoT, accelerating their intelligent upgrade.

- **New usage mode of sub-100 GHz will maximize spectral efficiency.** Spectrum is the most important resource in the wireless industry, and to achieve the industry vision, 5.5G needs more spectrum in the sub-100 GHz segment. Different spectrum types have different features. For example, FDD symmetric spectrum features low latency, TDD spectrum features high bandwidth, and mmWave can achieve ultra-large bandwidth and low latency. Within this context, one of the main goals involves tapping into the full potential of spectrum. The hope is to achieve maximum spectral efficiency by remodeling the sub-100 GHz spectrum usage through uplink and downlink decoupling and on-demand, flexible aggregation on all frequency bands.

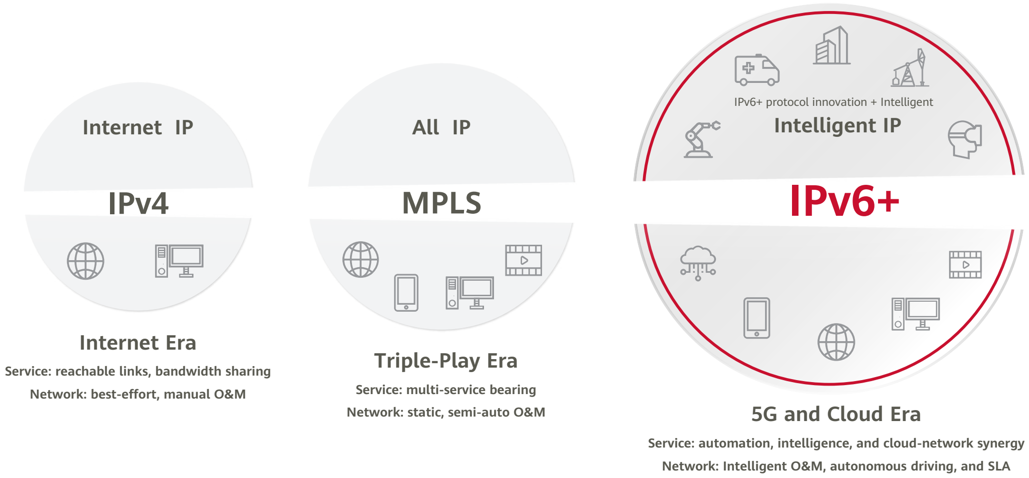
- **Intelligence will make 5G connections smarter.** In the 5G era, operators have to deal with considerably more frequency bands and types of terminals, services, and customers. Given this, 5.5G needs intelligent penetration from multiple perspectives to advance the L4 and L5 autonomous driving of wireless networks.

4-2 IPv6+: Innovation and Extention of IPv6

IPv6 was used by over 1 billion users in March 2020. IPv6 has become a priority particularly due to the exhaustion of the IPv4 address space. Additionally, several other factors are driving adoption, including that 5G and IoT require it, because verticals used IPv6 in their protocols, and because the evolution of Segment Routing with SRv6 is gaining a lot of interest in the CSP community. (IDC White Paper, Sponsored by Huawei, CSP Network Transformation: The Journey to 2025, Doc #EUR147425621, February 2021)

“IPv6+" is an extension and innovation of IPv6 technologies to enhance and unleash the potential of IPv6 and meet the requirements of large-scale, highly reliable, new services, and intelligent IP networks in the 5G and cloud era. IPv6+ includes a series of protocol and technical innovations, such as SRv6 network programming, network slicing (FlexE), in-flow detection (iFIT), emerging multicast (BIERv6), and application-aware network (APN).

