HUAWEI

Striding Towards
the Intelligent World
White Paper

wireless network

Striding to 5.5G, From IoE to Intelligent IoE

构建万物互联的智能世界

Foreword

Looking back throughout history, communications always develop at an astounding rate. While it took over 30 years for fixed-line services to go mainstream, it took only 10 years for mobile technologies to become the norm. Technology creates value, and innovation is the engine for future development. 5G has already become a key infrastructure to support digital transformation in society and the healthy development of the digital economy.

5G was first commercialized three years ago, and since then it has exploded rapidly compared to its predecessors. The world now has more than 230 5G commercial networks and over 700 million 5G users, which has given rise to the booming 5G UHD live streaming, 5G AR/VR, and other 5G-based new media and mobile applications around the world. Such services, in return, are pushing mobile services to migrate to 5G. Huawei predicts that the cellular data of usage (DoU) will reach 600 GB by 2030, most of which will be carried on 5G networks. In the next decade, 5G will evolve by enhancing its current capabilities tenfold and introducing new capabilities that boost user experience.

In the applications to businesses — termed as toB at Huawei, 5G has been widely adopted in various industries, like mining, port, manufacturing, steel, and healthcare, to accelerate their digital transformation. Huawei works with partners to explore diverse use cases, such as remote control and intelligent inspection, to help businesses become more efficient and cost effective. Based on extensive explorations, it is clear that industries value high uplink, high-precision positioning, and green sustainability. This signals the way for 5G innovations that are tailored to industries, helping accelerate digital transformation.

In 2020, Huawei took the lead by proposing its vision for 5.5G, boosted consensus on 5G evolution, and encouraged 3GPP to name the evolution as 5G-Advanced. Now, through a common business vision and formalized standards, the industry needs to innovate technologies for 5.5G, with a focus on boosting enhanced Mobile Broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communications (mMTC) and supporting new capabilities of high-precision sensing and positioning, passive IoT, and intelligence. Based on these innovations, we will build networks featuring 10 Gbps experience, 100 billion connections, and native intelligence, with a view to commercially launching 5.5G.

The wind rises and we set sail. Huawei passionately works with global operators and industry partners to create a 5.5G that has significant business value and serves as a benchmark for moving towards an intelligent world.

