HUAWEI

Striding Towards
the Intelligent World
White Paper

ADN

Building Self-fulfilling, Self-healing, and Self-optimizing Autonomous Networks

Building a Fully Connected, Intelligent World

FOREWORD

Digital technologies, such as 5G, cloud, and AI, are witnessing groundbreaking development beyond established boundaries. Human society is evolving towards an intelligent world at an unprecedented speed. Networks are becoming increasingly significant as the ICT foundation for achieving intelligent connectivity of everything.

The pandemic has made work from home+office, online+offline education, and virtual+real social entertainment the new norms. Home networks not only fulfill daily life and entertainment purposes but also meet the requirements for working from home, learning, and production. These requirements significantly increase the demand, usage duration, and quality standard for home networks.

Meanwhile, global enterprises are accelerating digital transformation. This trend is transforming networks from mere support systems to important components in production systems. Networks must feature on-demand readiness, provide deterministic SLA assurance, and deliver an optimal service experience. Enterprises are shifting towards network as a service (NaaS) in terms of deployment, delivery, and management.

The focus of Huawei's unceasing innovations is directed at the autonomous driving network (ADN), ubiquitous cloud services, pervasive AI, and low-carbon development benefiting from digital technologies. As a crucial strategy of Huawei Communications Network 2030, ADN is designed to deliver a new digital network service experience featuring zero-wait,zero-touch, and zero-trouble to customers, and enable self-configuration, self-healing, and self-fulfilling intelligent networks with efficient O&M capabilities.

IP technology reconstructed the forwarding architecture of the communications network two decades ago. Cloud technology profoundly transformed the network management and control architecture a decade ago. The next decade will witness the application of AI technologies across all layers in network architectures. This will facilitate the evolution towards high-level network autonomy and spark a revolutionary upgrade for the communications industry. AI will transform automated networks to intelligent networks, machines assisting humans to humans assisting machines, and on-demand readiness to real-time awareness and optimization of service experience.

Achieving full network autonomy calls for tremendous breakthroughs in key technologies (such as hyper-converged awareness, large-scale real-time simulation, and associated cognitive decision-making), as well as close collaboration among industry players in terms of technical architecture, interface standard, evaluation system, and business model.

Only our joint endeavor can overcome all the daunting challenges along this journey.

We firmly believe that a bright intelligent world is around the corner.

Lu Hongju
President of Huawei's General Development Dept

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Executive Summary and Keywords

1 Executive Summary

Over the past decade, 4G and cloud have profoundly transformed the way we communicate and live. Software-defined networking (SDN) and other network technologies continue to facilitate application-driven network automation. Instant communication technologies allow us to communicate anywhere anytime and have dramatically changed production methods. The next decade will be a golden decade for a thriving intelligent era, with networks fully evolving towards 5.5G by 2025. The transformation from 4G to 5.5G calls for a self-fulfilling, self-healing, and self-optimizing Autonomous Networks (AN) that make all things sensing, connected, and intelligent. In this white paper, Huawei and industry partners provide insights into the trend of network automation and intelligence, and offer suggestions on AN evolution to promote innovation and development across the AN industry.

2 Keywords

digital transformation, AN, AI, ADN, digital twins, intent driven

01

Overview of the AN Industry

We are living in times of significant changes and uncertainty, which have been the prelude to every single industrial revolution. The development and large-scale application of 5G technologies have created a fully connected, intelligent world. Booming digital technologies are revitalizing the economy, while the long-lasting COVID-19 pandemic further accelerates the digitalization of products and services. Over 170 countries have released their national digital strategies. Digital development has become an important consensus around the world. According to McKinsey, the pace of digitalization is seven years ahead of schedule on a world scale, and 10 years ahead of schedule in the Asia-Pacific region. The speed of digitalization for operator and enterprise services is 20 to 25 times faster than expected. Digitalization is no longer a difficult task as it was thought to be. Work from home+office, online+offline education, and virtual+real social entertainment will gradually become the new norms.

As the foundation of digital infrastructure, network connectivity is playing an increasingly important role in promoting sustainable development and digital transformation in various industries.

The total number of global connections is likely to reach 200 billion by 2030, as networks will evolve from connecting tens of billions of people to connecting hundreds of billions of things. New services such as next-generation human-machine interaction (AR/VR/XR), integration of housing and transportation, industrial interconnection, satellite broadband interconnection, and AI computing raise new requirements for network connections. All this sets the direction of network development, i.e., a stereoscopic cubic broadband and green network that features native intelligence, security & trustworthiness, deterministic experience, and integrated sensing and communication.

5G has resulted in an increasing network scale and the coexistence of old and new devices, as well as 2G, 3G, 4G, and 5G. Significant increase in the network, service, and O&M complexity will lead to a significant increase in operational expenditure (OPEX). The average EBITDA margin of global operators is approaching 30%. Network automation technologies, such as SDN and network function virtualization (NFV), cannot overcome these challenges. Over the next decade, the focus of network applications will shift from consumers to industries. Providing agile, on-demand, and personalized deterministic services and a differentiated experience for industry customers based on Connection+ will become the focus for industry competition. However, lack of business agility on operator networks and slow service innovation (the average rollout time of new services is longer than 12 months) create many obstacles for operators competing with OTT or cloud service providers (who can roll out over 300 new services a year). As network infrastructure providers, operators also need to take on social responsibilities, such as carbon emission reduction and security assurance. They need an efficient and intelligent energy consumption and security management mechanism based on the current architecture.

Global telecom operators are making tremendous efforts in making their networks autonomous and intelligent, finding ways to deploy AN over the next decade in order to improve O&M efficiency and promote business growth. Their goal is to deploy self-configuration, self-healing, and self-optimizing intelligent networks, develop efficient O&M capabilities, and deliver new, high-quality digital information communication services featuring zero wait, zero touch, and zero trouble for end users, and public sector and enterprise customers.

As a new industry, AN has been embraced by all industry partners (including standards organizations, operators, and suppliers) since the concept was proposed and has witnessed tremendous efforts and innovation across all domains. Over the past two years, AN has been incubated and is now in the planning and development phase. The industry has reached consensus on the vision, target architecture, and level standards of AN.

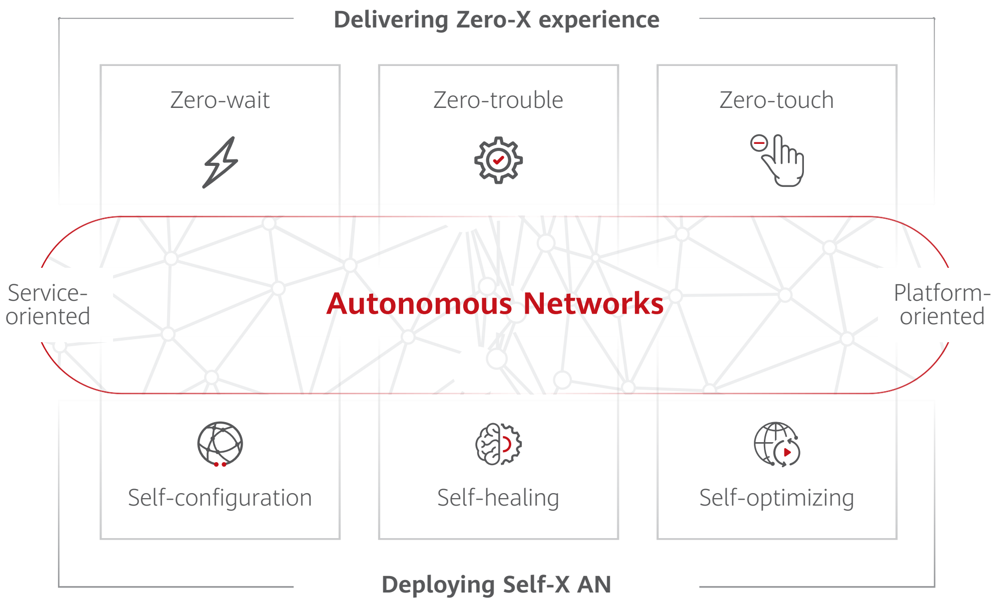


Figure 1-1 AN objectives and vision

Standard organizations, including TM Forum, CCSA, 3GPP, and ETSI, have set up ad hoc topics on AN, initiated technical research and standards projects, and collaborated through the AN Coordination Meeting of M-SDO to preliminarily develop universal and domain-specific standards. These standards cover five aspects: requirement cases, reference architecture, level standards, key technologies, and key interfaces, focused on improving AN standards and laying a solid foundation for more efficient industry collaboration and a thriving industry ecosystem. Multiple Standards Developing Organizations (M-SDOs) are collaborating with each other to formulate industry standards, while operators are speeding up AN deployment and practices.

AN has become a must for operators looking to implement digital transformation. They have set goals of achieving AN levels (ANLs), and are practicing AN based on four key elements (target architecture, level standards, effectiveness indicators, and operations practices) to develop innovative scenario-specific applications. China Mobile took the lead in setting the goal of achieving the Level 4 by 2025. It has evaluated the ANL for 31 provincial companies in China, and formulated targeted improvement strategies and plans. China Telecom considers AN key to their cloudification and digital transformation strategy and has announced the goal of reaching Level 4 in the short and medium terms. MTN proposed the goal of achieving Level 4 by 2025 to facilitate the Group's Ambition 2025 strategy. It has developed an AN framework featuring an AN blueprint, agile development & operations (DevOps) environment, high-performance network, and innovative high-value use cases (UCs).

02

ADN Trends and Suggestions

2.1 Trend 1: In the Post-pandemic Era, Home Office, Anywhere Operations, and Online+Offline Education Are Becoming the New Norms, Posing New Interaction Requirements for Home Networks

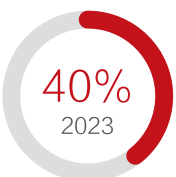
Pandemic prevention measures (such as home quarantine and social distancing) are moving a large number of operations and economic activities from offline to online, profoundly changing business models. Non-contact connection businesses and services are emerging rapidly, requiring home networks to not only fulfill daily life and entertainment purposes but also meet the requirements for remote office, learning, and production. These requirements significantly increase the demand, usage duration, and quality standard for home networks.

Since the COVID-19 outbreak, a large number of people have been working from home in many countries around the world. According to a survey conducted by Deloitte from May to August 2020, 24% to 47% of people worked from home in 16 countries. This number exceeded 40% in the UK, Belgium, Mexico, and Ireland. Work from home has become one of the key measures taken by enterprises and individuals to cope with the pandemic.

Face-to-face teaching is changing to remote teaching or online+offline education when schools in the basic education system are shut down. The demand for online education is increasing sharply, with a rapid growth in the user base. The number of online education users in China reached 342 million in 2020, with a year-on-year increase of 27.13%. In 2021, China invested over CNY 400 billion in online education. Despite the fact that the pandemic is now under control, China still has up to 298 million online education users, which is a slight decrease when compared with data from 2020. Online fitness, language, and hobby courses have matured and become popular choices.

These large-scale online activities would be impossible without IT support in various industries, which is also provided remotely due to the pandemic. Services deployed across distributed infrastructure are scheduled to preferentially meet digital and remote requirements, ensuring a quality online experience for employees and customers. According to Gartner, 40% of organizations will integrate virtual and real experiences by 2023 to improve productivity and attract more customers.

Number of users in the online education industry in China, in 2020



By 2023, 40% of organizations will integrate virtual and real experience to improve productivity and the customer coverage rate.

Network infrastructure is the cornerstone of all remote social activities and the key to continuous remote enterprise operations, especially in the education and healthcare industries. Network infrastructure will become as indispensable as water and electricity.

Diversified home network applications require higher network quality and pose more requirements on home network O&M.

First, remote office requires production systems based on network infrastructure, such as an email system, internal communication system, video conference system, and Office Automation (OA) system. These production systems require higher video conference quality, network security, and better and faster experience for certain applications.

Second, anywhere operations are required 24/7 to cope with the uncertainty of the pandemic. IT operations activities need to be machine-centered, instead of human-centered, in order to reduce the workload of operations personnel.

Last but not least, large-scale online teaching leads to a constantly high network load, causing many problems, such as frame freezing, audio asynchronization, and long-time image buffering. Live streaming for online courses has high network requirements. A high-quality, stable, and exclusive bandwidth of 20 Mbit/s to 50 Mbit/s is required for each course to ensure a satisfactory video interaction experience. A future-oriented education experience and scenarios require virtual reality/augmented reality (AR/VR) to deliver immersive, holographic digital classes. Smart home is becoming increasingly popular as people demand higher life quality. A large number of smart Internet of Things (IoT) devices are used at home, rapidly increasing the number of network connections. These devices include intelligent surveillance, robot vacuum cleaners, intelligent lighting, intelligent home appliances, and intelligent locks. Different devices have different network requirements. Some devices require high bandwidth, some require scheduled control, and others require real-time control. Users need a centralized home network-centric application O&M platform to achieve smart connections at home.

These trends and requirements create the following challenges for home networks:

Challenge 1: Lack of Proactive Home Network O&M Leads to Inaccurate, Slow Locating of Application-level Poor-QoE Issues, Affecting Network Security

In work from home+office hybrid mode, video conferencing has become the most effective method for multi-region and multi-department collaboration. The focus of broadband network upgrade is often directed toward improving the download rate, instead of uplink bandwidth. A low uplink rate will lead to many problems: frame freezing in audio and video conferences, sound and image asynchronization, echoes, and high cross-border access delay. These problems affect the working environment and efficiency at home or office. A large uplink bandwidth is required to provide Service Level Agreement (SLA) guarantee.

During an online class, the teacher may need to interact with many students. Poor video quality on home networks affects the quality of teaching. Video quality needs to be detected in real time to quickly identify deterioration, bandwidth and routes need to be automatically adjusted, and acceleration technologies need to be provided for teaching applications.

A large number of terminals used by employees (including operations personnel) in the public sector and enterprises need to access the Internet. This type of access has high security requirements. If a terminal is infected with viruses, the viruses may spread across the intranet through virtual private networks (VPNs). For the purpose of information security, different channels are required for enterprise traffic and individual traffic, such as Internet access, voice, and game traffic, to prevent enterprise information leakage or intranet attacks. In addition, office applications, including Tencent VooV Meeting, Zoom, WeCom, DingTalk, and Huawei desktop cloud, require application-based acceleration and SLA assurance capabilities to ensure optimal user experience.

Challenge 2: No Operator Can Provide a Quality Self-service Platform that Offers High-Quality Customer Services and Assurance for a Large Number of Home Network Users

In addition to remote office, anywhere operations, online education, and smart home, self-employed people (for example, an owner of a small fruit store) are also home network users. They also require high-quality home networks for multi-connection applications of goods management, cashiering, monitoring, and online advertising, and flexible, affordable, and reliable service packages. Customizing a solution for each individual customer is a heavy workload for operators. An optimal solution is to provide an e-commerce self-service mode for customers to subscribe to, change, maintain, and optimize network service packages. Operators need to develop a flexible and efficient e-commerce self-service platform for a large number of customers. Operators also need to identify typical service packages that can be recommended for different application types. Intelligent guidance needs to be provided in the entire self-service process to improve customer experience. These measures can liberate IT operations personnel from the work of communicating with customers and allow them to focus on how to better integrate online and offline experience.

Challenge 3: Home Wi-Fi Coverage Problems Lead to Frequent Complaints and Affect User Experience

Data of an operator shows that 60% of the complaints from home broadband users are caused by home conditions. Traditionally, home network O&M only focuses on network access and does not focus on users' home conditions. However, users often have little knowledge or experience about networks. Any network problem may trigger user complaints. Wi-Fi coverage is a major problem that needs to be resolved in order to reduce complaints and user churn. Wi-Fi coverage problems include how to reduce wall penetration loss, reduce co-channel interference, and optimize coverage for large houses. It is impossible for O&M engineers to manually solve all these problems due to various house types and requirements. Automatic and intelligent methods are required. For example, 3D survey can be performed before home network deployment to provide suggestions on selecting an indoor network device deployment solution, for example, fiber to the room (FTTR) all-optical gigabit network solution, or provide suggestions on device requirements and deployment locations. After a home network is deployed, a mobile app can be used to detect the Wi-Fi signal strength, interference, and network access rate at each location in the house, and provide intelligent optimization suggestions based on the user's house type and optimization cost. During network usage, the Wi-Fi signal coverage can be monitored to notify users of Wi-Fi coverage problems, and intelligent guidance can be provided to help them solve the problems by themselves.

To overcome these challenges, Huawei proposes the following:

1. **CMOs of operators can seize the new opportunities brought by diversified home services in the post-pandemic era,** attach importance to guaranteeing home network experience, proactively analyze poor-quality of experience (QoE) customers, identify potential customers of new products, and provide high-quality products that meet customer experience requirements. Meanwhile, anywhere operations will bring new opportunities for cyber security authentication and access, which require native security capabilities.

2. **CTIOs of operators can focus on providing e-commerce online self-service capabilities for new products** to deliver a zero-wait, zero-touch, and zero-trouble user experience.