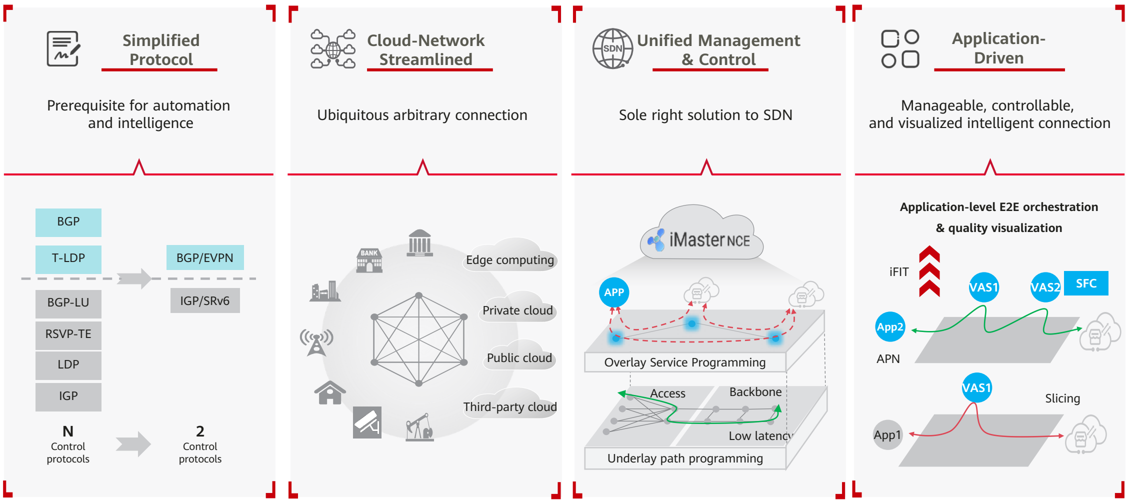
The data communication industry is entering the IPv6+ intelligent connection era



4-2-1 IPv6+ SRv6: Building Any-to-Any Connectivity

Segment routing (SR) allows explicit paths to be easily defined, with only segment routing information maintained for network nodes to cope with real-time and rapid service development. SRv6 can meet this requirement in the IPv6 era by extending IPv6 packet headers to implement a function similar to label-based forwarding. Specifically, SRv6 defines some IPv6 addresses as instantiated segment IDs, which can have their own explicit functions. As such, through different segment ID operations, SRv6 implements simplified VPN and flexible path planning.

IPv6+ SRv6 for Any-to-Any Connectivity

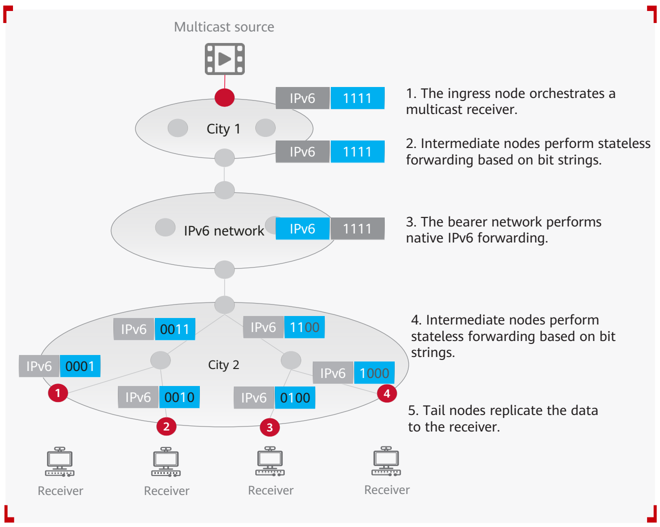


IPv6+ SRv6 provides a unified forwarding plane for all services, whereas EVPN provides a unified control plane for all services. Protocol simplification reduces the complexity of network modeling and O&M, thereby facilitating network automation and intelligence. Additionally, based on IPv6, SRv6 enables service reachability, which in turn allows new services to be quickly provisioned. IPv6+ SRv6 streamlines terminals, networks, edges, and clouds from the conventional metropolitan and backbone networks to campus data centers or edge clouds to future terminals and clouds, and provides any-to-any connections in the intelligence era, especially in the context of cloud-network synergy.

4-2-2 IPv6+ BIERv6: Optimal Solution for Multicast Services

For multicast traffic to be replicated along a specified distribution tree, conventional multicast solutions need a multicast distribution tree for each multicast stream. This means additional protocols are required, and each network node in the topology needs to maintain its status for each multicast distribution tree, resulting in poor scalability, complex O&M, high resource consumption, and slow fault evaluation.