Yang Chaobin
President of Wireless Solution, Huawei

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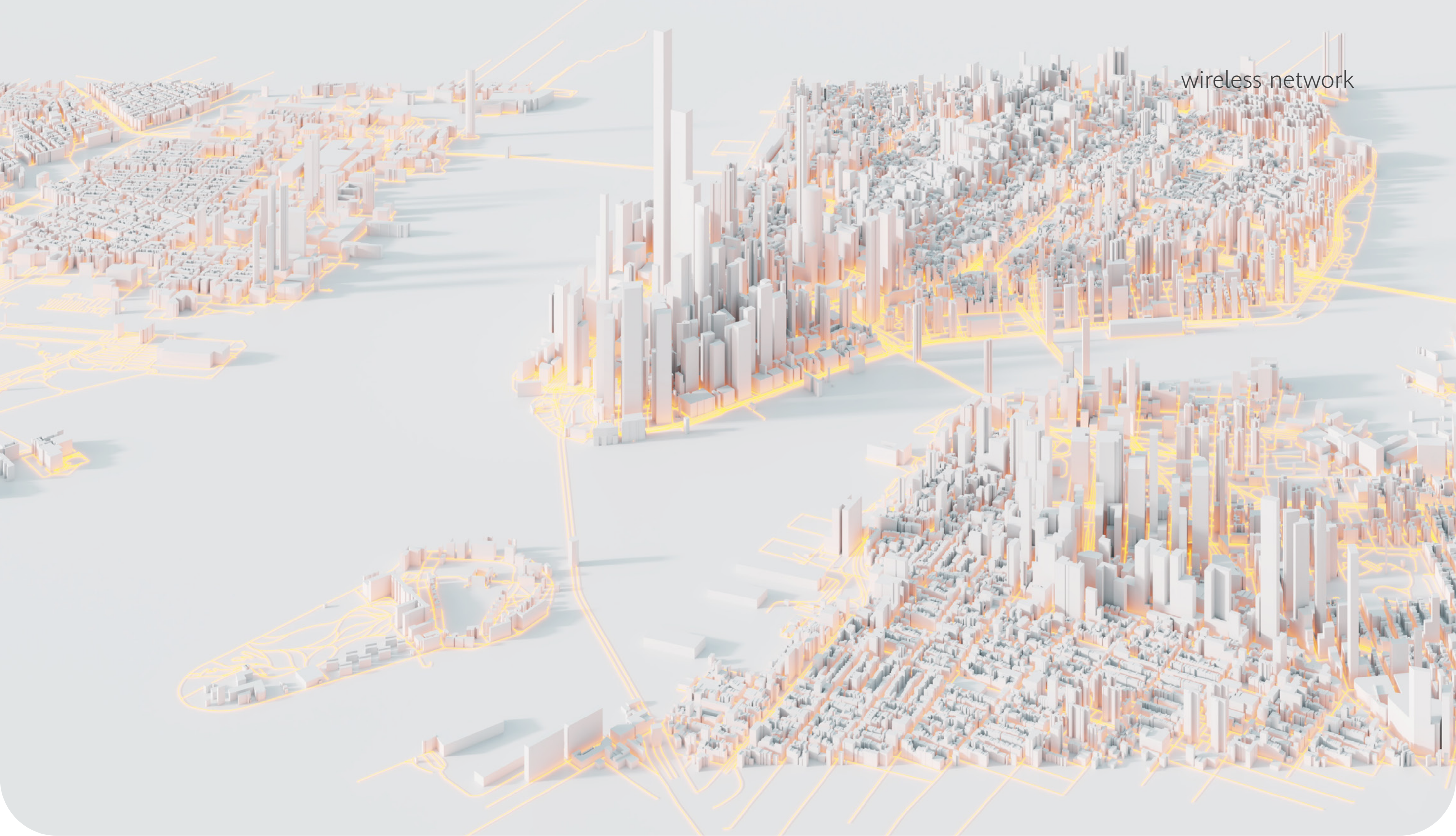
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Abstract

After only three years since it was commercially rolled out, 5G has reached further than any of its predecessors. By October 2022, more than 230 operators will have launched 5G commercial services worldwide with over three million 5G sites serving 700 million 5G users. Compared with 4G, which achieved a similar feat six years after it was first commercially adopted in 2009, 5G is advancing twice as fast. Now, 5G already boasts a mature industry ecosystem, with more than 1,400 devices available on the market at an entry-level price of CNY1,000. In January 2022, 5G smartphones contributed to more than half of the global smartphone sales for the first time, reaching a record-high share of 51%. The number of smartphone sales is expected to exceed 700 million throughout 2022.

5G has entered a new positive cycle with networks, users, devices, and services mutually driving one another. The increasingly mature device ecosystem and cheaper device prices have made 5G devices more affordable, which, in turn, has increased their popularity among users, providing extra motive for operators to improve 5G networks. The transformative experience of 5G networks has also motivated a plethora of new services, resulting in a multifold increase in data traffic from public users and enormous demand from industry users for 5G high uplink, low latency, and high reliability. This will in turn require 5G to further its capabilities.

5G is already bringing about change, but this is merely the beginning. 5G will create more profound and far-reaching changes over years to come, in addition to upgrading mobile communications. This justifies the need to continuously follow the 5G industry trends and introduce the policies desired to ensure a robust progression towards an intelligent world.

By analyzing recent industry progress and changes, this report proposes six trends for mobile communications.

Trend 1: User Experience-driven Revenue Increase Grows in Importance

ToC is still the fundamental business for operators. By using 5G to improve premium experience, operators are turning HD and interaction into a new mainstream mode of watching mobile videos among public users and also strategically developing XR and other innovative services. This 5GtoC trend will tangibly increase data of usage (DOU) and stimulate tariff plan upgrades, benefiting both users and operators.

Trend 2: 5GtoB Emerges as a Major Driver of Mobile Industry Growth

ToB is a major expansion of operators' business into various industries. By expanding high-quality connections, 5G private lines, and 5G private networks into industries, 5GtoB enables operators to experience a rapid growth of service revenues and promote multifold increase in DICT (devices,

platforms, applications, cloud, big data, intelligence, and integration) revenues. 5GtoB has become the fastest growing service domain for operators.