3. **CTOs of operators can pay more attention to home network Wi-Fi coverage and experience assurance** and develop self-service troubleshooting apps to extend network O&M capabilities to homes and ensure optimal user experience.

2.2 Trend 2: Innovative Government and Enterprise Services Have Become the Main Growth Point of Operators' Business, and the Profit Model Will Change from Traffic Monetization to Service Monetization

With the maturity of technologies such as 5G and cloud computing, innovative government and enterprise services are opening up new business growth for operators. In the next few years, the application of cloud-network synergy and IoT in the industrial field will become the main focus of operators' government and enterprise services. Government and enterprise services are transforming from scenario-specific applications to integrated solutions for vertical industry customers. The profit model of operators will change from traffic monetization to service monetization.

According to Gartner, by 2023, more than 60% of enterprises will regard networks and clouds as critical infrastructure that supports their digital strategies. Driven by the convergence of 5G and cloud services, operators' revenue for innovative services increased by more than 20% in 2021, accounting for 27% of the total revenue. Innovative services are becoming the second growth curve of operators' business.

By 2023, over 60% of enterprises will consider networks and cloud as the key infrastructure for their digital strategies.

By the end of 2021, 5G demonstration applications have been deployed in more than 20 industries around the world. 5G has broken through the bottlenecks of network capacity and latency in industrial applications, and has been verified as the most appropriate technology in scenarios such as steel turning/crown block in steel plants, remote crane control at ports, and PLC cloudification for 3C manufacturing, creating significant value. For example, if the steel industry realizes automated steel turning, the output value of one production line can be increased by CNY 100 million in one year. Global operators have signed more than 10,000 5G industry application contracts. GSMA predicts that from 2022 to 2025, all industries will enter the in-depth convergence phase; in 2025, 5G convergence applications will be popularized; and by 2030, the scale of the global vertical industry market enabled by 5G will reach nearly USD 700 billion.

The total market size in global vertical industries empowered by operators' 5G networks is expected to reach USD 700 billion by 2023.

In addition, the proportion of ICT+DT (DICT) cloud service revenue to operators' government and enterprise service revenue continues to increase. Operators' cloud service revenue has doubled in the past three years. For example, the proportion of DICT revenue of China Mobile to the total revenue has exceeded 50%. In the next five years, the application of cloud-network synergy and IoT in the industrial field, the new growth point of operators' business, will reach a compound annual growth rate (CAGR) of 19.1% and achieve a global market scale of USD 600 billion by 2025. Cloud transformation has become a consensus in the telecom industry. In the next five years, global operators will increase their investment in cloud transformation at a CAGR of 27%. By 2026, the expenditure will reach USD 20.6 billion. In response, operators' innovative services, including cloud, data center, video, and mobile payment services, are growing rapidly and gradually becoming the second growth curve.

The global market scale will reach USD 600 billion by 2025.

Expenditure will reach USD 20.6 billion by 2026.

With the booming of government and enterprise services, the boundaries of the telecom industry are becoming more blurred, and the competition is diverse and complex. Operators need to ensure scenario-specific network connections for government and enterprise services and cooperate with industry integrators to provide integrated solutions for vertical industry customers. Operators' profit model will change from traffic monetization to service monetization. However, this is a gradual development process that is faced with many challenges.

Challenge 1: Existing Network O&M Mode and Capabilities

During cloud transformation, there are various difficulties to overcome, such as a large number of access users and high requirements on network reliability and SLA assurance. For example, in the end to end (E2E) slicing scenario of a private network, the network reliability must be higher than 99.999%, and the network latency must be under 5 ms. The network must be able to automatically predict and optimize potential risks, diagnose and rectify poor-QoE problems and faults, and quickly evolve to high-level automation and intelligence.

Challenge 2: Operation Capabilities and Cost of Transformation from ICT to OT

During digital transformation, operators have much room for improvement in UC development, value quantification, ecosystem construction, E2E cost control, business model collaboration, delivery and O&M capabilities, and internal organizations and processes. Especially in the disruptive transformation from ICT to OT, operators are the most important part of the upstream and downstream industry chain consisting of enterprises, integrators, ISVs/IHVs, cloud service providers, and equipment vendors. In addition to coping with fragmented applications, long processes, and many breakpoints in government and enterprise services, operators also need to be responsible for the delivery and O&M of these services, as well as the optimization of resource configurations and the responsibility matrix to reduce delivery and O&M costs.

To address the preceding challenges and meet the requirements of the fast-growing government and enterprise market, it is recommended that both the network and operation systems be improved.

1. **Accelerate network simplification, automation, and intelligence:** Traditionally, networks were deployed based on services. With network cloudification, services are carried by cloud-based networks in a unified manner. The traditional independent bearer mode brings great complexity to E2E service control, increases joint commissioning and interconnection costs, and cannot make full use of resources. Therefore, network simplification is required.

   On the basis of fully decoupled architecture, network resources are SDN- and NFV-based to implement intelligent control of E2E networks. Cloud and network resources support resource sharing, elastic scaling, and on-demand allocation.

   Intelligent technologies such as AI are introduced to transform the existing fault O&M mode to an intelligent mode featuring risk prediction, fault self-healing, and network self-optimizing. In this way, zero-trouble networks and zero-wait experience are provided, meeting the core requirements of 2B customers for high reliability and differentiated SLA.

2. **Build a cloud-network integration operation system:** More flexible resource and capability scheduling and collaboration are provided through centralized display and unified

management of cloud and network resources and capabilities, enabling front-end services. Operators need to build a 2B service provisioning and O&M system that features cloud-network synergy across the network management system (NMS), a core network, SIM card management, cloud-edge collaboration, and O&M, and conduct integrated R&D, sales, and operations. In addition, they need to leverage open IT capabilities such as AI, cloud orchestration, and machine learning of cloud providers to accelerate the innovation and implementation of industry applications.

2.3 Trend 3: AI Is Transforming Network Architecture from All-Cloud to AI-Native and Has Achieved Initial Success

Network architecture, which has transformed from all-IP to all-cloud in the past two decades, is now evolving to AN based on AI-native. All-IP solves the structural problem of traffic increase without revenue growth due to high network OPEX, helping operators launch competitive services to explore new revenue streams. All-cloud solves the problem of high costs stemming from the management and maintenance of various network devices, and the structural problem that operators could only increase network capacity by increasing the number of devices on traditional telecom networks. In the next decade, AI-native will be the core of network architecture. The control closed-loop and knowledge closed-loop based on network digital twins will drive communication networks to achieve full autonomy, thereby fundamentally solving the structural problems caused by a large network scale and high complexity.

Network communication is widely prevalent in our lives. People rely on mobile phones and smart devices almost all the time. As more smart devices such as smart cars and wearables access the network, their influence on people will increase sharply. The substantial transformation of human society depends on increasingly intelligent, reliable, and flexible communication networks. Therefore, communication networks are facing many challenges including large scale and complex services, O&M, and connections. The best solution to these challenges is to deploy fully intelligent AN in order to simplify network O&M, improve network efficiency, implement network self-configuration, self-healing, and self-optimization, and achieve network autonomy.

According to GSMA's AI in Network Use Cases in China, "The convergence of AI and communications networks will inject new technological vitality into communications networks and open unprecedented possibilities and AI in Network is the key to success. This will truly promote the GSMA Intelligent Connectivity vision and connect everyone and everything to a better future."

The words in AI in Network Use Cases in China are not just slogans. After several years of exploration, remarkable achievements have been made in network planning and construction, network optimization and configuration, network energy saving and efficiency improvement, as well as in network maintenance and assurance. TM Forum's AN whitepaper 4.0 contains the latest AI network application success stories of multiple operators.

China Mobile's intelligent operations of home broadband services: The accuracy of proactive identification of poor-quality home broadband services is 95%, the user experience is significantly improved by 83%, and the average fault locating duration is reduced from 2.1 hours to 10 minutes.

China Mobile's intelligent optimization of wireless network coverage: On new 5G networks, the average cell coverage is increased by 15.8%, the road coverage is increased by 91%, and the outdoor download rate is increased by 30%.

China Unicom's intelligent operations of 5G bearer networks: The activation efficiency of a single line is reduced from 45 minutes to 2 minutes, and the activation accuracy reaches 99.999% without manual intervention.

MTN's congestion suppression on mobile bearer networks: The traffic suppression model is used to analyze real-time network congestion and provide guidance for accurate capacity expansion. The average daily traffic of MTN South Africa is reduced by 28%.

Implementing network automation and intelligence is a systematic project. Tremendous efforts have been made in this area and have achieved initial success. However, it still faces the following challenges:

Challenge 1: Fully intelligent AN is an inevitable trend. To smoothly evolve to such an innovative network architecture, especially Level 5, evolution path selection is the key. There are two evolution paths: disruptive innovation and iteration. Operators also need to choose between developing AN all on their own and collaborating with industry partners.

Challenge 2: The evolution of the network architecture not only affects network architecture selection, but also changes the network O&M mode and transforms organizations and processes. The evolution to AN enables human-out-of-the-loop network self-management, ultimately realizing always-on networks featuring autonomy. With such a network architecture, network O&M will transform from traditional human-centered O&M to AIOps featuring human-machine collaboration, and finally evolve to intelligent O&M featuring human-machine symbiosis. The evolution of the network architecture and O&M mode will change O&M personnel's knowledge and work habits and promote the transformation of O&M personnel, organizations, and O&M processes.

Challenge 3: Collaboration among industry organizations and alliances, including standards organizations, is critical to the development and large-scale application of AN. In the past, network automation standards were formulated by different organizations separately without coordination. AN involves more technical fields and requires stronger collaboration among industries and standards organizations in different fields. International and national standards organizations, including TM Forum, ETSI, 3GPP, IETF/IRTF, and CCSA, have carried out research on AN in their own fields. How to remove barriers between the different organizations becomes especially critical.

Challenge 4: The control closed-loop and knowledge closed-loop based on network digital twins are the basis of AN. Many key theories and technologies are involved, including network digital twins modeling and simulation, objective-driven automatic closed-loop and collaboration, network self-awareness, network environment awareness and modeling, self-fulfilling, self-healing, and self-optimizing autonomous network, and network adaptive learning and self-evolution. To make theoretical and technological breakthroughs, collaboration is required between academia and industry in many fields, including software engineering, computing platform and infrastructure, AI-based network cognition system, system and control theories and applications, human-machine interaction, information security, and trustworthy network design.

Network architecture transformation is a long-term systematic project. The following are suggestions to address the preceding challenges:

1. Evolving the architecture gradually, stably, and sustainably

Disruptive innovation involves self-development with operations support system (OSS) as the core, whereas iteration involves the combination of self-development and collaboration with network applications and network infrastructure as the two cores. Path selection requires comprehensive consideration of the product lifecycle from R&D to production and commercial use, O&M mode transformation, and O&M capability inheritance. Evolution of the network architecture shows that the iteration path is more suitable for network architecture transformation. This path allows vendors and operators to collaborate to achieve application-centric, data-driven, and intelligent AN. For example, it allows vendors to implement single-domain autonomy and self-closed-loop, while allowing operators to focus on new connection services, customer experience, and E2E process streamlining.

2. **Gradually establishing an intelligent domain O&M system based on architecture evolution**

Transforming the O&M mode requires organizational transformation. A new O&M system should be gradually established from four aspects: O&M organization structure, O&M positions, O&M scope, and O&M management system and process. The new O&M system should be implemented by phase based on the iterative evolution of the network architecture, gradually realizing human-out-of-the-loop intelligent O&M featuring human-machine collaboration and symbiosis.

3. **Promoting the healthy development of AN through cross-industry collaboration**

Implementing AN is a systematic project that involves the entire industry chain, including chips, devices, tools, integration, services, operations, and organizations. It is also a transformation from partial autonomy to full autonomy that requires continuous evolution. All industry organizations and alliances need to collaborate to define the evolution pace, intergenerational characteristics, and implementation path.

4. **Making breakthroughs in basic theories and key technologies through cross-disciplinary collaboration**

AN is also a new field that spans multiple disciplines, including communication science, computer science, control theories, and complex systems. It requires in-depth collaboration between academia and the industry for establishing academic organizations (such as IEEE, ACM, and CCF) and interdisciplines (such as interdisciplines based on computer software) that meet AN objectives, and for making comprehensive breakthroughs, from basic theories to key technologies.

It is recommended that the architecture design for AN comply with the following principles:

Six principles

Principle 1: Implementing hierarchical closed-loop autonomy

In the AN architecture, the resource operations layer is responsible for real-time and near-real-time infrastructure resource supply and assurance, the service operations layer is responsible for user service enablement and user experience assurance, and the business operations layer is responsible for business enablement, including offerings, subscriptions, and billing.

Principle 2: Implementing continuous learning and evolution

Self-learning continuously optimizes knowledge and models to quickly adapt to the dynamic environment, network status, device status, and user behavior. In addition, exploratory intelligent awareness quickly optimizes system parameters to ensure continuous system self-evolution.

Principle 3: Adopting the hybrid architecture driven by data and models

Most ICT infrastructure tasks are critical services. Incorrect decisions made by a black-box system will lead to serious consequences. The hybrid architecture driven by data and models improves the efficiency of awareness and problem identification, and ensures reasonable decision-making logic and predictable results.

Principle 4: Using human-machine symbiosis for task collaboration

To cope with uncertain and unpredictable tasks, such as handling network congestion and frequent faults, the infrastructure dynamically defines and initiates tasks and collaborates with humans to complete them, instead of pre-defined tasks in the R&D and network design phases. Ideally, backend personnel are responsible for specifying objectives and policies and implementing intent-based translation, while machines are responsible for breaking down objectives and directing onsite personnel and machines to collaborate in executing tasks.

Principle 5: Using distributed intelligence for machine-machine load balancing

To implement intelligent collaboration between network elements (NEs), intelligent protocols, semantic interfaces, or intent-based collaboration interfaces transfer status, semantics, or knowledge to each other in real time or near-real time, and multiple systems and domains collaborate to complete tasks. To implement intelligent collaboration between autonomous domains (ADs), multi-domain, multi-vendor service provisioning and network quality awareness and assurance are provided.

Principle 6: Enabling humans to take over systems

In case of a disaster, fault, or exception, humans can take over and control machines to intervene and direct critical tasks.

2.4 Trend 4: Operators Are Accelerating the Construction of AN, Transforming from Passive to Proactive O&M, and from Event-triggered Response to Proactive Prediction and Prevention

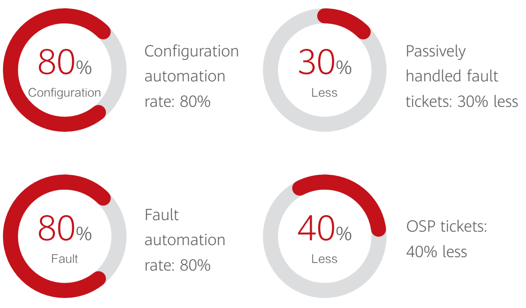
To achieve business agility and efficiency improvement, operators have developed automated and intelligent strategies and upgraded traditional siloed OSSs to platform+application systems.

China Mobile proposed a 2-3-4 architecture for automation and intelligence capabilities, formulated a 2+5+N O&M architecture at the OSS layer, and applied AI to network O&M production and practices, implementing proactive, preventive, and agile O&M.

China Unicom built automation and intelligence capabilities based on the application-platform-network layered structure, and developed a network operations ecosystem featuring platform+application, intensive IT, and capability openness. China Unicom also built a network AI capability center at the platform layer to apply AI capabilities to all network operations scenarios.

China Telecom built a cloud-network foundation and an AI-enabled platform. Vodafone performed intensive reconstruction at the OSS layer, integrated OSSs of its operating companies (OpCos), and developed NaaS capabilities that enable efficient operations and agile services. Telefónica developed a four-layer platform strategy and upgraded the AI capabilities of the 4th Platform to provide a distinct product experience.

The operators are focused on transforming from passive to proactive O&M, and from event-triggered response to proactive prediction and prevention. The quantifiable evaluation indicator system formulated by Vodafone and China Mobile is a typical example. The Zero-touch Operation (ZTO) strategy proposed by Vodafone focuses on E2E Ticket Journey automation and sets goals on cognitive automation, configuration automation, outside plant (OSP) digitalization and self-service, and AI proactive prediction. Vodafone plans to achieve a fault automation rate of 80% and configuration automation rate of 80%, and reduce 30% of passive fault ticket responses and 40% of OSP tickets by 2025. China Mobile has formulated effectiveness indicators based on Zero-X and Self-X, including service provisioning duration, service availability rate, customer self-service rate, configuration automation rate, fault automation rate, and poor-QoE self-analysis rate.



However, AN is a systematic engineering project. It is faced with a series of challenges, including uneven capabilities at each layer, unrealized closed-loop autonomy in each domain, and lack of evaluation standards for external services.