IPv6+ BIERv6 — the optimal bearer solution for multicast services in the IPv6 era



Simple Configuration and Cross-Domain Deployment

- Services are configured only on the ingress node and delivered on a single hop.
- Operators provide only IPv6 forwarding, facilitating cross-domain network deployment.

Fast Convergence and Guaranteed User Experience

- Intermediate nodes are unaware of services, and protocol convergence is fast (ms-level).

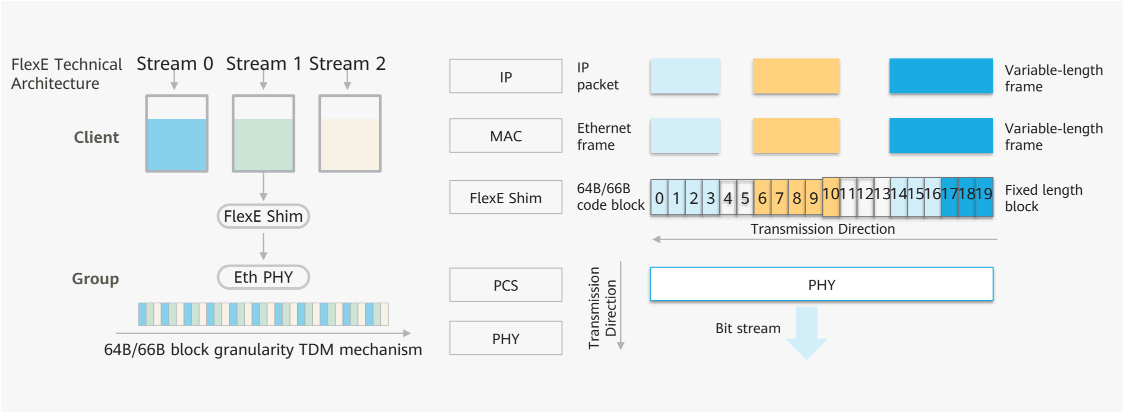
Bit Indexed Explicit Replication (BIER) is a mechanism in which each receiver is identified by a bit. The ingress node orchestrates the multicast stream receiver, forms a bit string by setting the corresponding bit to the initial value, and encapsulates the bit string into the packet header. Subsequently, the intermediate node searches the table for stateless forwarding based on this bit string in the packet header, without requiring additional multicast protocols. Intermediate nodes do not need to maintain their status for each multicast stream, which simplifies the protocol and O&M. In addition, the convergence does not depend on the number of multicast streams, significantly enhancing both user experience and reliability.

Based on IPv6 encapsulation, BIERv6 can easily traverse unsupported nodes and third-party networks to implement cross-region multicast services, such as remote VR/AR live broadcast and content distribution from countries to regions, cities, or counties.

4-2-3 IPv6+ FlexE: Ensuring Differentiated Cloud Connectivity Experience

As a core technology of the bearer network, network slicing enables bandwidth assurance and security isolation, allowing networks to physically isolate different services. The main network slicing technology is FlexE.

IPv6+ FlexE for differentiated cloud experience



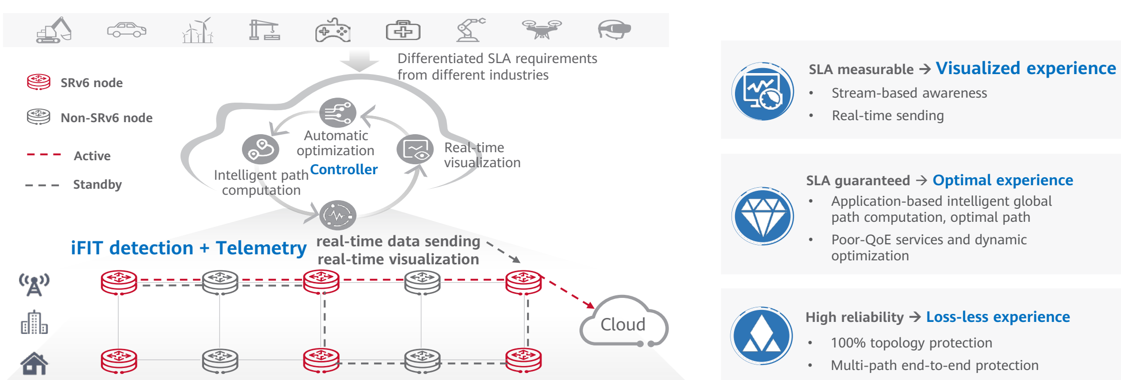
In the TCP/IP protocol, data packets are typically decapsulated and then forwarded on Layer 2 (MAC) or Layer 3 (IP). Unlike conventional IP packet switching, FlexE inserts a scheduling layer shim between Layer 2 (MAC) and Layer 1 (PCS and PMD), and uses TDM to forward packets.

