Issue 093
Volume 01 (2023)

INDUSTRY TRENDS
5.5G Innovation
Paves the Way to the Intelligent World

FUTURE TECHNOLOGIES
Hypotheses and Visions
for the Intelligent World

NEW SOLUTIONS
Eight Technologies Leading
Us into the Intelligent World

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Thrive with Digital
Striding Towards the Intelligent World

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YUE B NO. L019060003

267 Fortune Global 500 companies choose Huawei create New Value Together

Huawei integrates industry and new ICT technologies,
together with clients & partners accelerating digital transformation

Building a Fully Connected, Intelligent World

HUAWEI

Thrive with Digital, Striding Towards the Intelligent World

Sabrina Meng
Deputy Chairwoman, Rotating Chairwoman, CFO, Huawei

73 years ago, Alan Turing's imitation game set new expectations for the future by posing the question, "Can machines think?"

27 years ago, Don Tapscott introduced the concept of digital economy in his book *The Digital Economy: Promise and Peril in the Age of Networked Intelligence.*

Today, digital applications are springing up like mushrooms after rain. And the digital future is like a sea of stars, with industries the world over diving deep into digital transformation, one after another.

An old Chinese poem goes, "In thick forests, old leaves fall so that new leaves can grow. In raging rivers, the waves behind drive those in front." With every leap in productivity, time is the great writer – the ultimate witness to what changes we will see. As Kahlil Gibran writes in Sand and Foam, "Perhaps the sea's definition of a shell is the pearl. Perhaps time's definition of coal is the diamond."

Perhaps digitalization's definition of industry is a qualitative improvement in productivity.

5G and 5.5G are key to unlocking a new digital era, and there's growing consensus in the industry on how these technologies will evolve and how an ecosystem should be built around them. Nonstop innovation and the application of technologies like cloud, big data, storage, computing, and AI are accelerating the convergence of the physical and digital worlds, driving digital transformation across countless industries.

Of course, a single piece of lumber does not make a mansion. Huawei is more committed than ever to working together for shared success. Digitalization is a blue ocean of opportunity for the entire industry, so backed by our own experience and know-how in digital transformation, we will keep working with our customers and partners to open up a new chapter in a thriving digital future.

Greater heights await. We are all witnesses, creators, and fellow travelers as we make our way to a new intelligent world – the future of digitalization. By putting one foot ahead of the other, we will get there sooner than you might think.

Publisher ICT Strategy & Marketing Dept.
Huawei Technologies Co., Ltd.

Presented by Zhou Jun

Consultants Dang Wenshuan
Huang Chaowen
Huang Hua

Editor-in-Chief Xing Jingfan

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E-mail HWtech@huawei.com
Tel +86 755 89241326
Address G1, Huawei Industrial Base, Bantian, Longgang, Shenzhen 518129, China

Publication Registration No.:
Yue B No. L019060003

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Industry Trends

Future Technologies

New Solutions

01.

INDUSTRY TRENDS

Industry Trends

Thriving Together for a Digital Future

The world is going digital at an increasingly rapid pace, and digitalization has become a shared opportunity – a new blue ocean – for the whole industry. Digital technology is redefining productivity, driving a shift from quantity to quality, and gradually becoming the core driving force behind socioeconomic development. With years of experience transforming our own company, Huawei is joining up with industry partners to explore the best path forward. We hope to work more closely with both our customers and partners to thrive together in this new and exciting digital future.

Sabrina Meng

Deputy Chairwoman, Rotating Chairwoman, CFO, Huawei

Civilization has evolved with incredible momentum. We have gone from slash-and-burn farming to intensive agriculture, from the industrial revolution to a society built on information, and now one built on intelligence. Throughout this long process of development, people have been a nonstop source of new, enduring ideas, paving the way for a rich and vibrant civilization. Along the way, with every step of technological innovation, we have witnessed leaps in productivity. At its essence, the development of our society is a result of these leaps.

In this new age of digital transformation, the ability to change is key to long-term growth. Digital transformation is one of the most widely accepted, most definite trends today. It is common ground for countries, enterprises, and organizations, presenting both opportunities and challenges for industries and the world at large. Backed by increasingly mature digital infrastructure, digital technology is redefining productivity, driving a shift from quantity to quality, and gradually becoming the key engine for socioeconomic development. The time is ripe to thrive with digital.

Key takeaways from Huawei's own digital transformation journey

Most enterprises these days are actively looking into digital transformation, both to keep pace with the digital economy and make the most of new opportunities. Of course, going digital does not happen overnight. The process is fraught with all manner of twists and turns, but there's always light at the end of the tunnel.

Huawei's digital transformation process has gone from starting up, then scaling up, and now we are leading the industry. The journey has been a hard one, but also joyful. Over nearly 10 years of digital transformation, we have significantly improved our capabilities in domains like R&D, manufacturing, sales, delivery, and finance. Throughout this process, we have had to redefine productivity and production relations, restructure our business, and incorporate a wide array of changes into our management systems. This has helped us to cultivate the organizational capabilities we need to support our ongoing development, while gaining some experience and new ideas along the way.

1. Strategy is essential

At its essence, digital transformation is driven by strategy, not technology. Any successful digital transformation should, first and foremost, serve to fulfill an organization's strategic vision and predefined business goals. During the digitalization process, companies have to incorporate new tools and technologies as

needed to serve their strategic goals and business design, and then drive shifts in their business models, culture, organization, and workforce.

In 2017, Huawei put forward its new vision – bringing digital to every person, home and organization for a fully connected, intelligent world. In the same year, we also laid out our goals for digital transformation. Internally, all business domains would be digitized and turned into services, and we would break down information siloes across domains to boost operational efficiency and stay ahead of the industry. Externally, our goal was to make doing business with customers simpler, more efficient, and more secure to improve customer satisfaction.

Digital transformation needs to be championed by top management. It is a complicated, systematic, and in-depth process. If the transformation is not aligned with the organization's overall vision and culture, then digital solutions alone will not create any value.

2. Data is the foundation

Data governance is a huge challenge for enterprises these days. To start with, massive amounts of data cannot be readily collected. And furthermore, the sheer number of vertical business systems in an organization has given rise to considerable data islands. Only through systematic data governance can data flow smoothly across an organization. And then, by digitizing operations and building digital platforms, can that data be cleaned, visualized, and aggregated to lay the foundation for digital transformation.

First, data needs to be traceable and standardized. Take coal mining, for example. Huawei's Coal Mine Team and CHN Energy worked with partners to develop MineHarmony, a next-generation, industrial Internet operating system specifically designed for mining equipment. This operating system provides a shared language for different types of mining equipment to connect, work together, and incorporate intelligence. At the end of 2022, this system has been deployed in over 3,300 sets of equipment across more than 10 coal mines, helping them fully digitize their management and operations.

Second, data has to be integrated and paired. The digitization of objects, rules, and processes translates operational activities into usable data. Huawei's payment accounting process is a good example. After going digital, our IT system can automatically detect and integrate all documents, and data across multiple dimensions can be automatically paired within minutes. This has led to massive improvements in payment processing efficiency.

Finally, data has to be aggregated and shared. With data lakes and warehouses, we have laid the data-layer foundations for taking our company digital. Almost all of Huawei's financial and business data is now managed in data lakes, so our Business and Finance teams share the same sets of data in real time, based on which they can design and develop derivative applications.

3. Intelligence is the destination

To drive productivity with data, organizations need to put intelligence to use, making data on-demand, easier to understand, and actionable. This is the ultimate destination for transforming corporate management. Machines and equipment should be able to perform analysis and make judgements based on the data, information, and knowledge available to them. This enables automated decision-making and execution for smaller issues. For major issues, systems can escalate to people in charge, informing the analysis and decision-making process.

Over the past five years, Huawei has been implementing a strategy to make our finance knowledge more structured, explicit, and integrated. Step by step, we have crafted a precise knowledge graph that helps Finance digitally store, manage, and pass on expertise. Today, by referencing the knowledge graph, finance teams in the field can find all the answers they need, anytime and anywhere.

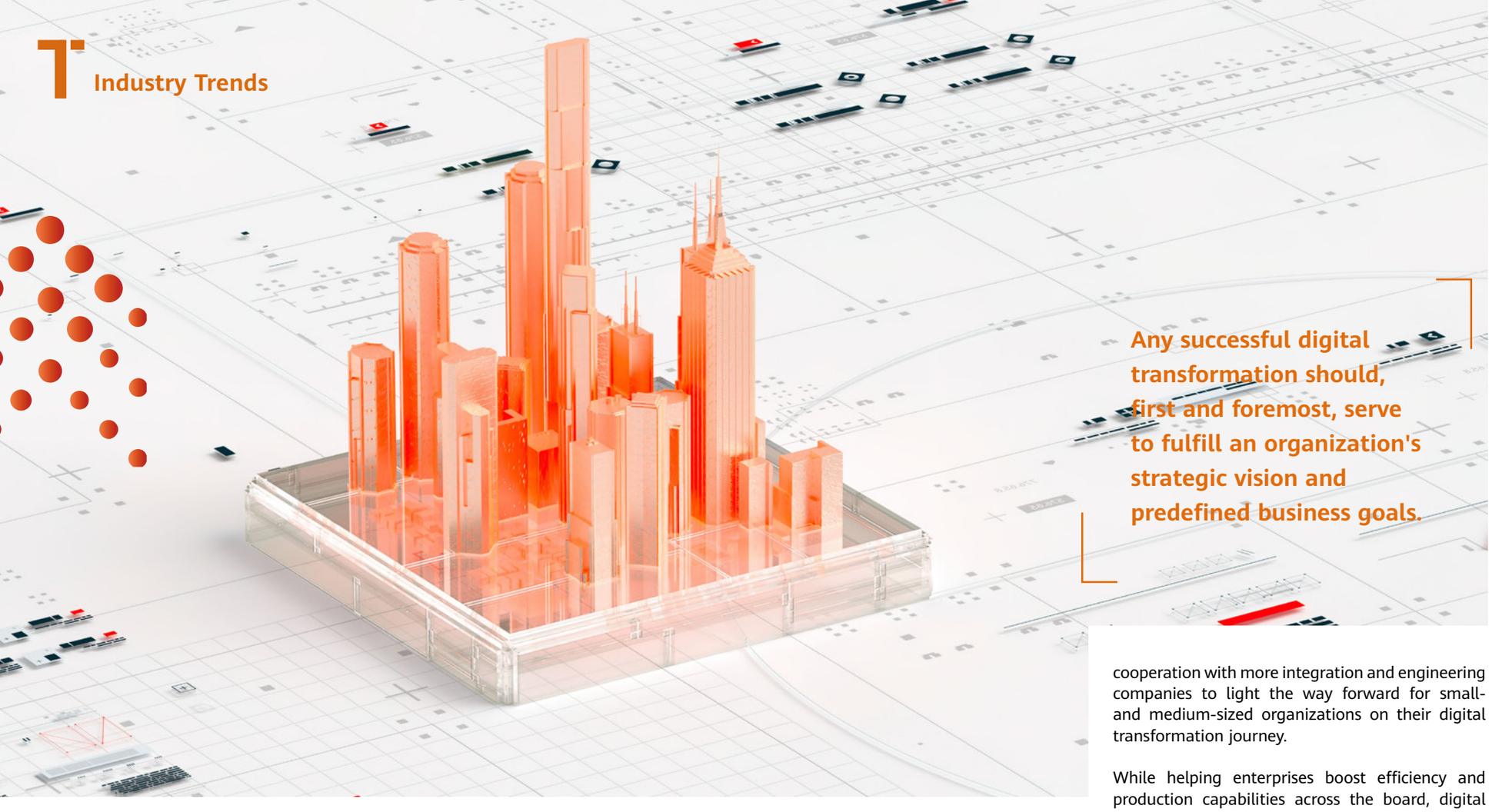
Scheduling automation for production lines is another good example of intelligence put to use. At Huawei, we have digitalized key manufacturing elements such as workshops, production flows, equipment, and procedures, and have created mathematical and data models for different scheduling scenarios. This has enabled us to phase out manual scheduling through automation. With scheduling now automated, we have been able to greatly increase production flexibility and efficiency.

Helping industries go digital

Working for your own benefit is necessary to survive, but working for the benefit of others is key to ensuring long-term growth. Both enterprises that are going digital and enterprises that are helping others go digital will have huge addressable markets and economic benefits. Now and in the distant future, as the power of digitalization is unleashed, boundaries between enterprises will fade. Dots will connect into lines, then into networks, and together they will bring about a new era of industrial interconnectivity.

Huawei is committed to working with customers to explore the way forward for digital transformation. We are working to build digital infrastructure that has the simplest possible architecture and the highest possible quality, that delivers the best possible experience at the lowest possible costs. The goal is to help customers progress along four stages of digital transformation: digitizing operations, building digital platforms, enabling platform-based intelligence, and achieving intelligent operations. In addition to building out solid digital infrastructure, Huawei has also formed a number of integrated teams that focus on specific sectors, such as coal mining, public services, electric power, finance, and transportation (airports, rails, roads, waterways, and ports). These teams work with ecosystem partners to integrate digital technology into industrial scenarios. Together, we develop innovative digital products and solutions that meet the specific needs of these scenarios, and help industries truly make the most of digital technology to drive new forms of productivity.

Huawei is driving coordinated development of data transport, computing, and storage capabilities. In terms of connectivity, we are advancing the development of leading 5.5G infrastructure, aiming to build networks that can support over 100 billion connections and deliver a 10-gigabit user experience. In computing, we are focusing on the diverse computational needs of different business scenarios, pushing the capabilities of both general-purpose and AI computing power. At the same time, we are investing nonstop in Huawei Cloud, making it the cloud foundation and enabler of industrial digitalization, to help enterprises migrate and use cloud technology more effectively. We are also working to grow the ecosystem by developing innovative foundational software and going open source with many of our systems. This brings more partners and developers into the fold, helping to cultivate a dynamic and prosperous industry ecosystem.



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To seize new opportunities, you have to keep up with the times. Today, the fruits of digitalization efforts are apparent. 5G applications are creating incredible value in smart mines. New opportunities are flowing from the assembly lines in smart factories. And a new era of intelligence is taking shape on cranes in smart ports.

One of our manufacturing customers is a great example. Before digital transformation, their business data was spread across dozens of different business systems, with disparate standards and rules for managing that data. Huawei helped them converge their IT data with the OT data collected from more than 200 types of manufacturing equipment, making their data more transparent and visualizable. Then, by building mathematical models with data collected from production processes, we helped them lay the foundation for digital operations. The data and models have enabled them to rapidly replicate best practices.

We are also paying special attention to SMEs. To better serve their needs, we are working closely with SMEs to extend digitalization into the far-reaching corners of their businesses. We are optimizing channel systems and expanding cooperation with more integration and engineering companies to light the way forward for small- and medium-sized organizations on their digital transformation journey.

While helping enterprises boost efficiency and production capabilities across the board, digital technology is also making education more inclusive. In China, many schools in coastal cities like Shenzhen and inland cities like Yueyang and Tianshui have been setting up smart classrooms. With digital displays and high-speed networks, teachers can use a rich variety of virtual teaching tools to draw and create together with students. These smart classrooms have not only made the learning environment more interactive, they are also giving children in different regions ready access to the best educational resources available.

Innovating with partners for win-win outcomes

Behind every leap in digital technology is the willingness to embrace change, giving rise to new vitality.

Underpinning the development of every domain is a strong digital foundation, paving the way for firm and steady steps forward.

Driving the growth of every industry is collective wisdom and strength, spinning out new chapters of potential.

One tree does not make a forest, so Huawei is joining forces with industry partners to drive digital transformation forward. We are doing this in several ways.

First, Huawei is helping develop the broader digital ecosystem by opening up hardware for integration and going open source with software. This allows more partners and developers to take part in the innovation process, producing a more vibrant array of digital products and solutions.

Second, we are increasing investment in our partners. Our guiding principle is to forge partnerships that are interest-bonded, integrity-centric, and rule-based.

And finally, we provide schools with the latest in digital best practices and case studies, give students hands-on digitalization experience, and work together to grow the digital talent pool.

Innovation is an ongoing process, and digitalization is an incredible journey. There are many twists and turns, but determination goes a long way. By putting one step ahead of the next, we have found that the road ahead is not as long as it once seemed. With some resilience and tenacity, together we can seize the day and forge a brilliant tomorrow.

We very much look forward to working with all industries and communities to build a bright digital future and stride towards a more intelligent world, together.

5.5G Innovation Paves the Way to the Intelligent World

5.5G has been developed to fill in 5G's gaps and enhance the key features of eMBB, URLLC, and mMTC. It will also improve capabilities in broadband, ubiquitousness, eco-friendliness, and intelligence.

Wu Hequan
Academician, Chinese Academy of Engineering
Director, Advisory Committee of the Internet Society of China
Director, China Standardization Expert Committee

Global 5G deployment is now well underway, with more than 230 5G networks already in commercial use and more than 1 billion 5G users accounting for 12% of all mobile users worldwide. This number is remarkable, because it means that in just three years since the start of commercial deployment, 5G has as many users as 4G had after five years. Operators have deployed tens of thousands of private networks for the 5GtoB market and by the end of 2022, 2.312 million 5G base stations had been built in China. That is 21.3% of all base stations in the country and 60% of all 5G base stations worldwide.

China now has 561 million 5G users, accounting for 33.3% of all mobile users in the country and 56% of all 5G users worldwide. China is also home to more than half the world's 5G private networks.

The high download rates 5G enables have driven global mobile data traffic to double for two consecutive years. However, the increased speeds delivered by 5G are not really perceivable when using average consumer applications. They are also not adequate for industrial applications. In terms of user experience, 5G has not shown obvious advantages over 4G. Both 4G and 5G high-end handSet can support 2K screen resolution without any obvious differences in fluency. 5G's ability to support simultaneous access for more users is also an often-ignored factor in scenarios other than large venues, like stadiums. Likewise, its low latency is rarely noticed outside applications such as IoV and XR. XR services that require a headset need 5G's high bandwidth, but existing 5G networks can barely support XR video experiences. At the same time, although 5G has been successfully applied to applications like machine vision and remote control, it has not been effective in bringing the industrial Internet to the next level. In many industrial scenarios, massive MIMO, one of the most prominent features of 5G, rarely comes into play, because industrial applications need more: larger uplink, lower latency, more determinacy, higher security, higher reliability, more massive connectivity, higher-precision positioning, and lower power consumption. Lightweight and low cost is also required for ubiquitous connectivity.

To stimulate 5G's potential and keep pace with market growth, the industry is turning to 5G-Advanced (5.5G) as a stepping stone to 6G. 5.5G primarily enhances three of 5G's features: enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communications (mMTC). This improves the technology's capabilities in broadband, ubiquitousness, eco-friendliness, and intelligence.

From eMBB to eMBB+

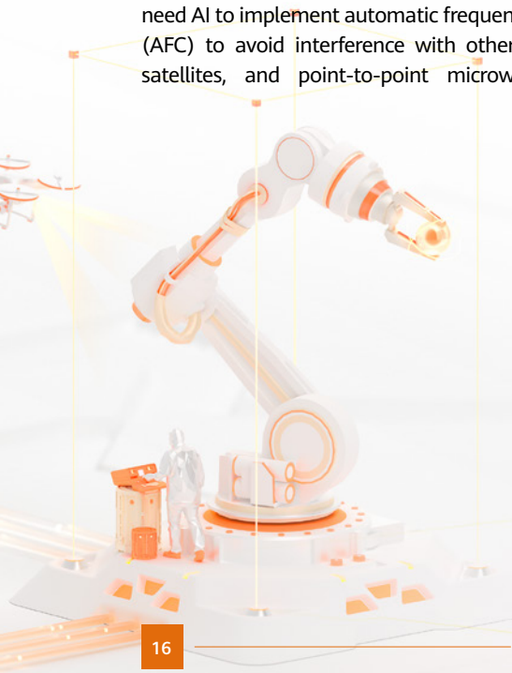
The speed of 5.5G will be 10 times higher than that of 5G, meaning a peak uplink rate of 1 Gbit/s and a peak downlink rate of 10 Gbit/s. Massive MIMO is still the main focus here, as it significantly increases air interface bandwidth by using 64T or 128T radio frequency (RF) channels and by increasing antenna element counts from 192 to 1,000 or even 2,000. Extremely large aperture array (ELAA) technology also allows antenna units to be deployed on the wall of a building in a distributed manner, overcoming the limitations of centralized deployment such as antenna panel size, weight, and wind load. Innovative materials and structures alongside advanced technologies, like adaptive high-resolution beamforming algorithms (such as AHR Turbo), intelligent sounding reference signal (SRS) interference identification and suppression, and intelligent beam direction prediction, can enable ultra-high-resolution beams as well as their fast alignment and real-time tracking. This will, in turn, improve uplink and downlink coverage by 3 dB, increase user perceived rates by 30%, and reduce energy consumption by 30%. However, the specificity of the ELAA electromagnetic field must be considered during design. Innovative distributed baseband processing algorithms and architecture can be employed to achieve low complexity and low fronthaul overhead given the large number of antenna elements.

Spectrum resources will also be key to the high bandwidth delivered by 5.5G. A virtual large carrier frequency technology that shares synchronization signals and physical broadcast channel blocks (SSBs) can be used to utilize discrete frequency bands to address carrier bandwidth requirements for 400 MHz (sub-6 GHz band) or 800 MHz (millimeter wave band). This would improve traditional carrier aggregation methods, reducing

common signaling overhead while supporting flexible scheduling across multiple cells. Unified division duplex (UDD) can also be used to enhance uplink by adding a pure uplink carrier or adding a carrier that adopts the TDD complementary frame structure through supplementary uplink (SUL). Furthermore, a 50-MHz SUL and 100-MHz TDD configuration can enable a peak uplink rate of over 1 Gbit/s per user.

Signals in high frequency bands have poor penetration performance and can easily be blocked, while repeaters lack flexible beamforming and interference management capabilities, which creates coverage weaknesses or blind areas on the network. 5.5G employs network-controlled repeaters (NCRs), which uses beam indication information to select and switch beams based on terminal conditions, improving both indoor and outdoor coverage capabilities.

In industrial applications, industrial licensed frequency bands can be set to provide large uplink services for large enterprises. This prevents interference due to inconsistent uplink and downlink TDD timeslot configurations when carriers are shared with consumers. Compared with LAN-based Wi-Fi networks, cellular-based NR in unlicensed spectrum (NR-U) can deliver better mobility, more accurate positioning and timing, and better support for QoS. However, NR-U will need AI to implement automatic frequency control (AFC) to avoid interference with other systems, satellites, and point-to-point microwave link.



In terms of terminals, smart 5.5G terminals will shift from 2T4R to 3T8R and support aggregation of at least four carriers to enable a 10-gigabit experience.

From URLLC to URLLC+

The key indicators of 5G URLLC are 1 ms E2E latency and 99.999% reliability. According to 3GPP R17, 5.5G URLLC reliability must reach 99.9999% though underlying technologies like blind retransmission, URLLC-eMBB coordinated complementary TDD frame structure, and cross-layer optimization.

Blind retransmission means retransmission is performed before feedback is received. This improves reliability and reduces latency at the cost of spectral efficiency. The URLLC service has a high priority and can preempt the resources of other services like eMBB services. However, the packet scheduling algorithm must be optimized to reduce the impact on eMBB service performance. Additionally, the configuration of an uplink and downlink complementary TDD frame structure on non-overlapping frequency sub-bands can enable simultaneous uplink transmission and downlink reception in any timeslot, thereby improving reliability and reducing latency.

Cross-layer optimization and multi-stream coordination are also needed for XR services, which involve multiple types of data streams, such as audio, video, control information, and data collection information. These data streams are layered so that they are not transmitted in the same QoS flow. In terms of priority, the base layer is higher priority than enhanced layers, and I-frames have a higher priority than B-frames and P-frames in the same layer. Different macroblocks

To fulfill 5G's potential and drive the industry forward, 5.5G is on the horizon

in the same frame also have different priorities. The network senses services and identifies frame priorities and integrity so that it can then selectively discard less important packets when there is congestion, ensuring reliable, low-latency transmission of high-priority data blocks.

5.5G's high bandwidth and low latency enable rendering to be moved from devices to the edge cloud, smoothly supporting XR services through collaboration between cloud, networks, edge, and devices.

From mMTC to mMTC+

5G expands the IoT from narrowband IoT (NB-IoT) to mMTC, which supports millions of connections per square kilometer, and broadband IoT, which features a channel rate of 100 Mbit/s. 5.5G will also expand IoT technologies and applications to make them more lightweight and ubiquitous. Reduced capability (RedCap) devices, for example, support medium-speed low-latency IoT. RedCap devices can realize 50 Mbit/s uplink and 100 Mbit/s downlink rates and 5- to 10-ms latency with a 20-MHz bandwidth by reducing the modulation order and the number of antennas and MIMO flows, as well as simplifying duplex mode, protocols, processes, and functions. RedCap channel bandwidth is 10 times that of LTE Cat 1. Compared with LTE Cat 4, RedCap devices can deliver doubled rates and 20% lower energy consumption at the same price. Their precision positioning and low latency features, as well as their low cost, make them well-suited for enterprise applications like monitoring cameras and large numbers of sensors. With 5.5G, lighter and lower-cost IoT devices that run at 5 MHz bandwidth will also become more common.

Ubiquitousness relies on passive IoT, which integrates cellular network and passive tag technologies, so that devices can gain power from 5G base stations and modulate the amplitude or phase of backscatter signals by adjusting antenna impedance. This enables a data transmission distance of 200 meters, which is ten times that of RFID technology and does not require a reader like RFID. Connection density with passive IoT can be a staggering 10 million connections per square kilometer.

This technology can be applied at very low cost to intensive and massive-amount applications, like fast moving consumer goods, logistics packages, product packaging, warehouse inventory, and smart meters.

5.5G has also triggered research into the standardization of harmonized communication and sensing (HCS). 5.5G base stations will adopt integrated air interface and hardware design; share software and hardware resources such as waveforms, frequency bands, antennas, and systems; and intelligently collaborate with each other, allowing them to function like radars.

Sensing-assisted communication enables more efficient beam management and more accurate beam tracking, while communication-assisted sensing enables functions like enhanced positioning, high-resolution imaging, environment reconstruction, and posture recognition. Actual test data shows that 5.5G can achieve a sensing distance of over 800 meters and sub-meter-level sensing precision. It outperforms traditional radar by three to five times in terms of coverage area, range resolution, and angle accuracy. HCS shows huge potential in applications that require both communication and sensing, such as the Internet of Vehicles, airports, drones, low-altitude security monitoring, high-speed rail perimeter detection, and hazardous chemicals transportation monitoring. 5.5G also marks the beginning of research into non-terrestrial networks (NTNs). Ubiquitous application of IoT can also expand to areas beyond the reach of terrestrial mobile communication signals, helping us achieve satellite-ground convergence.