Uneven automation and intelligence capabilities at each layer make collaboration difficult and hinders service innovation and business monetization. Potential growths in digitalized vertical industries and consumer life pose stricter and more diverse requirements on network bandwidth, latency, and reliability, and call for a transformation from static service provisioning to real-time adjustment. The automation and intelligence capabilities at the business operations layer, service operations layer, and resource operations layer lack centralized planning. Complex interaction interface of each layer and differentiated automation and intelligence capabilities make it difficult to achieve collaboration between layers, affecting service innovation efficiency and business closed-loop capability.

Closed-loop autonomy has not been implemented for any domain, hindering the improvement of network O&M management. The automation and intelligence level of each domain is still low, and this is not conducive for fault prevention and prediction, agile fault detection, root cause locating, and quick fault rectification. According to the data analysis on 1800 typical O&M activities, 95% of processes and operation nodes still require manual intervention.

The external services of hyper-automation networks lack evaluation standards. Standards organizations are formulating standards on network automation and intelligence to provide quantifiable evaluation solutions for network O&M capabilities of hyper-automation networks. However, there is still a lack of unified standards and evaluation methodologies for the business values that AN can bring to end users. It is difficult to evaluate external service capabilities, and this impedes the development of hyper-automation networks.

To address these challenges, it is recommended that telecom operators focus on the following points during AN construction:

1. **Making mid- and long-term plans by referring to best practices:** CTIOs should think three to five years ahead and learn from industry best practices of TM Forum to define evolvable O&M architectures, goals, and implementation paths. They can define service scenarios by business drives from top to bottom, improve network operations from bottom to top, and evolve toward automation and intelligence network based on service and network characteristics.

2. **Managing network by layers based on industry standards:** During autonomous system construction, CTIOs can refer to the network automation and intelligence standards formulated by standards organizations such as TM Forum, CCSA, GSMA, ETSI and 3GPP to ensure collaborative innovation and evolution of the business operations layer, service operations layer, and resource operations layer. Layer-based network autonomy should be considered. CTIOs can construct an autonomous system at each layer from bottom to top and use intent application programming interfaces (APIs) between layers to simplify interaction interfaces and achieve agile services.

3. **Applying various technologies and building single-domain closed-loop capabilities:** To realize quick closed-loop troubleshooting in each domain, operators and vendors should deepen technology collaboration, apply new technologies such as AI, digital twins, and simulation in innovative practices.

4. **Performing iterative evaluation for improvement and quantifying effectiveness from multiple dimensions:** Operators can refer to the practices of standards organizations and leading operators, iteratively and quantitatively evaluate the automation and intelligence capabilities of network O&M and the convenience and flexibility of external network services, and iteratively improve network capability weaknesses, ensuring orderly network transformation and quantifiable service effectiveness.

2.5 Trend 5: O&M Capabilities Are Moving Close to Users and the O&M Mechanism for Handling Network Faults Is Gradually Changing from a Long-Process Ticket Transfer Mechanism to a Zero-Touch Man-Machine Collaborative Processing Mechanism

Cutting down unnecessary procedures to respond to customers more quickly: Practice analysis shows that an added procedure in the troubleshooting process increases the cost by USD 100 and increases the customer waiting duration by 2 hours on average. With the development of digital intelligent capabilities, some operators have chosen to move the troubleshooting capability to the step closest to the fault to quickly realize closed-loop implementation, improving customer experience and E2E efficiency.

Some operators are exploring ways to transform the O&M mode in order to implement self-healing or one-hop closed-loop processing for events which affect services. For example, China Mobile has proposed to build a fault handling mode that integrates monitoring with maintenance. A monitoring room is transformed from "compressing alarms and generating tickets" to "identifying, handling, and closing service-affected events", that is, from "alarm-oriented monitoring" to "event-oriented closed-loop". This feature improves monitoring management efficiency, network service level, and customer experience. Vodafone has built an E2E automated troubleshooting mechanism using Ticket Journey. Based on capabilities such as cognitive intelligence and configuration automation, Vodafone plans to achieve an automatic fault closed-loop rate of 80% and a configuration automation rate of 80% by 2025.

The process of delivering O&M capabilities close to users and transforming the O&M mode is faced with the following challenges:

Challenge 1: Traditional O&M methods cannot adapt to the complexity of converged ICT networks. With the rapid development of the network cloudification, virtualization, and service convergence, devices and service processes become more complex, alarms increase exponentially, and sub-health problems surges. Traditional methods of adding sites and personnel and relying on expertise cannot meet the O&M requirements of complex services. The OPEX of operators has continued to increase in recent years. An industry report shows that a doubled CAPEX investment of an operator leads to three-fold increase in OPEX.

Challenge 2: Traditional O&M processes cannot fully utilize digitalized O&M capabilities. For example, a European operator uses a new automation engine to implement E2E automated troubleshooting. However, the lack of a corresponding O&M organization and process transformation makes production and implementation challenging for its OpCos.

To realize high-level ADN, we need to use cutting-edge technologies to improve capabilities and use advanced theories to develop new O&M mechanisms. We suggest the following:

1. **Finding a theoretical breakthrough point to ensure and improve the availability and reliability of complex networks:** Operators need to break the linear increase relationship between network complexity and O&M costs.

2. **Transforming O&M mechanisms, solving problems such as network faults and user complaints with a team closest to end users:** to achieve the goal of 15150 (1 minute discovery, 5 minutes diagnosis, 15 minutes recovery, and 0 service impact).

2.6 Trend 6: Exploring O&M Values from Edges. User Experience Is the Primary O&M Goal and O&M KPI for Business Success

Using network and O&M data to improve user experience and effectively increase revenues: A Huawei practice result shows that network data utilization accelerates the user development speed by 1.5x to 2x, and leads to 20% to 30% increase in user satisfaction, 5% to 8% increase in user value, and 0.5% to 1% reduction in user churn.

To maximize data value and improve user experience, operators are establishing dedicated data analysis teams. Having realized the value of data, operators have constructed data lakes over the past five years. However, it is impossible to maximize data value by merely relying on traditional data mining and analysis team. More and more operators are setting up dedicated data analysis teams. For example, LG U+ and XL Axiata have established data departments. LG U+ has set up a CDO position responsible for data service integration and development. The core goals of these operators are data-driven innovation, better customer experience, and improved productivity.

The process of exploring O&M values from edges and improving user experience is faced with the following challenges:

Challenge 1: It is getting difficult to evaluate user experience with indicators and rules. According to a practice of a Latin American operator, it is difficult to measure user experience simply with network quality indicators. In some areas with good network quality, user experience is not as good as expected. In complex service scenarios, user experience cannot be evaluated simply by testing network speed.

Challenge 2: There is a lack of spatiotemporal methods for analyzing user experience. A Chinese operator finds it hard to accurately optimize user experience based on the traditional cell mechanism, which fails to identify the dynamic complaining time and locations. Operators need dynamic spatiotemporal analysis methods to upgrade current measurement methods and assurance mechanism.

Utilizing O&M data value to improve user experience is one of the key points of high-level AN. We provide the following recommendations:

1. **Using AI technologies to evaluate user experience and providing support for O&M value exploration:** Network indicators and rules alone cannot accurately or dynamically evaluate user experience. AI technologies can be used to evaluate user experience in real time. Based on the practice and analysis of an operator in Latin America, a network key quality indicator (KQI) and user experience association AI model accurately identifies and optimizes poor-QoE areas, improving

the user-perceived rate by over 90% and releasing 71% more suppressed traffic. AI technologies maximize the network data value that is not fully used and apply network data analysis to develop the user base, increase user satisfaction, deliver more value, and retain users, continuously improving intelligence on user- and business-oriented decision-making.

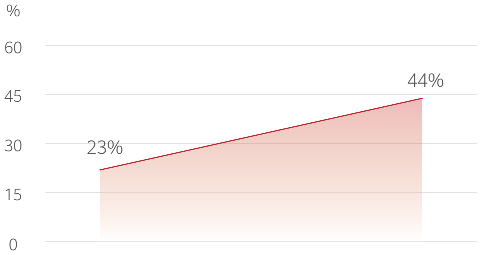
2. **Promoting spatiotemporal technology application and experience-driven network optimization:** The application of key capabilities needs to be accelerated, including AI-evaluated user experience and Traffic Autonomous Zone (TAZ). Driven by high business value scenarios requiring network optimization, such as complaint handling, customer satisfaction improvement, and performance benchmarking, operators should build a flexible and configurable poor-QoE feature framework (which includes indicators highly relevant to service experience and all-element data, such as events, time, and space data) based on cross-domain data (experience data, CHRs, traffic statistics, dialing test data) to provide optimal decision-making grounds for closed-loop network optimization.

2.7 Trend 7: IT Personnel Are Transforming into Technical Enablement Service Personnel. O&M Knowledge Is Injected in Low-Code Mode Through Digital Intelligent Means for Machine Training and Supervision

Agility and DevOps create digital-intelligent positions: Since 2019, Deutsche Telekom has shifted to a scaled agile framework (SAFe) that involves 10,000 IT personnel in agile product management and development, covering over 40% of employees. Telekom is upskilling personnel to adapt to future technical requirements. In Telekom's IT department, the proportion of personnel skilled with key technologies, such as software/system engineers, DevOps engineers, data scientists, architects, and agile experts, will increase from 23% to 44% by 2024. (*Transformation Case Study: Deutsche Telekom – 2021*)

Low-code platforms lower the entry barriers:

By 2024, more than 65% of applications will be developed in low-code mode. 90.2% of service personnel hope to quickly respond to service changes in a low-code manner, 88.9% hope to improve the productivity of technology development and O&M management, and 73.4% hope to explore agile innovation in a low-cost manner. (*LowCode: China's Low Code & No Code Industry Research Report in 2022*)



Increase in the proportion of personnel skilled with key technologies

Operators are trying different exploration methods: Over the past few years, Operators have been cooperating with IT vendors to implement network O&M automation. A European operator is cooperating with an IT vendor. In later years, an increasing number of operators have started to cooperate with communications vendors. A case in point is a Chinese operator's cooperation with Huawei, which involves equipping service personnel with scenario-based low-code technologies, long-term O&M experience of the operator, and the operator's understanding of Huawei technologies to make network O&M digital and intelligent.

The transformation of O&M personnel faces the following challenges:

Challenge 1: IT personnel domination stifles in-depth digital-intelligent service reconstruction. A European operator cooperated with an IT vendor to build an E2E automatic O&M platform, which thus far has not been effectively applied to practical network O&M to fulfill the 3-year goal of "reducing first-line support personnel's workload by 80% through automation." The reason is that the cognitive automation team members (automation experts, process analysts & engineers, and cognitive experts) are mainly IT personnel. Although this skill model can quickly implement automation capabilities in some scenarios, it is difficult to effectively control maintenance services with complex scenarios and discrete problems. Therefore, the model cannot resolve actual problems in the production environment of each subnet.

Challenge 2: The application effect of common low-code platforms in network O&M scenarios is insufficient. Common low-code technologies achieve agile development by means of balancing high flexibility and high encapsulation as well as balancing communication-based orchestration and IT-based orchestration in common scenarios. However, these technologies do not make it easier for O&M personnel to manage services in different scenarios, meet different network security requirements, process different data formats, use control instructions of different granularities, or operate devices provided by different vendors in the same system. Therefore, the applications of common low-code technologies are limited to non-core scenarios, such as online management, process orchestration, and third-party integration, and are difficult to replicate.

A highly skilled workforce is essential for digital transformation. We suggest increasing investment in upskilling personnel to realize the evolution toward high-level AN. We provide the following suggestions:

1. **Encouraging and carrying out employee training and reskilling, and driving service personnel to participate in the digital process.**

2. **Introducing a proper low-code platform to build development, data governance, and analysis processes and methods:** For example, China Mobile Zhejiang and Huawei analyzed and abstracted fault cases of the cloud core network spanning over a year, classified the faults into dozens of atomic troubleshooting capabilities by means of systematic design, implemented high encapsulation of network and O&M capabilities, and simplified the development process of upper-layer service applications. Consequently, the service planning and rollout period was shortened from three months to one month.

3. **Combining organizational and process transformations with incentive mechanisms to stimulate employees' creativity and encourage employees to create value together with customers.**

2.8 Trend 8: AI Foundation Models Gradually Go Beyond Voice & Images into Vertical Fields. The Telecom Industry Has the Huge Amount of Data Required to Build Foundation Models in Scenarios Like Energy Saving, Prediction, and Unknown Fault Handling. Compared with the Existing Solutions, Such Models Will Yield Breakthrough Results

Tech giants and AI research institutes around the world are all researching pre-trained foundation models. Since Google released its foundation model, BERT, in 2018, global tech giants have focused their efforts on the foundation model technology. In the US, organizations such as OpenAI, Google, Microsoft, and Facebook have developed foundation models with hundreds of billions or trillions of parameters — prominent examples include GPT-3, Switch Transformer, and MT-NLG. In China, we have many foundation models, including M6 from Alibaba, Wenxin from Baidu, Hunyuan from Tencent, and Pangu from Huawei. Foundation models have evolved from NLP to CV, cross-modal, biological computing, and industry-specific models, and have enabled various industries. Their applications in law, healthcare, education, and telecom have resulted in a positive impact on industry development. In August 2021, more than 100 scholars, including prestigious AI experts Percy Liang and Feifei Li, jointly published the paper On the Opportunities and Risk of Foundation Models, which systematically explains the opportunities and challenges regarding pre-trained foundation models. In the same year, Stanford University established Center for Research on Foundation Models (CRFM).

With the support of foundation models, generalization is now possible with big data. Before the emergence of foundation models, AI development was by no means a "general-purpose" process. Any application in any scenario requires a group of technical experts to develop dedicated AI models. If a new application is required, development has to start from the very beginning, which is as time-consuming and labor-consuming as manual work. This represents one of the biggest obstacles in implementing AI in industries. Foundation models provide a new solution to this long-standing problem. Built on huge amounts of data and innumerable parameters, foundation models possess the basic capabilities that are required in a large class of scenarios. After initial development, the models can be fine-tuned and then applied to a wide range of downstream tasks to meet different application requirements. Foundation models have three main advantages:

- Higher model development efficiency: Foundation models are trained in advance. When they are used in different scenarios, they only need to learn a little more to get themselves ready for the scenarios. This allows AI applications to be quickly deployed and applied, transforming manual work into automated assembly lines.

- Lower cost: Foundation models adopt a self-supervised learning method, so they are less dependent on data labeling. To some extent, this method solves the problems of high cost and long periods that are characteristics of manual labeling. Downstream developers can get what they need simply by training small samples, which greatly reduces development cost.

- Breakthrough: In order to improve model precision, existing AI models typically optimize the neural network structure, but this approach hits a bottleneck. Foundation models, on the other hand, expand the data and parameter scales, and will therefore improve model precision.

In future telecom networks, AI will be widely used in various service scenarios. Given that telecom service scenarios have abundant data samples, foundation model technology can be leveraged to solve engineering problems, such as AI generalization and model fragmentation, and the "pre-trained foundation models + downstream task fine-tuning" pattern can be introduced to accelerate the implementation of AI and improve the effects of AI applications. After being researched and practiced across industries, foundation models have demonstrated their value in some telecom scenarios: Taking core network as an example, the machine language foundation models that have been developed to learn features from massive amounts of data through a large number of parameters, yielding more precise models for core network fault demarcation and wider coverage of services. In terms of model development, secondary development of pre-trained models shortens the time required to develop AI models and improves development efficiency by 80%. In terms of application effects, horizontal demarcation across NEs and vertical demarcation inside an NE take mere minutes to pinpoint the smallest recoverable unit. In addition to higher accuracy in identifying known faults, unknown faults can be automatically demarcated. This signals a qualitative leap forward.

Foundation models have stringent requirements on computing resources and data volume. In view of these technical limitations, the telecom industry still has a long way to go with regard to the research and application of these models. The following suggestions may be helpful for developing foundation models in the telecom field:

1. Currently, the technical architecture of foundation models is applicable to a limited range of scenarios. Considering the numerous service scenarios in the telecom industry, it is unrealistic thus far to use a one-size-fits-all foundation model to solve all tasks. A more feasible approach would be to start from a few domains, for example, the core network. In the core network, which is mostly cloudified now, it is easy to collect a large number of data samples from O&M. Once the application effect is self-evident, the foundation models will be widely adopted across the telecom field.

2. Foundation models need massive amounts of data, but it is difficult to collect sufficient data samples from one operator network alone. To support the innovation and research of foundation models, it is recommended that an industry alliance be set up to organize all parties in building a unified data sample library, which in turn will supply sufficient data samples to all parties during innovation and research. This will also facilitate large-scale adoption of telecom foundation models.

3. Due to factors such as training costs, foundation models are fraught with heavy investment and high risks. A wise move for the telecom industry would be to "have big vendors pre-train models and operators apply the models". The essence is to unite the efforts of different parties that have different focuses so as to save on resources while also implementing more and better AI applications.