FlexE allows devices to allocate exclusive or shared resources to each network slice, implementing multi-purpose networks, deterministic forwarding, and differentiated cloud experience.

4-2-4 IPv6+ iFIT: Real-Time Visualized SLA Quality

iFIT is one of the key technologies used by telemetry to provide packet-by-packet information on the data plane. During network measurement, proactive probe packets are not sent; instead, OAM instructions are carried in and then forwarded together with user packets to complete the measurement.

IPv6+ iFIT for real-time visualized SLA quality



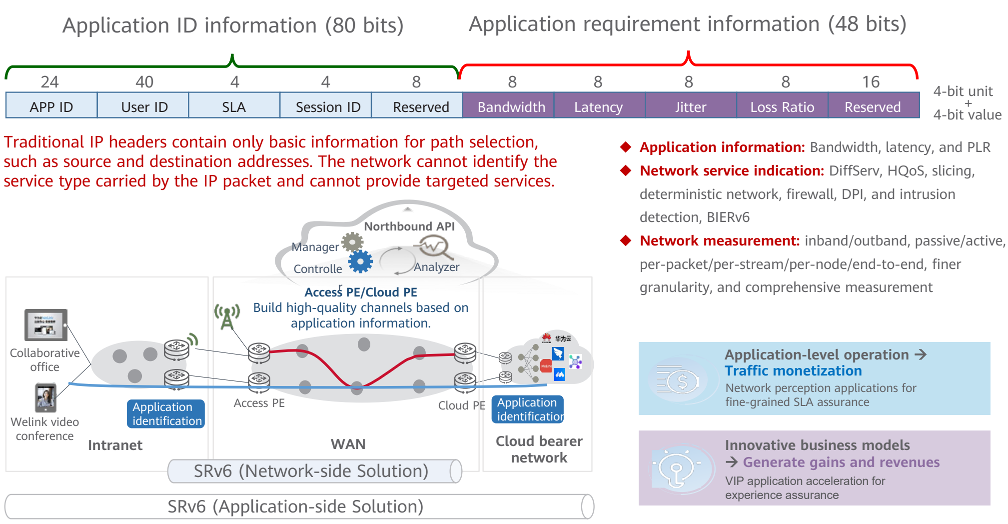
Based on iFIT, OAM instructions and time labels are embedded into IPv6 user packets to implement segment-based and end-to-end detection of packet loss and latency, and support future deterministic networks. The service cloud experience can be detected in real time, achieving measurable and guaranteed SLA, optimal experience, and high network reliability.

4-2-5 APN6

The application-aware IPv6 networking (APN6) uses the programmable space of IPv6 or SRv6 packets to carry application information (application identifiers and network performance requirements) into the network, which becomes aware of applications and their requirements in native mode, thereby providing SLA assurance.

APN6 can use the differentiated channels of cloud-based applications to implement refined operation of cloud-network services.

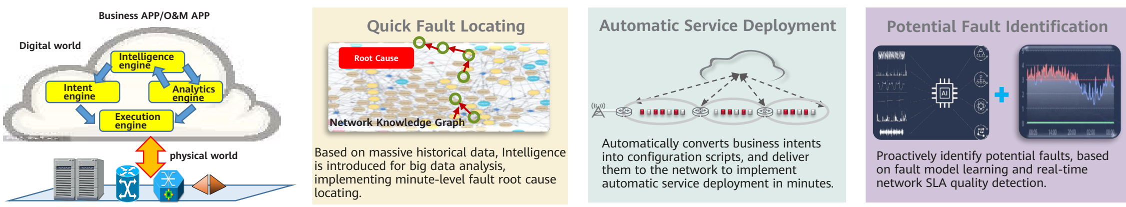
IPv6+ APN6, enabling refined operations of differentiated applications



4-2-6 IPv6+ Intelligence: Enabling Autonomous Driving Network

Based on the series of IPv6+ technologies and protocols, the solution implements automatic service deployment and fault locating, improving O&M efficiency. As illustrated in the following figure, four engines are involved, including the intent engine (from intent to design), execution engine (from design to instruction), analytics engine (from data to analysis), and intelligence engine (from analysis to decision-making).