Trend 3: Intelligence Is Key to Addressing Growing Network Complexity

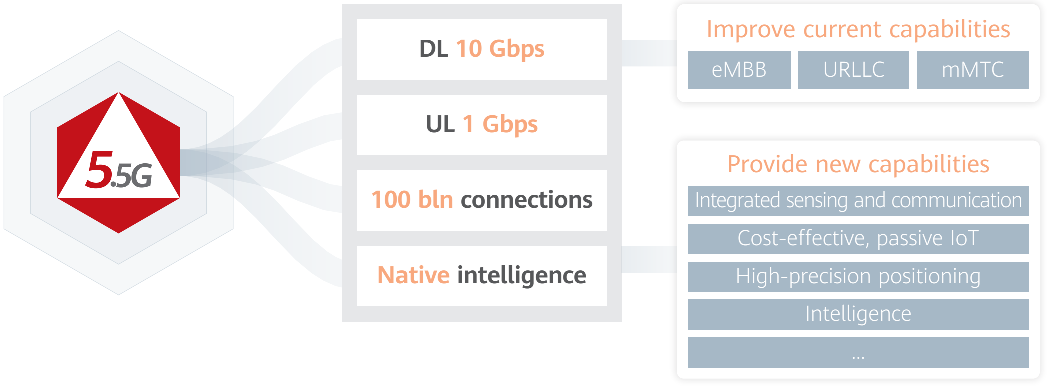
Growing network complexity drives mobile networks to become intelligent. A natively intelligent architecture will enable mobile networks to support real-time sensing, modeling and prediction, and multidimensional decision-making. With these intelligent capabilities, mobile networks will be intelligently optimized with resources to be configured on demand for optimal user experience and capacity. Operation and maintenance will be intelligently simplified with site planning, deployment, and troubleshooting to be automated. Energy saving will be intelligently executed with both energy efficiency and performance to be maximized.

Trend 4: Green ICT Requires Hundredfold Traffic Demand to Align with a Slight Increase in Energy Use

Low-carbon growth has become a hot topic across industries. Green ICT highlights the necessity of establishing a standard system to evaluate the energy efficiency of mobile networks, innovating devices, sites, and networks, and accelerating user migration to 5G. This will help operators meet the needs of hundredfold traffic with a minimal increase in energy use, maximizing both energy efficiency and performance.

Trend 5: Evolution to 5.5G Provides 10 Gbps, 100-Billion Connectivity, and Native Intelligence

5.5G innovation has become a common undertaking of the ICT industry that sees various new toB and toC demands keep emerging in the market. These demands require mobile networks to boost the enhanced Mobile Broadband (eMBB), ultra-reliable low-latency communication (URLLC), and Massive Machine-Type Communications (mMTC) and support new capabilities of high-precision sensing and positioning, passive IoT, and intelligence. This means that the industry must advance mobile networks to 5.5G to enable 10 Gbps experience, 100 billion connections, and native intelligence, in preparation for its commercial launch in 2025.



Evolution to 5.5G for 10 Gbps experience, 100-billion connectivity, and native intelligence

Trend 6: Native Security Ensures Full-Lifecycle 5G Security

Scaled 5G replication would not be possible without the context of network security — an essential industry element, used to measure the quality of just mobile networks (quality attribute), now becomes an indicator of how capable the entire industry is (industry attribute). By combining security technology innovations and network native security mechanisms, the industry must systematically consolidate security capabilities to ensure that operators can build secure and resilient mobile networks in a simplified fashion. This will be crucial in providing secure and reliable information services across industries to safeguard their digital transformation.

Wireless networks, now with 5G at the core, are the technical backbone for the world moving towards a fully connected intelligent future. By publishing this report, Huawei looks to explore the trends of the 5G industry and define future wireless networks together with all industry partners to build a better intelligent world.

Trend 1

User Experience–driven Revenue Increase Grows in Importance

In the last decade, thanks to the soaring popularity of the mobile Internet, data services have contributed enormously to mobile service revenue, becoming the biggest chunk of operator revenue sources. In 2021, global mobile services generated more than 50% of operator revenue. In China, mobile data services saw their shares in the total mobile service revenue grow by more than 10 times over 10 years, from less than 5% to 80%.