2.9 Trend 9: Cognitive Intelligence Integrates Telecom Expertise with the Advantages of Data-based Deep Learning, and Is Expected to Become the Key Technology for Developing the Next-generation Intelligent Network Operations System

Computational intelligence and cognitive intelligence are the different phases of AI. Computational intelligence involves basic logic operations and statistical analysis. Limited by regulated data logic rules, computational intelligence cannot use expertise to perform in-depth, dynamic, and heuristic reasoning. Cognitive intelligence technology is regarded as the next phase of intelligent development. It uses expertise to analyze, determine, and make decisions based on its understanding of data logic. Cognitive intelligence effectively integrates data and knowledge, and further promotes AI and system innovation. Besides solving complex problems, cognitive intelligence can improve the explainability of intelligence.

The development of cognitive intelligence represents a new era, which will accelerate the application of AI in the telecom industry. There is a positive attitude in the industry with regard to the future of cognitive intelligence. In June 2022, China's Artificial Intelligence Industry Alliance (AIIA) and CAICT jointly released the White Paper on Knowledge Computing, pointing out that in the AI 2.0 era, data and knowledge are the two most important basic elements, and various types of knowledge should be fully used. The collaboration of knowledge and data will facilitate the innovation of AI algorithms and systems. According to a Deloitte survey, 40% of operators, media, and technology executives say they have benefited from cognitive intelligence, and 25% have invested more than USD 10 million in it. More than 75% expect cognitive computing to "substantially change" their companies over the next three years. In addition, Gartner released the Emerging Technologies and Trends Impact Radar 2021, which listed Advanced Virtual Assistants (with cognitive intelligence at its core) as one of the 23 most influential technologies. Some telecom operators are attempting to incorporate knowledge into the overall digital intelligent network solution based on the cognitive intelligence technology, build a Knowledge as a Service (KaaS) framework, and take the lead in integrating knowledge into fault diagnosis.

In the telecom industry, services are heavily reliant on expertise and require secure and reliable AI applications. Based on current research, cognitive intelligence is expected to inject new impetus to network intelligence.

- As a national infrastructure, telecommunication relies upon secure operations and explainable inference that underpins major operations. Cognitive intelligence applies knowledge deduction to inference. Take fault diagnosis as an example. Besides fault demarcation, knowledge inference+machine learning can visualize the propagation and causal process of abnormal events, which improves explainability.

- Cognitive intelligence makes intelligent applications perform better in complex scenarios. Cross-domain fault demarcation and locating in telecom networks involve various types of NEs, data sources, and multi-layer deployment resources (NEs/PaaS/IaaS). Traditional AI cannot apply expertise in complex scenarios, making challenges in precise demarcation difficult. The cognitive intelligence technology integrates the relationships between networking and service modules into fault diagnosis, and analyzes and identifies diagnosis results based on knowledge, performing high-precision fault diagnosis in complex scenarios.

- Cognitive intelligence enables knowledge evolution in the telecom industry. Take the core network as an example. Cognitive intelligence is used to obtain knowledge about fault propagation in machine data and automatically confirm the knowledge using technologies such as abduction, thereby implementing self-learning and self-evolution.

Evolution towards ADN Level 5 means that people are less involved in the network lifecycle. Cognitive intelligence technology uses human-like decision-making methods to make the network more intelligent, supporting the evolution towards Level 5. In fault O&M scenarios, this technology increases the fault demarcation accuracy to more than 95% and makes fault demarcation results highly explainable. Recovery commands can be automatically generated based on knowledge to implement automatic network recovery. In carrier network O&M scenarios, cognitive intelligence technology can be used to automate fault O&M and implement self-learning of fault knowledge. As a next-generation AI technology, cognitive intelligence is about generalization and explainability. Being a key technology for ADN, cognitive intelligence is still in the innovation and exploration phase. To accelerate its application in the telecom industry, we provide the following suggestions:

1. **Applying cognitive intelligence in the O&M domain first in view of the complex O&M scenarios and massive expertise requirements:** Based on the idea of integrating knowledge with data, cognitive intelligence technology can be used to implement automated, accurate fault O&M, and improve explainability.

2. **Starting from the usage of virtual assistants:** Before ADN Level 5, man-machine symbiosis is still required where virtual assistants based on cognitive intelligence can collaborate with people and gradually participate in network decision-making and execution to implement self-learning and self-evolution. The autonomy and self-healing of ADN Level 5 in O&M scenarios can be achieved.

3. **Establishing standards:** The telecom industry standards for knowledge should be established to facilitate knowledge sharing, interaction, and development of cognitive capability by all stakeholders in the industry.

2.10 Trend 10: Digital Twins Become a Crucial Intelligent and Automation Technology for the Full Network Lifecycle

Since Dr. Michael Grieves first proposed the concept of digital twins in 2002, it has been successfully applied in various industries, including city construction, aerospace, and smart manufacturing. It was elected one of Gartner's top 10 strategic technology trends for three consecutive years from 2017 to 2019. Digital twins are expected to reach the Plateau of Productivity in the Gartner Hype Cycle over the next five years.

In the field of smart manufacturing, digital model design technologies are used to map the attributes of physical devices to a virtual space, generating digital images that can be disassembled, replicated, transferred, modified, deleted, and repetitively operated. In the three-dimensional digital virtual space, the sizes and assembly relations of components and products can be quickly and conveniently modified, significantly reducing the number of physical prototypes and reducing the time and cost of making the prototypes. In addition, digital twins collect a limited amount of key performance indicator (KPI) data from sensors, and use historical data patterns and machine learning to predict KPIs that cannot be directly measured. This method can be used to evaluate the current status, diagnose problems, and predict future trends. The analysis results can be used to simulate all possible scenarios and facilitate decision-making. After being developed for over more than a decade, digital twins have been successfully applied in urban construction, satellite networks, and production environments.

In the field of smart city, digital twins improve the quality and standard of city planning, facilitate city design and construction, and assist city management and operation, improving the urban environment. Take Xiong'an New Area, a state-level new area in the Baoding area of Hebei, China, as an example. It has set the goal of evolving towards a world-leading digital city. A digital twins city includes five aspects: physical city, virtual city, big data, virtual-reality interaction, and intelligent services. Sensors are deployed on urban construction devices to detect and monitor the city's running status. A digital twins model is developed to simulate the entire physical city. Running data is collected to optimize the digital twins. The virtual-reality interaction of the digital twins can provide intelligent services, such as city planning and design, and municipal planning optimization. Singapore has collaborated with Dassault Systèmes to build a digital twins city that monitors everything from bus stations to buildings. Cityzenith has deployed a 5D Smart City to digitalize infrastructure development and city management throughout the entire lifecycle.

The role of network infrastructure is becoming increasingly important in a developing global economy. Home quarantine, as a most effective measure against the COVID-19 pandemic, has increased the demand for Internet access. The network load and scale continue to increase, and the number of connections is growing exponentially and is expected to reach 200 billion by 2030. Meanwhile, cloud and virtualization technologies are increasing network complexity. We are faced the following challenges:

1. Evaluating the impacts of network changes becomes a new challenge due to the lack of simulation and verification methods.

2. No effective method is available to evaluate the risks and potential threats, affecting network stability.

3. It takes longer to develop innovative network technologies and services.

Digital twins can create virtual images of physical network infrastructure to build a digital twin network with the same NEs, topologies, services, and data as those on the physical network. The digital twin network is a test bed for verifying network configurations and new technologies. It can significantly reduce live-network risks and prevent faults caused by incorrect configurations. It is also key to various scenarios, such as holographic visualization of network traffic and full-lifecycle NE management. Real-time interaction between the physical network and twin network can lower the trial-and-error cost, facilitate intelligent decisions, and improves the efficiency of innovation, achieving simplified and intelligent O&M.

Digital virtual twins can be created for physical network entities in order to build a system that can interact with and map physical network entities in real time. The core elements of the digital twin network are data awareness, model definition, twin mirroring, and virtual-reality interaction.

1. Data awareness: High-performance approximate network measurement is studied to achieve approximately error-free measurement. Data at the physical network layer, including physical entity data, space data, resource data, protocols, interfaces, routes, signaling, processes, performance, alarms, logs, and status, is collected and stored to the data warehouse in real time or non-real time. The data is then used to build and empower network twins.

2. Model definition: Layered network abstraction is implemented to study and define layered abstract models oriented to network twins. The models are defined based on data for various network applications.

3. Twin mirroring: Network twins are used to map physical network entities on a high-fidelity page in visualized mode in order to form a twin mirror for the twin network and physical network.

4. Virtual-reality interaction: Various technologies, including big data analysis, AI algorithms, and cognitive intelligence, are used to implement full-lifecycle analysis, diagnosis, simulation, and control of physical networks, achieving closed-loop control of the digital twin network and physical network.

03

Huawei ADN Solution

The vision and mission of Huawei is to bring digital to every person, home, and organization, and build a fully connected, intelligent world. Building a fully connected, intelligent world is a process of helping various industries to implement digital transformation. Huawei is committed to continuous innovation in cloud services, AI, networks, and low-carbon development to accelerate digital development, spark a new revolution for human civilization, and stimulate industry innovation, industry upgrade, and social development.

Ubiquitous cloud services

Pervasive AI

ADN

Low-carbon development benefiting from digital technologies

Huawei ADN solution is designed to embrace the trend in the AN industry. As one of Huawei's four initiatives for continuous digital innovation, ADN aims to leverage connectivity and intelligence to deploy a self-fulfilling, self-healing, and self-optimizing autonomous network. ADN implements single-domain autonomy and cross-domain collaboration to develop self-configuration, self-healing, and self-optimizing network O&M capabilities with operators and enterprises, delivering a zero-wait, zero-touch, and zero-trouble experience to both individual consumers, and public sector and enterprise customers.

According to Huawei's Intelligent World 2030 report, a seamless intelligent network that covers land, sea, and air is the future. The network will provide ubiquitous cloud-edge-device convergence services in all production scenarios, achieving fully autonomous communications networks. Such communications networks will continue to play a leading role in promoting the development of the world and accelerate the advent of a more intelligent world. ADN is a core strategy of Huawei Communications Network 2030.

3.1 Architecture and Features of Huawei ADN Solution

The telecom industry needs a clear service architecture as a reference and the consensus to carry out production practices in order to achieve the goal of reaching high ANLs. Based on this architecture, operators can systematically evaluate and analyze the architecture of current OSSs, integrated NMSs, vendor NMSs/controllers, and network devices from top to bottom, and formulate a feasible evolution roadmap that meets their own requirements. Based on the suggestions for the service architecture provided by TM Forum in IG1218 and various innovative practices jointly carried out with global operators, Huawei proposes the following ADN service architecture.

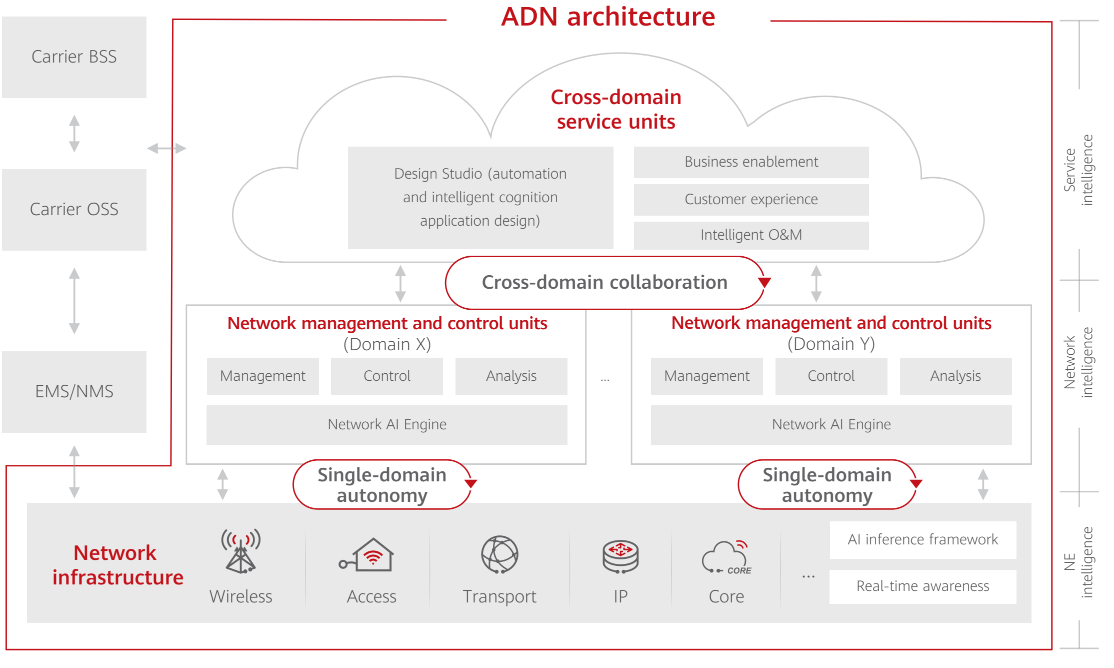


Figure 3-1 ADN service architecture

Intelligent network infrastructure is fundamental to high-level AN. Network devices need to have more real-time sensing components and AI inference capabilities to detect the changes of resources, services, and surrounding environments, and the capabilities for intelligent analysis, decision-making, and execution.

A network management and control unit integrates network management, control, and analysis modules to automatically translate upper-level intents of services and applications into network behavior, realizing single-domain autonomous closed-loop and continuous SLA assurance. Meanwhile, based on the built-in network AI engine, it continuously conducts AI training and knowledge extraction to constantly strengthen AI models and enrich network experience, making the network more intelligent.

Cross-domain service units provide three capabilities (intelligence business innovation, customer experience improvement, and service and network O&M assurance), an application design and development platform, and cloud services. This platform focuses on O&M and business process streamlining, and flexible service orchestration based on network characteristics. It can be used to quickly and iteratively develop new business models, O&M processes, service applications, and business products and services. This is the key for operators to achieve business agility and improve the skills of new O&M personnel and business design personnel.

The network AI unit, a basic platform for network AI design and development, performs continuous AI training and knowledge extraction for various types of telecom network data to generate AI models and network knowledge. The AI models and network knowledge can be injected into the other three units to make the network more intelligent. The network AI unit also acts as an asset center for operators' AI assets. It manages AI models and network knowledge developed and trained by operators during planning, construction, maintenance, and optimization. The AI models and knowledge can be fully shared and reused to reduce repetitive development and training.

Features of the ADN Solution

Native Intelligence

As the foundation of ADN, network infrastructure plays an indispensable role. For AN to advance toward higher levels, the network infrastructure needs to provide more powerful capabilities, including real-time awareness, local reference, and edge computing. As a thriving technology, AI empowers the infrastructure layer with new capabilities. NE AI uses distributed computing power to implement local inference based on a large amount of KPI data generated by NEs. This enables quick risk awareness and analysis, while reducing the amount of data sent to the network layer and the amount of computing power required in the management system. NE AI also implements AI-based edge inference and NE-level quick fault self-healing and decision-making.

For example, Huawei's innovative IP service flow detection protocols, such as In-situ Flow Information Telemetry (IFIT), enable EMSs to quickly and automatically locate faults in complex IP network topologies when service poor-QoE problems or faults occur. IPv6+ greatly simplifies service provisioning processes and improves the automation level of service provisioning. AEC boards on access network optical line terminations (OLTs) can analyze application KPIs or KQIs to identify poor-QoE users. The optical iris technology of DQ-ODN can visualize last-mile dumb fiber resources. Huawei's optical transmission products can identify co-cable fibers to prevent SRLG problems.

Single-Domain Autonomy

The network infrastructure layer and the network management and control layer are coupled. Different network domains have different characteristics. The increasing network complexity and improved capabilities in terms of network infrastructure make network management and control more complex. In particular, cross-layer and multi-domain management becomes challenging. Autonomy must be achieved for each network domain before cross-domain management can be realized through cross-domain orchestration. Different ADs provide standard northbound interfaces (NBIs) for the upper-layer OSS or service orchestration system. The upper-layer OSS or service orchestration system invokes and orchestrates the capabilities of each domain to provide services across multiple domains. Devices at the network infrastructure layer introduce many new functions. Standard interfaces cannot be quickly developed for these new functions. Coupling devices at the infrastructure layer and the network management and control system of the device vendors can speed up and improve single-domain autonomy.

For example, intelligent energy saving for wireless base stations requires dynamic and precise adjustment of many device parameters by a network management and control system at the base stations. Huawei's network management and control systems can predict cell traffic based on real-time network data and quickly adjust energy saving policies to realize energy saving while keeping KPIs stable.

Open Collaboration

Most telecom services are dependent on single-domain autonomy and open collaboration. The upper-layer OSS and service layer focus on service policies and innovation, and the lower-layer network management and control layer and infrastructure layer focus on service implementation and technology innovation. Standard intent APIs are developed for the network management and control system in each AD to completely decouple the network management and control layer from the service layer and OSS layer. Services and OSSs invoke these APIs to implement cross-domain service management, including service provisioning and fault correlation analysis.