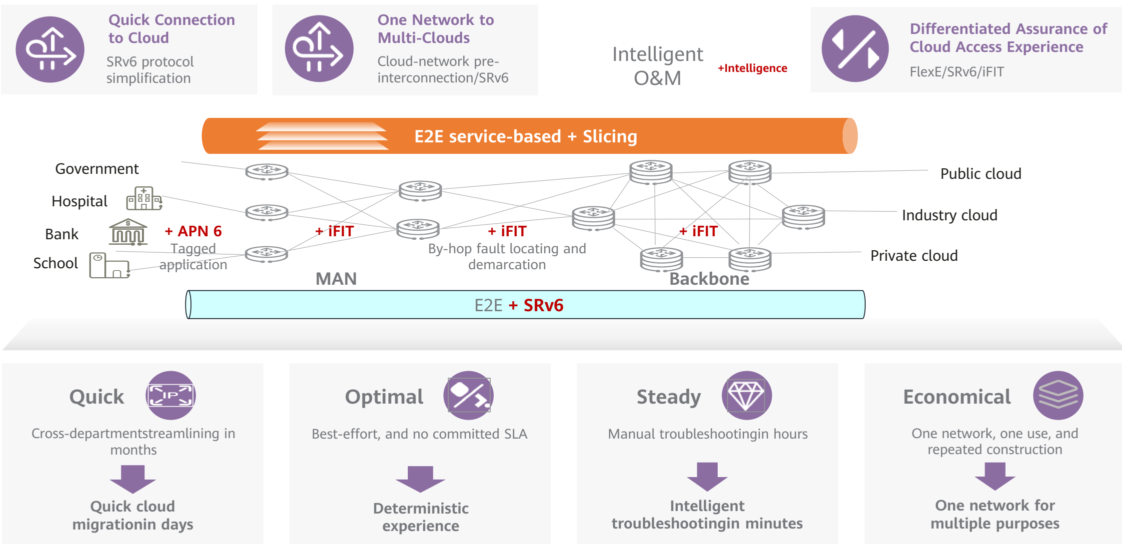
IPv6+ intelligence to enable autonomous network driving



4-2-7 IPv6+ Cloud-Network: Agile Cloud-Network Protocol

Based on the series of IPv6+ technologies and protocols, the solution enables and accelerates cloud-network convergence to quickly migrate services to the cloud, select multiple clouds on demand, and deliver a differentiated cloud access experience. It also provides the deterministic experience of the cloud-network, fast intelligent troubleshooting, and the slice-based multi-purpose network.