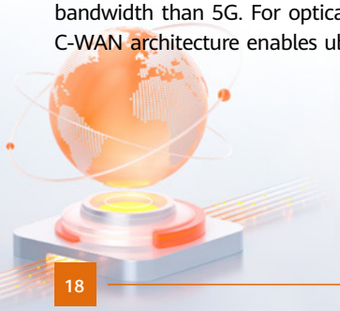
Multi-dimensional energy saving for eco-friendliness

Eco-friendliness is another prominent feature of 5.5G. According to GSMA, the energy cost of mobile networks accounts for about 23% of total operations costs for operators, making air-interface energy saving especially critical. For example, Huawei's MetaAAU uses new materials, ultra-large-scale antenna arrays, ultra-wideband RF front-end technology, and an innovative wide-angle array scanning algorithm to achieve the precise and wide-amplitude sweeping of narrow

beams, fast adaptive beam optimization, and high-resolution beam-domain noise reduction. Signal direct injection feeding (SDIF) technology is used to optimize cabling inside an antenna, greatly reducing the number of feeders and cables. This improves amplitude and phase precision and greatly reduces impedance loss, improving antenna efficiency by 15%. This technology can reduce the transmit power of base stations, reduce energy use by 30%, and ensure high energy efficiency even when the load is light, all without effecting coverage.

5.5G will fully utilize AI to save energy in the time, frequency, space, and power domains. In the time domain, network traffic shows an obvious tidal effect. When network loads are light, 5.5G can intelligently put some cells and channels to a dormant mode. In the frequency domain, 5.5G can dynamically and adaptively shut down some carriers or adjust transmit and receive bandwidths based on service traffic. In the space domain, 5.5G base stations can adaptively adjust the number of activated spatial elements to save energy, including the transmit unit, antenna panel, and logical antenna port. In the power domain, 5.5G base stations can adaptively optimize the TX/RX algorithm and process dynamics to adjust the power or power spectral density (PSD) of TX downlink channels, while ensuring uncompromised coverage areas and key performance indicators (KPIs) or key quality indicators (KQIs).

Simultaneously developing alongside 5.5G are F5.5G (F5G Advanced) for optical fiber transmission and Net5.5G, which is based on IPv6 Enhanced. Based on F5G's enhanced fixed broadband, all-optical connectivity, and reliable transport capabilities, F5.5G will enable real-time elasticity, green intelligence, and sensing capabilities. For radio access networks, fiber fronthaul will have to be based on 5.5G to deliver 10 times higher bandwidth than 5G. For optical access networks, C-WAN architecture enables ubiquitous 10 Gbit/s capabilities. For optical transport networks, the single-wavelength coherent polarization division multiplexing of 400 GHz will expand from 80 wavelengths to 120 wavelengths in C-band as well as further expand to L-band. This is expected to increase per-fiber capacity to 100 Tbit/s, which is adequate to support connections at million-server data centers. Pooled WDM supports the extension of optical-layer grooming to metro aggregation and access layers to realize all-optical connectivity.



In October 2022, the Ultra-Broadband Forum (UBBF) specified for the first time that Net5.5G aims to meet the predicted requirements of network data services in 2030. It is estimated that, by 2030, global computing power will increase 100-fold and storage latency will decrease 100-fold. Net5.5G will enable end-to-end IPv6 Enhanced/SRv6 (segment routing) networking capabilities and embed various end-to-end intelligent network management services on IP private lines to enable integrated sensing and scheduling of computing and network resources. Breakthroughs are expected in six areas: Green Ultra-Broadband, IPv6 Enhanced, High Resilience & Low Latency, Ubiquitous Trusted Network, Multi-domain Network AI, and Heterogeneous Massive IoT.

3GPP has also specified that the 5.5G period of mobile communications began with the R18 standardization released in 2022, as it defined new goals and capabilities for 5G development beyond 2025. This will enable 5G to generate greater social and economic value through comprehensive evolution and enhancement. In February 2023, GSMA led industry partners in establishing a 5.5G community at MWC Barcelona 2023, further accelerating the move towards 5.5G. According to the The Mobile Economy 2023 report published by GSMA Intelligence, the mobile industry's contribution to global GDP will amount to over US$6 trillion in 2030, up from US$5.2 trillion in 2022, and 5G will account for more than 15% of the mobile economy. This means that 5G will benefit the global economy by more than US$950 billion by 2030, and 5.5G will play an important role in this.

5G-Advanced Architecture Evolution: An Analysis Based On Rel-18 Progress

This article summarizes the progress of standards in network architecture evolution defined by 3GPP in Release 18 (Rel-18), elaborates on key study and work items, and looks at the potential main features of Rel-19.

Sun Tao
Chief Expert, China Mobile Research Institute and Vice Chair, 3GPP SA2

Since 5G has been commercially launched for more than three and a half years, its deployment and usage have continued to increase.

By the end of November 2022, there were 22.87 million 5G base stations in China. The China Academy of Information and Communications Technology (CAICT) predicts that by 2025, the 5G penetration rate in China will exceed 60% for individual users and 50% for large industrial companies. For example, by the end of 2022, China Mobile had already developed 16,000 industrial 5G use cases, more than 4,400 premium private 5G networks, and over 1,200 5G smart factories. China Mobile has deployed a private 5G network for CATL spanning six provinces, with a total coverage of more than five million square meters, the largest of NPN (Non Public Network) in the industry.

Industry Trends

Rel-18 is the first release of the 5G-Advanced standard, which acts as a bridge between 5G and 6G.

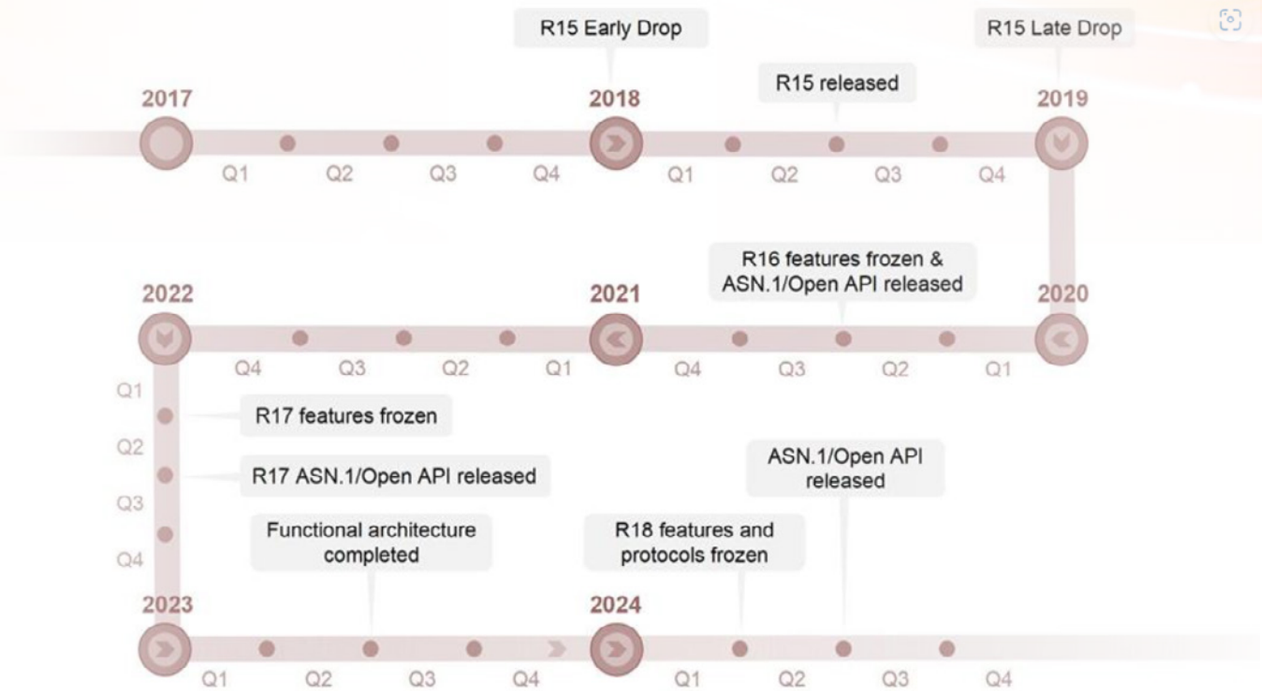


Figure 1 Timeline of 3GPP 5G releases

I. Rel-18 progress

Generally, 3GPP publishes one release of 5G technical specifications every two years (see Figure 1), starting from Rel-15. The timeline of each release is revised following several rounds of discussions due to the inclusion and the content of new features. Recently the timeline for 5G releases was also impacted by COVID-19. Rel-17, for example, is the first release that was completed remotely via online sessions due to travel restrictions. At the 3GPP SA plenary meeting held in December 2022, 3GPP fine-tuned the Rel-18 timeline. As the System Architecture and Service Working Group 2 (SA2) needed more time to complete some feature definitions, 3GPP extended the Rel-18 freeze date by three months. The final stage-2 specification will be finalized by June 2023; protocol design will be completed by March 2024; and Open API and ASN.1 will be released in June 2024, which will serve as a development guidance for vendors.

Rel-18 is the first release of the 5G-Advanced standard, which acts as a bridge between 5G and 6G, and Rel-18 and Rel-19 technologies will facilitate the incorporation of potential 6G technologies into 5G standards. Certain Rel-18 features, for example, are designed to support emerging requirements of existing network deployment, while others reflect the evolution from 5G to 6G.

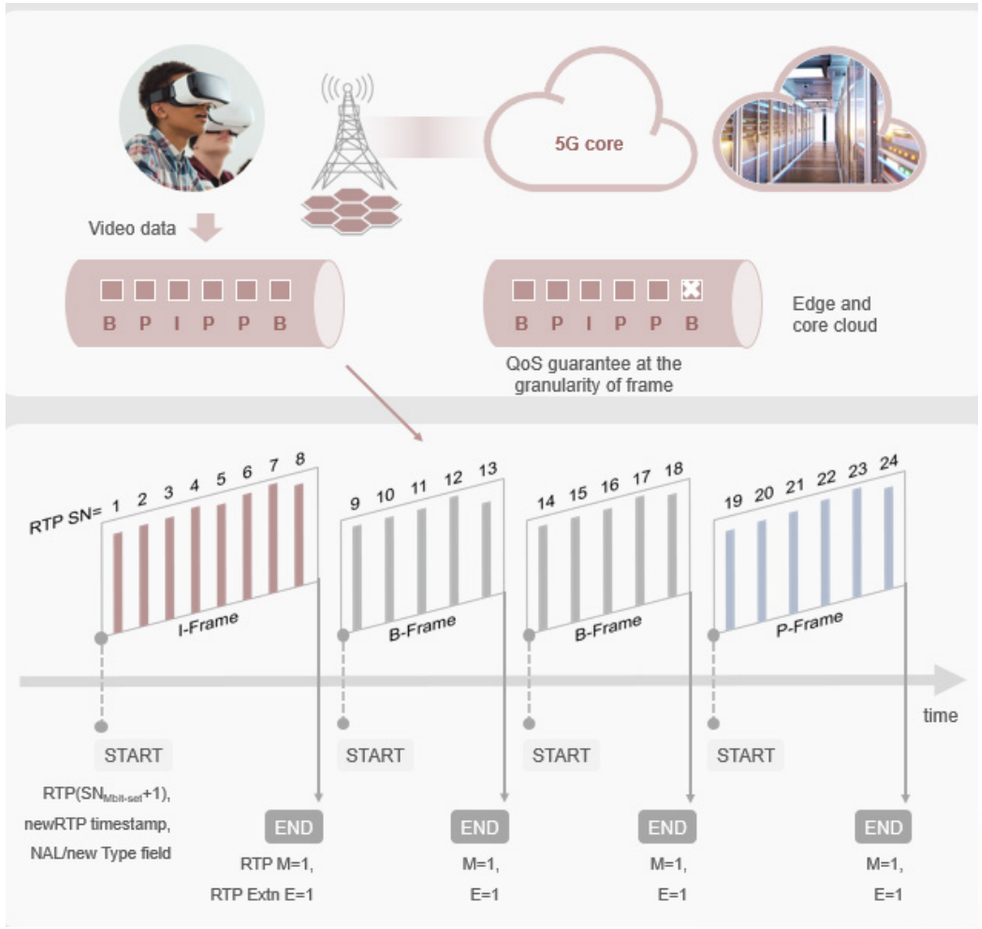


Figure 2 QoS mechanism with PDU Sets introduced

II. Rel-18 architecture and typical technologies

1. Vertical markets: Further improvement of local networking capabilities

Since the commercial deployment of 5G networks, edge computing has emerged as 5G's most successful network capability targeting vertical industries. According to a survey on 5G network industrial usage, more than 80% of enterprise requirements are related to edge computing. This is attributed to its simple deployment requirement and the obvious gains (local service access) it delivers. The related 5G LAN, which is defined in Rel-16, also became one of the most promising features introduced to production networks. Rel-18 has addressed some challenges that edge computing now faces in deployment and scalability by supporting local access for roaming UE (user equipment), inter PLMN edge server access, and the selection of common edge service server.

There are two major types of non-public networks (NPNs). The first is Standalone Non-Public Networks (SNPNs), which are private networks that offer powerful functions. It enhances idle and connected mode mobility and connectivity via non-3GPP networks (e.g., WLANs). The second type is Public network integrated NPNs (PNI-NPNs), which are non-standalone private networks built upon public networks that provide enhanced capabilities through the enhancement of network slicing.

Rel-18 further enhances network slicing. It enables third-party usage of slices based on the maximum number of UEs accessing the network, load prediction, and time restriction. Unlike previous releases, network slicing in Rel-18 has drawn relatively less attention from enterprises. A major reason is that network slices are deployed a bit slower than expected and the current solutions for slice management and roaming support are too complex. Further studies are needed to determine how to simplify network slice deployment.

2. Individual users: Systematic support for immersive XR and multimedia services

To better support immersive XR and multimedia services, Rel-18 working groups have made systematic efforts in RAN, network architecture, and codecs. For end-to-end systems view, multiple working groups including RAN and SA have performed enhancements for XR and multimedia services.

The RAN working group is conducting research on XR, with a focus on the following three areas:

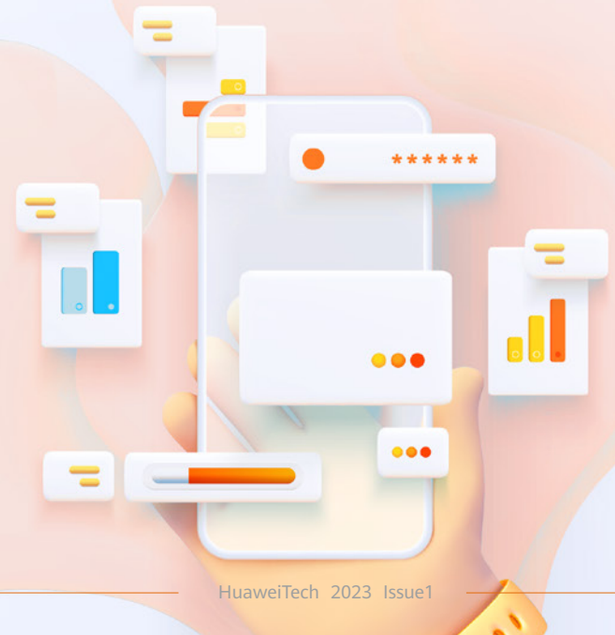
(1) XR service awareness, based on awareness of XR service features in the uplink and downlink characteristics and application-layer parameters to assist RAN scheduling
(2) Power savings for XR services, based on data characteristics such as periodicity and reliability requirements
(3) Capacity improvements, covering improvements to resource allocation and scheduling for XR services to support multi-modality flows and reduce jitter

System architecture enhancement includes the coordinated transmission of multi-modality flows for XR and tactile services, how network exposure supports interaction between 5GS and applications, QoS and policy enhancement, and UE power saving. Special attention will need to be given to the coordination of multi-modality flows and the new QoS mechanism.

In terms of coordinating multi-modality flows, problems to be addressed by Rel-18 include:

- How to enable interaction between applications and 5GC.
- Application-layer synchronization and QoS policy coordination for the multi-modality flows (video, audio, and tactile services) of a single UE.
- Whether QoS policy coordination between multiple UEs is required.
- QoS policy coordination and adjustment enhancement of multi-modality flows of multiple UEs and coordination between applications.

Other tasks include marking data packets of different levels of importance within the same XR service and implementing a consistent network policy assurance mechanism for multi-modality flows (video, audio, and tactile data).



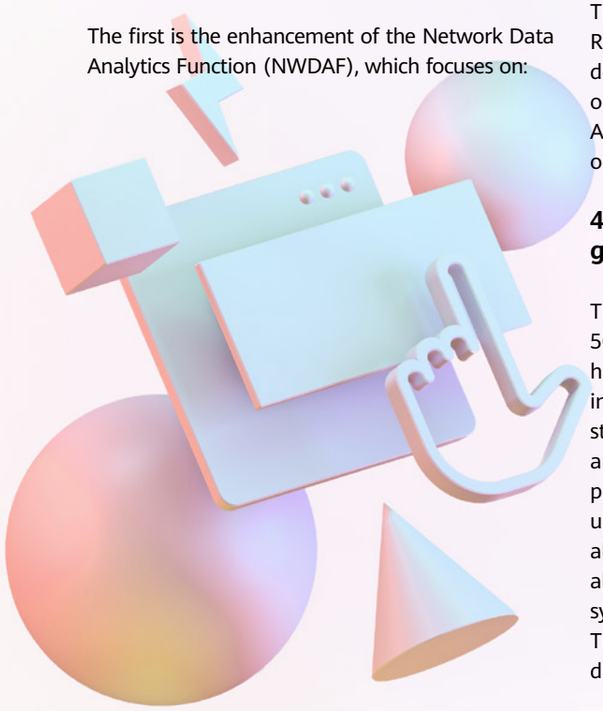
Current networks provide QoS guarantees with QoS flow as the finest granularity, and transmit data at the granularity of Packet Data Unit (PDU). This means that they cannot provide a QoS guarantee for video services at the granularity of frame. This is an issue that needs to be addressed for XR and multimedia services. Specifically, the parsing of B-frames and P-frames depends on the successful transmission of I-frames. Thus, it is important to ensure the integrity of frame-based information transmission. To address these issues, 3GPP introduced the PDU Set concept, which provides QoS guarantees at a finer granularity and ensures frame integrity during packet transmission (see Figure 2).

Based on the above work, GSMA is expected to introduce separate slicing requirements for XR and multimedia services, and the standard types of XR slices will be specified in 3GPP standards accordingly.

3. Usage of AI in networks is being explored

Two Rel-18 work items relate to the usage of AI in networks.

The first is the enhancement of the Network Data Analytics Function (NWDAF), which focuses on:



(1) Combining federated learning and mobile communications technologies to develop a commercial solution under the data privacy protection consideration. This will maximize the value of the massive amounts of data within telecom networks.
(2) Using execution results as an input in the model training and inference phase to improve the training model and make analyses more accurate.
(3) Coordination with the Management Data Analytics Function (MDAF), Using the intelligent analysis result from the network management domain and the additional analytics of the network input to improve accuracy.

The second work item is 5G network support for AI/machine learning (ML)-based services, which focuses on:

(1) 5G-assisted AI/ML model distribution, transmission, and training to serve diversified applications (see Figure 3) such as video and voice recognition and robot control.
(2) Network information exposed to AI/ML applications and associated QoS and policy enhancements.

The functionality of NWDAF was defined in Rel-15, but it has not yet been commercially deployed on networks. Further study is required on how to better use network data and combine AI with 5G networks to create tangible value for operators or users.

4. Further enhancement of space-air-ground integrated communications

The research and standardization of new 5G-based satellite communications systems have also been drawing wide attention in the industry in recent years. Satellite communication standards have been discussed by 3GPP, ITU-T, and IETF. Satellite communication systems are part of non-terrestrial networks (NTNs), an umbrella term defined by 3GPP that refers to all non-terrestrial flying objects, including high-altitude platform systems (HAPS), air-to-ground systems, and unmanned aerial vehicle (UAV). The characteristics of NTN systems include long distance, fast mobility, and wide coverage.

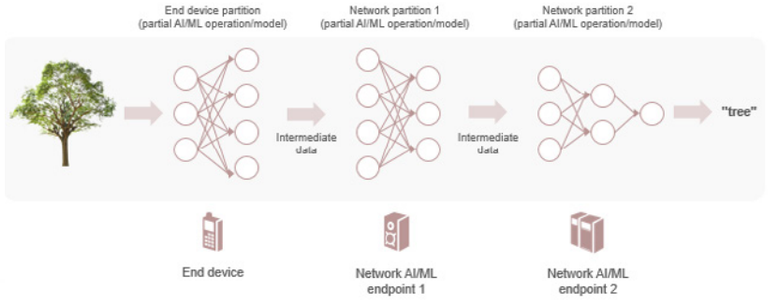


Figure 3 AI model distribution on device, edge, and cloud

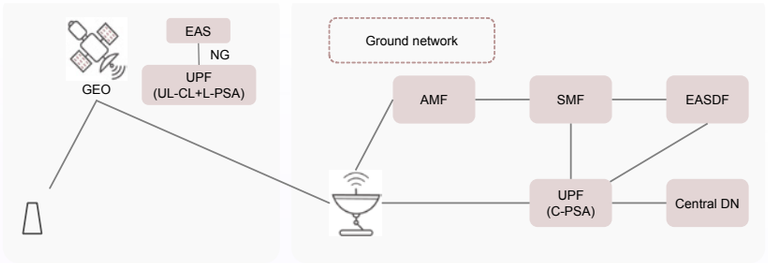


Figure 4 User plane functions (UPFs) deployed on geosynchronous equatorial orbit (GEO) satellites

In terms of networking architecture, Rel-18 supports satellite-based edge computing via UPFs on-board (see Figure 4) and enables two local switch models:
(1) A single session management function (SMF) with the UPF on-board functioning serving as the Uplink Classifier (UL-CL)/Branching Point (BP) or as the locally deployed PDU Session Anchor (PSA) UPF (the SMF instructs the UPF on establishing the N9 tunnel).
(2) A UPF on-board functioning as the PSA UPF (rules for the N4 session in the UPF are instructed by the SMF).

As 3GPP cellular network protocols and standards become widely adopted, we can quickly expand subscribers of non-territorial networks by taking advantage of the 5G ecosystem and existing subscribers of mobile networks. This can dilute the effort of construction, maintenance, and promotional costs of space-air-ground integrated networks. The integration of networks involves the integrated value chain, which requires both technical and industry support. Technologies are further converging from transparent packet forwarding to deploy base stations and UPFs on satellites. Some architectural changes have been preliminarily discussed, but they are limited to GEO satellite deployment scenarios. Mobility for low-earth orbit (LEO) satellites and network functions convergence will bring topology changes, which can be discussed in 6G standards.

3GPP Rel-19 will define new scenarios for satellite communications, including support for IoT devices for storing and forward operations in discontinuous links, positioning enhancement for satellite access independent with Global Navigation Satellite System (GNSS), and communication between UEs within the same satellite. For users, the immediate change will be direct access to satellite networks via their phones. Preliminary prototypes have been verified to achieve this goal. For commercial terminals, many cell phone manufacturers began releasing phones that support satellite communications since 2022. These products have attracted wide attention across the industry, although they are generally only used for emergency scenarios.

III. Four Rel-19 highlights

Rel-19, the second release of 5G-Advanced, will continue to explore new network service capabilities. 3GPP SA1 has already initiated 13 projects to study related requirements and scenarios, and is expected to complete the definition of requirement standards by November 2023. These projects will study new items such as integrated sensing and communication and the metaverse applied in mobile networks.

1. 5G-enabled XR and media services will be further enhanced to support the metaverse.

The study on XR and media services in Rel-18 was derived from the "tactile and multi-modality communication services" defined by 3GPP SA1. With the rise of the metaverse, some of the requirements that seemed ahead of market requirements have become more acceptable to standard organizations.

The Localized Mobile Metaverse Services study item (see Figure 5) under SA1 studies how to:

· Offer the shared and interactive user experience of local content and services to users in the proximity or remotely.

· Support interactive XR shared among multiple users in a single location.

· Identify users and other digital representations of entities interacting within the metaverse service.

· Acquire, use, and expose local physical and digital information to enable metaverse services.

These are part of a next-generation communication infrastructure that will underpin the metaverse, which is a hybrid of the physical and digital worlds.

2. Integrated sensing and communication (ISAC) is a 6G technology that will be incorporated into 5G standards.

China's IMT-2030 (6G) Promotion Group and IMT-2020 (5G) Promotion Group have both launched research projects on ISAC. Chinese companies are important contributors to this technology. As a new network capability, its usage scenarios, key technologies, privacy and security, and other aspects require significant work before it can be considered mature enough to be deployed.

Improvements in radio access technologies are crucial to make ISAC reality, and there are still a number of other core technical problems that need to be overcome. For example, high-frequency bands enable higher sensing accuracy but provide poor coverage. While, low-frequency bands cover a wide area but provide low sensing accuracy. Despite these issues, ISAC remains attractive to operators and vendors, and will become a trending tech in future.

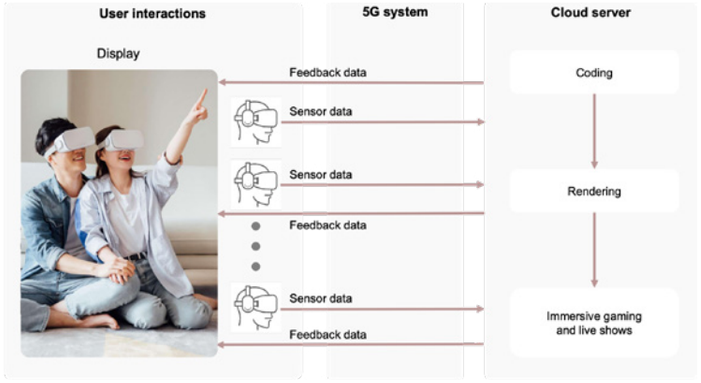
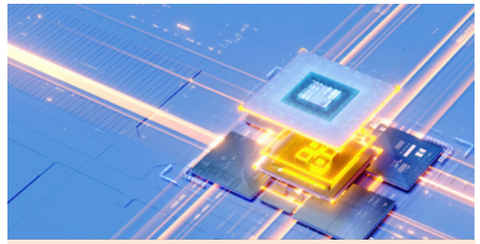


Figure 5 Mobile metaverse supporting immersive gaming and live shows

3. A systematic approach is needed for low-carbon designs.

Energy saving is another key issue that the industry focuses on. Unlike the traditional design approach that considers energy saving individually, like in the domains of terminals or wireless networks, new systematic approaches will consider energy saving across the entire communications system. In addition, information about the source of energy (e.g., solar energy or electricity from fossil fuel) in networks can guide service usage. For example, when the cost of energy is low, networks can run energy-intensive services. Passive IoT and ambient IoT are good examples of how to minimize power consumption of UEs by harvesting power from the surrounding environment (e.g., radio waves, solar, wind, vibration, and heat), which allows for battery-less or limited storage devices. When a fire occurs, passive IoT devices can be used to track personnel without power source concerns. As the world aims to reach a carbon emissions peak by 2030, the energy consumption of 5G-Advanced and 6G systems will be at the core of sustainable development.