Take service provisioning as an example. An OSS uses open APIs to deliver service intents, such as source and sink nodes and service SLAs, to the network management and control system in each domain. The network management and control system in each domain independently plans and prepares functions and parameters required for provisioning services in the domain and deliver configurations to devices in the domain, including device addresses, tunnel addresses, tunnel types, and tunnel parameters. Finally, multiple domains collaborate to quickly configure services.

3.2 Panorama of Huawei ADN Solution

Since Huawei first proposed the concept of ADN at UBBF 2018, it has developed a series of innovative ADN schemes for various domains, including wireless, core, access, transport, IP networks, data centers, and enterprise campuses. Adhering to the concept of Intelligence for ICT, Huawei is committed to systematically applying AI technologies to ICT infrastructure in order to overcome key challenges and fulfill the vision of building an intelligent world.

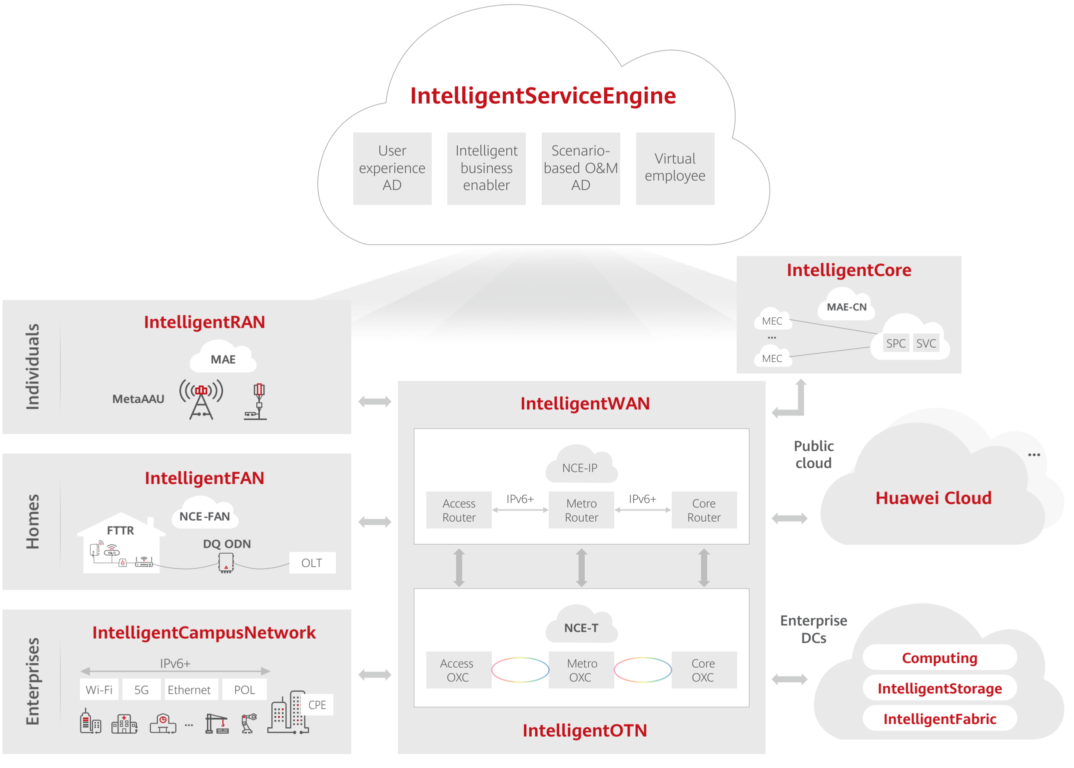


Figure 3-2 Products and panorama of the ADN solution

3.2.1 IntelligentRAN — Wireless ADN

As the Huawei ADN solution for wireless networks, IntelligentRAN will enable wireless networks to evolve from automatic O&M to intelligent networks. IntelligentRAN focuses on intelligent functions on the RAN side. It uses iMaster Mobile Automation Engine (MAE) to implement single-domain single-vendor basic O&M in the wireless domain. In addition, it features the Mobile Intelligent Engine (MIE), providing intelligent UCs in cooperation with NEs. Intelligent atomic capabilities are opened to the cloud through an intent interface.

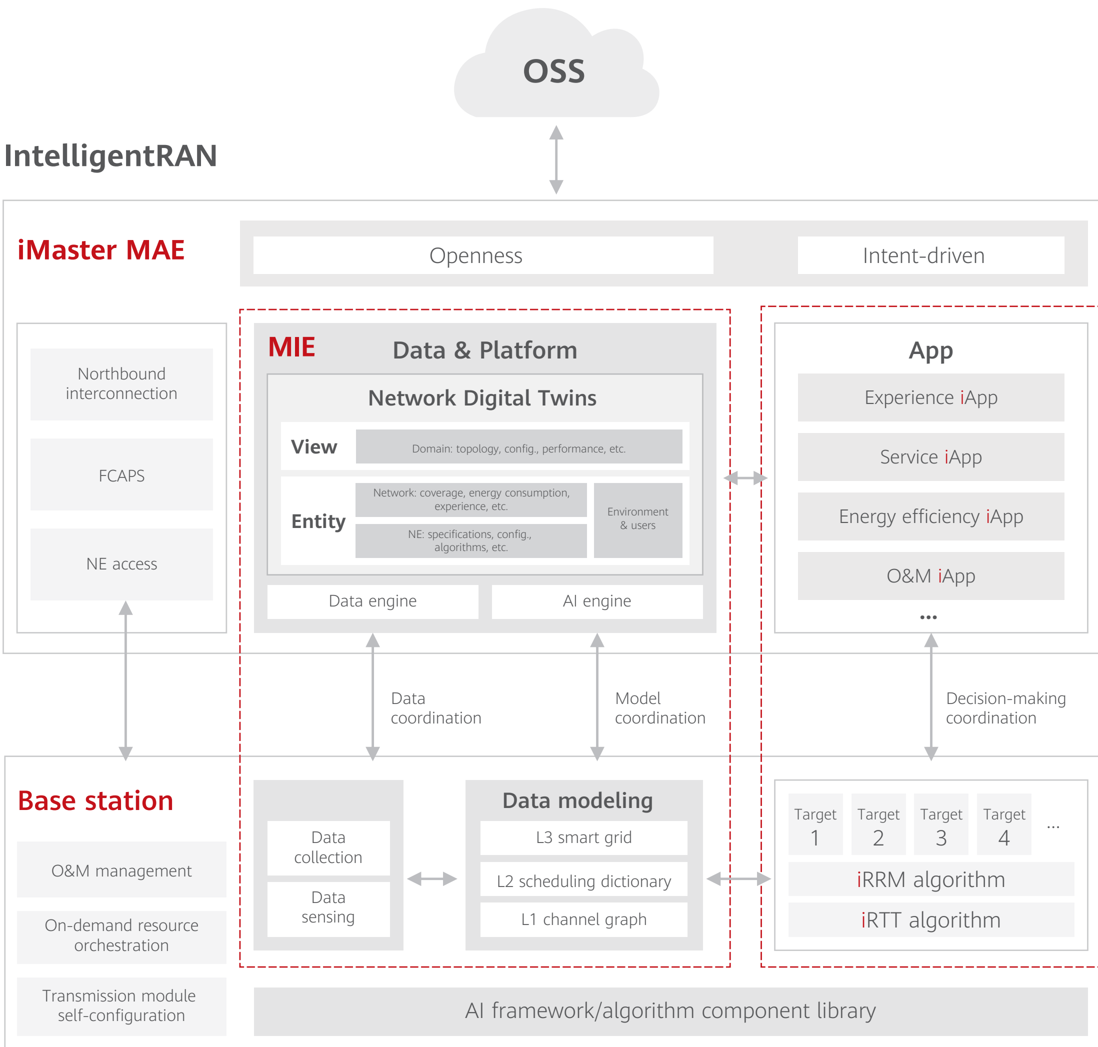


Figure 3-3 IntelligentRAN

Highlights

With the continuous evolution of mobile networks from 2G, 3G, and 4G to 5G, 5.5G, and 6G, mobile network capabilities will be further upgraded and services will be increasingly diversified, and network complexity will continue to increase. The following structural challenges of mobile networks will become more prominent.

1. Challenge 1: how to implement simplified

O&M with increasing network complexity

2. Challenge 2: how to cope with 100-fold traffic growth with energy consumption slightly increased

3. Challenge 3: how to ensure optimal service experience while providing diversified services

In response to these challenges, IntelligentRAN integrates intelligent capabilities into wireless network services, experience, O&M, and energy saving to build a wireless ADN network that features intelligent and simplified O&M, intelligent network optimization, and intelligent service operations.

- Intelligent and simplified O&M: Based on key platforms and technologies such as the expert knowledge base, prediction algorithm, and neural network, intelligent alarm management in the wireless domain is provided to accurately identify alarms, quickly locate faults, and predict and prevent faults. This feature helps operators transform from responsive O&M to predictive and preventive O&M, achieving "zero" network faults.

- Intelligent network optimization: Intelligent NEs are introduced for intelligent resource scheduling in order to optimize user experience and capacity and maximize spectral efficiency in the multi-band and multi-site heterogeneous network. In addition, the network-level intelligent engine is used to implement intelligent collaboration based on multiple intents and objectives, helping operators transform their goals from optimal performance to optimal performance+energy consumption, maximizing network energy saving while ensuring a stable network performance.

- Intelligent service operations: Based on differentiated service SLA requirements, user-level dynamic simulation is used to implement precise network planning based on coverage, rate, and latency, enabling fast service deployment and provisioning. In addition, based on prediction capabilities, real-time dynamic resource scheduling is implemented to ensure service experience and implement service-oriented network adjustment.

Key UCs

1. Intelligent and simplified O&M

- Prediction-based fault management, transforming troubleshooting from passive and responsive O&M to proactive troubleshooting: ToC and ToB services carried on mobile networks are required to be always online. Traditional responsive O&M based on post-event work orders cannot meet these requirements. iMaster MAE accurately identifies alarms and locates faults by enhancing fault awareness capabilities. In addition, iMaster MAE predicts and analyzes software and hardware faults and performance deterioration (such as high temperature of boards, optical module faults, and short power backup duration) on the network based on long- and short-period awareness data obtained through collaboration between the NMS and NEs. This facilitates fault rectification and eliminates risks, achieving "zero" network faults and improving performance reliability.

2. Intelligent network optimization

- Intelligent selection of multi-band carriers based on smart grids, achieving optimal network performance: A wireless network typically uses multiple frequency bands, each of which has different characteristics. Coordination between frequency bands is critical to improving the spectral efficiency of the entire network. In complex multi-band networks, intelligent schemes are used to improve multi-band coordination efficiency and combine the advantages of different frequency bands to achieve optimal network performance.

- Multi-intent-based multi-dimensional collaborative energy saving, optimizing both performance and energy saving: Low-carbon emissions have become a common concern of the communications industry and the global society. Energy efficiency has become an important indicator for mobile communications networks. Intelligent algorithms and models are therefore introduced to determine optimal policies for saving energy dynamically, multi-dimensionally, and coordinatively based on the traffic and environment, achieving network scenario auto-adaptation, one policy for one site, and multi-network coordination.

This maximizes the network energy saving effect while ensuring a stable network performance, and strikes an optimal balance between energy consumption and KPIs. It enables the transition from performance-oriented networks to networks that balance performance and energy consumption.

3. Intelligent service operations

- SLA-oriented precise network evaluation and planning, facilitating precise and fast service provisioning: There are a variety of 5GtoB services. The services have high SLA requirements and the application environments are complex. The traditional mode of manual network planning based on expert experience cannot meet the deterministic network planning requirements of thousands of industries. In a scenario involving public network for dedicated use, the network coverage and data rate of given areas are accurately evaluated, greatly reducing the cost of onsite measurement and evaluation. In industry-specific network scenarios, industry profiles, environment modeling, user-level simulation evaluation, and SLA-based precise planning are used to meet SLA requirements of various services on the live network, improving network planning efficiency.

- Prediction-based slice SLA assurance, enabling service-oriented network changes: Traditionally, resources are reserved for slice SLA assurance. To ensure services run stably, largely redundant resources are reserved, resulting in resource idleness. The prediction capability is therefore introduced to implement adaptive slice SLA assurance, improving resource utilization while ensuring slice SLA.

3.2.2 IntelligentCore — Core Network ADN

Adhering to the cloud-based O&M transformation concept "high network stability, intelligent and simplified O&M, and optimal user experience", Huawei core network ADN solution integrates and innovates many core network products and professional service tools to make network-wide data assets visualized, manageable, and traceable. AI technologies, such as data native, intelligent analysis, model training, AI inference, and intent insight, are introduced to provide automation and intelligence capabilities at different network layers (including the telecom cloud base, 5GC, and SVC at the NE layer, and iMaster MAE-CN at the management and control layer). In this way, this solution helps operators build a core network that features full-process automation, automatic self-healing, and self-optimization.

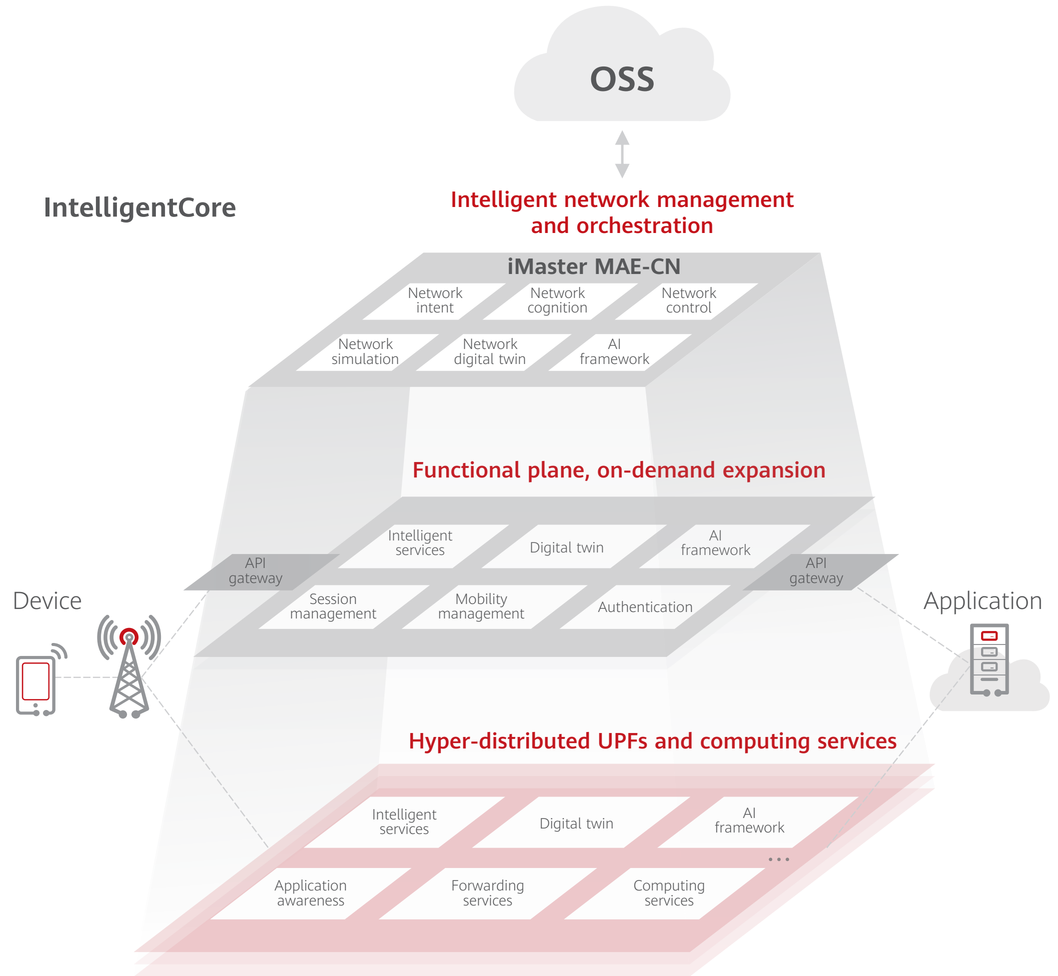


Figure 3-4 IntelligentCore

Highlights

Catering to the requirements of cloud-based O&M transformation and new 5G services, the Huawei core network ADN solution builds capabilities in network maintenance, operation delivery, and experience closed-loop management, helping operators achieve intelligent data transformation.

- High stability of always-online services: Based on expert experience, knowledge graph, AI self-learning, and digital simulation, single-domain fault maintenance of telecom cloud and core network NEs is implemented in a closed-loop manner. NE/module-level fault management capabilities are built to implement sub-health prediction, precise fault demarcation, and quick self-healing. This ensures that always-online communication services can be provided for consumers and enterprise users, and enables operators to transform their O&M mode of cloud-based infrastructure from passive response to proactive drilling, detection, prevention, and treatment.