IPv6+ as an intelligent agile protocol suite in the cloud-network era



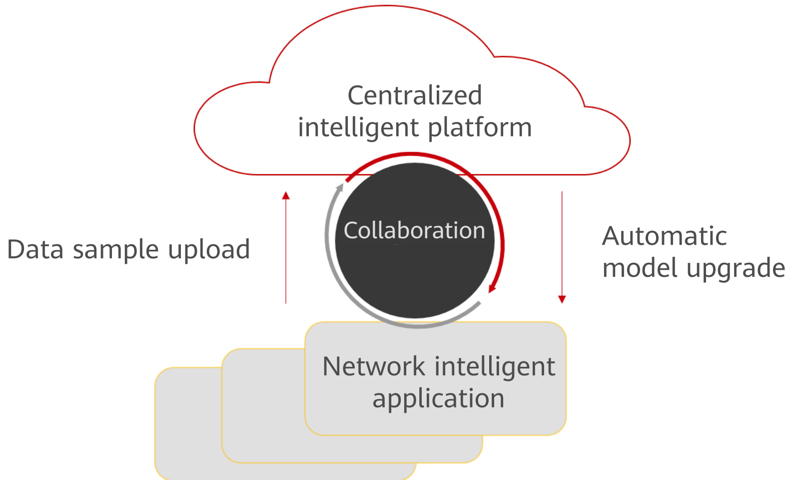
4-3 Intelligence

It is widely acknowledged that intelligent telecom networks are inevitable. In the next five years, intelligent applications in the telecom industry will scale up to tens of billions of US dollars, covering various service scenarios including network O&M, network operation management, customer experience management, customer service and marketing, and CRM systems. Thanks to intelligent applications, operators speed up digital transformation with higher O&M efficiency, lower power consumption, and better customer service. However, scaling up telecom intelligent applications is challenging, as it involves widely replicating intelligent applications for large-scale commercial use, converting intelligence capabilities from theories into business, and ensuring high reliability and security for intelligent applications. To deal with the challenges, innovation on telecom intelligence will be tailored to the telecom industry and keep up with the latest intelligence technologies. The development of target network will branch out into new intelligentization trends.

Automatic evolution of telecom intelligent applications through economic, efficient, and continuous online learning and model iteration

The future target network is an intelligent autonomous network capable of automation, self-healing, and self-optimization, meaning that intelligent applications themselves develop iteratively. In practice, network status (such as traffic volume and capacity) varies with time, and the intelligent models cannot always accommodate data characteristics of the network. Consequently, performance of intelligent applications may deteriorate, which compromises foundation of telecom intelligence. Therefore, the key to an intelligent target network lies in an innovative network architecture and an autonomous collaboration mechanism, as they facilitate effect monitoring, online learning, and automatic iterative development of intelligent applications.

To develop an economic and efficient collaboration mechanism, a centralized telecom intelligent platform is the choice of many operators considering economy and efficiency of computing resources. In addition to data services and model training services, the centralized intelligent platform monitors performance of intelligent application models on the entire network in real time. Upon detection of performance deterioration in any intelligent application, the platform starts training of a new model and automatically updates the model for the intelligent application, ensuring performance of intelligent applications.

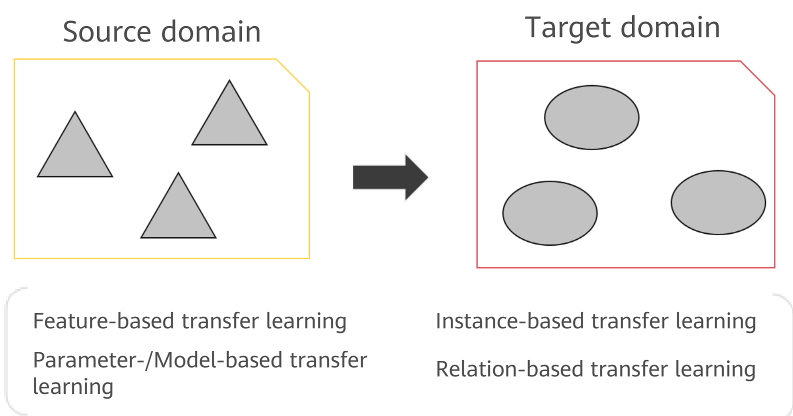


Autonomous collaboration mechanism

With the autonomous collaboration mechanism, various functions are available through collaboration between the centralized intelligence platform and intelligent applications. The functions include data sample upload to the cloud, model status management, model retraining, and model delivery, selection, and update, which empower online learning and model iteration and enable automatic evolution of intelligent applications. The intelligent target network is upgraded in an iterative and intelligent way.

Acceleration of the conversion from intelligence theories to intelligence business with intelligence engineering capabilities based on transfer learning and learning materials

Intelligence features perform well when applied in many verification projects, however, there is still a long way to go from experimental projects to engineering applications. The conversion to engineering requires quick development and training of a model and rapid replication of the intelligent application, thereby catering for a specific scenario. In the telecom sector, intelligent applications developed dedicatedly for a network cannot be directly replicated and applied on other networks due to varied data characteristics. In most cases, models need to be trained and learned again when being applied across sites. Given that starting from scratch is costly, intelligence engineering capabilities need to be obtained through transfer learning, learning materials, model templates, and model generation services, where new knowledge or new models are quickly attained with acquired knowledge.