4. Mobile computing networks can be built by integrating computing and 5G-Advanced.

Can computing power become a service like network connectivity and emerge as the second source of revenue growth for operators? The answer to this question will largely determine whether operators can evolve from communication service providers to information service providers. Computing force networks have become a buzzword in China's communications industry over the past two years. They have attracted special attention from many Chinese operators, including China Mobile, which has made computing networks part of its company strategy. To make mobile computing networks reality, we need to seek innovation in network architectures and make further advances in computing technologies, including computing power measurements and computing task decomposition.will be at the core of sustainable development.

IV. Summary and outlook

Since the advent of 5G, the mobile communications industry has adjusted its focus from communications services to information services. This trend has been driven by the need to build a thriving mobile communications industry and digital society. As the first release of 5G-Advanced, Rel-18 will support both live network deployment requirements and future network evolution. Many Rel-18 projects are currently underway, including 28 projects under 3GPP SA2. This paper has touched on just a few of them.

There are also some questions relating to standardization that we need to answer: How can we effectively manage the number and quality of projects in a limited time with a limited workforce? This problem has drawn the attention of experts from various standards organizations, and related stakeholders have discussed the timeline and operation modes for Rel-19 projects.

It is more and more encouraging that this problem can be solved in Rel-19.

Jointly Promoting the Development of F5G Advanced for a Prosperous Broadband Industry

Tang Xiongyan
Vice President and Chief Scientist of China Unicom Network Technology Research Institute

New F5G standards and the vision of Fiber to Everywhere and Everything have attracted wide attention in the industry. New requirements in four scenarios will drive the future direction of F5G Advanced: optical to the home, optical to the enterprise, optical to computing, and green all-optical base.

In February 2020, ETSI released the Fifth Generation Fixed Network (F5G) standards and proposed the industry vision of Fiber to Everywhere and Everything. ETSI defined the technical architecture of this next-gen fixed network based on core technologies such as 10G PON + fiber to the room (FTTR) for broadband access, Wi-Fi 6, and single-wavelength 200G for optical transmission + optical cross-connect (OXC).

F5G standards and the new vision quickly attracted wide attention across the industry.

After more than two years, F5G has achieved rapid development in both standards organizations and industry applications. ETSI's Industry Specification Group (ISG) F5G has nearly 100 members who have submitted more than 1,000 contributions, significantly advancing standardization for F5G industry applications.

Established at the end of 2021, the World Broadband Alliance (WBBA) has strengthened the industry's drive to translate F5G standards into industry applications. In response, China's Ministry of Industry and Information Technology released the Action Plan for Coordinated Development of Double Gigabit Networks in March 2021 to promote the construction of F5G and gigabit optical networks, putting China's F5G industry on the fast track towards success.

After the F5G standards were officially released, research on F5G's future development paths began. From 2025 to 2030, more new requirements and applications are expected to emerge, driving F5G evolution. For example, in homes, VR/AR and smart home applications will increase in popularity, resulting in drastic increases in the number of devices. With factories and machines connected through optical fibers, optical networks will extend from the ICT industry to vertical industries. All-optical transmission networks will serve as infrastructure for Computing First Networks (CFN) and support ultra-low latency and extensive access. A general consensus on energy conservation is also driving optical fiber networks towards greener network architectures.

Based on these requirements, ETSI released the F5G Advanced and Beyond White Paper in September 2022, which described the driving forces, scenarios, and key technologies of F5G Advanced and defined a host of future F5G objectives and capabilities. At the end of 2022, ETSI had already completed F5G Advanced project initiation and started standard formulation.

China Unicom's all-optical network strategy opens a new chapter of intelligent integrated services

In 2021, China Unicom proposed its CUBE-Net 3.0 network innovation system and a target architecture featuring computing and network int egration to drive the transformation of traditional communications networks into next-generation digital infrastructure. Such infrastructure would better support digital economic and social development. The system and architecture defined next-gen digital information infrastructure as "connectivity + sensing + computing + intelligence + security". Their release also marked the beginning of a new chapter for the company that would feature intelligent integrated services. The development concepts of CUBE-Net 3.0 and F5G Advanced are highly consistent. By delivering comprehensive optimization of overall network architecture, networking solution, device forms, and service capabilities, this system can better match diversified and complex service scenarios.

In November 2022, China Unicom and 21 industry partners worldwide jointly released the F5G Advanced Industry White Paper. The white paper proposed an industry vision for F5G Advanced of "10G Fiber to Everywhere for ubiquitous optical access, OTN to EverySite with low latency, all-optical autonomous networks, and integrated sensing". It described the new architecture and capabilities needed for F5G Advanced based on the new requirements of four scenarios: optical to the home, optical to the enterprise, optical to computing, and green all-optical base. It also defined the core features, network capabilities, evolution paths, and key support technologies of F5G Advanced.

All-optical base target networks enable new service scenarios

To meet the new requirements of home, enterprise, and computing scenarios, China Unicom will

integrate its architecture for all-optical base target networks end-to-end and build up its differentiated competitiveness.

Optical to the home

China Unicom provides high-quality connectivity for smart homes through FTTR, and uses OLT + OTN to integrate edge computing capabilities for lower latency and better user experience.

Home broadband has evolved from FTTH with one optical fiber to FTTR that provides one optical network. In the future, all-optical home networks will continue to evolve and enable smarter homes. The green, low-carbon, high-bandwidth, low-latency, and stable nature of all-optical networks in the FTTH phase has laid a solid foundation for all-optical homes. Next, with the development of smart home services, broadband packages will gradually be upgraded to 500–1000 Mbit/s, and new high-value services will continue to gain traction, like 4K/8K/VR, smart home, online office/education, and live streaming.

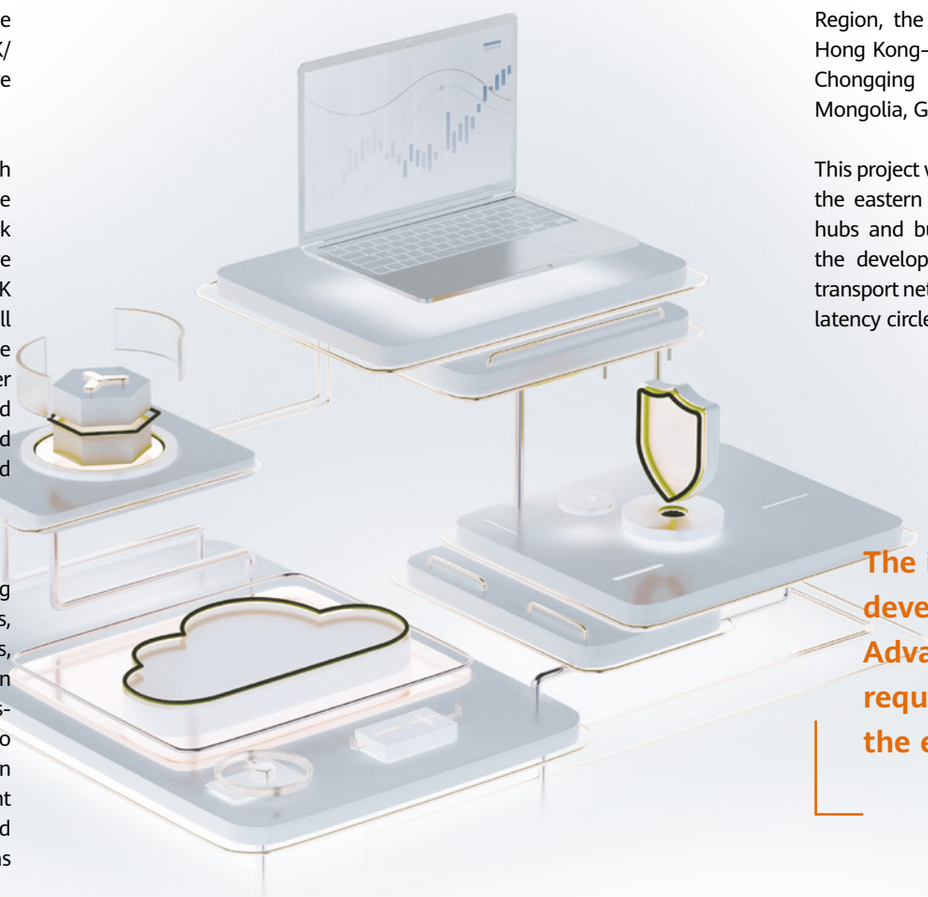
By providing 10G PON and FTTR gigabit bandwidth services, China Unicom has been able to take the lead in building a brand-new gigabit home network with premium broadband. Diversified immersive applications and production services, such as XR, 8K UHD, cloud gaming, and healthcare applications, will become increasingly common in the smart home phase. These types of applications all pose higher requirements on service quality, and so upgraded network technologies like 50G PON, Wi-Fi 7, and beyond will be needed for stronger broadband access and home IoT services.

Optical to the enterprise

Enterprises and manufacturers are progressing quickly with their own digital transformations, while XR is now widely used across offices, schools, and hospitals. Data cloudification has become an inevitable trend, and the momentum driving cross-region intelligent collaboration is also continuing to increase. Examples of how these advancements can be applied include remote diagnosis and treatment in hospitals, XR intelligent teaching in schools, and interactive offices. In industrial manufacturing, as intelligent, unmanned, and flexible manufacturing technologies continue to advance, 3D machine vision quality detection, cloud-based PLC, and centralized control applications will gradually become mainstream technologies. These applications pose higher requirements on network reliability, bandwidth, and latency.

F5G Advanced will deliver new capabilities like 50G PON and FTTR Wi-Fi 7 that will in turn bring seamless 1 Gbit/s to 10 Gbit/s coverage with microsecond-level deterministic latency. This will give enterprise customers an optimal network experience while building an all-optical foundation for the industrial Internet.

China Unicom, for example, provides large enterprises with reliable and secure P2P OSU/OTN connections. For small- and medium-sized enterprises, we provide



PON+OTN private lines, which offer differentiated and quality connections with lower latency. The OSU (N*2 Mbit/s) small-granularity connection technology enables high-quality connections to greatly improve the utilization of hard pipe resources and facilitate industrial digital transformation. In industrial optical networks, OSU is strengthening the industrial Internet and lean manufacturing by providing microsecond-level latency and 99.9999% reliability.

Optical to computing

In February 2022, the National Development and Reform Commission, Cyberspace Administration of China, Ministry of Industry and Information Technology, and National Energy Administration jointly launched the "Eastern Data and Western Computing" project and announced eight computing hubs would be built in the Beijing-Tianjin-Hebei Region, the Yangtze River Delta, the Guangdong–Hong Kong–Macao Greater Bay Area, the Chengdu-Chongqing Region, and the Provinces of Inner Mongolia, Guizhou, Gansu, and Ningxia.

This project will optimize the direct network between the eastern and western networks and computing hubs and build a transport network that supports the development of computing power. All-optical transport networks, and their low "1 ms–5 ms–20 ms" latency circles, will be needed to achieve data center interconnection and computing power scheduling. China Unicom's all-optical foundation is designed to meet these needs by upgrading all-optical anchors to computing anchors only several hundred meters away from users, enabling one-hop computing access. This means latency can be as low as 1 ms from the anchor to the municipal computing hub, 5 ms from the anchor to the provincial computing hub, and 20 ms from the anchor to the cluster computing power hub.

The improvement and development of F5G Advanced standards require the joint efforts of the entire industry.

Green optical networks

Green development has become a globally recognized mission. Network energy efficiency upgrades have become a must to enable widespread industrial digital development and as network capacity requirements grow rapidly. The most energy efficient transmission solution to these demands will be end-to-end all-optical networks, as they significantly reduce energy consumption.

The energy efficiency of all-optical networks is improved in three ways.

Architecture: All-optical OXC technologies can be used to optimize traditional ROADM architecture. They can reduce site areas by 90% and power consumption by over 60%. Expanding C+L spectrum resources and increasing the line rate can also greatly improve system capacity and reduce system power consumption per bit.

Sites: Upgrading legacy SDH networks to OTN networks can significantly improve space utilization and energy efficiency. Unified OSU transport technology can greatly improve network channel utilization and service transmission energy efficiency.

O&M: Dynamic energy-saving technologies are used to dynamically adjust equipment power consumption based on the actual transport bandwidth of service ports, significantly improving network energy efficiency.

The improvement and development of F5G Advanced standards require the joint efforts of the entire industry. China Unicom is committed to providing referable scenario requirements and technology trends for F5G Advanced development, and exploring feasible paths for network evolution. The company will work hard to drive industry consensus and promote application integration so that we can stride, hand-in-hand, towards F5G Advanced.

Industry Trends

The Technology Prospects of New-type Storage-compute Decoupled Architecture

Shu Jiwu
Fellow, Director of Information Storage Technology Committee, China Computer Federation; Professor, Tsinghua University;
Dean, School of Information, Xiamen University

Traditional data center architecture that integrates storage and computing presents a number of challenges, but storage-compute decoupling offers an effective way out.

The continuous advancement of digitalization is crucial to progress in IT infrastructure, including computing and storage. The cloud and connectivity industries have built the largest IT infrastructure platform in China, storing and processing the majority of data across all industries. It is estimated that by 2025, China will have 300 EFLOPS of computing power, while the country's data volume will reach 48.6 ZB[1]. The continuous advancement of China's Eastern Data and Western Computing project constantly sets higher requirements for data centers to be green, intensive, and independent.

Traditional big data storage solutions that integrate storage and computing are represented by server-based, hyper-converged systems that centrally manage server resources. However, a lack of alignment between storage and computing requirements cause problems like inflexible scaling and low utilization. Storage-compute decoupling means storage and compute resources are divided into independent modules, which has significant advantages for the efficient sharing of storage resources. This solution has been applied in numerous scenarios, strengthening storage systems in terms of data sharing and flexible scaling.

Technology-driven construction of a storage-compute decoupled architecture

1. Four challenges to traditional storage-computing integrated architecture

The storage domain of cloud and the Internet are primarily based on the integration of distributed storage services through servers. Today, this model faces the following challenges:

Data storage periods and server update periods are not aligned. The massive amounts of data from emerging services should be stored in accordance with their lifecycle policies (e.g., 8 to 10 years). However, the updating period of server-based storage systems depends on the corresponding processor upgrade period (e.g., 3 to 5 years)[2]. The huge gap between these periods causes an enormous waste of system resources and a higher risk of data loss during migration. For example, when server components in the storage domain are retired due to CPU upgrades, data migration is required[3].

The trade-off between reliable performance and resource utilization. Generally, there are two types of distributed storage systems: performance-oriented and capacity-oriented. Performance-oriented storage systems run key services like databases. Typically, three copies of the same data are stored

and redundant arrays of independent disks (RAID) are used. However, only 30% of storage space is actually utilized, representing a massive waste of storage resources. In comparison, capacity-oriented systems use erasure coding (EC) to improve resource utilization. However, EC calculation consumes a large amount of system resources and provides low refactoring efficiency, leading to risks (see Figure 1).

New distributed applications require simplified, efficient, and shared storage.

New distributed applications, such as serverless applications, are now emerging. Applications are expanding from stateless to stateful, and demand for shared data access is increasing. Additionally, applications like artificial intelligence require a large amount of heterogeneous computing power, meaning a need for shared memory access. These applications focus more on high bandwidth and low latency, and require only lightweight shared storage without complex enterprise features.

"Data center taxes" result in inefficient data-intensive applications.

CPU-centric server architectures and applications are paying heavy 'data center taxes' to acquire data. For example, 30% of CPU computing power is consumed by storage input/output (I/O) requests[4].

In conclusion, data storage for cloud and the Internet requires a balance between requirements for resource utilization, reliability, and more, as well as a new storage-compute decoupled architecture based on new software and hardware technologies.

2. Technological advances pave the way for architecture refactoring

The rapid development of dedicated data processors and new-type networks has laid the technical foundation for restructuring data center infrastructure. This will address challenges such as capacity utilization and storage efficiency.

First, to replace local disks in servers, many vendors have launched high-performance EBOF disk enclosures. This solution focuses on adopting new data access standards, such as NVMe over Fabric (NoF), to deliver high-performance storage.

Second, more dedicated DPUs and IPUs are emerging in the industry to replace general-purpose processors, improving computing power usage effectiveness. Network-storage collaboration based on programmable switches is another area of major research, with examples like NetCache[5] and KV-Direct.

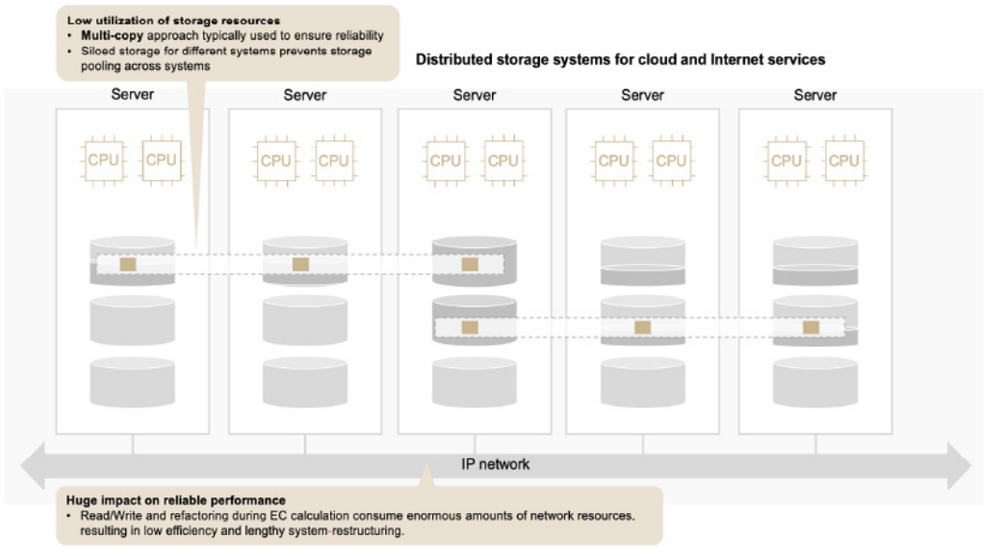


Figure 1: Resource utilization of distributed storage

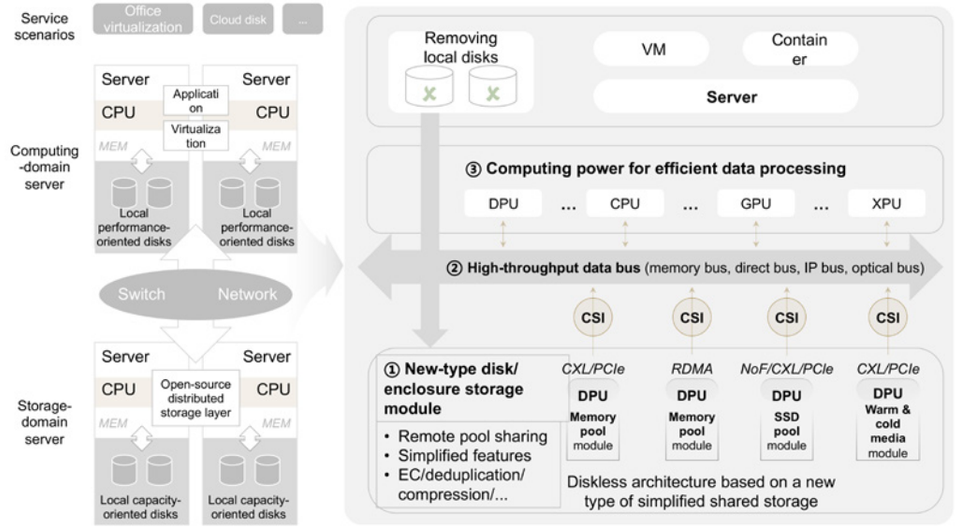


Figure 2: Comparison between traditional storage-compute decoupled architecture and its new counterpart

Third, data access network standards are constantly being enhanced. An example includes the Compute Express Link (CXL) protocols that have enhanced memory pooling features.

3. Characteristics of storage-compute decoupled architecture

The development of new hardware technologies, like remote direct memory access (RDMA), CXL, and non-volatile memory express (NVMe) SSD, call for a new type of storage-compute decoupled architecture. This will address the need to ensure that storage-domain services in the cloud and Internet can strike a good balance between numerous factors like resource utilization and reliability. This new type of architecture differs from the traditional architecture in two ways: First, storage and computing are completely decoupled to form hardware resource pools that are independent of each other. Second, fine-grained task division enables dedicated accelerators to replace CPUs in areas where CPUs perform poorly, such as data processing, ensuring optimal energy efficiency (see the right side of Figure 2).

The new type of architecture boasts the following characteristics:

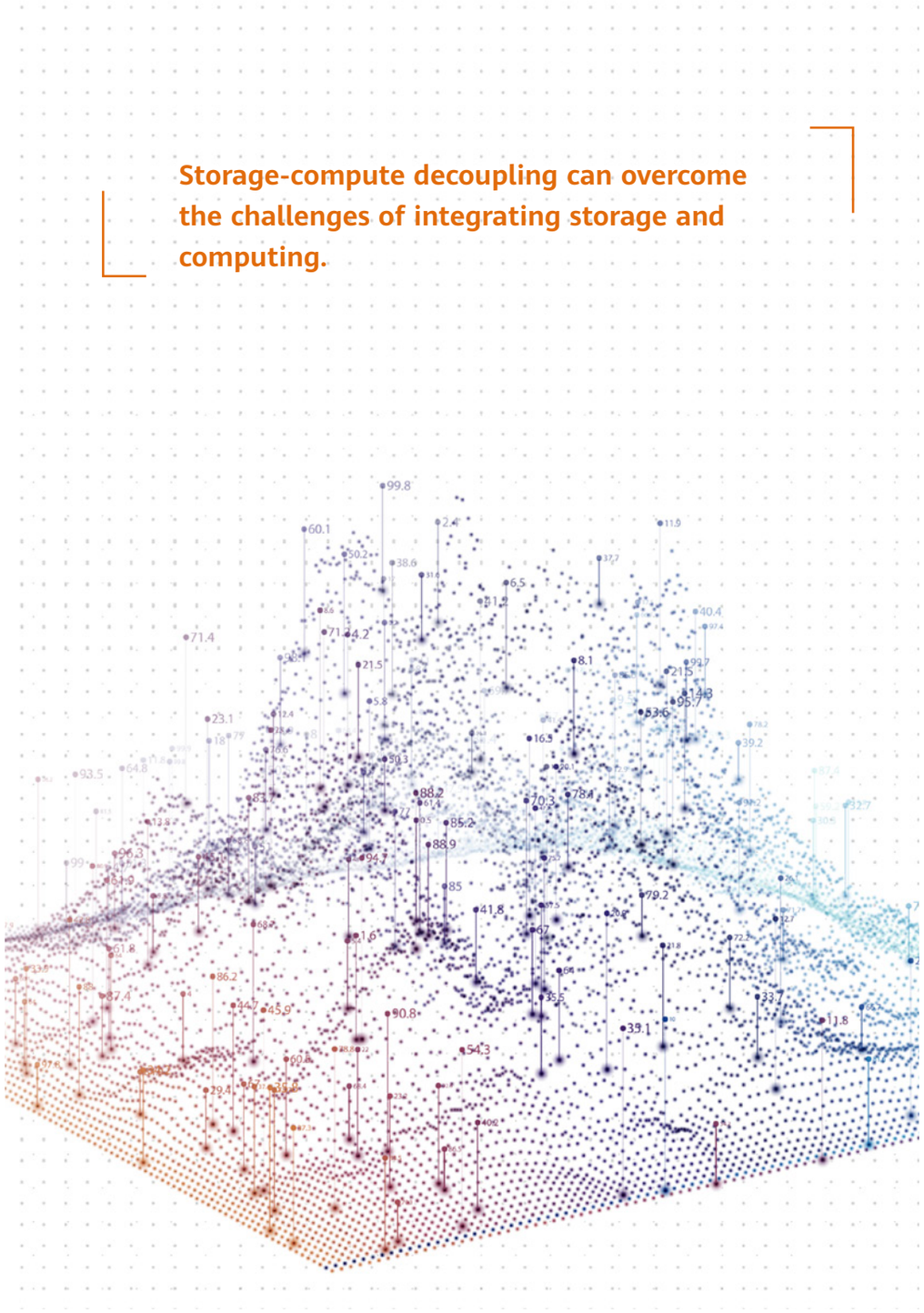
Diskless servers. The new type of architecture replaces the local disks traditionally found in servers with diskless servers and remote storage pools, while also using remote memory pools to expand local memory. This essentially decouples storage and computing, greatly improving storage resource utilization and reducing the need for data migration.

Diversified network protocols. The network protocol between compute and storage is now extending from either Internet Protocol (IP) or Fibre Channel Protocol (FCP) to a combination of protocols (CXL + NoF + IP). CXL reduces network latency to sub-microseconds and enables memory pooling, while NoF accelerates SSD pooling. Therefore, high-throughput networks built based on the combination of these protocols can support access to various resource pools.

Dedicated data processors. Data storage tasks are no longer handled by general-purpose processors, and are instead offloaded to dedicated data processors. In addition, specific data operations, such as erasure coding, can be further accelerated by dedicated hardware accelerators.

Storage systems featuring ultra-high storage density. Separated storage systems are a key part of the new type of architecture. As the foundation of persistent data, they integrate the space

Storage-compute decoupling can overcome the challenges of integrating storage and computing.



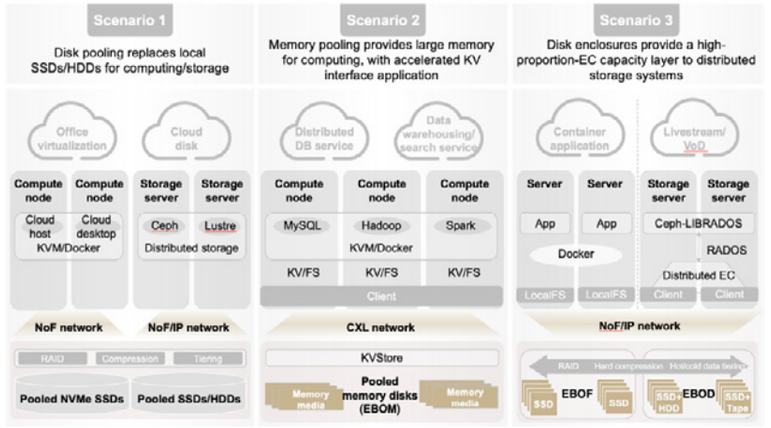


Figure 3: Three typical application scenarios of storage modules

management capabilities of both the current system and disks by applying the intensive management of storage media and the in-depth collaborative design of chips and media. In addition, the systems use the high-proportion erasure coding algorithm to reduce the percentage of redundant resource overheads. Furthermore, the systems use scenario-based data reduction technology, based on chip acceleration, to provide more available data storage space.