- E2E network operation automation: Intelligent and simplified delivery capabilities are built for routine operation scenarios, such as upgrade, capacity expansion, migration, and testing. Based on the digital twin technology and cloud-based Continuous Integration Continuous Delivery (CICD) tool chain, the solution exponentially reduces the complexity of routine operations on cloud-based networks. Driven by user intent, the solution streamlines the delivery process, achieves automatic delivery throughout the entire process based on the pipeline, and ensures lossless and secure change operations.

- Refined and personalized experience optimization: Native AI is used to transform from network quality-centric management to personalized user experience-centric management (service experience standard, experience awareness, and experience closed-loop), and provide enterprise-level service SLA assurance for customers in different industries, achieving experience monetization.

Key UCs

1. Fault Scenario — High-Stability Network

The core network is crucial for the entire network. It bears services for a large number of users, and its fault has a wide impact scope. Therefore, high stability is always a priority for the core network. Huawei core network ADN solution introduces intelligent methods to provide routine DR drill, health check, prediction, and diagnosis and troubleshooting capabilities, ensuring high stability and reliability of the core network.

- Health check: The solution evaluates network reliability, ensures the availability of key resources, and prevents emergency faults.

- Routine drill: The entire process is visualized and the DR drill efficiency is high.

- Expert diagnosis: The solution provides fast fault detection and accurate demarcation and locating capabilities. Faults are demarcated to the minimum risk operation unit, facilitating service recovery.

- Health prediction: The health management mode is transformed from passive handling to proactive prevention, and subhealth issues can be prevented without human intervention.

2. Network Change Scenario — Intelligent and Simplified Operations

Traditionally, network changes (such as upgrade and capacity expansion) are performed manually. The operation procedure is complex, and requires a large amount of manual intervention, leading to low efficiency and high possibility of upgrade risks. Based on the advanced DevOps concept in the industry, Huawei core network ADN solution implements efficient and secure change operations.

- Automation: The E2E tool chain eliminates the breakpoints of manual operations, reduces manual intervention, and improves the delivery efficiency in all scenarios, including upgrade, capacity expansion, and cutover.

- Lossless change: The operation simulation capability is used to implement low-cost trial-and-error of operations such as dynamic elastic capacity expansion, realizing seamless service operation changes.

3. Optimization Scenario — Optimal User Experience

User experience management faces new challenges in different phases of 5G commercial use. Good user experience is the basis for user satisfaction. Huawei core network ADN solution transforms the goal from being network-centric into being user experience-centric and value-centric, improving user experience.

- Experience optimization: To improve user experience for key services such as VoNR and ViNR, native AI is used and the tool chain is optimized. This ensures quick call setup, high voice quality, and zero call drops during communication, reducing the subscriber churn rate.

3.2.3 IntelligentWAN — IP ADN

Huawei IP ADN solution has a set of key components, including intelligent IP network routers (such as NetEngine, NE, ATN, and CX series) and intelligent network management and control system (iMaster NCE). For IP networks, iMaster NCE offers Path Computing Element, intelligent O&M, and open programmability to implement full-lifecycle automatic scheduling of network traffic, helping operators build leading next-generation E2E intelligent IP networks.

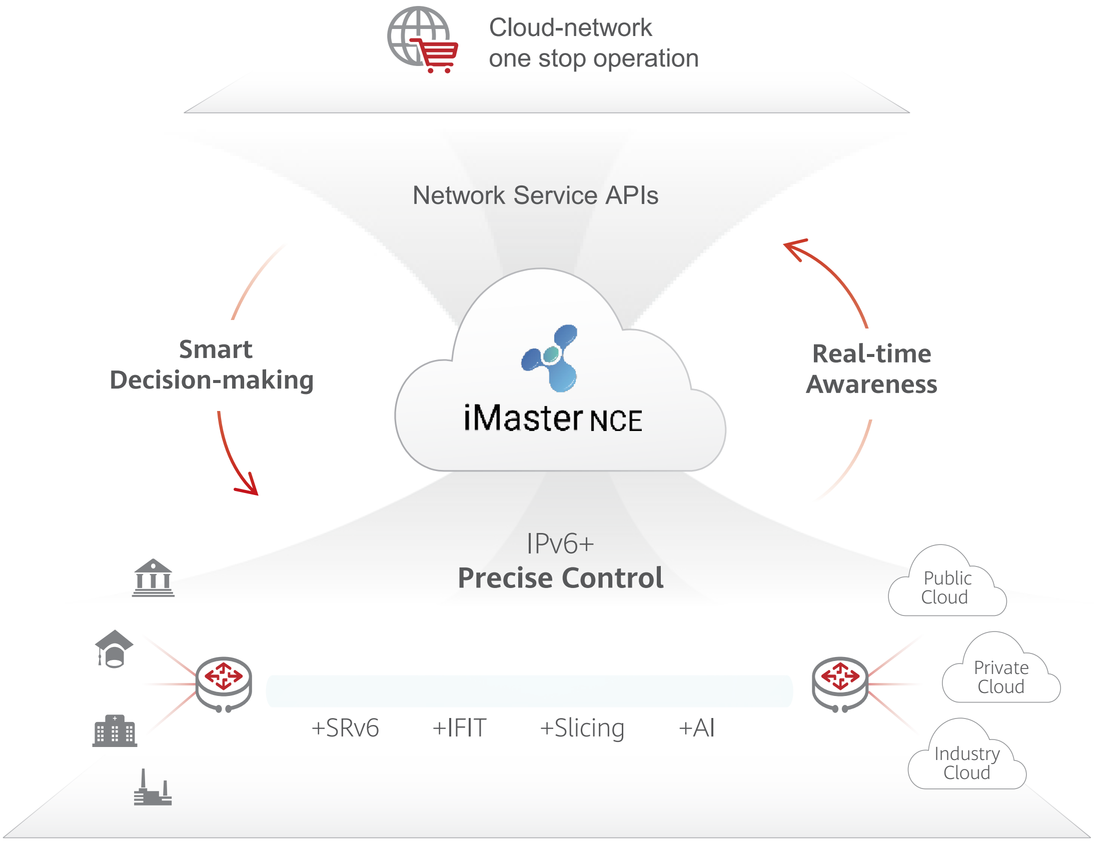


Figure 3-5 IntelligentWAN

Highlights

1. **Path Computing Element and One Connection for Visualization reduce integration complexity by 50%.** Multidimensional indicators such as latency and bandwidth utilization are displayed on the network digital map in real time. During path computation and optimization, up to 15+ factors are flexibly combined to automatically schedule network traffic throughout the lifecycle.

2. **"Congestion Free" facilitates "Troubleshooting 0-1-3-5".** "Troubleshooting 0-1-3-5" is a fault-oriented closed-loop solution in which "0-1-3-5" refers to the minutes needed for "prevention-identification-demarcation/locating-recovery". This solution aims to build a self-optimizing and self-healing IP transport network with the best possible service experience.

3. **Open programmability accelerates service rollout with "three 1s".** Based on YANG models, iMaster NCE provides end-to-end open programmability, including device driver programmability, network service programmability, and open APIs for devices and services. These capabilities make it possible to complete prototyping in 1 week, testing in 1 month, and commercialization in 1 quarter. More importantly, operators' O&M personnel are empowered to don the IT hat.

Key UCs

1. **Network digital map:** Thanks to technologies like BGP-LS and Telemetry, indicators such as network latency, bandwidth, and utilization are visualized in a topology, in real time. Navigation-like path computation and one-stop provisioning in a map make configuration simple and efficient. Network paths are automatically optimized based on SLAs to continuously guarantee user experience.

2. **Network risk analysis:** In the big data + three-layer AI architecture (device/network/cloud), devices are built with AI chips for real-time awareness, networks leverage AI models to construct local knowledge bases, and the cloud provides an AI training platform for federated learning. All this enables risk-centric predictive O&M that features configuration check, device KPI detection, device resource prediction, strong/weak signal analysis, co-routing impact analysis, and risky link identification.

3. **VPN service assurance:** The IFIT technology visualizes tenant-level service SLAs and provides differentiated private line services. In addition, VPN service topology restoration and KPI association analysis are used to demarcate faults in minutes, quickly identify fault points, and accurately dispatch trouble tickets.

4. **Mobile transport congestion analysis:** From the perspective of base stations, iMaster NCE displays the quality trend of network-wide/regional base stations, and supports E2E topology restoration and SLA association analysis in order to identify congestion points and provide root causes and optimization suggestions. From the perspective of transport networks, iMaster NCE proactively identifies congestion bottlenecks and guides network planning. In particular, by analyzing four typical types of congestions as well as the impact of transport network KPIs on base stations, iMaster NCE proactively identifies bottlenecks in transport networks, which can be used as the basis for network planning.

5. **Network slicing:** Up to 10,000 slices can be planned and automatically deployed with a single click. Network-wide slices are visualized to facilitate management. If necessary, they can be losslessly scaled up or down with a single click. Automatic management is woven throughout the entire lifecycle of slices, providing differentiated SLA assurance in the 5G and cloud era.

6. **Intelligent incident management:** Huawei's massive O&M data is trained online and intelligent algorithms are used to transform the focus of O&M from being based on a massive number of alarms to being based on "one incident, one ticket". This increases alarm compression rate to 99%+ and results in much higher ticket dispatch accuracy and O&M efficiency, as well as a better user experience.

7. **Agile Open Container (AOC):** Users can define service YANG models themselves, and programming is as easy as constructing toy blocks. Whenever a new service is needed, it can be quickly developed and rolled out, achieving the agile development goals of prototyping in 1 week, testing in 1 month, and commercialization in 1 quarter. In addition, standard northbound APIs and southbound device configuration scripts are automatically generated based on YANG models, enabling minutes-level automatic provisioning of end-to-end services.

3.2.4 IntelligentCampusNetwork — Enterprise Campus ADN

Huawei's ADN solution for campuses has three main components: CloudEngine campus switches, AirEngine access points (APs), and iMaster NCE-Campus. Providing management, control, and analysis functions for campus networks, the solution delivers full-lifecycle automated network management and intelligent O&M services, leading the industry in implementing Level 3 ADN.

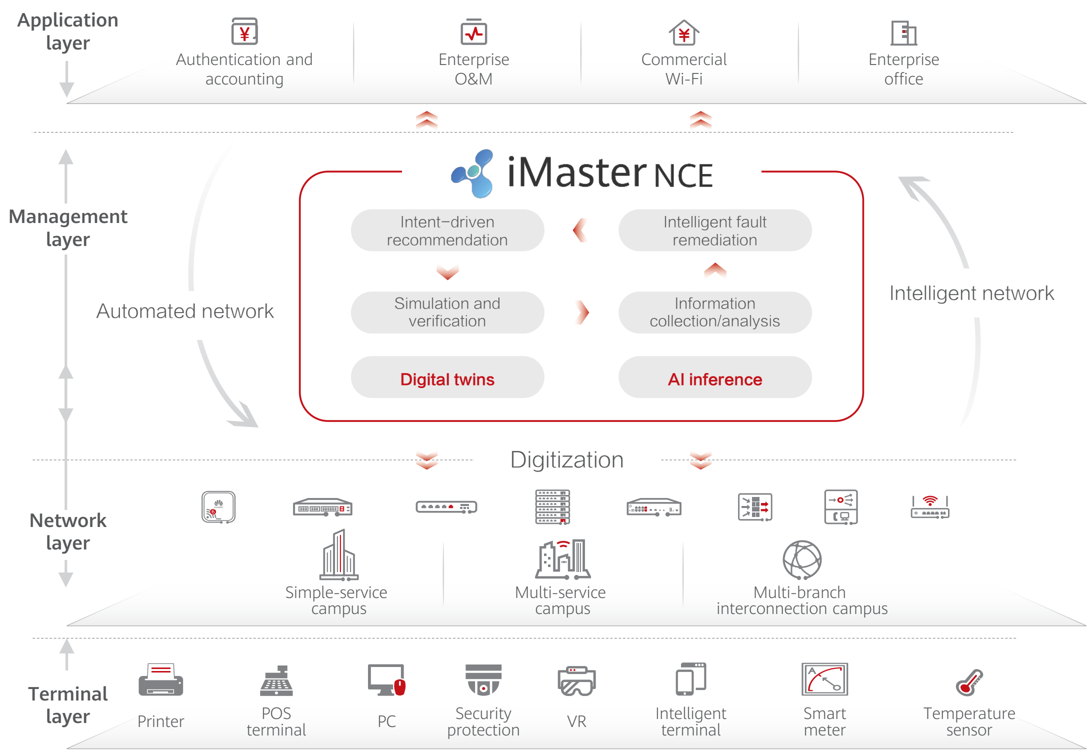


Figure 3-6 IntelligentCampusNetwork

Highlights

1. **Zero-wait:** Network management is automated, no longer relying on expert experience. This ensures zero wait time for network provisioning and reduces OPEX by 85%.

2. **Zero-intervention:** On traditional networks, terminal access needs to be manually controlled. In contrast, Huawei's ADN supports automatic terminal access, achieving second-level seamless access.

3. **Zero-interruption:** In terms of network O&M, passive responses are transformed to minute-level automatic optimizations without service interruption.

Key UCs

1. **Intent-driven deployment:** With the scenario knowledge base and collaborative recommendation algorithm, iMaster NCE-Campus accurately maps service scenarios with networking models and recommends optimal network solutions by analyzing service intents. In this way, networks can be provisioned in minutes, without the need for professional personnel.

2. **Intelligent verification:** iMaster NCE-Campus provides a much faster network change verification method than conventional options. Normally, a change takes just 10 minutes but verification lasts for 4 hours, and there could be many complaints if verification is not sufficient. With iMaster NCE-Campus, verification takes just minutes and assures changes without errors.

3. **Free mobility:** In Huawei's ADN solution for campuses, free mobility is orchestrated using natural language, achieving matrix-based simplified management, cross-vendor deployment through IP-security group mapping, and one-off policy configuration. This delivers consistent service experience to users anytime and anywhere on all-wireless campus networks.

4. **Intelligent terminal management:** iMaster NCE-Campus supports intelligent terminal management. It features a conventional terminal fingerprint database and innovative application AI clustering identification capabilities. Such strengths allow iMaster NCE-Campus to accurately identify networked terminals (98% of known types and 95% of unknown types), allocate them with correct networks, and prevent access by spoofed terminals. This reduces manual intervention and assures secure access in seconds.

5. **360-degree network health:** Based on the evaluation of network health status from various dimensions, iMaster NCE-Campus can proactively identify more than 200 typical problems and reduce potential network problems by 85%.

6. **360-degree user experience:** iMaster NCE-Campus can visualize the journey experience of each user at any time, reducing user complaints by 90%.

7. **360-degree application assurance:** With the capability to identify more than 1000 mainstream applications, iMaster NCE-Campus can intelligently detect the application quality and reduce the time for locating a fault from hours to minutes.

8. **360-degree intelligent optimization:** In routine network optimization, iMaster NCE-Campus analyzes and predicts future AP loads based on data of the previous seven days and implements intelligent and automatic network optimization. It also continuously trains terminal profiles and differentiates roaming steering for terminals based on AI algorithms, such as reinforcement learning. This improves the roaming success rate by 70% and roaming speed by 30%.

3.2.5 IntelligentFabric — Data Center ADN

Huawei's ADN solution for data centers consists of CloudEngine data center switches and iMaster NCE — Huawei's autonomous driving network management and control system. This sophisticated solution unifies the computing, storage, and service networks with an all-IP architecture. It is also IPv6-capable and offers unique Level 3.5 ADN capabilities. What's more, this future-proof solution supports full-lifecycle automation and network-wide intelligent O&M for data center networks, reducing OPEX by 30% and enabling intelligent upgrades for enterprises.