Transfer learning

In essence, transfer learning is to find the affinities between gained knowledge (source domain) and new knowledge (target domain), and re-apply these affinities to develop new knowledge. It transfers knowledge from the source domain to the target domain. For example, skills obtained while learning to play chess can apply when trying to learn international chess. Skills used for learning English can be used for learning French. Transfer learning can be implemented based on instances, features, models, or relations. Transfer learning can be categorized into instance-based transfer learning, feature-based transfer learning, model-based transfer learning, and relational-based transfer learning. Instance-based transfer learning is completed by weighting specified samples in the source domain. Feature-based transfer learning is implemented by mapping the source and target domains to the same space and minimizing their difference. Model-based transfer learning combines the models and samples of the source and target domains to adjust the model parameters. Relational-based transfer learning learns the relations between concepts in the source domain and compares them with those in the target domain.

In addition, learning materials, model templates, and model generation services are also crucial to implement telecom intelligence engineering. Learning materials help to quickly build intelligent models one-stop by accumulating and sharing data, models, and modeling experience. Users can flexibly customize models using pre-trained models, and in-depth integration of algorithms and expert experience facilitates modeling in complex scenarios. Based on predefined experience, knowledge, and algorithms in telecom intelligence scenarios, model templates and production services help reduce development workloads such as data modeling, algorithm selection, and commissioning, greatly improving intelligent application development efficiency.

In future intelligent target networks, intelligence engineering capabilities such as transfer learning, learning materials, and data templates can drive the learning of network intelligent model data features and save model development and training time so that the experience of intelligent applications can be quickly re-used for other networks, facilitating large-scale commercial adoption of telecom intelligent applications.

From big data-based machine learning to symbolic, machine learning-based, explainable intelligence

The telecom sector requires professional knowledge for network planning, construction, maintenance, and optimization as well as expert experience. In future target networks, network intelligence is not mere big data-based machine learning. In addition, the network must be able to identify, learn, search, and process the knowledge converted from expert experience. Therefore, telecom intelligence needs to be upgraded from big data-based machine learning intelligence to intelligence based on symbolism and machine learning. Meanwhile, to continuously improve the security and trustworthiness of intelligence, intelligence will have to be more explainable.

The implementation of intelligence that combines symbolism and machine learning means that many new intelligence technologies, such as knowledge graph, need to be introduced to the telecom sector. Knowledge graph is essentially a semantic network, which is a graph-based data structure consisting of points and edges. In a knowledge graph, each node indicates an entity in the real world, while each edge indicates a relationship between entities. A knowledge graph is the most effective way to express a relationship. In other words, a knowledge graph is a relational network that connects all different types of information. A knowledge graph provides the ability to analyze problems from a relational perspective and transforms human knowledge into a language that can be recognized by machines.

Professional knowledge and expert experience in the telecom field fall into two types. One type is various corpuses, including product documentation, case library, O&M experience manuals, and term explanation websites. The other type is expert experience, which is reflected in defining product faults and symptom schemas, defining inference rules, analyzing and locating faults, and sharing fault locating experience. The knowledge graph processes the experience and knowledge through knowledge modeling and extraction to build a knowledge base for the telecom domain. The knowledge can be identified, searched, and processed by machines as well as be widely used in various telecom intelligence scenarios, such as knowledge Q&A and assisted fault locating.

Vision

Infrastructure planning is one of the main priorities regarding the acceleration of digital transformation. The planning and evolution of operator networks is a long-term process, and innovative ICT technologies centered on 5G, F5G, cloud, and intelligence will drive the transformation of future information infrastructure. Huawei will continue to innovate, improve its competitiveness, and help operators build new infrastructure to take the global communications industry forward.

Huawei believes that aside from exploring new business models and service types, we also need to concentrate on planning and building a stable, reliable, flexible, and efficient network infrastructure. Only a sound and robust infrastructure can turn our vision into business success. As such, joint endeavors across industries are imperative to building a future-oriented target network and creating business success. Huawei will work with operators and industry partners to achieve the promising business outlook by 2025.

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