A new type of storage-compute decoupled architecture and key technologies for cloud and Internet applications

1. Simplified and layered storage-compute decoupled architecture

The new type of storage-compute decoupled architecture is designed to solve several major challenges presented by traditional architecture. To achieve this, it decouples different functions, forms resource pools, and restructures them into three simplified new modules: storage module, bus network, and computing module.

Storage module: Typically, cloud and Internet services have three main application scenarios (see Figure 3). The first of these is for virtualization services, which replaces the local disks of storage-domain servers found in data centers with remote disks. The second scenario is to provide large memory and key-value interfaces for services that require ultra-hot data processing, such as big data services, to accelerate data processing speeds. The third scenario is new services like containers, which directly provide file semantics for distributed applications, like Ceph, and support warm data tiering to colder mechanical disk storage modules like EBOD to improve storage efficiency.

In the new type of storage-compute decoupled architecture, storage modules mainly take the form of new types of disk enclosures like EBOF and EBOM. Additionally, traditional storage capabilities, such as EC and compression, are moved to the new types of disk enclosures to enable 'disks as storage media'. This allows for the provision of standard block and file storage services through high-speed shared networks like NoF networks.

Regarding internal architecture, the media layer can consist of either standard hard disks or chip-integrated boards, while disks and enclosures can be integrated to minimize costs. In addition, storage modules need pool-based subsystems. This will allow the modules to pool local storage media through the use of reliable redundancy technologies like RAID and EC, and also use technologies like deduplication and compression to further improve effective capacity. To support the high-throughput data scheduling of the new architecture, more efficient data throughput will be needed. Generally, fast data access paths are constructed based on technologies like hardware passthrough. Compared

with traditional storage arrays, such paths avoid inefficient interleaving of user data and control data (e.g., metadata), reduce complex feature processing (e.g., replication), and shorten I/O processing paths, enabling superior performance that offers high throughput and low latency.

Storage modules are a new form of storage that provides intensive, compact, and superior storage power. They are accelerating transformation towards diskless servers, whilesupporting the evolution of traditional data center architectures to simplified and layered storage-compute decoupled architecture.

Computing module: As Moore's Law slows, only dedicated processors will be able to further unleash the computing power required for the next stage of development. The introduction of dedicated processors makes the pooling of computing power a necessity. Without such pooling, the configuration of a heterogeneous computing card for each server will mean massive power consumption and low resource utilization. Dedicated data processors like DPUs offer lower costs, lower power consumption, and plug-and-play, ensuring both normal service operations and service quality.

High-throughput data bus: Over the past decade, 10GE IP networks have enabled the pooling of hard disk drives (HDDs), as well as the development of IP-based access protocols that support the sharing of both blocks and files. Currently, NVMe/RoCE is driving the pooling of solid-state drives (SSDs) for hot data processing. Additionally, the NVMe protocol is undergoing rapid development and starting to incorporate siloed protocols. Moving forward, memory-oriented networks (e.g., CXL) will enable the pooling of memory resources for ultra-hot data processing (see Figure 4).

2. Key technologies enabled by the new type of storage-compute decoupled architecture

The new type of storage-compute decoupled architecture has changed the way hardware resources are combined and given rise to a range of key technologies such as scenario-based data reduction and high-throughput, hyper-converged networks.

Scenario-based data reduction: In the new type of architecture, data reduction is handled by the storage module. This, alongside frontend and backend reduction tasks, reduces impact on performance and improves reduction rate. Different reduction techniques can be used based on the data characteristics in different scenarios.

High-throughput hyper-converged network: Based on deployment scenarios and agile and adaptive service requirements for diverse networks, storage and compute modules can be networked according to a combination of CXL Fabric, NoF, and IP. The following key technologies must be considered in that regard: First, network connectivity has two modes: direct connection, and pooling. In direct connection mode, network interface cards (NICs) are exclusively used by equipment. In pooling mode, NICs are pooled and shared by different pieces of equipment, which improves utilization. Second, cross-rack communication typically uses the RDMA mechanism. Because the number of traditional RDMA connections is limited, the problem of scalability regarding large-scale connection needs to be solved. An example solution is the application of connectionless technology to decouple connection status from network applications, thereby supporting tens of thousands of connections.

Network-storage collaboration: Intelligent NICs (iNICs) and DPUs are the data gateways of servers. Fully utilizing the acceleration capabilities of iNICs and DPUs, such as hardware NoF offloading and compression, and coordinating task scheduling between hosts and DPUs to reduce host data-processing overheads will improve I/O efficiency. Programmable switches act as the data exchange hubs between servers and storage devices, and they play a special role in the system. Their programmability, centralization, and high performance mean efficient collaborative data-processing is possible.

Disk-storage collaboration: Deep collaboration between storage media and control chips can facilitate best end-to-end TCO and efficiency. For example, in redundancy design, new types of storage modules possess integrated storage chips and build a high-proportion EC pooling space at the chassis level. This facilitates the offloading and acceleration

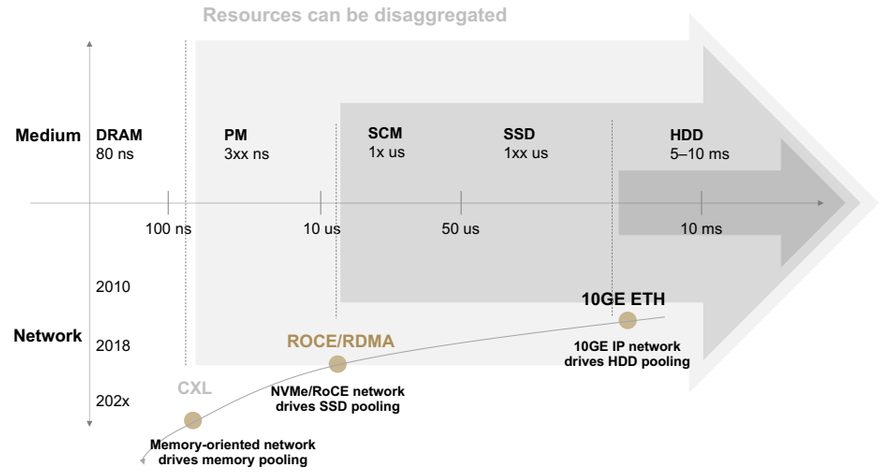


Figure 4: Network technology development

of dedicated chips, simplifying the original multi-layer redundancy design, such as in-disk and in-chassis, and improving resource utilization.

New types of storage modules based on dedicated chips provide traditional I/O interfaces and bypass interface acceleration, allowing metadata to bypass the heavy I/O stack and improve parallel access capabilities through remote memory access.

Challenges to the new type of storage-compute decoupled architecture

In the wake of China's Eastern Data and Western Computing project and energy conservation and emission reduction initiative, the new type of storage-compute decoupled architecture is set to become a heated topic. Of course, the architecture also faces many technical challenges that must be addressed by experts in various fields.

The data access interface and standards between computing and storage primarily run in the master-slave request response model, mainly transporting block storage semantics. However, with the rapid development of heterogeneous computing power in memory disks and iNICs, performance in terms of memory access semantics and storage-computing collaborative semantics is falling short of requirements.

Further exploration is needed to determine how to leverage existing ecosystems and realize the potential of infrastructure based on the new architecture. Examples of major, long-term challenges include maximizing the potential of new data processors and globally shared storage systems, and designing more efficient application service frameworks.

References

[1] David Reinsel, Wu Lianfeng, John F. Gantz, John Rydning, IDC: China Will Have the Largest Data Circle by 2025 [OL], http://www.d1net.com/uploadfile/2019/0214/20190214023650515.pdf, January 2019

[2] Bozman J S, Broderick K. IDC: Server Refresh: Meeting the Changing Needs of Enterprise IT with Hardware/Software Optimization[OL]. https://www. oracle.com/us/corporate/analystreports/corporate/idc-server-refresh-359223.pdf, July 2010.

[3] Zhang T, Zuck A, E.Porter D, et al. Flash Drive Lifespan is a Problem[C]// Proc. of the 16th Workshop on Hot Topics in Operating Systems (HotOS 2017), 2017: 42–49.

[4] Kanev S, Darago J, Hazelwood K, et al. Profiling a warehouse-scale computer[C]//The 42nd International Symposium on Computer Architecture (ISCA 2015), 2015: 158–169.

[5] Jin X, Li X, Zhang H, et al. NetCache: Balancing Key-Value Stores with Fast In-Network Caching[C]// The 26th ACM Symposium on Operating Systems Principles (SOSP 2017), 2017: 121–136.

[6] Li B, Ruan Z, Xiao W, et al. KV-Direct: High-Performance In-Memory Key-Value Store with Programmable NIC[C]// The 26th ACM Symposium on Operating Systems Principles (SOSP 2017), 2017: 137–152.

Extracted from Communications of the CCF, Issue 11, 2022

02.

FUTURE TECHNOLOGIES

Future Technologies

Hypotheses and Visions for the Intelligent World

Dr. Zhou Hong
President of the Institute of Strategic Research, Huawei

AI is developing rapidly and so we need to consider how to ensure AI development progresses in a way that benefits all people and ensures that AI execution is accurate and efficient. This article analyzes the theoretical and technological challenges, hypotheses, and visions for AI, and touches on Huawei's recent endeavors in this field. We hope that rapidly developing AI will become a force for good, better serve social progress, and lead us to an intelligent world.

As we move towards an intelligent world, information sensing, connectivity, and computing are becoming key. The better knowledge and control of matter, phenomena, life, and energy that result from these technologies are also becoming increasingly important. This makes rethinking approaches to networks and computing critical in the coming years.

In terms of networks, about 75 years ago Claude Shannon proposed his theorems based on three hypotheses: discrete memoryless sources, classical electromagnetic fields, and simple propagation environments. But since then, the industry has continued to push the boundaries of his work.

In 1987, Jim Durnin discovered self-healing non-diffracting beams that could continue to propagate when encountering an obstruction.

In 1992, L. Allen et. al. postulated that the spin and orbital angular momentum of an electromagnetic field has infinite orthogonal quantum states along the same propagation direction, and each quantum state can have one Shannon capacity.

After AlphaGo emerged in 2016, people realized how well foundation models can be used to describe a world with prior knowledge. This means that much information is not discrete or memoryless.

With the large-scale deployment of 5G Massive MIMO in 2018, it has become possible to have multiple independent propagation channels in complex urban environments with tall buildings, boosting communications capacity.

These new phenomena, knowledge, and environments are helping us break away from the hypotheses that shaped Shannon theorems. With them, I believe we can achieve more than 100-fold improvement in network capabilities in the next decade.

In computing, intelligent applications are developing rapidly, and AI models in particular are likely to help solve the fragmentation problems that are currently holding AI application development back. This is driving an exponential growth in model size. Academia and industry have already begun exploring the use of AI in domains like software programming, scientific research, theorem verification, and theorem proving. With more powerful computing models, more abundant computing power, and higher-quality data, AI will be able to better serve social progress.

Three challenges AI faces in understanding the world

AI capabilities are improving rapidly, and so we need to consider how to ensure AI development progresses in a way that benefits all people and ensures that AI execution is accurate and efficient. In addition to ethics and governance, AI also faces three big challenges from a theoretical and technical perspective: AI goal definition, accuracy and adaptability, and efficiency.

The first challenge AI faces is that there is no agreed upon definition of its goals. What kind of intelligence do we need?

If there is no clear definition, it is difficult to ensure that the goals of AI and humanity will be aligned and to make reasonable measurements and classifications and scientific computations. Professor Adrian Bejan, a physicist at Duke University, summarizes more than 20 goals for intelligence in his book The Physics of Life, including understanding and cognitive ability, learning and adaptability, and abstract thinking and problem-solving ability. There are many schools of AI, which are poorly integrated. One important reason for this is there are no commonly agreed upon goals for AI.

The second challenge AI faces is accuracy and adaptability. Learning based on statistical rules extracted from big data often results in non-transparent processes, unstable results, and bias. For example, when recognizing a banana using statistical and correlation-based algorithms, an AI system can be easily affected by background combinations and tiny noises. If other pictures are put next to it, the banana may be recognized as an oven or a slug. These pictures can be easily recognized by people, but AI makes these mistakes and it is difficult to explain or debug them.

The third challenge for AI is efficiency. According to the 60th TOP500 published in 2022, the fastest supercomputer is Frontier, which can achieve 1,102 PFLOPS while using 21 million watts of energy. Human brains, in contrast, can deliver about 30 PFLOPS with just 20 watts. These numbers show that the human brain is about 30,000 to 100,000 times more energy efficient than a supercomputer. In addition to energy efficiency, data efficiency is also a major challenge for AI. It is true that we can better understand the world by extracting statistical laws from big data. But can we find logic and generate concepts from small data, and abstract them into principles and rules?

Breakthroughs and visions

We have come up with several hypotheses to address these three challenges:

- Knowledge comprises the concepts, attributes, relationships, and rules induced and abstracted from the facts and phenomena that we find in the external environment and ourselves.
- Intelligence is the ability to achieve goals in complex environments with limited resources through sensing and interaction, computing, and trial-and-error.

Future communications and computing are two key features of building the intelligent world.

- We can achieve intelligence by extracting probability distributions from existing big data for model fitting and derivation, as well as by using deduction, hypotheses, and trial-and-error to ask questions and find creative solutions with little data or even no data at all.

Starting from these hypotheses, we can begin to take more practical steps to develop knowledge and intelligence.

At Huawei, our first vision is to combine systems engineering with AI to develop accurate, autonomous, and intelligent systems. In recent years, there has been a lot of research in academia about new AI architectures that go beyond transformers.

We can build upon these thoughts by focusing on three parts: perception and modeling, automatic knowledge generation, and solutions and actions. From there, we can develop more accurate, autonomous, and intelligent systems through multimodal perception fusion and modeling, as well as knowledge and data-driven decision-making.

Perception and modeling are about representations and abstractions of the external environment and ourselves. Automatic knowledge generation means systems will need to integrate the existing experience of humans into strategy models and evaluation functions to increase accuracy. Solutions can be directly deduced based on existing knowledge as well as internal and external information, or through trial-and-error and induction. We hope that these technologies will be incorporated into future autonomous systems, so that they can better support domains like autonomous driving networks, autonomous vehicles, and cloud services.

Our second vision is to create better computing models, architectures, and components to continuously improve the efficiency of intelligent computing. I once spoke with Fields Medalist Professor Laurent Lafforgue about whether invariant object recognition could be made more accurate and efficient by using geometric manifolds for object representation and computing in addition to pixels, which are now commonly used in visual and spatial computing.

In their book Neuronal Dynamics, co-authors Gerstner, Kistler, Naud, and Paninski at École Polytechnique Fédérale de Lausanne (EPFL) explain the concept of functional columns in the cerebral cortex and the six-layer connections between these functional columns. It makes me wonder: Can such a shallow neural network be more efficient than a deep neural network?

A common bottleneck for today's AI computing is the memory wall. Reading, writing, and migrating data often takes 100-times more time than computing itself. So, can we possibly bypass conventional processors, instruction sets, buses, logic components, and memory components under von Neumann architecture, and redefine architectures and components based on advanced AI computing models instead?

Delivering more value with AI applications

Huawei has been exploring this idea by looking into the practical uses of AI. First, we have worked on "AI for Industry", which uses industry-specific large models to create more value. Industries face many challenges when it comes to AI application development. They need to invest a huge amount of manpower to label samples, find it difficult to maintain models, and lack the necessary capabilities in model generalization. Most simply they do not have the resources to do this.

To address these challenges, Huawei has developed L1 industry-specific large models based on its L0 large foundation models dedicated to computer vision, natural language processing, graph neural networks, and multi-modal interactions. These large models lower the barrier to AI development, improve model generalization, and address application fragmentation. The models are already being used to improve operational efficiency and safety in major industries like electric power, coal mining, transportation, and manufacturing.

Huawei's Aviation & Rail Business Unit, for example, is working with customers and partners in Hohhot, Wuhan, Xi'an, Shenzhen, and Hongkong to explore the digital transformation of urban rail, railways, and airports. This has improved operational safety and efficiency, as well as user experience and satisfaction. The Shenzhen Airport has realized smart stand allocation with the support of cloud, big data, and AI, reducing airside transfer bus passenger flow by 2.6 million every year. The airport has become a global benchmark in digital transformation.

"AI for Science" is another initiative that will be able to greatly empower scientific computing. One example of this in action is the Pangu meteorology model we developed using a new 3D transformer-based coding architecture for geographic information and a hierarchical time-domain aggregation method. With a prior knowledge of global meteorological phenomena, the Pangu model uses more accurate and efficient learning and reasoning to replace time series solutions of hyperscale partial differential equations using traditional scientific computing methods. The Pangu model can produce 1-hour to 7-day weather forecasts in just a few seconds, and its results are 20% more accurate than forecasts from the European Centre for Medium-Range Weather Forecasts.

AI can also support software programming. In addition to using AI to do traditional retrieval and recommendation in

a large amount of existing code, Huawei is developing new model-driven and formal methods. This is especially important for large-scale parallel processing, where many tasks are intertwined and correlated. Huawei has developed a new approach called Vsync which realizes automatic verification and concurrent code optimization of operating system kernels, and improves performance without undermining reliability. The Linux Community once discovered a difficult memory barrier bug which took community experts more than two years to fix. With Huawei's Vsync method, however, it would have taken just 20 minutes to discover and fix the bug.

We have also been studying new computing models for automated theorem proving. Topos theory, for example, can be used to research category proving, congruence reasoning systems, and automated theorem derivation to improve the automation level of theorem provers. In doing this, we want to solve state explosion and automatic model abstraction problems and improve formal verification capabilities.

Finally, we are also exploring advanced computing components. We can use the remainder theorem to address conversion efficiency and overflow problems in real-world applications. We hope to implement basic addition and multiplication functions in chips and software to improve the efficiency of intelligent computing.

As we move towards the intelligent world, networks and computing are two key cornerstones that underpin our shift from narrow AI towards general-purpose AI and super AI. To get there, we will need to take three key steps. First, we will need to develop AI theories and technologies, as well as related ethics and governance, so that we can deliver ubiquitous intelligent connectivity and drive social progress. Second, we will need to continue pushing our cognitive limits to improve our ability to understand and control intelligence. Finally, we need to define the right goals and use the right approaches to guide AI development in a way that truly helps overcome human limitations, improve lives, create matter, control energy, and transcend time and space. This is how we will succeed in our adventure into the future.

Networks and computing are two key cornerstones that underpin our shift from narrow AI towards general-purpose AI and super AI.

03.

NEW SOLUTIONS

New Solutions

Eight Technologies Leading Us into the Intelligent World

Digital and intelligent transformation is driving us towards an intelligent world. How will the ICT industry develop to fuel this journey?

Dang Wenshuan
Chief Strategy Architect, Huawei

To bring our vision for the intelligent world to life, the ICT industry needs to continuously explore new ways to improve and innovate. Two pillars underpin our vision of accelerating the intelligent world: "ICT for Intelligence" and "Intelligence for ICT".

· "ICT for Intelligence" is about constantly innovating and evolving in different ICT domains to improve key capabilities.
· "Intelligence for ICT" is about how the ICT industry will become more intelligent and achieve architectural innovations to deal with complex O&M, deliver a positive user experience in a wider range of applications, and enable green development.

Based on these two pillars, this articles looks at our development approaches to eight key ICT areas: wireless networks, cloud core networks, all-optical networks, data communication, autonomous driving networks, computing, data storage, and cloud computing.

Wireless Networks: Striding towards 5.5G and Intelligent IoE

5G has greatly improved mobile user experiences. In the 4G era, SD videos were mainstream, but in today's 5G world, 60% of videos are already HD. Many new types of mobile interactions, such as short videos, live-streaming e-commerce, and virtual concerts with tens of millions of viewers, are emerging and gaining in popularity. Cost per bit has dropped sharply and new consumer behaviors have formed. These new behaviors have driven a surge in mobile traffic, redefined standards for user experiences, and changed the rules of the game.

As services like XR and new calling mature, we predict that by 2025 average mobile data traffic per user per month (DOU) will increase from 15 GB to 100 GB, while data rates will increase from 1 Gbit/s to 10 Gbit/s.

To prepare for these changes, the mobile industry should focus on four key areas.

First, we must free up more spectrum across different bands for 5G to build a universal mobile broadband network. Second, we need to begin deploying millimeter wave and 6 GHz around 2024 or 2025 to support these spikes in data traffic. Third, we must introduce AI into wireless networks to make them more autonomous and intelligent. Finally, we need to define and shape the development of 5.5G.

Our goals are to improve the basic performance of 5G wireless network tenfold, achieve AI native and 10-Gbit/s mobile experiences, and support 100 billion IoT connections.

Developments in spectrum resources are paramount. Currently, there are only a few hundred MHz available for most operators, including new mid-band TDD spectrum and existing FDD spectrum. This can reliably support X Gbit/s and 15 GB DOU. However, from 2025 onwards, telecom operators will each need at least 1 GHz of spectrum to deliver a 10-Gbit/s experience and support over 100 GB DOU. Making the most of the sub-100 GHz section of the spectrum is the key to achieving this.

That is why we have proposed IntelligentRAN. It has two parts: Intelligent base stations and the intelligent management platform iMaster MAE. With this new architecture, we can create digital twins of wireless networks through data reconstruction, use layered AI engines to support diversified AI application scenarios, and enable layered autonomy for network elements and the management platform through multi-target management and intelligent decision-making.
The idea behind this is to build AI-native wireless networks with zero-wait provisioning, optimal experience and energy efficiency, zero faults, and continuous learning and evolution.

The goal of IntelligentRAN is to achieve autonomy in the wireless network domain.

The industry recognizes 5.5G as the way forward. But, to take it to the next level, we must jointly develop standards and clarify the development direction of key technologies such as ultra-large bandwidth, uplink spectrum reconstruction, passive IoT, green air interface, and AI native.

Cloud core networks: Creating better business value with full service enabling

VoLTE and VoNR have emerged as the basis of 5G voice networks due to the high-quality voice experiences they deliver and the reduced use of spectrum for 2G and 3G. Operators have also started developing video calling services, which we expect to take off in the near future and achieve a penetration rate of more than 15% by 2025.

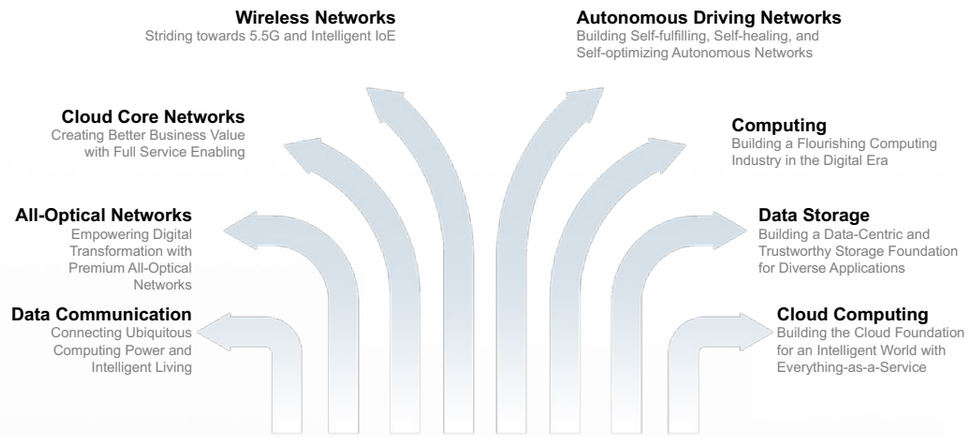
To support a richer user experience, core networks must undergo three changes. First, they need to support full-service enablement. Second, they should adopt AI to make core networks autonomous and intelligent. Third, the industry must come together and define and shape the development of 5.5G core networks.

To build core networks that feature full-service enablement, we need to continuously improve new calling, video, and multi-access edge computing (MEC) capabilities.

For new calling, we need to introduce data channels and technologies like real-time rendering to deliver intelligent and interactive call experiences. The future of video is volumetric and social, which requires frame scheduling and converged video and communication technologies. We also need to improve MEC reliability and private WAN capabilities, and extend industry private networks from limited scenarios at certain sites to all scenarios anywhere.

The rapid development of core networks will put pressure on architecture, so introducing AI will be essential to help meet these demands.

Therefore, we have proposed IntelligentCore. It consists of two parts: intelligent core network elements and iMaster MAE-CN. Based on this new architecture, we can create digital twins of core networks, and analyze and operate live networks through simulation. AI-native core networks will enable zero-touch network configuration and zero network interruptions, with a better, lossless



Eight Technologies Leading Us into the Intelligent World

user experience. Ultimately, IntelligentCore will achieve autonomy in the core network domain.

As an essential facet of mobile 5.5G networks, core networks must continue to evolve. Huawei has proposed its vision for 5.5G core, which has six major components: trustworthiness, automation, cloudification, MEC to Everywhere, new calling, and new video. Combined, these will support full-service enablement.

To support the development of 5.5G core, we must clarify the development direction of key technologies such as data channel, frame scheduling, all-scenario MEC, and AI native.

Empowering digital transformation with premium all-optical networks

Multiple factors are driving the explosive growth of all-optical networks globally. We predict that:

- Global FTTH penetration will increase from 28% in 2020 to 40% in 2025.
- During the same period, gigabit FTTH penetration will soar from 1% to 26%, and FTTR penetration will reach 8%.
- Leading markets will start shifting from gigabit FTTH to 10-gigabit FTTH in 2025.

To prepare for these changes, the all-optical network industry needs to take four actions. First, accelerate FTTH deployment and increase FTTR penetration. Second, start commercial 50G PON and Wi-Fi 7 deployment around 2024 or 2025. Third, apply AI to optical access and transport networks to make them autonomous and intelligent. Finally, jointly define and shape the development of Fixed 5.5G.

To deliver a ubiquitous 10-gigabit experience, we can consider several measures from the perspective of network evolution:·

- Move from FTTH to FTTR and from Wi-Fi 6 to Wi-Fi 7 for homes.
- Evolve OLTs from GPON and 10G PON to 50G PON.
- Upgrade metro and backbone networks to increase transmission from 100G or 200G per lambda to 400G or 800G per lambda, which will support higher access bandwidths and larger user bases. We also need to widely deploy optical cross-connect (OXC) to further reduce transmission latency, enable one-hop connection, and improve user experience.

To introduce AI into all-optical access networks, we have proposed IntelligentFAN, which has two parts: intelligent network elements, including FTTR, ODN, and OLT, and iMaster NCE-FAN. Based on this new architecture, we can create digital twins of all-optical access networks through digital modeling; support the application scenarios of all-optical access

networks through layered AI engines; and enable layered autonomy for network elements and the management platform through intelligent decision-making.

AI-native all-optical access networks will deliver ubiquitous gigabit or even 10-gigabit experiences, and enable precise operations and elastic planning. The goal is to achieve the access network domain autonomy and bring digital technology to homes and industries.