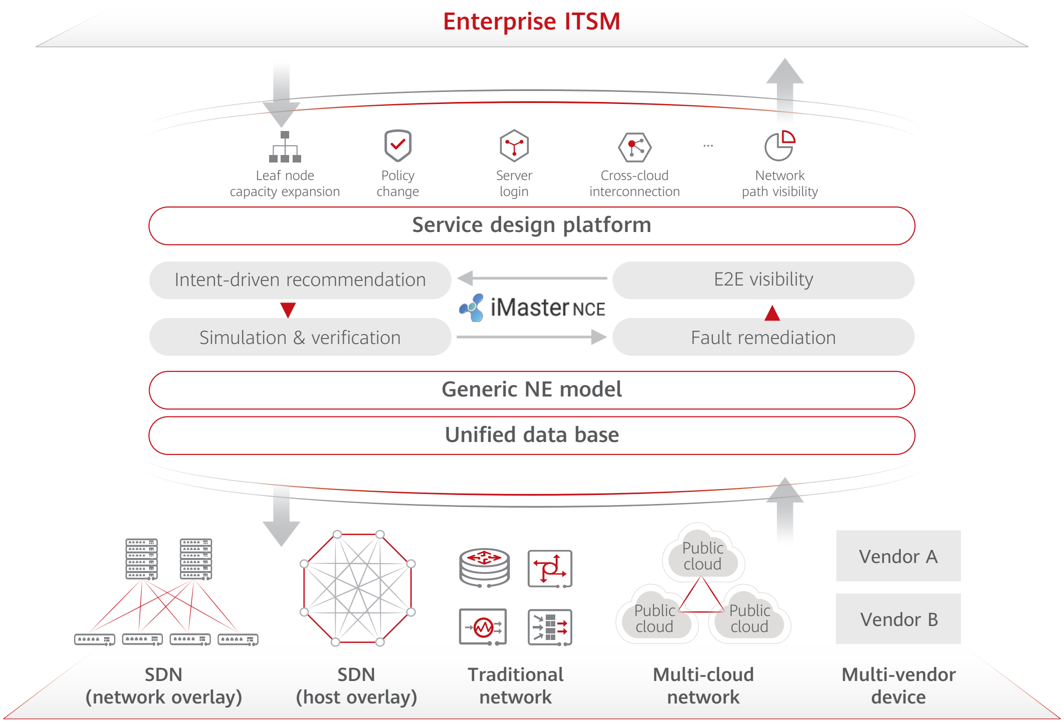


Figure 3-7 IntelligentFabric

Highlights

1. **Zero-wait:** The service deployment and rollout time is slashed to minutes, greatly reducing the O&M workload and improving the O&M efficiency.

2. **Zero-error:** Evaluating network change risks helps prevent faults caused by manual errors for maximized productivity.

3. **Zero-interruption:** Network trend prediction prevents network quality deterioration and failures, minimizing the possibility of faults. Even though a fault occurs, it can be quickly and accurately demarcated and located.

Key UCs

1. **Intent-driven planning and deployment:** By understanding and translating customers' service and network intents, iMaster NCE automatically selects the optimal network deployment solution, enabling E2E automated service provisioning and automated closed-loop management of intents throughout the lifecycle.

2. **Network change simulation and evaluation:** Based on the device configuration, topology, and resource information on the live network, iMaster NCE uses network modeling and formal verification algorithms to evaluate network change risks and eliminate design logic defects and configuration errors, thereby ensuring 100% configuration correctness.

3. **"1-3-5" intelligent O&M:** Telemetry technology is used to collect network performance data and comprehensively evaluate network health based on service experience to proactively identify more than 60 potential risks and over 90 typical faults within 1 minute. Based on knowledge graphs and Huawei's unique AI algorithms, fault aggregation and source tracing are performed, locating root causes within 3 minutes. And thanks to the intelligent decision-making system, the impact of faults is analyzed and the optimal remediation solution is recommended, rectifying typical faults within 5 minutes.

4. **Open industry ecosystem:** Huawei's ADN is seamlessly integrated into enterprises' O&M systems, becoming a key part of the O&M process. This helps achieve automated closed-loop management on the entire data center network. In the northbound direction, iMaster NCE uses the runbook service designer to flexibly orchestrate service flows and seamlessly interconnect with enterprises' O&M systems. In the southbound direction, AOC — Huawei's open programmability platform — implements fast adaptation of devices from multiple vendors, achieving automated provisioning of heterogeneous multi-vendor and multi-cloud networks in minutes. On top of that, full open network data services facilitate integration with the service performance monitoring system, implementing unified O&M of services and networks.

3.2.6 IntelligentFAN — All-Optical Access ADN

The core components of Huawei's all-optical access ADN solution include the all-optical access networks (comprising FTTR, Digital QuickODN (DQ ODN), as well as smart ONT and OLT) and the iMaster NCE intelligent management and control system.

Through digital modeling and introduction of cloudification, big data, and AI technologies for all-optical access networks, ODNs and home networks are visualized and full-lifecycle intelligent O&M is provided. This helps to meet requirements of differentiated application scenarios and high-quality broadband experience. Against this backdrop, single-domain autonomy of all-optical access networks can be achieved. The following figure shows the solution architecture.

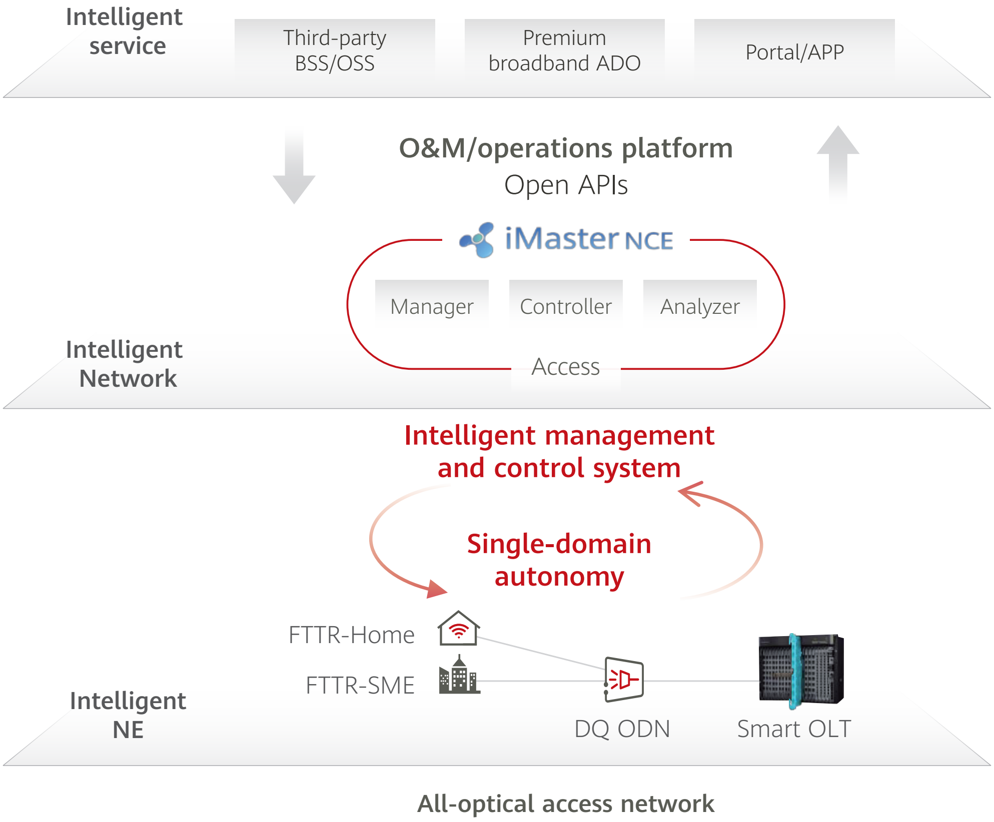


Figure 3-8 IntelligentFAN

Benefits

1. **Zero-wait service provisioning:** DQ ODN, one-stop FTTR planning and acceptance, accurate resource information, and quick service provisioning

2. **Zero-trouble service:** Intelligent O&M, self-identification, self-diagnosis, and self-optimization of PON and Wi-Fi faults and experience issues, and guaranteed broadband network experience

3. **Zero-touch service:** Insights into STAs, networking, applications, and experience bottlenecks, user self-service of home network, precision marketing, and auxiliary operations

Key UCs

1. **Visualized ODN resource management:**

Based on image recognition and the DQ ODN optical iris solution, ODN topologies can be automatically analyzed and restored, ODN networks are visualized and manageable, and the resource information is accurate.

2. **Remote ODN acceptance and precise locating:** Intelligent boards on OLTs and the optical iris solution enable automatic and remote ODN network acceptance and optical line locating at the meter level on iMaster NCE.

3. **Automatic identification of poor-QoE Home Wi-Fi:** Home Wi-Fi faults make up a large proportion of home broadband faults. With intelligent boards on OLTs, the all-optical access ADN solution can capture undistorted traffic features. In addition, with the unique intelligent Wi-Fi experience analysis algorithm, the solution comprehensively identifies faults including poor Wi-Fi coverage and interference of network-wide subscribers, visualizing Wi-Fi experience faults.

4. **Broadband poor-QoE root cause locating:** The first segment-based speed test capability is used to accurately demarcate poor-QoE faults between STAs, Wi-Fi router, ONT, ODN, OLT, and bearer network. In addition, the Huawei-developed spatiotemporal association intelligent diagnosis algorithm is used to identify more than 30 types of home broadband (HBB) poor-QoE root causes of Wi-Fi network congestion, 100BASE-T cables, and weak optical signals on optical lines, greatly reducing workload for O&M engineers, who would otherwise need to go door-to-door for diagnosis and fault check. Instead of carrying out home visits, O&M engineers can remotely optimize and rectify non-hardware faults on the intelligent management and control system.

5. **Precise identification of potential HBB subscribers:** Insights into applications, experience, networks, and bottlenecks help identify potential subscriber requirements and generate labels for potential subscribers. The insights also help operators identify broadband package upgrades, Wi-Fi networking, and scenario-based potential subscriber requirements, greatly improving marketing success rate and improving the quality of HBB.

6. **One-stop FTTR acceptance:** The FTTR field service app provided in the solution can be used to perform one-stop acceptance on more than 10 broadband KPI types (such as networking, rate, delay, and roaming), and automatically generate acceptance reports to ensure networking standardization as well as eliminate further home visits.

7. **Proactive FTTR assurance:** The FTTR "Optical+Wi-Fi" networking integrates innovation in two aspects. First, remote management of network-wide topologies and device statuses and the 24/7 playback function are supported. These functions, which are similar to CT scans, detect network deterioration and facilitate troubleshooting. Second, the speed test assurance solution enables O&M personnel to remotely test the network speed between STAs, slave FTTRs, the master FTTR, and Internet segments with one click to identify potential risks of substandard bandwidth. In this way, network faults can be rectified before they are perceived by subscribers, ensuring user experience.

3.2.7 IntelligentOTN — All-Optical Transport ADN

The core components of Huawei's all-optical transport ADN solution include the all-optical transport networks (such as OXC and OTN) and the iMaster NCE intelligent management and control system. Through digital modeling of all-optical networks and introduction of cloudification, big data, and AI technologies, dumb fiber resources are visualized, and an intelligent, green, and highly-reliable all-optical base is built, providing a premium private line service experience to customers.

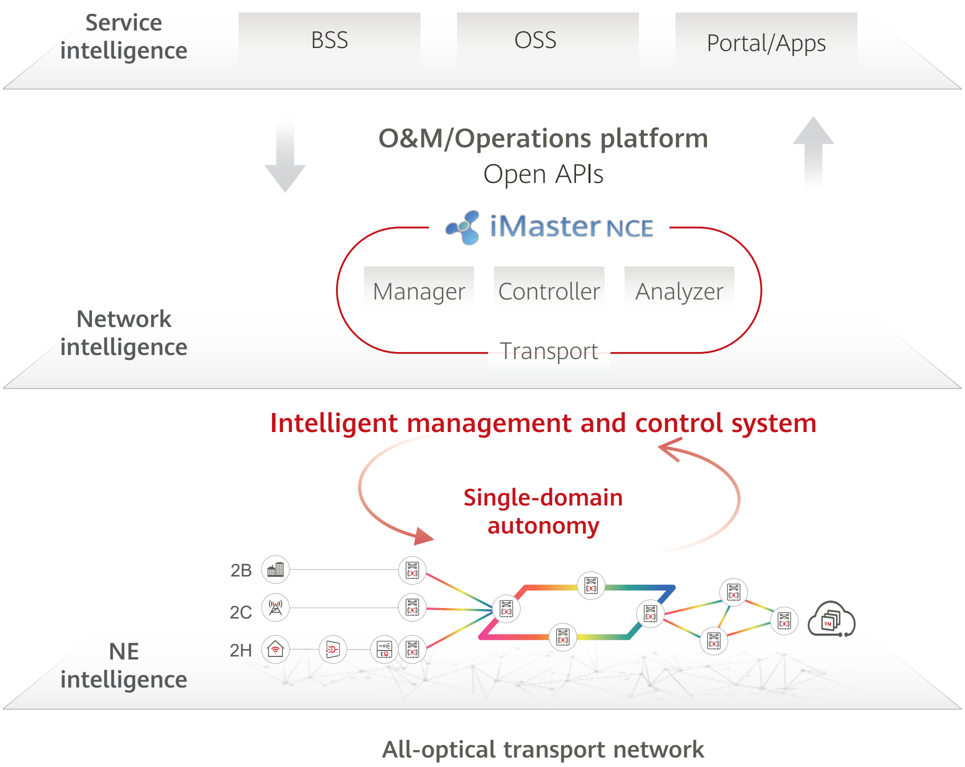


Figure 3-9 IntelligentOTN

Highlights

1. **Visualization of dumb resources:** Visualizes and predicts fiber health status, locates faults, intelligently identifies optical fibers in the same cable, and provides GIS-based display of optical cable networks, eliminating the problems of managing dumb resources through visualization.

2. **Intelligent and simplified O&M:** Covers the entire lifecycle of planning, construction,

maintenance, optimization, and operations, transforms O&M from passive to proactive, and builds networks with 99.999% reliability, providing ultra-high-bandwidth, low-latency, and highly-reliable transport capacity to customers.

3. **Intelligent premium experience:** Provides visualized and manageable SLA performance, automatic provisioning of private line services, and after-sales SLA assurance.

Key UCs

1. **Optical network resource assurance:** Optical network resource data and planning and design data are managed and analyzed in a unified manner to implement unified visualization, analysis and forecast, online check, and capacity expansion planning of network resources. This helps customers learn about resource usage, identify network resource bottlenecks in advance, and accurately expand capacity, realizing zero-wait time for resources and shortening the service TTM.

2. **Optical network health assurance:** For OTS fiber and OCh performance deterioration faults on WDM networks, intelligent forecast and analysis of optical network subhealth status are performed based on seconds-level awareness and edge inference capabilities on the device side, achieving visualized and predictable fiber and OCh health status and fault locating, transforming O&M from passive to proactive, and reducing potential risks of optical line interruptions.

3. **Availability assurance:** Availability of fibers and services are automatically evaluated and analyzed, potential risks and bottlenecks to availability on the live network are identified, and optimization suggestions are provided to improve availability.

4. **Intelligent identification of optical fibers in the same cable:** Built-in intelligent sensors of optical NEs detect and analyze performance data changes caused by the Rayleigh scattering effect, Brillouin scattering effect, and Raman scattering effect of optical fibers in real time, and automatically identify risks of working and protection fibers in the same cable. In this way, services can be rectified to eliminate potential accidents.

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

6. **Latency map:** A microseconds-level, real-time, and dynamic network-level latency map makes private line latency, which could not be perceived or measured earlier, perceivable and accurately measurable. Similar to web mapping service applications, the latency map allows operator marketing personnel to evaluate whether the latency and bandwidth between sites meet tenants' requirements. This facilitates mapping of network resources and marketing of private line services that have differentiated SLAs.

7. **Agile service provisioning:** Support is available for multiple service scenarios (including Client, EoO, EoS, SDH, and MPLS-TP services) and automatic service configuration with only specified source and sink ends. Network capabilities are fully

opened through standard ACTN APIs, and integration with the OSSs/BSSs is simplified for quickly integrating NCE into carriers' private line service production processes, implementing automatic provisioning of private line services, and improving the self-service level.

8. **Private line SLA:** The SLA performance (such as latency, bandwidth, and availability) of private line services is monitored in real time. Warnings are generated when the performance indicators exceed thresholds, so that potential risks can be eliminated and there is no breach of contract.

3.2.8 IntelligentServiceEngine — Intelligent O&M

Huawei IntelligentServiceEngine implements closed-loop management to meet operators' service objectives and domain objectives, and facilitates systematic, scenario-specific digital transformation for operators. It consists of various key modules, including the domain knowledge engine, business intelligence engine, hyper-automation engine, domain app development engine, and network and environment digital twins. Based on the digital intelligent transformation practices from its partnership with over 100 operators around the world, Huawei has launched three digital intelligent O&M solutions (AUTIN, SmartCare, and ADO) to achieve efficient O&M, deliver a superior experience, and facilitate agile businesses.

AUTIN: Intelligent O&M

Commercial use of 5G networks, large-scale complex networks, and diversified new services pose many O&M challenges for operators in terms of cost, efficiency, quality, and talent transformation. Operators' digital intelligent transformation for network O&M is speeding up due to the COVID-19 pandemic and has become an industry trend.

AUTIN, an intelligent Huawei O&M solution, meets three key O&M requirements: quality improvement, efficiency improvement, and rapid talent upskilling. The solution helps operators quickly implement digital intelligent transformation towards Zero-X network O&M.