To introduce AI to all-optical transport networks, we have proposed IntelligentOTN. This also has two parts: network elements, including OXC and OTN, and iMaster NCE-T. AI-native all-optical transport networks will deliver ultra-broadband, low-latency, and highly-reliable transmission, SLA-guaranteed services, and unattended network O&M. Ultimately, these features will achieve transport autonomy.

Huawei proposed Fixed 5.5G to boost the development of fixed networks. We are continuing to improve the existing capabilities of F5G and have added three new capabilities that will bring about three new changes alongside changes to the AI-native feature and ubiquitous 10-gigabit experience. These include:

- Industry-grade real-time resilient connectivity that cuts latency to microseconds and increases availability to six nines, which will better enable industrial digital transformation.
- Replacing electrical components with optical components and upgrading to an all-optical network architecture will increase energy efficiency tenfold and enable green, sustainable development.
- Transitioning from optical communication to optical sensing will bring the environmental monitoring error margin down to one meter, leading to scenarios and applications that go beyond connectivity.

Connecting ubiquitous computing power and intelligent living

Two pillars underpin our vision of accelerating the intelligent world: "ICT for Intelligence" and "Intelligence for ICT".

millions of paths.

Third, data center networks will evolve to 800 GE and become lossless networks with zero packet loss. Data plane convergence and dynamic congestion control algorithms will continuously reduce end-to-end latency and unleash computing power.

From the network architecture perspective, the rapid development of WANs is creating new requirements on network architecture such as ensuring an optimal service experience across all scenarios and maximally utilizing networks. To meet these requirements, we are introducing AI into WANs and have proposed IntelligentWAN, which has two parts: intelligent routers and iMaster NCE-IP.

XR collaboration and more cloud applications will lead enterprises into the 10-gigabit era. Looking ahead to 2025, we will build 10-gigabit enterprises. Evolution in three areas is required to achieve this:

First, campus wireless access must evolve to Wi-Fi 7. We expect Wi-Fi 7 APs to hit the market in 2023 and see large-scale commercial deployment in 2025. These APs will support up to 320 MHz channel bandwidth, 12x12 MIMO, and 4K QAM, as well as a peak data rate of over 10 Gbit/s. This will help provide full-wireless coverage from offices to production facilities. The port rate of campus access switches will increase from 10 GE to 50 GE, while the port rate of aggregation and core switches will jump from 100 GE to 400 GE.

Second, in terms of WAN, the backbone port rate will increase to 800 GE, network capacity will increase, and the IPv6 Enhanced protocol will continue to evolve. This will enable SRv6 and APN6 to deliver more capabilities like network programmability and application awareness. It will also support multi-factor path computation across hundreds of thousands of network elements and

As campus networks continue to develop rapidly, we will need to ensure an optimal service experience across all campus scenarios and better connect things on campus. To achieve this, we have proposed IntelligentCampusNetwork, which comprises two parts: network elements, which includes campus Wi-Fi APs and switches, and iMaster NCE-Campus. AI-native campus networks will offer zero-wait, zero-fault, and zero-touch capabilities, and achieve autonomy in the campus network domain.

The rapid evolution of data center networks has created new requirements for ensuring lossless connections; meeting performance requirements across various scenarios, such as general-purpose computing, high-performance computing, and AI computing; and building lights-out data centers. To introduce AI into data center networks, we have proposed IntelligentFabric, which consists of data center switches and iMaster NCE-Fabric. AI-native

data center networks will offer zero errors, zero wait times, and zero interruptions, and achieve autonomy in the data center network domain.

To evolve data communications, Huawei has unveiled its vision for Net5.5G, covering six areas: Green Ultra-Broadband, Massive Heterogeneous IoT, High Resilience & Low-latency Networking, IPv6 Enhanced, Multi-domain Network AI, and Ubiquitous Network Security.

- Green, ultra-broadband networks provide mobile users, homes, and office campuses with 10-gigabit access.
- IPv6 Enhanced, Multi-domain Network AI, and Ubiquitous Network Security provide enterprises with elastic, agile, secure, and easy-to-access multi-cloud networking.
- High-Resilience & Low-latency Networking interconnects millions of compute nodes, accelerates centralized industrial control, and makes flexible manufacturing a reality.
- Massive heterogeneous networking enables ubiquitous IoT connections in industrial facilities and campuses.

Autonomous driving networks: building self-fulfilling, self-healing, and self-optimizing autonomous networks

Architecture transformation that systematically introduces AI and enhances network autonomy is becoming a must, with standards for different levels of autonomous networks following the same structure as standards for autonomous vehicles. Communication networks are moving from L2 – partial autonomy, and L3 – conditional autonomy, to L4 – high autonomy.

We have developed a series of intelligent solutions that cover multiple fields like networks, computing, and storage. For example, IntelligentServiceEngine helps operators implement closed-loop management, from service goals to network domain goals. The key components of the solution include a domain knowledge engine, business intelligence engine, hyper-automation engine, domain app development engine, and digital twins. These will enable a superior user experience,

We have developed a series of intelligent solutions that cover multiple fields like networks, computing, and storage.

support efficient O&M, and enable business success.

With AI and digital twins for the network and environment, IntelligentServiceEngine can intelligently assess real-time experiences for different situations, tasks, times, and locations. This can help create a new experience-driven model that enables continuous optimization.

The solution can connect data breakpoints and help create a model that supports real-time, accurate business-network linkage and forecasts, enabling intelligent business operations that can make sense of the present and predict the future.

For simple O&M events, the virtual employee supports zero-touch O&M. For complex events, we can implement event analysis and decision-making based on domain knowledge and machine intelligence, and then develop a professional scenario-based O&M system where different roles, sites, and tasks can be coordinated.

Building a flourishing computing industry in the digital era

The rapid growth of the digital economy has driven an exponential increase in data. We estimate that the amount of new data generated in 2030 will exceed 1,000 zettabytes, 23 times the amount generated in 2020.

Unstructured data, such as text, images, audio, and video, is expected to account for over 80% of the data in 2030. Processing such massive amounts of diverse data requires diversified computing power. We estimate that by 2030, total general-purpose computing power will increase tenfold to reach 3.3 ZFLOPS, while AI computing power will increase by a factor of 500 to hit 105 ZFLOPS.

In response, the computing industry must change and pursue architecture innovations to overcome bottlenecks with CPU-centric architectures. This will allow the industry to meet requirements for massive and diverse data processing and adapt to the era of diversified computing.

Moving forward, we will need to redefine computing architectures to realize DC as a Computer and increase effective computing power by a factor of 10. How?

First, we need to evolve from the current CPU-centric heterogeneous architecture to a decentralized, peer-to-peer computing architecture that supports diversified computing power. This decentralized approach can break down both I/O and memory walls, greatly improving bandwidth and reducing computing latency. Ultimately, this will significantly boost system performance.

Second, we must upgrade the hardware system from a server-based to a cluster-based system. We continuously innovate in cluster computing architectures, and leverage the technical expertise we have built up in the ICT field to integrate computing, storage, networks, and energy. This will turn a data center cluster into a set of hardware, maximizing computing power density and minimizing power consumption.

Third, at the foundational software layer, we will see a shift from siloed architecture that supports single computing power to convergent architecture that supports diversified computing. This means reshaping foundational software like acceleration libraries and compilers for different processing units to improve application development efficiency and performance.

Data Storage: Building a data-centric and trustworthy storage foundation for diverse applications

Storage has always been a strong foundation for high-value data. There are three clear changes in the storage field:

First, unstructured data is starting to see wide adoption in enterprises, with 56% of enterprises using AI for at least one business function and numerous scenarios based on unstructured data. Second, data applications are becoming more diverse. As well as traditional database applications, new technologies and applications like virtualization, containers, big data, and AI, are emerging. On average, an enterprise has over 100 applications.

Third, multi-cloud strategy is the new norm for enterprises, with 89% of enterprises that migrate to cloud now using a multi-cloud strategy.

As we enter an era of diversified data storage, we must redefine storage architectures and improve storage performance. This will allow us to address the rapidly growing amount of unstructured data and meet enterprise requirements for diverse applications and multiple clouds. We also need to use AI to enable autonomous and intelligent data storage.

Storage architecture innovations mainly focus on reshaping hardware and software architectures through a data-centric approach and various data application acceleration engines. These combined can improve storage performance by a factor of 10.

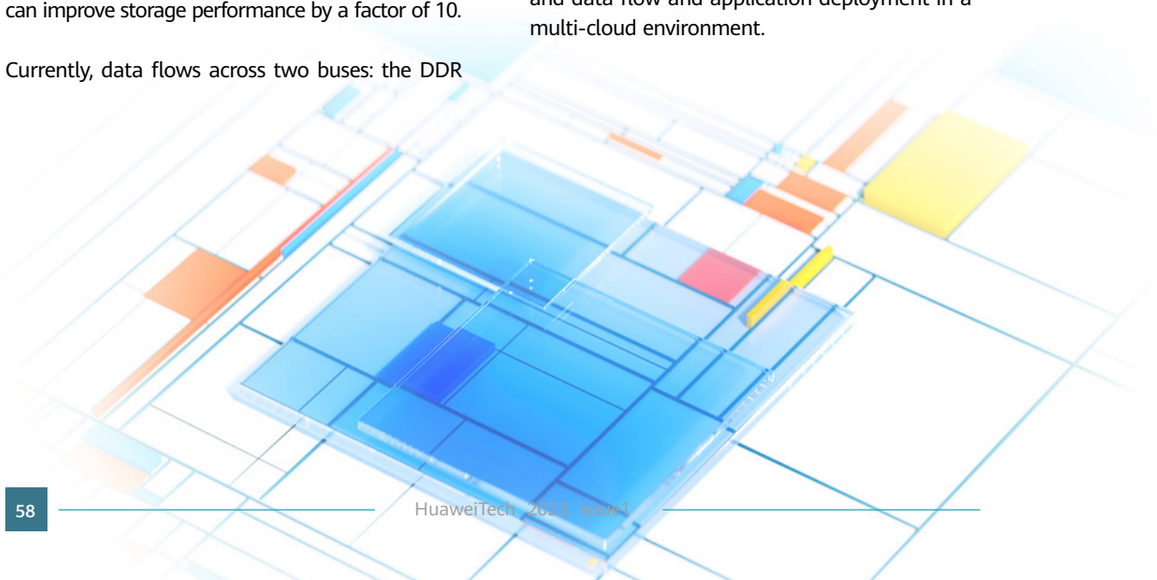
Currently, data flows across two buses: the DDR memory bus and the system PCIe bus. A global data bus with high throughput allows us to integrate these two buses, greatly improving data flow efficiency.

In the past, data was indexed and cached at each layer, from application and computing to network and storage. In the future, control and data plane separation will slash data access latency between applications and the storage pool.

For all applications, including service logic and data processing, we can place processing power near the storage system based on application features. This will enable near-data processing and accelerate applications.

As data storage rapidly grows, enterprises want to provide a consistent experience both on and off the cloud and enable real-time data processing and automatic management. To meet these requirements, we propose the IntelligentStorage solution, which embeds AI into data storage to enable autonomous and intelligent data storage.

With IntelligentStorage, we can support autonomous decision-making in scenarios like the layout, scheduling, and reduction of different types of data within storage devices, and intelligently allocate CPU and memory resources to overcome local resource bottlenecks. The solution also enables automatic root cause analysis for unknown faults across all scenarios and data flow and application deployment in a multi-cloud environment.



Cloud computing: Building the cloud foundation for an intelligent world with Everything-as-a-Service

Cloud-native is now the preferred choice for enterprises to migrate to cloud because it can bring new value. By 2025, Gartner estimates that over 95% of new digital projects will run on cloud-native platforms, so it is fair to say that cloud-native platforms are the way to deepen digitalization.

Moving forward, the cloud industry will drive ongoing evolution to cloud-native platforms to create greater value. For data and security, we will harmonize AI development and data governance to unlock more value from data, and use Cloud Security Brain to enable efficient and secure enterprise operations. Security is the foundation for enterprises to go digital.

97% of organizations are now investing in big data and AI, and the value of data is increasingly clear. How can we unlock more value from data? We believe that harmonizing AI development and data governance is the key.

There are three steps to this:

One, we need to unify data storage, reduce redundant storage, and cut invalid data transfers.

Two, we must unify metadata. This requires five unified capabilities: engine metadata, permission controls, data indexes, data directories, and transaction mechanisms. This will make data globally visible, allowing every piece of data to flow freely and be rapidly shared across multiple engines.

Three, we need to create a unified development environment, where different roles can play to their strengths and obtain what they need. For example, data engineers can use tools they are familiar with to invoke AI capabilities, enabling collaboration between big data development and AI development.

Through these innovations, we hope to further improve data development efficiency, cut data storage costs, and unlock more value from data.

Cloud-native is essential for deepening digitalization, while security is the foundation of cloud. Today, industry-leading enterprises spend over 10% of their IT investment on security. Security covers both system building and operations, meaning that security operations and defenses are equally important.

Huawei Cloud has built seven layers of defense for platform security. Through DevSecOps, we have embedded security into the development and operations of all services and, with DevSecOPs, developed over 220 secure and trustworthy cloud services. We provide customers with a wide range of security services, including over 20 in-house security services and more than 400 security ecosystem products. With these services and products, we want to help customers build comprehensive security protection systems.

Almost all businesses invest in building security systems. However, these systems can still be compromised during business operations because they lack the right operations capabilities, experts, or configurations, or they fail to effectively monitor, detect, and handle such threats.

In response to this, Huawei Cloud has launched Cloud Security Brain based on the security capabilities Huawei has built up over 30 years alongside Huawei Cloud's operation experience. We provide these capabilities and expertise as services, so customers can build their own security systems from over 300 threat detection models and more than 100 security response scripts that automatically handle threats. Customers can respond to 70% of threats within 2 minutes and to 99% of threats within 5 minutes.

Generally, fewer than 10 events need to be manually handled each day.

Cyber security and privacy protection are, and will always be, Huawei's top priorities. Security, stability, and high quality are the lifeblood of Huawei Cloud. As a cloud service provider, we are committed to building a secure, reliable, and trustworthy cloud platform, so that customers can migrate to the cloud free from worry.

A bright, intelligent world lies ahead. Let's work together to advance the industry towards the intelligent world.

Striding to 5.5G: From IoE to Intelligent IoE

Cao Ming
President, Wireless Network Product Line, Huawei

Coordinated efforts across the communications industry have created a positive development cycle with networks, users, devices, and services driving each other forward and paving the way to 5.5G.

Technology creates value, and innovation is the main engine of future development. 5G has already become a key part of the infrastructure needed to support digital transformation and the healthy development of the wider digital economy. Since its commercial rollout three years ago, 5G has grown faster than any previous generation of mobile technology. By the end of 2022, more than 240 carriers around the world had launched commercial 5G services and deployed more than three million 5G sites to serve one billion 5G users.

5G is advancing twice as fast as 4G, and already boasts a mature industry ecosystem. It is already bringing about change, but this is merely the beginning. As we inch closer to the intelligent world, new changes, scenarios, and needs will continue to emerge, raising higher requirements on network infrastructure. 5G is now able to deliver Gbit/s-level experiences and support tens of billions of connections, making it an important pillar for sustainable development and the global digital economy. 5.5G will deliver 10-fold higher network capabilities, enabling 10 Gbit/s experiences, 100 billion connections, and native intelligence for a broad diversity of services. This makes 5.5G an important milestone on the path to an intelligent world（as shown in Figure 1）.

Gigabit to 10 gigabit: 10x better connectivity experience for users

5G is changing how people watch video, allowing them to enjoy a superior experience. HD and interactive videos have become popular services among users. The number of panoramic videos and videos that support skipping and variable-speed playback is increasing rapidly. With 5G, the proportion of HD mobile videos increased to 60%, from 4G's 40%. Better user experience leads to a tangible increase in DoU and stimulates tariff plan upgrades, benefiting both users and carriers（as shown in Figure 2）. In countries and regions that have seen rapid 5G development, such as China, South Korea, and Kuwait, carriers have invested heavily in 5G and maximized its value by offering outstanding experiences. As a result, carrier revenue and profits in these countries have grown significantly faster than the global average.

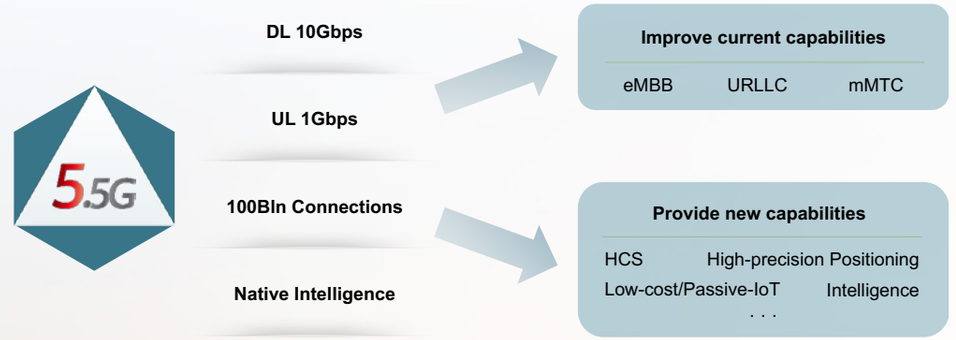


Figure 1: Key characteristics of 5.5G networks

Innovative services such as XR have also become a driving force behind 5GtoC development. The large-scale deployment of XR services requires synergies between 5G networks, cloud, and devices. The ultra-large broadband and low latency delivered by 5G networks are essential for the real-time rendering and 3D reconstruction commonly used in XR services. In the future, applications like XR Pro and metaverse will significantly blur the lines between the virtual world and real world, creating a digital mirror of the real world. Users will be able to explore the real world through simulated experiences powered by advanced computing and haptic feedback technologies. These kinds of real-time immersive interactive applications require 10 Gbit/s mobile networks and millisecond-level transmission latency.

Ultra-large bandwidth spectrum is essential for upgrading from 5G's gigabit networks to 5.5G's 10 gigabit networks. To guarantee spectrum resources for 5.5G, we need to make the most of sub-100 GHz spectrum and open up more high-frequency and large-bandwidth spectrum, such as 6 GHz and millimeter wave. We also need to change how the sub-6 GHz spectrum is used to achieve ultra-large bandwidth. Extremely large aperture array (ELAA) technologies can help address coverage issues in high bands and allow them to achieve coverage as large as C-band, making 10 Gbit/s possible anytime, anywhere.

5G2B applications: Deployment in core production activities will unleash the potential of 100 billion IoT connections

After three years of 5G2B development, 5G is being applied at scale in multiple industries, including mining, ports, and healthcare. Underground coal mines (as shown in Figure 3) are now seeing more than 100 HD cameras, a large number of sensors, and workers deployed and connected using 5G networks, enabling workers to complete 60% of underground work safely from an office above ground. One fully-connected 5G factory (as shown in Figure 4) has used 5G in 15 production processes

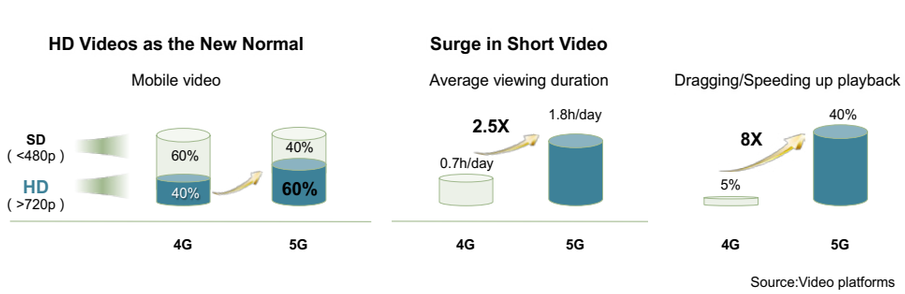


Figure 2: 5G changed how personal applications are used

Figure 3: 5G coal mine

to connect more than 2,500 units of production equipment, significantly improving the factory's production efficiency.

Chinese carriers are already making 5GtoB a new engine for revenue growth. In 2022, 5GtoB enabled carriers to generate more than US$20 billion in DICT revenue, making it the fastest growing service domain for carriers. 5GtoB is also expected to see its revenue exceed US$30 billion while contributing hundreds of billions in DICT revenue by 2025.

5.5G will be able to meet the increasing needs of industry digitalization. As 5G moves beyond just assisting production to becoming an integral part of key production activities, networks will need to provide new capabilities such as high-speed uplink transmission and high-precision positioning. In particular, as services such as machine vision and remote control require high uplink rates to upload multi-channel UHD videos in real time, high-speed uplink transmission has become a must-have for 5G2B industry applications.

The industry is already exploring new methods of improving 5G uplink capabilities. Uplink and downlink decoupling technologies, for example, reconstruct spectrum usage models, allowing for the multi-band convergence of uplink and downlink spectrum on different bands. This enables existing FDD spectrum and uplink-only spectrum to be fully used to provide Gbit/s-level uplink rates.

Many industries have extensively explored IoT, but have so far failed to achieve economies of scale due to fragmentation in existing connectivity technologies. Nevertheless, the economies of scale being seen in the mobile industry can help three 5G-centered IoT technologies deliver business success: Reduced Capability (RedCap), Narrowband IoT (NB-IoT), and passive IoT. NB-IoT is currently the mainstream low-power wide-area (LPWA) network technology, and is rapidly gaining momentum. RedCap is also ready for commercial use, is cheaper and consumes less power than eMBB, and has the potential to create billions of medium- and high-speed connections. Passive IoT combines cellular communications and passive tagging, enabling long-distance coverage with low-cost terminals. It is expected to facilitate the connection of tens of billions of passive IoT devices. Wireless networks will boast integrated communication and sensing. The use of mmWave can increase sensing accuracy and thus facilitate new applications, such as speed and distance measurements and imaging.

Figure 4: Fully-connected 5G factory

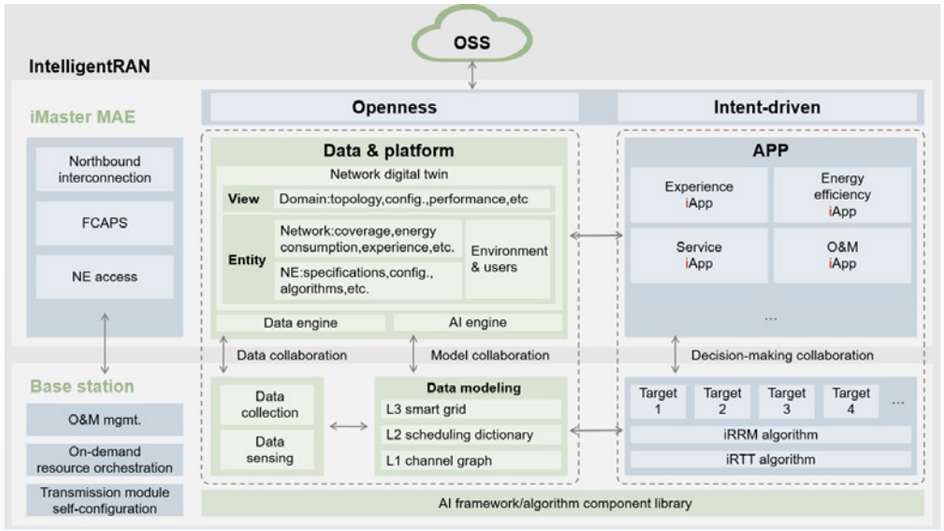


Figure 5: Intelligent architecture for mobile networks

Intelligence is key to addressing growing network complexity

Any carrier seeking to tap into the new markets and business models created by 5G and 5.5G and pursue digital and intelligent transformation will need to integrate intelligence into wireless network services, experience, O&M, and green development. Many carriers outside of China have proposed intelligent transformation strategies to build intelligent capabilities for simplified O&M, superior performance, and an ultimate experience. One Chinese carrier has proposed an autonomous network strategy, aiming to achieve network-wide L4 autonomous driving networks by 2025.

The expected exponential increase in network complexity will also drive networks to become intelligent. A natively intelligent architecture (see Figure 5) enables mobile networks to support real-time sensing, modeling and prediction, and multidimensional decision-making. With these intelligent capabilities, mobile networks will be intelligently optimized with resources that can be configured on demand for optimal user experience and capacity. O&M will also be intelligently simplified by automated site planning, deployment, and troubleshooting. Significant energy savings can then also be intelligently achieved while maximizing network performance.

Green ICT: Addressing a hundred-fold increase in traffic with only a slight increase in energy consumption

Industries today are focusing on achieving green and sustainable development. The mobile industry is no exception. With the introduction of technologies such as Massive MIMO, 5G has greatly reduced power consumption per bit and is able to transmit ten times more data than 4G for each watt consumed.

Network traffic will continue growing rapidly,

Integrating intelligence into wireless network services, experience, and O&M can support operators' expansion in the 5G/5.5G era.

Figure 6: Three-layer (device-site-network) architecture for energy-saving

with DoU projected to reach 600 GB by 2030. This has prompted the mobile industry to develop innovative technologies for high-performance, energy-efficient networks that can address a hundred-fold increase in traffic with only a slight increase in energy consumption.

Huawei has proposed an architecture for improving network efficiency across three different layers: equipment, sites, and networks (see Figure 6). Our innovation in system architecture, materials, and heat dissipation technology has led to increased equipment integration. At the site level, in addition to single site simplification, we now support intelligent coordination between whole-site facilities. And at the overall network level, we are using AI to perform dynamic, real-time optimization, laying a technical foundation for green 5G networks.

At the 2020 Global Mobile Broadband Forum (MBBF), Huawei launched its 5.5G industry vision, and defined three new scenarios that build on the original three 5G scenarios of eMBB, mMTC, and URLLC. These three new scenarios are Uplink Centric Broadband Communication (UCBC), Real-Time Broadband Communication (RTBC), and Harmonized Communication and Sensing (HCS). They will enable evolution from IoE to intelligent IoE.

After two years of concerted efforts across the industry, 5.5G has seen huge progress and three things have become clear. First, the standardization of 5.5G is already underway and right on track. Second, the industry has made breakthroughs in key technologies for 5.5G, and ultra-large bandwidth and ELAA can now deliver a 10-Gbit/s experience. Third, the industry has a clear vision for the IoT landscape. The three types of IoT technologies supported by 5.5G — NB-IoT, RedCap, and passive IoT — are developing rapidly and will support numerous IoT connections.

At the new stage for 5.5G, the industry needs to prepare well in five areas: standards, spectrum, products, ecosystems, and applications. First, we need to continue setting standards and promoting key technological research. Second, we need to prepare more spectrum. For example, we should fully utilize sub-100 GHz resources to build ultra-large bandwidth. Third, we need to prepare for 5.5G with mature networks, devices, and chips. Both our networks and devices need to be upgraded to deliver a 10 Gbit/s experience. Fourth, the industry needs to coordinate to plan and prepare for different scenarios for a thriving 5.5G ecosystem. Fifth, all players across the industry need to collaboratively explore how to pave the way for more diverse applications to emerge.

An industry-wide consensus has been reached on the vision, standards, and technologies that will underpin 5.5G. Moving forward, we will need to continuously strengthen technological innovation and collaborate with ecosystem partners to pave the way for the commercialization of 5.5G.

So, the wind is rising and it is time to set sail. Huawei is passionate about working with global carriers and industry partners to create a 5.5G that has significant business value. I have no doubt that it will soon serve as a benchmark we can use to move towards an intelligent world.

5.5G Core: Boosting Connectivity and Enabling Services

George Gao
President of the Huawei Cloud Core Network Product Line

Huawei proposes 5.5G Core, a pioneering concept and practice to boost network connectivity, enable services in more scenarios, and build future-ready businesses. 5.5G Core is a key step on our journey towards the intelligent world.

As 5G is developed on a bigger scale and rolled out to more users, its commercialization is becoming a focal point of the industry. New services and applications are increasing pressure on networks and driving the evolution of standards, technologies, applications, and ecosystems. The industry is poised for the 5.5G era.

The key to ensuring future business success is developing and supporting a comprehensive set of services which can be applied to a wider range of domains and offer a differentiated user experience. Core network construction and evolution are paramount to achieving this.

Some of the most impressive features of 5.5G Core are New Call, mobile edge computing (MEC) to X, and New Video. New Call upgrades audio/video calls to immersive intelligent experiences. MEC to X extends industry-specific private networks from a single application in an individual domain to a range of applications across all domains. New Video transforms videos from entertainment on a single screen to multi-screen social networking that transcends reality.

By leveraging these capabilities to bring services to more consumer-, business-, and household-facing scenarios, the core network will place the industry in a strong position to build new businesses and thrive in the intelligent world.

The 5G market is maturing

After two years of early deployment and large-scale rollout, the 5G market has entered a more mature stage of creating tangible value for consumers and industries.

In the consumer market, where user experience has improved significantly in recent years, 5G users spend 1.5 times more time viewing short videos and the proportion of high-definition (HD) video traffic has increased by 20%. At the same time, 5G optimizes carriers' businesses. Since voice over LTE (VoLTE) is mandatory for 5G voice services, the development of 5G also improves VoLTE and facilitates the retirement of carriers' earlier-generation networks, helping them optimize network efficiency. Furthermore, the commercial benefits of 5G in industry-specific markets are remarkable. In China, for example, carriers have already deployed more than 6,000 5G virtual private networks in over 40 industries.

Calling for industry transformation

As 5G is commercialized on a larger scale and industries undergo digital transformations, there is increasing pressure on network infrastructure and capabilities.

In terms of network infrastructure, virtualization technologies will move from virtual machines to containers, which will involve complex adaptation to multiple management planes and virtualization engines. The introduction of new virtualization technologies and hardware will have a huge impact on network evolution. In addition, as networks become more complex, AI technologies will be needed to upgrade operations and maintenance (O&M) from the current manual mode to the autonomous driving network (ADN).

As the list of 5G applications grows, there will be higher expectations in terms of network capabilities.

For example, metaverse applications need networks to deliver an immersive communication experience anytime and anywhere. Therefore, for media applications such as XR, new technologies need to be introduced to support frame-level scheduling, multi-stream collaborative transmission, real-time rendering and interaction, and closed-loop experience optimization. In industry-specific markets, 5G is being applied to an even more diverse range of scenarios.

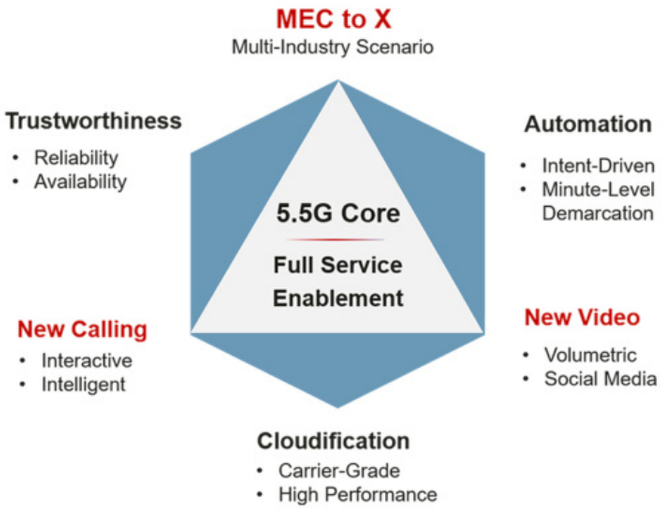
According to the Intelligent World 2030 report, the number of 5G virtual private networks will reach 1 million by 2030. This means that 5G needs to be able to connect to many different industries.

5G networks need to continuously evolve to keep up with these network and service demands. All parties in the industry are cooperating and innovating to this end. 3GPP has established the 5G Advanced project to review and clarify industry standards.

5.5G Core: Empowering digital transformation across industries

Huawei is driving the industry forward by proposing 5.5G Core and actively promoting industry cooperation, business innovation, and technology implementation. By working to extend the reach of 5G, Huawei can capitalize on the opportunities brought by 5G and help facilitate the digital transformation of other industries.

5.5G Core represents a step towards service enablement because it will deliver important improvements in the following three areas:



Voice services: 5.5G Core improves the quality of mobile network calls, and upgrades the call experience from simple audio and video to intelligent interaction, making voice services more than just a communication tool. Instead, they become a platform for carriers to potentially offer even more new services.

First, 5.5G Core adds a data channel based on the existing IMS audio and video channels. Having "three channels on one network" creates a more interactive user experience. Second, 5.5G Core introduces features such as AI-based media identification, rendering, and synthesis, thereby making calls smarter and expression methods more diversified. These two capabilities open up the potential for new assistive functions, such as social security services for the elderly and people with disabilities, and services that simplify business processes, such as one-stop insurance claims settlement.

Business-facing scenarios: 5.5G Core meets the requirements for multi-service private networks by improving the "connectivity + edge computing" feature to redirect industry-specific private networks from covering a single scenario in a service domain to all scenarios in all domains. 5.5G Core also builds the mobile network into a Data, Operation, Information, Communication Technology (DOICT) foundation that can empower all industries. Here are some examples of improved connectivity:

For industrial Internet of Things (IoT): 5.5G Core uses technologies such as 5G LAN and operation technology user plane function (OT-UPF) for ultra-high reliability and ultra-low latency in industrial applications.

For enterprise WAN interconnection: 5.5G Core uses mobile VPN to implement WAN mesh interconnection between enterprise private networks so that enterprise intranets can be reliably and effectively accessed anytime and from anywhere.

For multiple services in industry-specific applications: In addition to video surveillance and remote-control data access, digital voice trunking is provided to better support the daily operation of enterprises.

Enterprise services that have not been moved to the cloud rely heavily on edge computing. 5.5G Core uses private network connections and builds a converged foundation of edge computing and networking based on the telecom cloud platform. This converged foundation is very stable, offers real-time scheduling, and is designed to support all critical enterprise applications in one place, making it a one-stop platform for customers.

Video services: 5.5G Core integrates the communication and video features of mobile phones and TVs to build a platform for social interaction and entertainment based on video services. Video services will evolve from simple entertainment on a single screen to social networking across multiple screens for both individuals and families. 5.5G Core will develop XR and spatial video capabilities in the new media age. By introducing intelligent media identification and scheduling capabilities, the core network will offer a more immersive experience in cases with massive connections. In addition, technologies such as intelligent transcoding, intelligent stitching, and multi-stream synchronization will be used to deliver a multi-dimensional spatial video experience. Moreover,

Developed by Huawei, 5.5G Core is a key step on our journey towards the intelligent world.

through 5.5G Core, we will improve multi-screen communication and video capabilities, and provide new call and social networking services. These will help improve the user video experience and increase customer loyalty to our brand.

Full-service enablement: Building new business paradigms

By improving consumer-, business-, and household-facing services, 5.5G Core will help carriers build new businesses and thrive in the intelligent world. The mobile industry has not developed evenly, and it is clear that 5.5G evolution will be gradual. Based on the first phase of 5G rollout, carriers may see the best results by implementing technology and network evolution on the following four fronts:

- **Voice networks:** Carriers need to have VoLTE audio and video infrastructure networks in place to innovate new call services in phases based on the maturity of terminals and industries. To start with, carriers can develop terminal-independent ultra-HD video and smart video services. For example, China Mobile plans to launch fun call services and smart translation services to improve user experience and increase customer satisfaction. Then, with the development of native terminals, carriers can develop more interactive calls, build platform products based on calls, and build service closed loops during interactions. This will boost the industry's value and help improve efficiency.

- **Business-facing services:** Carriers can leverage the network scale and build layered, multi-dimensional networks to provide industry-specific private network services on demand. In WAN scenarios, carriers can leverage the advantages of dedicated public networks to deliver electric power and campus WAN. In addition, carriers can provide cost-effective shared 5G private networks for small- and medium-sized enterprises. In LAN scenarios, the on-premises network keeps the data within the campus, so carriers can use enhanced connectivity to extend the 5G private network from peripheral to core production systems. Carriers can also draw on the computing power and platform capabilities of the MEC telecom cloud foundation to integrate heterogeneous hardware and third-party software and help industry customers streamline private network construction and O&M.

- **Video services:** Carriers can stay competitive by offering a better experience. They can popularize 4K HD and 8K VR as entry-level video experiences, and then develop 8K video and 12K VR to appeal to high-end users. At the same time, carriers can introduce new experiences such as free-view, multi-view, and 3D videos to tap into new markets. They can also add video features to their social networking capabilities to open up new opportunities in the entertainment and social spheres. 5.5G Core offers effective ways for carriers to optimize their business models.

- **AI capabilities:** AI will become a basic capability of the core network, and will be particularly important in the following three scenarios: highly stable networks, efficient O&M, and experience optimization. For example: AI-enabled fault detection, diagnosis, isolation, recovery, prevention, and prediction will facilitate a more proactive and preventative approach to network assurance. ADN L4 automation can be implemented through intentional network provisioning, change, configuration, and smart traffic analysis. SLA assurance for high-value users can be carried out through smart UPF selection and reselection, mobile VPN path optimization, and load-based smart slice selection.

Huawei continuously invests in the innovation and development of new services. Huawei will work with industry stakeholders to grow the 5.5G business together by building on the full-service enablement platform encompassing New Call, New Video, and MEC to X.

F5.5G Unlocks Fiber's Potential and Brings 10 Gbps Everywhere

Optical fiber networks will be strategic infrastructure in the future. As the fixed network industry moves from F5G to F5.5G, technological innovation in areas like home and enterprise applications and optical sensing will unleash the potential of optical fiber in improving user experience, enable new application scenarios, and facilitate the stride towards the intelligent world.

Richard Jin
President, Optical Business Product Line, Huawei

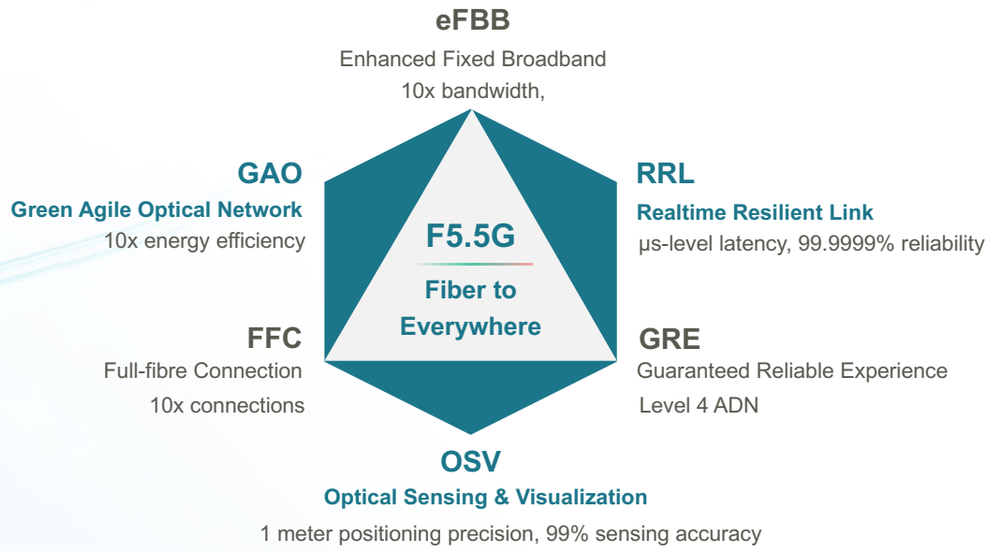
The fixed network industry is rapidly moving from F5G to F5.5G, driven by the twin engines of new network technology developments and growing application demand. The true value of optical fiber will only be able to further shine through this process as technological innovation continues in areas like home and enterprise applications and optical fiber sensing.

Prosperous F5G

Over the past two decades, fixed networks have evolved from meeting just basic connectivity needs to allowing users to enjoy 4K ultra-HD video experiences. F5G standards have also taken shape as fixed network technology evolved to meet booming demand in the digital era. In 2020, the European Telecommunications Standards Institute (ETSI) officially launched F5G and its industry vision of "Fiber to Everywhere". They also defined three technical characteristics of F5G: enhanced fixed broadband (eFBB), full-fiber connection (FFC), and guaranteed reliable experience (GRE). This marked the beginning of the rapid development of fixed broadband networks worldwide.

Then, over the past three years, gigabit fiber broadband rapidly went mainstream as more and more online video and video call services emerged. The number of connected homes with 1 Gbit/s or higher speeds now exceeds 100 million worldwide and is expected to exceed 200 million by the end of 2023. The world's leading information service providers are also already starting to deploy Fiber-to-the-Room (FTTR) solutions to bring high-speed, low-latency, and low-jitter fiber connectivity to every corner of the home. This will meet consumers' expectations for a high-quality Wi-Fi connectivity experience. 2022 alone saw 1 million new FTTR users.

F5G's high bandwidth, low latency, stable transmission, and anti-interference features are making it possible for many industries to go intelligent and digital, facilitating the implementation and success of many new application scenarios. F5G has made its way into more than 10 industries, including transportation, energy, education, and healthcare, covering more than 40 application scenarios. More than 20,000 companies worldwide have developed all-optical Fiber-to-the-Office (FTTO) campuses and all-optical industrial Fiber-to-the-Machine (FTTM) networks, driving industry digital transformation forward.



Digitalization stimulates industry transformation

Given the global progress of informatization and digitalization, we are due for a new wave of transformation. Society is rapidly going networked, digital, and intelligent. The global Internet has continued to expand and transform from meeting consumer demand to addressing industrial requirements, and the availability of data, communications, and computing power has grown exponentially. The needs of consumers, businesses, and other organizations for digital services are also increasing at unprecedented rates.

Network infrastructure is the foundation for digital transformation as well as the foundation of the future world that we will all live in. So what requirements does the future intelligent world have for networks?

We have been pursuing a better video experience, steadily moving from standard definition and high definition to 4K and 8K, as well as real-time, interactive, and immersive experiences delivered by XR and glasses-free 3D video. Metaverse and AR/VR applications are set to change consumer habits and raise higher requirements for communications networks. Excellent broadband quality and low-latency connectivity are required to deliver superior experiences. For example, light-field, glasses-free 3D display requires about 1 Gbit/s of bandwidth and a network latency of less than 5 ms for intensive interactions. Optical reconstruction-based glasses-free 3D display has even higher requirements, requiring about 10 Gbit/s of bandwidth and a latency between 1 and 5 ms. Home networks with 1 to 10 Gbit/s bandwidth and 1 to 5 ms latency are basic requirements for satisfying glasses-free 3D experiences.

Mainstream network applications are also extending from consumer applications to vertical

Huawei is continuing to look into forward-looking technology research and product solution innovation for F5.5G to help operators improve user experience and expand business boundaries.

and industrial applications. Industrial applications are often characterized by low latency, deterministic communications, and accurate positioning, while high security and reliability are prerequisites for most vertical applications.

Let's look at power grid as an example. As renewable energy accounts for an increasing percentage of all power generated, different services must be strictly isolated, while scheduling frequency using a supervisory control and data acquisition (SCADA) system must be 10 times higher to ensure stable power supply. This in turn requires a network availability of 99.9999%, meaning an annual outage time shorter than 30 seconds.

Network technology development and application demand growth are driving each other forward. F5G evolution and enhancement will be critical if we hope to meet the requirements of different service scenarios. Multiple industry players have begun discussing the next-generation evolution of fixed networks, and ETSI already released their F5G Advanced and Beyond white paper in September 2022 and initiated F5G Advanced standardization.

F5.5G facilitates ubiquitous 10-Gbps optical connections

In April 2022, Huawei proposed the concept of F5.5G to enhance the three existing features of F5G (eFBB, FFC, and GRE) and extend three new features: green agile optical network (GAO), real-time resilient link (RRL), and optical sensing & visualization (OSV).

F5.5G will bring four major changes to the industry. First, it will help us transition from gigabit speeds to ubiquitous 10G speeds. Second, we will change from carrier-grade connectivity to real-time and reliable industrial-grade connectivity, with microsecond-level latency and 99.9999% availability, enabling digital transformation of industries. Third, electric solutions will be replaced with an energy-efficient optical network architecture that is ten times more efficient, enabling green and sustainable development. Fourth, we will transition from optical communications to optical sensing, facilitating integrated optical fiber communications and sensing and digital operation capabilities.

Huawei is also continuing to look into forward-looking technology research and product solution innovation for F5.5G to help operators improve user experience and expand business boundaries.

FTTH to FTTR: The boom in digital home services that we have seen in recent years and the increasing amount of consumer upgrade in home broadband services is setting higher bars for user experience in terms of coverage, rate, roaming, latency, and the number of concurrent connections. More than 100 carriers around the world have deployed FTTR services, tackling the previous obstacles that prevented 100 Mbit/s room access, despite gigabit home access being already common. FTTR unlocks new growth for carriers around the world as it has increased average revenue per user (ARPU) by 30% and reduced Wi-Fi complaints by 60%.

Next-generation FTTR based on the C-WAN architecture further improves the Wi-Fi experience by boosting the effectiveness of collaboration between optical and Wi-Fi solutions through centralized management and control. With it, home users can enjoy over 1 Gbit/s rates and imperceptible roaming handover in less than 20 ms, all while concurrently connecting more than a hundred smart home devices. FTTR helps carriers transform from bandwidth-based operations to experience-based operations, while providing carriers with an optimal approach to smart home services.

10G PON to 50G PON: Many carriers are also making efforts to upgrade their FTTH broadband networks to 10G PON so that more users can enjoy a gigabit ultra-broadband experience. Some leading information service providers have started to verify next-generation high-speed PON technologies. ITU-T officially published the first version of their 50G PON standard in September 2021 as the standard for the next generation of PON technology following 10G PON. This laid the foundation for broadband's evolution from the gigabit era to the 10G era. During commercialization, 50G PON will coexist with GPON and 10PON while also facilitating smooth evolution. It will be crucial for 50G PON to be compatible with existing optical distribution networks (ODNs) to protect carriers' existing investments. With new, innovative device structures and techniques, Huawei's 50G PON optical modules can support 40 km coverage while maintaining compatibility between GPON, 10G PON, and 50G PON on a single port. This will help carriers smoothly upgrade their live networks to 50G PON without network reconstruction and quickly develop the ability to offer ubiquitous 10Gbps experience.

E2E all-optical networks: With the rapid growth of traffic generated by individuals, homes, and enterprises, agile service provisioning and network automation requirements are also increasing. This makes the establishment of E2E all-optical networks and the deployment of OTN/WDM at sites extremely important. OTN/WDM equipment has already been deployed at 85% of aggregation sites and 41% of CO sites worldwide, and is expected to eventually be deployed at all sites to support ubiquitous 10G connectivity. The need for wide-scale deployment at CO sites makes reducing network deployment costs and improving O&M efficiency a top priority for carriers. Huawei's metro Alps-WDM solution uses all-optical switching, an innovative pooling

architecture, metro coherent modules, and optical label technologies to realize efficient wavelength sharing and network-wide automation. This improves network energy efficiency, reduces CAPEX during network deployment by 30%, and reduces OPEX by 90%. The WDM pooling solution enables carriers to build a simplified architecture, superior experience, and future-oriented target networks.

Facilitating enterprise digital transformation: FTTR and 50G PON were first designed to optimize home networks and improve bandwidth. However, their technical architectures are also well suited for enterprise campus networks. For small- and medium-sized enterprises (SMEs), Huawei's enterprise FTTR solution enables carriers to extend their Internet private line services to within enterprises by offering Wi-Fi networking services. In addition, 50G PON, alongside Wi-Fi 7/8, will be able to handle rapid growth in enterprise campus service traffic, as office, IT, and OT services eventually converge, and as 90% of enterprise services go cloud-based and 80% of devices are connected. This creates an urgent need to increase the access bandwidth for enterprise campuses.

In manufacturing and industrial interconnection scenarios, E2E OSU technologies, including OSU over PON, enable bandwidth-adjustable hard pipe connections, and high-density timeslot technology can reduce transmission latency to microseconds. These technologies can enable enterprises to build industrial optical networks that are reliable, secure, and constantly evolving while also delivering low latency. Industrial requirements will need these features for ultra-reliability, precision control, and ultra-long-distance coverage. Such networks can also be widely used in scenarios like factories, electric power, transportation, subways, mining, ports, and highways to facilitate industrial digital transformation.

The development of 1Gbps/10 Gbps fixed network technology will unleash the full potential of optical fibers and lead the industry to stride from 1Gbps everywhere to 10Gbps everywhere. However, collaboration across the entire industry is needed to define the evolution direction of F5G, enrich F5.5G's application scenarios, and en able a prosperous fixed-network industry that can serve as a foundation for the coming intelligent world.

Stride Towards Net5.5G, Grow as Digital Network MSPs

Kevin Hu
President, Data Communication Product Line, Huawei

Net5.5G innovations can drive new B2B business growth by enabling operators to upgrade their existing network and service portfolios.

As new growth opportunities emerge for government and enterprise services, leading operators are looking to upgrade their government and enterprise networks and services. To realize this, they are leveraging cloud, network, digital, intelligent, and security technologies to upgrade from private lines to digital private networks, expand network connectivity services to network management services, and use industrial digital private network services to drive new growth. At the same time, the entire industry is exploring Net5.5G innovations to drive new B2B business growth.

Digitalization is the new reality for all industries, with organizations increasingly relying on digital technologies to enable hybrid offices, enhance remote collaboration, connect devices, accelerate data analytics, and achieve higher levels of automation.

As a result, the information architecture and technical architecture of enterprises are undergoing profound changes. Key applications are increasingly deployed on the cloud or provided as cloud services. Wide Area Network (WAN) traffic continues to grow, campus networks are becoming fully wireless, and network management and security operations are increasingly complex. Against this backdrop, leading operators are transforming into digital network managed services providers (MSPs) to enable industrial digitalization and boost new growth in B2B business.

Upgrading from private lines to digital private networks

The cloudification of IT architecture has entered a new phase, with up to 85% of applications today hosted on cloud. Even mission-critical applications are increasingly deployed on cloud or provided as a service. Enterprises need to not only connect headquarters, campuses, and branch offices, but connect to multiple data centers simultaneously, so they have higher requirements on WAN data protection, security, and performance, which cannot be met using only the public Internet. The path forward for software-defined WAN (SD-WAN) is going back to private lines and private networks. Operators need to help enterprises access multiple clouds more easily and reliably by offering digital private network services bundled with managed SD-WAN services. This can enable access to multiple clouds through one private network and multiple applications through one private line.

According to Gartner, global enterprises will increase spending on multi-cloud networks at a CAGR of about 24% between 2021 and 2026 to purchase agile, reliable, and high-speed cloud access services.

In China, a major operator used its industrial digital private network services to significantly improve customer satisfaction and achieve a year-on-year increase of 25% in revenue from the healthcare sector in 2022. Powered by new technologies like end-to-end network slicing, the operator's private networks enabled a range of digital healthcare services like connected hospitals, health insurance settlements, and online offices, while delivering security isolation and guaranteed performance. In Europe, an operator decided to upgrade its traditional private line offerings and launched the 'Digital private network + Managed SD-WAN' suite. The solution comes with a variety of value-added services for supermarket chains, including DIY Portal, E2E encryption, QoS enhancement, and multi-cloud access. This allowed the operator to increase its average revenue per user (ARPU) by 14%, and more importantly, the contract renewal rate of traditional private line customers.

The cloudification of IT architecture has entered a new phase, with up to 85% of applications today hosted on cloud.

Traditional multiprotocol label switching (MPLS) VPNs cannot meet the requirements of the cloud era. Instead, digital private networks enabled by new technologies such as SRv6, slicing, and network digital maps will better support industrial digitalization. By providing enterprises with premium private network services featuring multi-cloud and multi-application access, operators are better positioned to realize new growth from sweeping industrial digitalization.

Expansion from WAN connectivity to managed LAN/WLAN

Campus networks are increasingly wireless thanks to constant developments in wireless technologies like Wi-Fi 6. Ubiquitous gigabit Wi-Fi access in high-density office areas and service centers delivers not just productivity gains, but higher customer satisfaction. Devices that were not connected to wired networks can now be connected through Wi-Fi, bringing enterprises a step closer to digitalization. As connected devices gradually outnumber traditional office devices, we are also seeing narrowband IoT applications give way to ultra-broadband IoT applications. For example, next-generation Wi-Fi 7 technology can enable 30 Gbit/s bandwidth delivered by APs and up to over 10 Gbit/s speeds for connected devices, allowing for dense deployments of ultra-broadband IoT devices such as automatic optic inspection (AOI) machines. This new development has strategic value for the real economy, especially in the intelligent manufacturing sector.