Quality improvement: In 5GC scenarios, major faults have a large impact scope, and

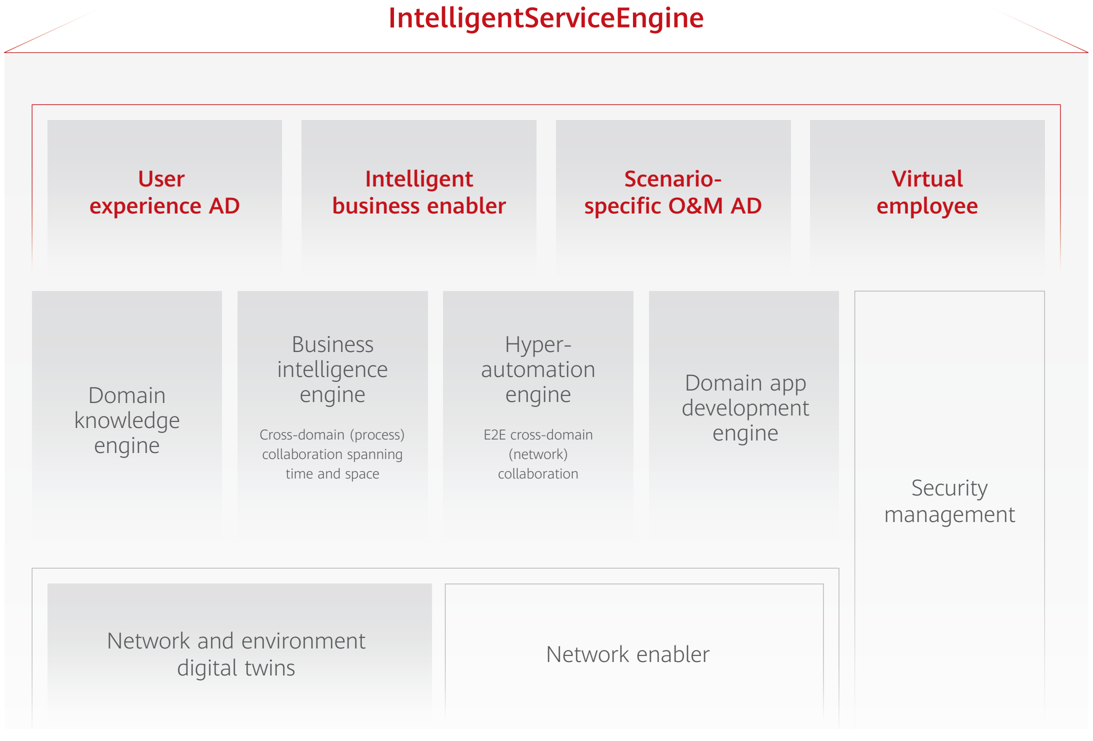


Figure 3-10 IntelligentServiceEngine

it takes a long time to demarcate and locate them. Huawei AUTIN intelligently predicts service impacts and risks, and automatically diagnoses faults within just a few minutes, significantly cutting the MTTR.

Efficiency improvement: Over 70% of daily operations in a network operations center (NOC) are repetitive, inefficient, and depend heavily on expertise. Huawei AUTIN helps NOCs implement integrated, automated monitoring and maintenance, intelligent diagnosis, and self-service, closed-loop management of onsite operations through mobile phones. Faults can be automatically diagnosed and managed in a closed-loop manner, reducing the number of tickets per NE and greatly improving O&M efficiency.

O&M talent upskilling: O&M personnel need to upgrade their skills after O&M operations are automated. Huawei's open platform and abundant O&M knowledge assets enable orchestratable, low-code O&M application development, simplifying O&M talent upskilling. The systematic Accompanying Service and enablement service for talent upskilling are provided to shorten the O&M application development period from months to weeks.

AUTIN continuously integrates expertise and iteratively optimizes domain-specific automated, digital, intelligent engines to improve its level of automation and intelligence.

SmartCare: Superior Experience

Delivering a scenario-specific, superior user experience is the backbone of development strategies for most operators. This goal helps operators deploy high-performance networks, achieve business success, and maintain a leading market position.

Scenario 1: Optimal voice over LTE (VoLTE) experience. Operators need to remove 2G and 3G networks, and deploy a high-quality fundamental VoLTE network. Huawei SmartCare performs multi-domain, multi-interface data association analysis and slicing to accurately locate VoLTE experience problems and provide proactive assurance, preventing surges in user complaints. The VoLTE experience assurance solution helps operators greatly reduce complaints regarding voice services. The convergent data platform associates wireless network, core network, terminal, and registration information to facilitate VoLTE user migration.

Scenario 2: Optimal 5G experience. Quickly increasing 5G users and traffic is the key for operators looking to create a positive 5G business cycle. Algorithms are improved to focus on optimal experience instead of coverage in order to allow more users to camp on 5G networks and maintain the optimal rate for these users. SmartCare helps operators significantly improve the camping ratio. The convergent data platform and the insights about mobile phones, networks, and packages help operators attract more target 5G users and increase the proportion of 5G traffic.

Scenario 3: Highest experience ranking. Network experience ranking is the key to the brand image of operators. Traditional optimization based on drive tests is inefficient. SmartCare makes use of third-party crowdtest data to perform analysis and device-pipe-cloud collaborative optimization in order to maximize the usage of network resources, help operators achieve a high 5G network experience ranking, and improve their market share.

The convergent data platform of Huawei SmartCare converges and analyzes data from multiple domains. Built-in intelligent operators, out-of-the-box intelligent prediction models, and abundant expertise models help operators create digital twins to improve network experience, and achieves efficient data-driven network operations, superior network performance, and leading business results.

ADO: Business Enablement

ADO is a premium home broadband solution. Based on in-depth awareness of user-level service experience indicators, ADO models services for poor-QoE users, causes of poor QoE, and potential users. It provides functions such as Internet access quality analysis, single-user quality query, potential user identification, and VIP experience assurance to support closed-loop poor-QoE rectification and precision marketing.

Ultimate home broadband experience: This solution helps operators build a home broadband user experience model based on the analysis of user complaints, user experience, user behavior, and Internet access quality, and allows operators to add service tags to models. The prediction accuracy for poor QoE is 80%, and operators can implement proactive O&M to eliminate potential faults, reduce the complaint rate, and improve user experience.

Grid-based precise operations: To meet differentiated service requirements of individual users, family users, governments, and enterprises, this solution analyzes and predicts the network bearer capability based on grid-based service insights, matches the resource capability of the live network, and allows operators to expand capacity and plan the network in advance. In addition, grid-based poor-QoE identification and rectification help realize precise grid-based service development.

3.2.9 ADN Evolution Path and Method

AN evolution is a long-term process. The first AN white paper released by TM Forum in 2019 provided a phase-by-phase evolution from manual O&M Level 0 to full autonomous Level 5.

Level Definition	L0: Manual operation& maintenance	L1: Assisted operation& maintenance	L2: Partial autonomous network	L3: Conditional autonomous network	L4: High autonomous network	L5: Full autonomous network
Execution	p	P/S	S	S	S	S
Awareness	p	P/S	P/S	S	S	S
Analysis	p	P	P/S	P/S	S	S
Decision	p	P	P	P/S	S	S
Intent/ Experience	p	P	P	P	P/S	S
Applicability	N/A	Select scenarios				All scenarios

P: Personnel, S: Systems

Table 3-1 AN levels

Level 0 - Manual O&M: The system delivers assisted monitoring capabilities, which means all dynamic tasks have to be executed manually.

Level 1 - Assisted O&M: The system executes certain repetitive sub-tasks based on pre-configurations to improve execution efficiency.

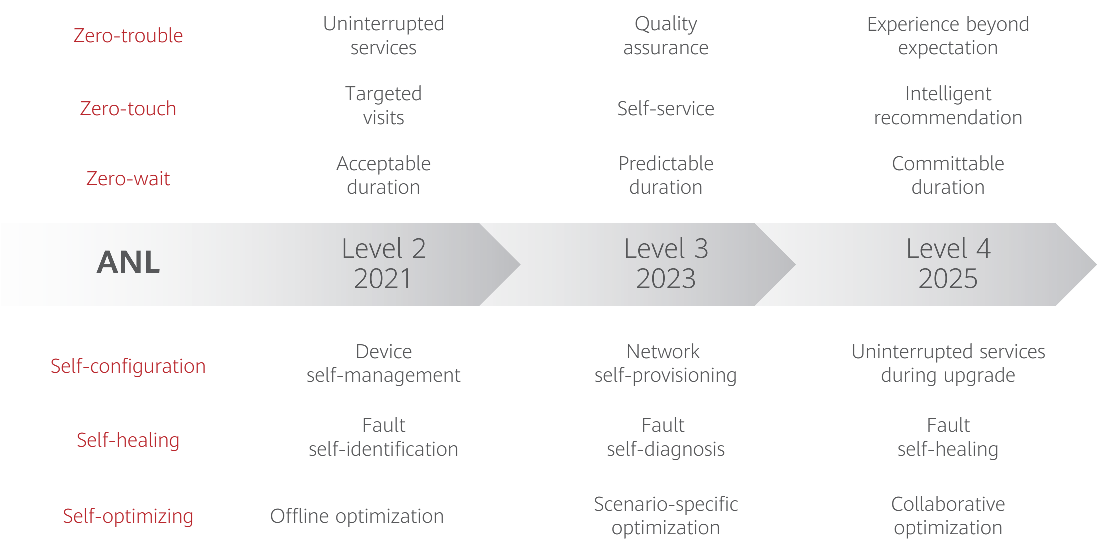
Level 2 - Partial autonomous: The system enables closed-loop O&M for certain units based on pre-defined rules/policies under certain external environments.

Level 3 - Conditional autonomous: Based on Level 2 capabilities, the system senses real-time environmental changes, and optimizes and adjusts itself to the external environment in certain network domains.

Level 4 - High autonomous: Based on Level 3 capabilities, the system performs analysis and makes decisions based on predictive or active closed-loop management of services and customer experience-driven networks in more complex cross-domain environments.

Level 5 - Full autonomous: This level is the ultimate goal for telecom network evolution. The system provides closed-loop automation capabilities across multiple services, domains, and the entire lifecycle.

To highlight the commercial value and measure customer experience, Huawei ADN solution further defines the vision, objectives, and roadmap for each level based on the TM Forum's ANL definitions.



Providing Zero-Wait, Zero-Touch, and Zero-Trouble Innovative Network Services for Individual and Industry Customers

Service provisioning and change duration: Reach Level 3 by 2023 to reduce the duration to an acceptable level, and reach Level 4 by 2025 to guarantee a committed duration.

Self-service level: Reach Level 3 by 2023 to achieve full self-service, and reach Level 4 by 2025 to provide intelligent recommendation services.

Customer experience assurance: Reach Level 3 by 2023 to provide quality assurance, and reach Level 4 by 2025 to deliver the best customer experience.

Deploying Self-configuration, Self-healing, and Self-optimizing High-Quality Network O&M and Infrastructure

Network deployment and service provisioning: Reach Level 3 by 2023 to implement self-provisioning for basic network services, and reach Level 4 by 2025 to ensure service continuity during network device upgrades.

Fault diagnosis and rectification: Reach Level 3 by 2023 to implement self-detection and self-diagnosis of most faults, and reach Level 4 by 2025 to achieve self-healing for common faults.

Network performance and quality optimization: Reach Level 3 by 2023 to perform scenario-specific optimization, and reach Level 4 by 2025 to use various methods to perform collaborative optimization for multiple objectives.

Four Elements Key to Solid Industry Development

Based on the overall evolution path and objectives, Huawei has summarized four key elements after joint research on AN with leading operators over the past two years.

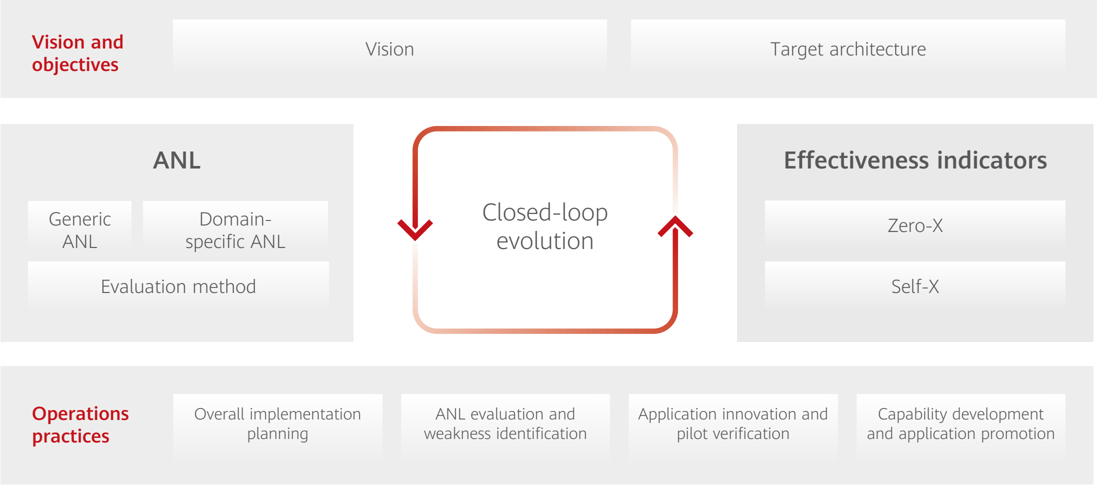


Figure 3-11 AN evolution

1. **Target architecture:** Based on TM Forum's target architecture of AN and operators' business strategies and objectives, a mid- and long-term target architecture is defined to facilitate AN development from top to bottom.

2. **Level standards:** Under the target architecture, generic ANL, domain-specific ANL, and evaluation methods are developed to comprehensively and objectively measure the ANL, identify weaknesses, formulate improvement strategies, launch technological research, and develop innovative applications.

3. **Effectiveness indicators:** The business value and service effectiveness are defined for each ANL to explicitly and quantitatively measure AN evolution, ensuring AN capability development meets enterprise strategies and

service development goals. Both effectiveness indicators and ANL are required to fulfill the AN vision.

4. **Operations practice:** Operations practices are iteratively carried out and summarized through overall planning, level-based evaluation, weakness identification, pilot verification, capability development, and application promotion, facilitating the evolution towards Level 5.

04

Outlook and Initiatives

IP technology reconstructed the forwarding architecture of the communications network two decades ago. Cloud technology profoundly transformed the network management and control architecture a decade ago. In the next decade, AI technology will be introduced into each layer in the network architecture to promote evolution toward intelligent networks. NE status data and AI need to be integrated, and innovative algorithms need to be developed to approach the theoretical limit, transforming uncertainty to certainty and improving network performance. Network O&M data and AI also need to be integrated, and big data analysis and closed-loop optimization are required to comprehensively improve the level of network automation and service capabilities in all scenarios. Edge intelligence is required to detect diversified service requirements in various industries and improve service experience.

Communications networks are full of potential as well as uncertainties. Standards and industry organizations, operators, suppliers, research institutes, and industry management departments need to work together to evolve towards high-level AN. In this regard, we propose the following suggestions:

1. **Focus on innovation, revenue growth, quality improvement, and efficiency improvement, and continuously develop innovative applications:** We recommend that all industry partners focus on innovation, revenue growth, quality enhancement, and efficiency improvement, and continuously develop innovative applications for planning, construction, maintenance, optimization, and marketing in all network domains, and in high-value scenarios, such as 5GtoB, enterprise cloud access, and home broadband, contributing a host of mature commercial solutions for AN.

2. **Encourage operators to accelerate large-scale Level 3 deployment to create a positive business cycle and advance the industry:** According to the latest survey of TM Forum, 37.1% of the respondents believe that AN will reach Level 3 over the next three years

and create significant business value. We recommend that operators speed up the process of introducing and experimenting new AN technologies, products, and solutions, and the process of replication and promotion of mature technologies, products, and services. We also suggest that they accelerate the process of using autonomous capabilities to deliver business value and operations benefits, seize new opportunities for digital transformation, and promote a virtuous business cycle for industry development.

3. **Establish an industry collaboration platform to co-develop and approve standards, and promote efficient collaboration among the industry, academia, research institutes, and business circle:** We recommend that M-SDOs further collaborate with each other and utilize a top-level design and efficient communication mode to achieve standards recognition between different network domains and establish a standard co-construction and mutual recognition mechanism. They should also accelerate the transformation from industry standards to business and technical implementation solutions, achieve efficient collaboration between industry, academia, research, and application, and promote joint innovation with upstream and downstream industry partners.

4. **Jointly define Level 4 target profiles, launch basic theoretical research, and make technological breakthroughs:** AN evolution from Level 3 to Level 4 is a huge progress that creates tremendous value but is also fraught with challenges. All parties in the industry should focus on business and service requirements, target architecture, key technologies, core capabilities, evolution path, and product and solution innovation, and jointly define Level 4 target profiles to continuously improve AN capabilities, such as accurate real-time detection in complex scenarios, real-time simulation based on digital twins, and data-driven user experience analysis and decision-making.

The large-scale deployment of AN calls for close collaboration across the industry. Huawei is willing to work with industry partners to launch more basic theoretical and technological research, and leverage Huawei's technological advantages in the ICT field and further contribute to standards, technologies, and business innovation, promoting high-quality network development toward building an intelligent world.

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