Ubiquitous wireless networks and real-time applications are also making Wi-Fi network planning, deployment, O&M, and optimization increasingly complex, creating new challenges for enterprise IT teams. The good news is that operators can help, using their established expertise in the wireless domain. Next-generation digital network MSPs are adopting the AIOps-as-a-Service model to provide managed services, allowing users to easily manage their networks on their phones. To enable plug-and-play functionality, all they need to do is scan a QR code attached to network equipment through a mobile app. Maintenance

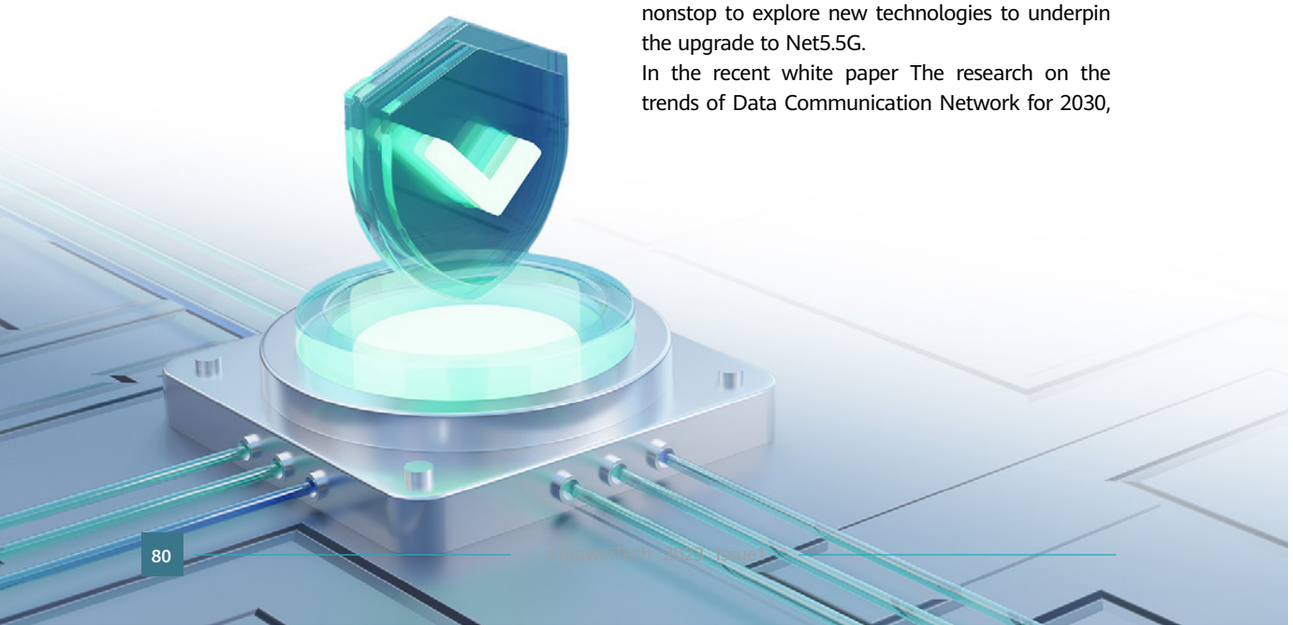
personnel can remotely check network quality and adjust network configurations, allowing them to perform predictive maintenance to improve network reliability. These types of digital network services not only help operators improve customer satisfaction, but also enable new growth in industrial digital private network services. Unlike traditional managed services, the data analysis-based AIOps-as-a-Service model no longer needs on-premise expert services. This greatly reduces labor costs and helps achieve economies of scale. Gartner forecasts that enterprises worldwide will spend more than US$28 billion annually on managed LAN/WLAN services by 2026, which presents enormous growth opportunities for operators.

An operator in Asia, for example, doubled its ARPU with one-stop 'Private network + SD-WAN + Wi-Fi' services for gas stations.

Extension from WAN connectivity to network security service

In the past, small- and medium-sized enterprises (SMEs) and other smaller organizations did not prioritize network security due to the limited uptake of digital technology. In today's increasingly digitalized world, network security has become an imperative. The problem is that SMEs and other smaller organizations generally lack network security expertise and cannot afford on-premise expert services.

How can we solve this problem?



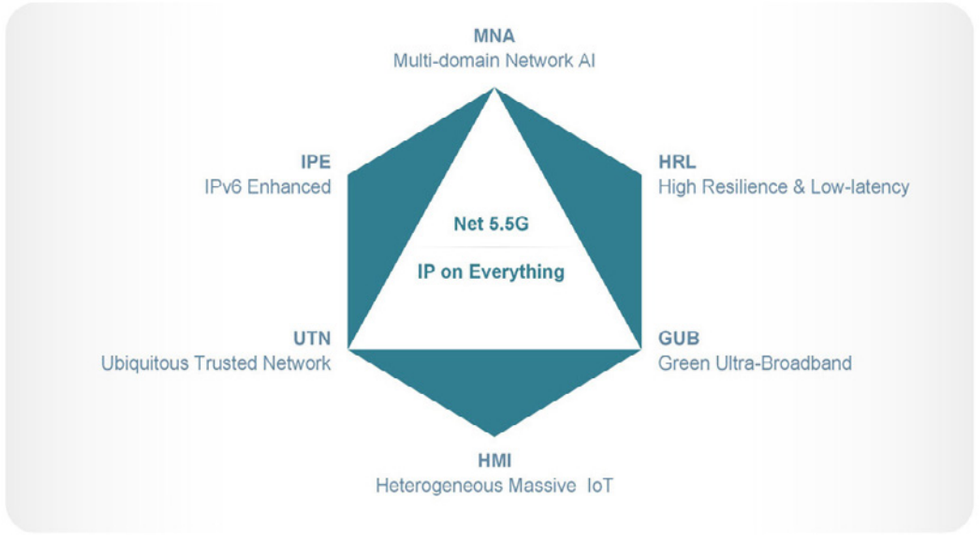
Some operators offer the 'Digital private network + Cloud-based security service' bundle, allowing organizations to subscribe to cloud-based network security services on demand and deploy lightweight security gateways. The cloud platforms can automatically analyze security incidents based on logs reported by security gateways, deploy protection policies, perform real-time detection, and block potential threats in a closed loop. This new service model provides strong safeguards to SMEs and other smaller organizations. It will further drive industrial digitalization and bring operators new growth opportunities in managed security services. One Chinese operator achieved a 20% ARPU increase and a significant revenue boost through its 'Digital private network + Cloud-based security service' suite. This portfolio features device-cloud synergy and allows enterprises to detect and protect against security threats in real time, significantly lowering the threshold for implementing security safeguards. According to Gartner, the global managed security service market grew by 8.3% at US$12.7 billion in 2020, creating a huge market opportunity.

Net5.5G industry outlook

Amid fast-paced industrial digitalization, leading operators are looking to achieve new growth from industrial digital private network services by comprehensively upgrading and expanding their enterprise network and service portfolios. The ICT industry is also researching and innovating nonstop to explore new technologies to underpin the upgrade to Net5.5G.

In the recent white paper The research on the trends of Data Communication Network for 2030,

Omdia expounds the industry vision for Net5.5G, outlining six areas where network capability can be improved. These are green ultra-broadband (GUB), multi-domain network AI (MNA), ubiquitous network security (UNS), IPv6 Enhanced, high resilience and low-latency (HRL), and heterogeneous massive IoT (HMI).



Net5.5G Vision

Source: *The research on the trends of Data Communication Network for 2030*, Omdia

The global industry is also promoting the development of standards and business practices. The IETF has already released SRv6-TE specifications and is working on multiple Ipv6 Enhanced specifications like BIER 6 and APN 6. Network equipment vendors have launched 800GE routers and Wi-Fi 7 APs, boosting network bandwidth throughput and making 10 Gbit/s ubiquitous. Major operators are transforming towards digital network MSPs to unlock new growth opportunities. In its fourth white paper on autonomous networks (AN), TM Forum describes 19 typical AN use cases, shedding light on how operators can grow B2B revenue.

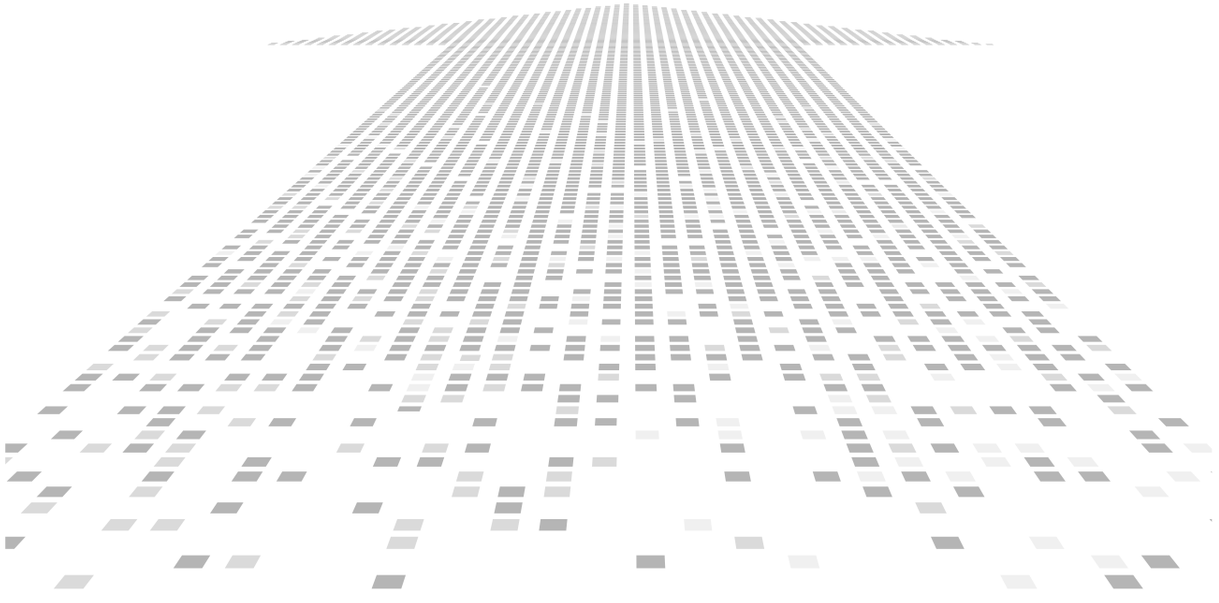
As a leading provider of ICT products and solutions, Huawei continues to research cutting-edge technologies and develop innovative products and solutions. The company boasts a diverse data communication product portfolio and network management platforms powered by AI and machine learning. In the WAN domain, Huawei's full-service converged routers support 400GE/800GE metro and backbone ultra-broadband capabilities, and use new technologies such as network digital map, SRv6, and slicing to help operators provide premium private lines featuring minute-level service provisioning and superior user experience. In the wired and wireless LAN domain, Huawei has launched a simplified campus network solution featuring a central switch + remote unit architecture, third-generation smart Wi-Fi antennas, the industry's first L3 autonomous driving network for campuses, and a flexible cloud management platform model that supports flexible deployment options. All of this has made Huawei a leader in the 2022 Gartner® Magic Quadrant™.

Moving forward, Huawei will continue investing heavily in R&D, tackle technical bottlenecks, and conduct joint innovations to help operators navigate the era of industrial digitalization by transforming towards digital network MSPs, providing industrial digital private network services, and driving new growth.

ADN Paves the Way Towards High-level Network Autonomy

Lu Hongju
President, General Development Dept, Huawei

The rapid growth of the digital economy is driving the widespread upgrade of the communications industry, and ongoing network evolution with higher-level autonomy has emerged as a key driver of the intelligent world.



Technological innovation is happening rapidly in multiple domains, with new technologies like 5G, cloud computing, and AI driving massive changes to economies and society, and positioning the digital economy as a core engine of global economic growth. The growth of the digital economy has significantly outpaced annual GDP growth over the last three years in 47 countries, and the combined value of the local digital economy jumped from US$30.2 trillion to US$38.1 trillion.

Network automation: The foundation of digital economic growth

The digital economy has become an integral part of life and work, helping new digital applications go mainstream. The public is quickly adopting and adapting to applications like remote work, education, and healthcare; VR-based social networking and entertainment; scenario-based smart home experiences; and smart manufacturing and logistics. Even the 2022 FIFA world cup benefited from this new wave of digitalization, implementing a video assistant referee (VAR) system for the first time. The emergence of new applications is in turn facilitating rapid growth within the digital economy.

In 2022, 460 million people in China worked remotely and more than 350 million people took advantage of online education. Hybrid models of work, education, entertainment, and social networking that utilize both online and in-person interactions have become normal since the beginning of COVID-19.

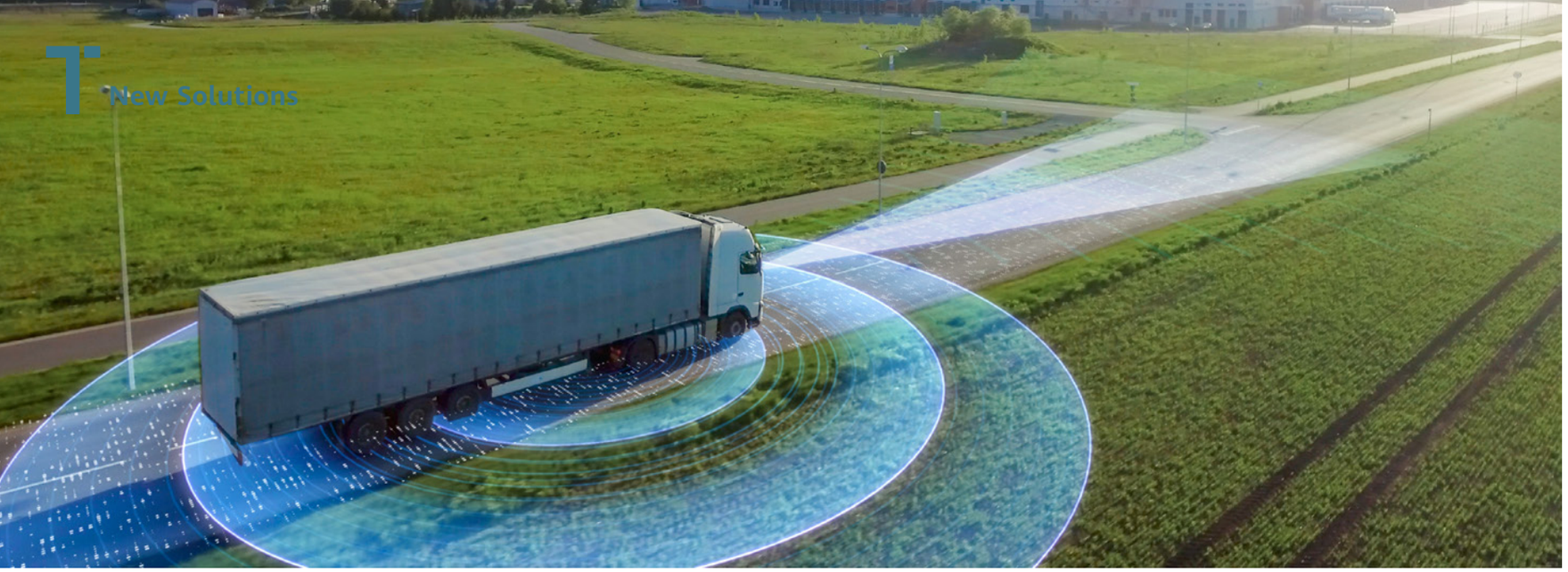
Communications networks are the tool that connects individuals, homes, and organizations, creating new critical infrastructure essential to everyday life. The role of home networks now extends well beyond entertainment and information access. In today's world, it is essential for work, education, and even production, with enterprise networks acting as core production systems. The demand for clear and smooth live online classes, secure and reliable remote access, and ultra-low-latency interconnection in industry scenarios is setting a higher bar for networks.

And high-quality network connectivity has emerged as a core facet of the digital economy.

To ensure optimal service experience, networks with guaranteed SLAs need to be ready anytime, anywhere, and planning, construction, maintenance, and optimization must become automated and intelligent. To meet these needs, network acquisition, delivery, and management are shifting towards a Network as a Service (NaaS) model. In fact, most carriers have launched some kind of digital strategy to accelerate network evolution on the road to becoming NaaS and digital service providers. Research has found that more than 90% of global carriers have included network automation in their core business strategies for 2023.

Technological innovation and industrial transformation within the communications industry will also transform the landscape for industrial productivity. Twenty years ago, IP technology reshaped the forwarding architecture of communication networks. Ten years ago, cloud technologies profoundly impacted network management and control architecture. And now, AI technology is set to be embedded into every layer of network architecture to drive high-level network autonomy over the next 10 years. Upgrading the telecom industry with automation will unleash the full potential of carrier networks and empower industries with digital capabilities. AI will make automated networks intelligent, replace machine-assisted manual labor with human-assisted machine labor, and enable real-time experience awareness and optimization of on-demand services.

This wave of network automation and digitalization has resulted in a wide array of industry players coming together to define an industry-specific definition of "autonomous networks". TM Forum, standards organizations, such as 3GPP, the GSMA, ETSI, and CCSA; carriers, network equipment suppliers; and OSS software developers have all contributed to this definition, which includes a unified vision and grading criteria to ensure network upgrades are both effective and regulated. By the end of 2022, more than a dozen leading operators around the world announced their intention to achieve level-4 network autonomy by 2025, making it clear that they believe autonomous networks will be key to both digital and intelligent transformation as well as rapid growth.



ADN: The driver of the autonomous network industry

Autonomous Driving Network (ADN) is Huawei's solution for the autonomous network industry. For three years, from architecture to application, Huawei has explored autonomous networks and evolved ADN to deliver level-3 autonomous networks.

ADN leverages innovations in high-precision digital twins, compressive sensing, parallel and incremental simulations, and self-closed loop of knowledge to achieve this. Huawei has also established joint innovation working groups with leading carriers around the world, such as China Mobile, China Telecom, AIS Thailand, MTN, and Vodafone to help carriers use ADN to simultaneously improve network quality and revenue, O&M efficiency, and energy savings.

These carriers can now offer upgraded home broadband services using new capabilities like precisely perceiving user experience and accurately locating QoE issues, reducing poor-QoE rates by 83%. Potential customer identification has also helped improve FTTR and gigabit service marketing success rates from 3% to 10%. These achievements have enabled proactive O&M based on user experience and improved carriers' brand reputations for home broadband services.

Intelligent fault analysis enables feature extraction, cleaning, and the aggregation of alarm and associated data. It also uses machine learning training and inference to identify correlations and derivative relationships between alarms to identify and locate fault root causes, increase fault identification accuracy to over 90%, reduce fault tickets by over 30%, and shorten average recovery time for each fault by at least 30 minutes. These improvements represent a massive leap in O&M efficiency.

As part of ADN, our base station energy-saving solution creates models for base station energy consumption, frequency bands, coverage, and performance, and dynamically generates power-saving policies. This enables site- and time-specific precise energy saving, and ensures optimal network experience and energy efficiency, reducing average energy consumption per site by more than 10%.

Three key targets for level-4 autonomous networks

The ADN solution features AI-powered network elements (NEs), networks, and services that can help carriers achieve level-3 network autonomy by 2023 and level-4 network autonomy by 2025. ADN is designed to provide end users with a new digital network service experience characterized by zero wait times, zero touch interactions, and zero fault experiences. It also provides network O&M personnel with self-configuring, self-healing, and self-optimizing intelligent networks to increase the efficiency of their work. Looking to the future, Huawei will continue investing heavily in this ADN solution to achieve three key targets: native AI, single-domain autonomy, and cross-domain collaboration.

At the NE layer, ADN uses smart hardware and computing-network convergence to build hyper-converged perception capabilities. Innovative technologies like optical iris and intelligent optical modules, as well as real-time sensing devices, are deployed on NEs to enable active, millisecond-level sensing that replaces passive, minute-level sensing. Integrated technologies like low-power computing and stream computing pre-analyze and compress NE data, improving the local inference and decision-making capabilities of NEs.

At the network management layer, high-precision network maps provide real-time simulation services. To enable intent-based networking, ADN adopts predictive maintenance, multi-objective adaptive optimization, key technologies such as polymorphic configuration, high-precision simulations, on-duty digital employees, telecom network foundation models, and the dynamic identification of multiple fault models. These functions realize real-time online simulations, predictive global optimization, and adaptive closed-loop control on large-scale complex networks.

Cross-domain collaboration capabilities are improved at the service collaboration layer through platform evolution, service process optimization, and personnel transformation. Platforms are evolved from siloed support systems to unified systems that integrate all-domain data and expert experience, transforming service processes from network-oriented and driven by work orders to experience-oriented processes that require zero touch. The low-code development system makes it easier for CT personnel to go digital and intelligent, evolving O&M team members into versatile DICT talent.

Unified standards for a prosperous industry ecosystem

Over the past three years, the industry has reached a consensus on autonomous networks in terms of vision, architecture, grading criteria, and core ideas. We are now well on our way to turn this strategy into reality. At the Autonomous Networks Summit held in October 2022, TM Forum, together with 54 industry partners, including CCSA, China Mobile, and Huawei, jointly released the AN4.0 white paper Autonomous Networks: Empowering Digital Transformation – from Strategy to Implementation. In this paper, the partners lay out critical technological challenges that must still be overcome to achieve high-level network autonomy. Overcoming these challenges will require collaboration between industry partners on interface standards, evaluation systems, and business models. They will specifically require the industry to:

·Accelerate the commercial adoption of L3 network autonomy by refining professional grading criteria and defining business-oriented effectiveness indicators.
·Jointly define L4 network autonomy, explore new business use cases, and drive leapfrog development within the industry.
·Define target profiles, and plan fundamental theoretical research and technical breakthroughs that will eventually lead to L5 network autonomy.

The telecom industry has long viewed autonomous networks as a goal that is just out of reach. However, the potential to revolutionize the industry and create an ICT foundation for the future intelligent world where all things are connected with intelligence is undeniable. Autonomous networks will soon be a key production tool for the digital economy. And so, with its ADN solution, Huawei plans to ride this wave of network autonomy and collaborate with industry partners to realize this once remote ambition that will unfold a true intelligent world.

Embracing the Multi-cloud Era with Reliable Data Storage Infrastructure

Peter Zhou
President, IT Product Line, Huawei

Huawei Data Storage is embracing cloud-native technology and working alongside storage customers and partners worldwide to forge a bright future for the data storage industry.

The evolution of civilization has always gone hand in hand with recording and spreading information. From tying knots in strings to bone script, from paper to hard disks and flash memory, the methods of recording information have seen enormous leaps throughout history.

Today, civilization uses digital storage to retain data. The data storage industry has been evolving alongside the development of data applications. Early on, databases were simply data applications, and the earliest IBM mainframes primarily ran database systems. Redundant arrays of independent disks (RAID) technology connects disks together as disk arrays, and it was with this technology that EMC launched the world's first specialized storage device in 1991. This device marked the upgrade of mainframe architecture from separated computing and storage to integrated computing and storage, and was the origin of the storage area network (SAN) architecture

Around the year 2000, the emergence of the Internet paved the way for network-attached storage (NAS), making highly reliable storage and the efficient sharing of document data possible. Then, around 2010, the emergence of cloud computing represented by virtual machines led to the popularization of unified storage that integrates SAN and NAS. In 2015, all-flash storage started replacing hard disk drive (HDD) storage at scale, delivering advantages in performance, reliability, and energy efficiency. Moreover, emerging applications based on massive amounts of unstructured data, such as video, big data, and AI, gave rise to scalable distributed storage.

Two drivers of the storage industry's future growth

Driver 1: New demand for applications, data, and security

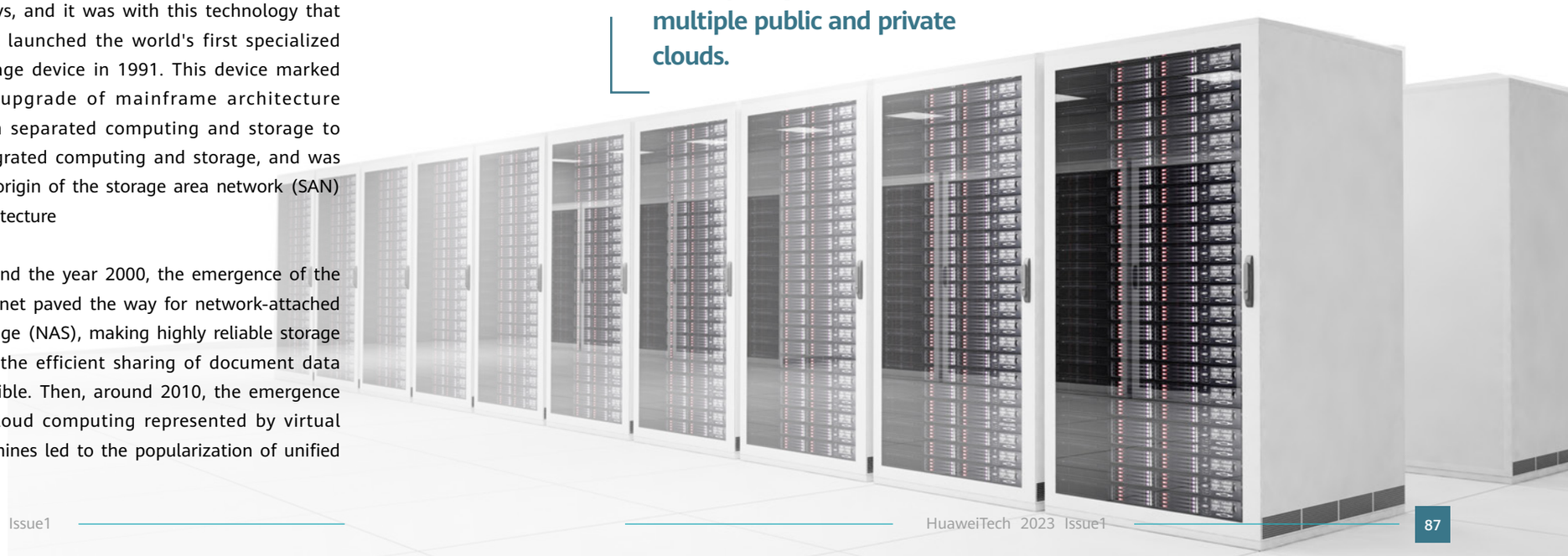
The digital transformation of industries is approaching a critical stage of rapid growth, and new demand for applications, data, and security is driving continuous innovation and development throughout the data storage industry.

This demand is impacting the storage industry in three key ways:

First, data-based applications are quickly emerging. In addition to conventional database service applications, new applications in areas like virtualization, containers, big data, and AI have emerged. Furthermore, requirements for data reliability are becoming increasingly prominent. The widening gap between the lifecycle management of computing and data means there is a growing need to flexibly and separately plan and maintain computing and storage resources. The adoption of decoupled storage-compute architecture and specialized storage solutions that are elastic, reliable, and cost-effective can ensure the quick deployment of innovative services that offer higher reliability, lower costs, and greater profitability.

Second, unstructured data is becoming widely used across enterprises as a key factor in production decision-making, with 56% of enterprises now using AI to analyze and process unstructured data. With enterprises' improving their data governance capabilities, data-driven service growth is becoming increasingly possible. Efficient and reliable distributed storage solutions designed for massive amounts

Today's enterprises need to develop IT systems based on multiple public and private clouds.



of unstructured data are now the foundation for enterprise data governance.

Third, frequent data security incidents are resulting in huge economic losses, making the improvement of digital resilience a priority for enterprises. In recent years, the main focus of data security protection has expanded from damage caused by physical factors to those caused by humans. Statistics show that in 2021, the average cost of recovering enterprise data from ransomware attacks totaled a staggering US$1.85 million. Following a ransomware intrusion, the affected network loses the ability to prevent ransomware from damaging data. This is where storage solutions can be an invaluable last resort in data protection, thanks to ransomware detection, secure snapshot, data isolation, and data recovery capabilities.

Driver 2: Common adoption of multi-cloud access

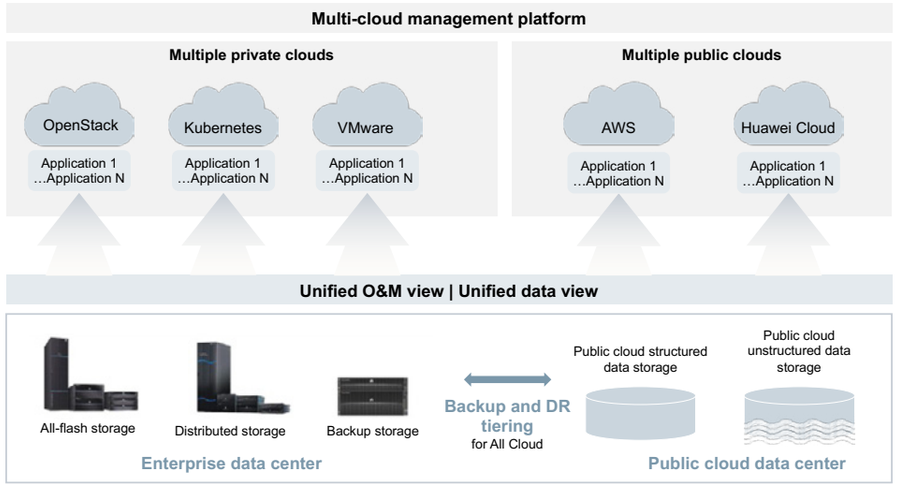
With more enterprises becoming cloud-based, cloud-native technologies like containers are gaining traction. Storage solutions are required to support container-based application resource provisioning and disaster recovery (DR) and backup. Statistics show that 89% of enterprises around the world have already formulated a multi-cloud strategy to leverage the strengths of multiple cloud platforms. However, the multi-cloud model typically results in cloud data silos, making it incredibly difficult to share data across multi-cloud applications. Moreover, due to the differences in services between cloud platforms, interoperability between ecosystems is practically impossible.

Some enterprises have adopted an IT architecture that features centralized data sharing and multi-cloud application deployment as a way to address these challenges, maximizing both data resource sharing and circulation.

Additionally, many enterprises have chosen to deploy different types of applications and data in either their data centers or public clouds, depending on application types and data security requirements. This enables unified cross-cloud data management and effective data flow, maximizing data storage and management efficiency. Storage solution providers across the industry are also using integrated hardware-software or software-only approaches to deploy specialized storage solutions that are already widely used in data centers on public cloud platforms, realizing the smooth cross-cloud evolution of enterprise data storage.

Huawei Data Storage builds reliable multi-cloud-era data infrastructure for industries

Over the past few years, Huawei's OceanStor Dorado All-flash Storage solution has earned the trust of many customers thanks to its high performance, stability, and reliability. For



example, in the financial industry, more than 40 of the world's top 100 banks have chosen Huawei. Today, Huawei's data storage portfolio is building reliable data infrastructure of the multi-cloud era for enterprises across more industries. These products boast the following features:

First, full coverage, from data center solutions to enterprise branch solutions. Huawei provides a full range of data storage solutions, including high-performance OceanStor Dorado all-flash solutions, OceanStor Pacific distributed storage for massive amounts of unstructured data, OceanProtect dedicated backup storage, and FusionCube hyper-converged infrastructure.

Second, structured data to unstructured data storage. Building on its leadership in SAN, Huawei Data Storage has gone all out on NAS file applications. In addition, Huawei's latest OceanStor Pacific distributed storage system is the only product in the industry that supports mixed loads to support diverse applications including high performance data analytics (HPDA), big data, video, backup, and archiving.
Third, data storage to intelligent O&M. The automation of O&M based on a data management engine (DME) frees O&M personnel from tedious, routine work so that they can focus on more creative tasks.

Fourth, data protection to data security. Huawei Data Storage provides comprehensive anti-ransomware storage solutions that range from primary storage to backup storage. These solutions employ a self-developed ransomware detection engine alongside AI algorithms to analyze user behavior and file damage, realizing up to 99.9% ransomware identification accuracy.

Embracing the multi-cloud era in four key areas

To address diverse data application scenarios in the future, Huawei Data Storage will embrace multi-cloud technology in four focus areas. We will integrate enterprise-level storage capabilities within enterprise private and public clouds to build reliable multi-cloud-era data infrastructure for customers. This infrastructure will feature global sharing and consistent capabilities both on and off the cloud.

Area 1: Building unified data infrastructure for multi-cloud access to enable free cross-cloud data flow

Huawei Data Storage consolidates diverse storage devices within a unified resource pool and supports open, standardized interface protocols to connect and integrate storage and multiple clouds. This enables a cross-cloud and cross-data-center global storage resource pool that maximizes data sharing and circulation.

The key to data flow is that data can be classified into hot and cold data within an enterprise data center and also that data can also be easily transferred and backed up by this classification between an on-premises data center and public cloud. Huawei Data Storage intelligently distinguishes hot, warm, and cold data, and enables on-demand data flow between local production storage, backup, and archive storage, and cloud.

The storage of different data in different media minimizes the total cost of ownership (TCO).

Area 2: Building cross-cloud data sharing capabilities for unified data views and scheduling

With the adoption of a multi-cloud model by enterprises, data is distributed across different cloud platforms. Differences between cloud service providers in terms of APIs, data exchange standards, and technologies impede interoperability between ecosystems and data invocation across clouds, making data sharing difficult and costly.also be easily transferred and backed up by this classification between an on-premises data center and public cloud. Huawei Data Storage intelligently distinguishes hot, warm, and cold data, and enables on-demand data flow between local production storage, backup, and archive storage, and cloud.

The storage of different data in different media minimizes the total cost of ownership (TCO).

Area 3: Building container storage capabilities to enable cloud-based data center applications

To address the requirements for more agile and elastic applications, enterprises must containerize traditional applications and migrate cloud-native application ecosystems to on-premises data centers. Therefore, enterprises need to upgrade their data infrastructure to better support container technology.

Huawei Data Storage provides the Container Storage Interface (CSI) plug-in that is compatible with a wide range of mainstream container cloud platforms. This allows enterprises to use Huawei storage solutions to provide persistent storage resources that feature high performance, high reliability, and on-demand configuration, with 30% higher resource provisioning efficiency than the industry average.

Huawei also provides the Container Disaster Recover (CDR) plug-in, which provides application-level, cross-cloud, and cross-data-center disaster recovery (DR) for containers. This gives key cloud-native applications the same DR capabilities as traditional applications and improves data security and reliability for containerized service applications.

Area 4: Building a diskless data-center architecture to overcome challenges in efficient and massive data storage across clouds

When dealing with the surge in the amount of data, cloud and Internet enterprises traditionally use an integrated server architecture for storage that couples applications and local disks. This storage-computing integrated architecture causes issues like resource waste, poor reliability and storage efficiency, and limited scaling elasticity, impeding the full use of computing power.

Designed for the diskless server architecture, Huawei's OceanDisk Smart Disk Enclosure can replace local server disks with diskless servers and a remote storage pool, so that computing and storage resources can scale independently and elastically. OceanDisk also connects the remote disk pool to servers through high-speed NoF+ Ethernet, realizing high-performance storage comparable to local disks. In addition, OceanDisk employs multiple technologies, such as data reduction and disk sub-health management, which reduces costs; simplifies O&M; and enables greener, more powerful, and more reliable cloud and Internet data centers.

Over the past three decades, data storage has served as a solid foundation for high-value data, evolving side-by-side with data applications. Now, as we usher yottabyte (1024 bytes) data volumes, in which data applications will boom, Huawei Data Storage is embracing the multi-cloud era and working alongside storage customers and partners worldwide to forge a bright future for the data storage industry.

Everything as a Service: Building the Cloud Foundation for the Intelligent World

Zhang Yuxin
Huawei Cloud CTO

Huawei Cloud provides convenient, secure, and premium cloud services to help enterprises address new challenges on the digital transformation journey.

Cloud native brings new value to various industries and is essential for enterprise digital transformation. While many enterprises are currently migrating their applications to cloud, as part of a new application-centric cloud transformation, some remain reluctant or unsure about how to migrate to the cloud, leaving them unable to fully utilize its benefits. This is because cloud services have been resource-centric over the past decade, focusing more on infrastructures like compute, storage, and networks.

As digital transformation advances, cloud has been used across more areas in greater depth. Enterprises have started rethinking how to apply digital technologies to change business applications and transform customer experience, operating efficiency, and business models. This is driving cloud to become application-centric, and promoting the innovation and evolution of overall cloud technical architecture.

1. Cloud native unlocks new value

In cloud computing, cloud native is becoming essential for enterprise transformation and upgrade, as it creates new value for various industries. Cloud native is empowering emerging enterprises and traditional industries, such as financial services, automotive, manufacturing, and ports, to improve business efficiency, accelerate business innovation, and boost value.

Finance

The finance industry, which has extremely strict data-security requirements, encountered bottlenecks in developing its traditional business model. Eliminating concerns about public cloud security prompted banks to start building reliable platforms with systematic security protection provided by cloud vendors, covering technologies, personnel, operations, and processes. These platforms possess fully-integrated, cloud-native capabilities such as resource elasticity, agile innovation, and high concurrency. In Thailand, the system enabled one century-old bank to develop a new service for digital growth. It gained 45,000 online customers within three months of launch and developed a credit line of 204 million baht (approx. US$5.9 million). Thanks to automatic, data-driven processes, a large number of loan services could be approved in just five minutes, doubling transaction performance over traditional loan services.

Automotive

The automotive industry is in the middle of an enormous transformation characterized by rapidly growing data. By leveraging elastic cloud-native infrastructure resources, enterprises can allocate more computing power during peak daytime hours of connected vehicle services and reduce computing power at night, thus reducing costs by more than 40%. More importantly, carmakers can use cloud-based data and AI analytics technologies to better understand driving behaviors, resulting in many innovative services such as smart stores, smart after-sales, and intelligent manufacturing. Car sales are expected to at least double in 2022.

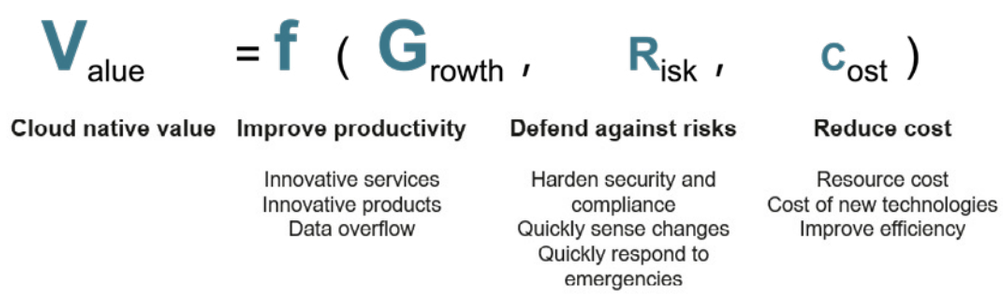


Figure 1: Cloud native value

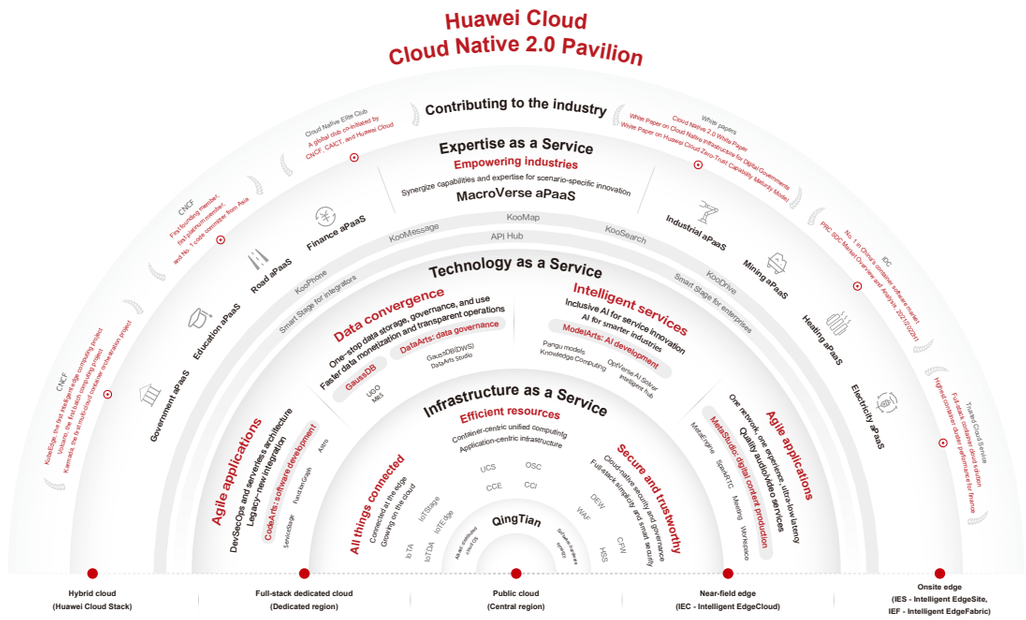


Figure 2: Cloud Native 2.0 panorama

Manufacturing

The supply chain system is the key to success in the manufacturing industry, but comes with serious systemic risks. Enterprises must make their supply chain operations more intelligent by using scenario-based algorithm models that streamline all links between suppliers and customers and building a high-quality data foundation. Intelligent supply chain operations allow enterprises to develop optimal supply resource configurations, while considering a range of variables such as demand, order, inventory, logistics, production capacity, and external environment. This enables enterprises to complete scenario-based, supply-demand simulation within minutes, shorten planning from weeks to days, and agilely cope with uncertainties.

Ports

The port industry faces many challenges in terms of talent and technology as it undergoes digital transformation. Port operators have developed a platform + operation transformation path by fully migrating to public cloud. This has allowed the platforms to accumulate successful experience and data to drive continuous business operations. Port operators have streamlined the data of ports, logistics, the industrial sector, and ecosystem partners. They have also built and rolled out the global digital supply network (business foundation) and OCC digital operation platform (operation foundation). On this basis, port operators have developed many innovative applications through the application of convenient development tools on the cloud. On the way to full digitalization, these applications have shortened container circulation time at ports by 13% and reduced the time needed for sea-rail combined transportation by a full day.

Emerging enterprises

Emerging enterprises are full of ideas about future development, which is in turn creating surging requirements. Through cloud-native and microservice transformation, all their resources are hosted by cloud vendors. This enables the second-level scaling capabilities of cloud native and allows these enterprises to handle fluctuations in service development and focus on core business innovation.

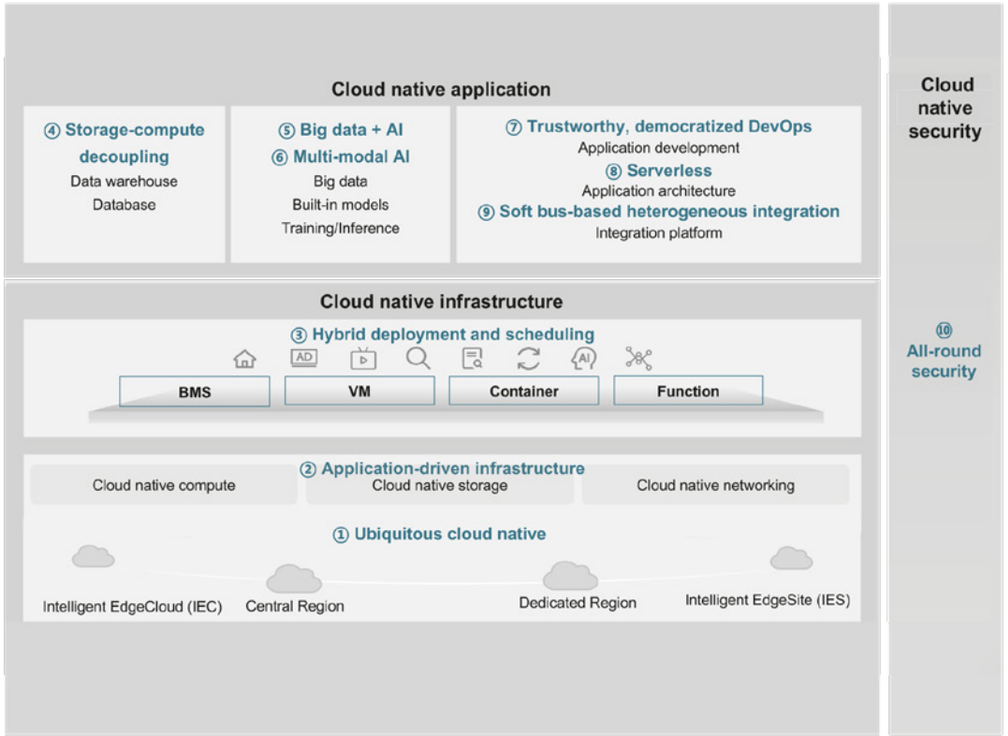


Figure 3: Key Cloud Native 2.0 technologies

These examples show that an increasing number of enterprises care about more than just the cost of cloud. They are now interested in using it to drive developments in the new era by deeply integrating scenario-based applications with cloud, and data and AI on cloud. They have also gained a broader understanding of the value of cloud with the new value being created by cloud driving the cloud industry to new heights (as shown in Figure 1).

2. New value drives the emergence of new technology concepts

Gartner predicts that more than 95% of new digital projects will use cloud-native platforms by 2025, positioning these platforms as a must to dive deep into digitalization. However, digital transformation is still challenging for the majority of enterprises. It requires a combination of technologies, including all-element data connection, security protection, intelligent decision-making and operations, and knowledge and experience about digital transformation. To support the successful transformation of every enterprise into new cloud-native enterprises, Huawei proposed the Cloud Native 2.0 concept in 2020 (as shown in Figure 2). Cloud Native 2.0 realizes continuous innovation in three areas and provides users with an upgraded cloud-native experience from multiple dimensions.

In terms of Infrastructure as a Service, Huawei Cloud has deployed 29 Regions and 78 availability zones (AZs) that cover more than 170 countries and regions. It has also built global cloud infrastructure with a unified architecture, providing infrastructure services like compute, storage, network, and security and quickly delivering a premium cloud experience with just 50 ms latency worldwide.

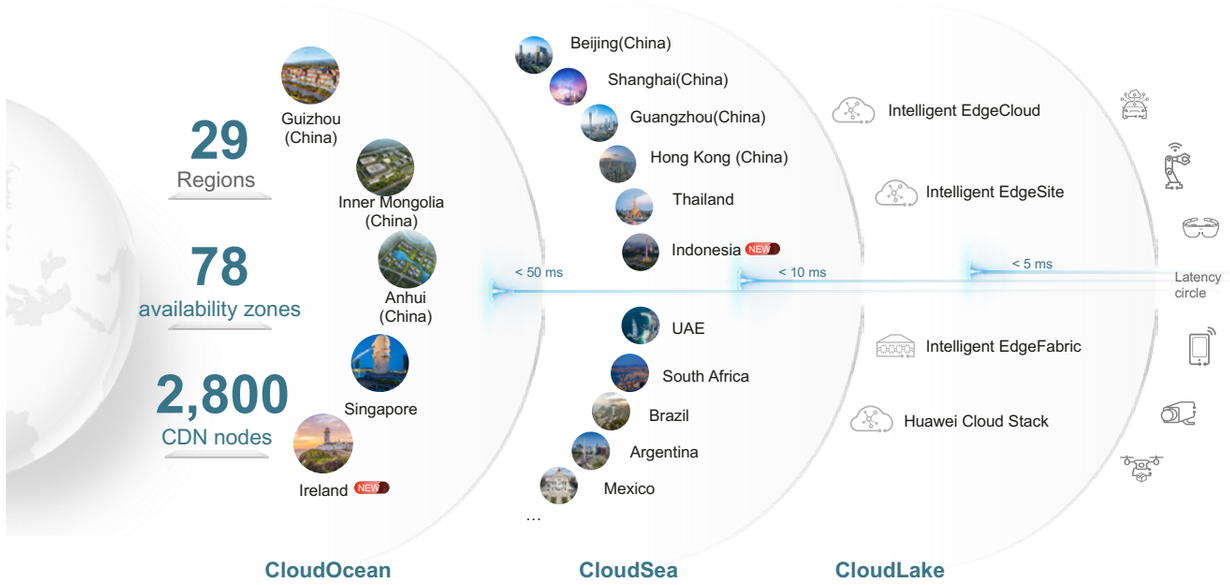


Figure 4: Huawei Cloud KooVerse

In terms of Technology as a Service, Huawei Cloud keeps innovating to make breakthroughs in fundamental technologies, and builds the most simplified and most easy-to-use tools for developers, realizing easily-accessible innovation. DevCloud integrates the multiple production pipeline capabilities of Huawei Cloud to support collaborative development and the on-demand orchestration of data, AI models, and digital content. It also allows application developers, data engineers, and AI scientists to work on the same platform and share R&D capabilities and assets, improving multi-team collaboration efficiency and achieving faster application modernization.

In terms of Expertise as a Service, Huawei Cloud enables digital transformation across industries. Working with 41,000 partners and over four million developers, we provide the best practices of Huawei and global customers and partners, delivering services for customers via more than 100,000 APIs.

3. Technological innovation of Huawei Cloud

To make it easier and more convenient for customers to use the latest cloud services, we have made numerous innovations and

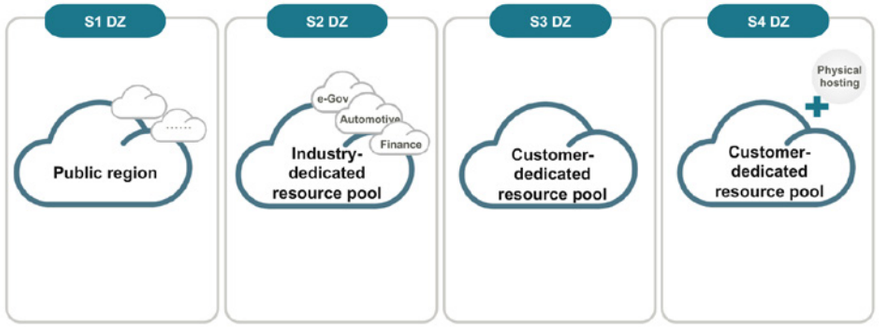


Figure 5: Dedicated security zones

breakthroughs across many technologies, including those related to compute, applications, data analysis, artificial intelligence, and security, to form a systematic technical architecture (as shown in Figure 3). This section will explain KooVerse, security zones, and data and AI convergence in detail.

Focusing on data protection, Huawei Cloud provides a highly reliable, autonomous, and intelligent cloud security protection and O&M system. Cloud Security Brain identifies and resolves security risks, threats, and attacks in near-real time, creating a cloud platform that offers customers greater security than

KooVerse is a distributed cloud infrastructure with unified architecture that covers the entire world. It provides customers compute, storage, and network infrastructure services and delivers a consistent global experience. Huawei Cloud KooVerse delivers a 50-ms user experience through CloudOcean, CloudSea, and CloudLake (as shown in Figure 4), thus meeting the differing latency requirements of enterprise services. CloudLake edge access provides an ultra-low cloud-to-device latency of 5 ms, allowing it to meet the requirements of hot applications that require ultra-low latency in, for example, manufacturing and autonomous driving scenarios, with a maximum of 5,000 servers. CloudSea regional center offers a latency of less than 10 ms for about 100,000 servers. The million-node CloudOcean global center, which is set to be deployed in China's Guizhou, Inner Mongolia, and Anhui, can provide customers with cloud resources that have a latency of 50 ms. By combining tech with local geographical advantages, we provide our customers with greener, more efficient cloud services that can meet requirements for massive computing power in the future digital economy.

Streamlining data governance and AI development is the key to realizing data value and data-driven operations. Huawei Cloud converges DataArts and ModelArts to provide customers with cost-effective, easy-to-use data solutions (as shown in Figure 6).

·Decoupled storage and compute architecture based on cloud native. The three-layer decoupled architecture of cloud storage, caching, and compute is highly cost-effective and offers flexible compute. Cloud storage is a large storage pool, where resources are fully shared between multiple tenants. This reduces cost per unit, and allows users to store all historical data and respond to unpredictable analysis requirements. Remote storage enables elastic scaling and on-demand, separate use of compute and storage resources. Caching is used to compensate for performance losses caused by remote storage, keeping losses within a small range that is imperceptible to services.

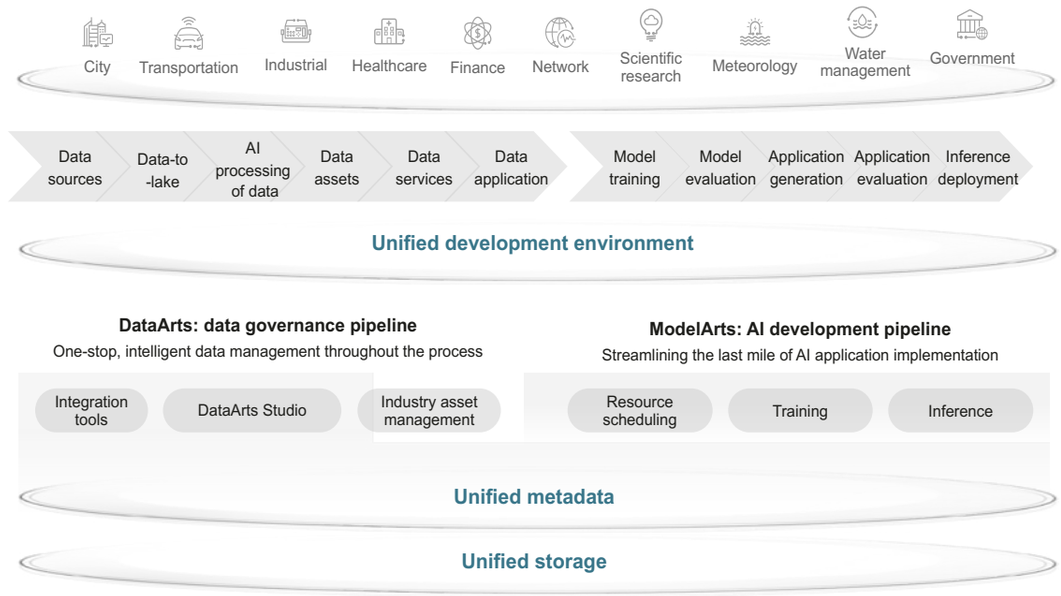


Figure 6: Data and AI convergence

Cloud will play a fundamental role in shaping the intelligent world.

New Solutions

- Unified metadata enables innovation on the data and AI convergence platform. The platform connects the data silos of big data, data warehouses, and AI, and consolidates capabilities like data catalogs, data permissions, and multi-version management into a single point, where data can be accessed. In this way, data usage is not restricted by isolated systems, such as when the same table is analyzed by different analysis engines. The same table can be used across data warehouse, big data, and machine learning tasks. Different users do not need to move data back and forth between dedicated systems, regardless of the engines they use to process data.
- AI for Data: Our AI-assisted, one-stop data governance platform supports one-click integration of over 40 heterogeneous data sources and various Huawei Cloud basic data services. The platform can govern data development and provide quality assurance throughout the data lifecycle, accumulate model assets, and build industry knowledge bases.
  Data for AI: A unified data and AI development environment allows different roles to take advantage of their own strengths and meet their goals. For example, data engineers can use familiar tools to invoke AI capabilities, facilitating collaboration between big data and AI development.

Huawei has opened up its cumulative technology expertise in cloud, network, edge, device, and chip to global customers and partners in the form of cloud services, lowering the threshold for customers to use digital technologies and accelerate innovation.

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