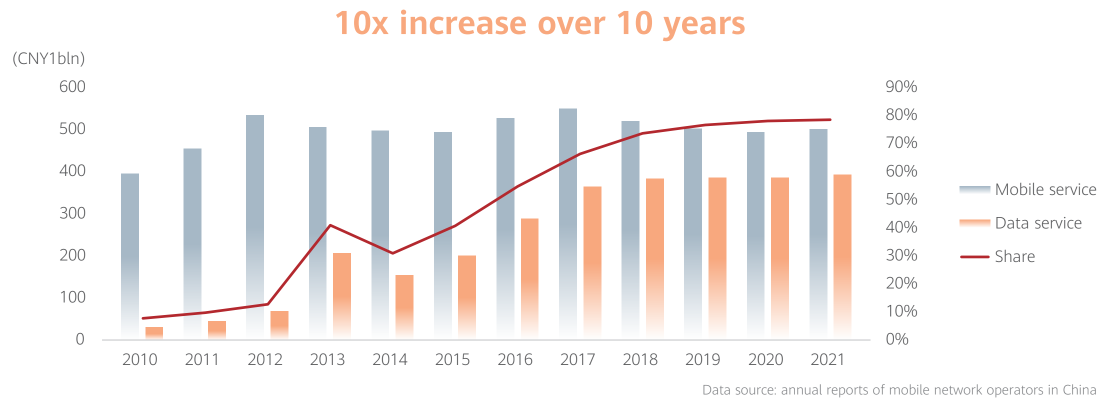


Figure 1 Proportion of data service revenue to the total service revenue in China

ToC is still the fundamental business for operators and also the starting point of 5G development. 5G has developed rapidly in China, South Korea, Kuwait, and other countries and regions, due to extensive investment, bringing an outstanding experience to users and steadily growing the value of mobile connections. As a result, operators there are running their business back on an upward track, reaping impressive return.

This shows that user experience-driven revenue growth has never played such an important role in operator's business landscape.

1.1 5G Provides Superb Experience to Drive a Significant DOU Growth

5G's superb experience is hugely beneficial to the public. According to third-party tests, 5G is 10 times better than 4G in user experience thanks to the support of multi-antenna and high-bandwidth. This attracts users to increase their mobile connections, creating more data traffic for better services. Now, 5G DOU is twice that of 4G on average.

- In South Korea, Ookla tests found an average 5G download speed of 492 Mbps, benefiting from C-band's large bandwidth and continuous Massive MIMO coverage. This has pulled 4G users over to 5G networks, enabling 5G DOU to double compared with 4G on average. 5G is generating an increasing proportion of data traffic: 20% in November 2019, 30% in June 2020, and over 50% in February 2021, while 4G traffic peaked in July 2020.

- In the Middle East, 5G enables operators to upgrade FWA services to provide fiber-like experience, increasing DOU by 5 to 10 times. The average revenue per user (ARPU) of FWA users per line has also increased by 2 to 3 times.

- In China, a 5G speed report released by the China Academy of Information and Communications Technology (CAICT) showed that the 5G download and upload speeds reached 300 and 50 Mbps, respectively, compared with 4G's 28 Mbps and 2.9 Mbps, which have increased over tenfold. As a result, 5G users consumed as twice as much data traffic than 4G users, boosting DOU from 8 GB to 15 GB after commercial 5G rollout.

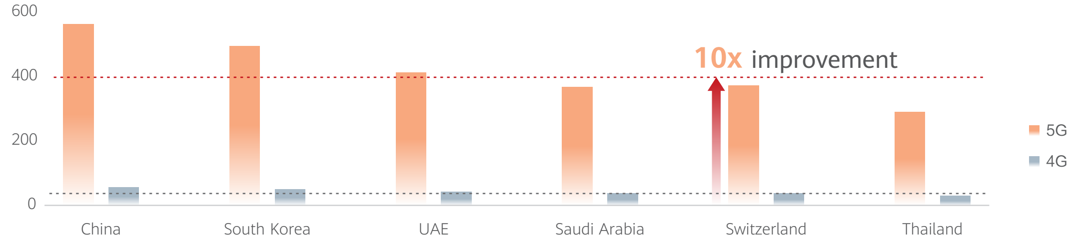


Figure 2 A comparison of 4G and 5G user experience

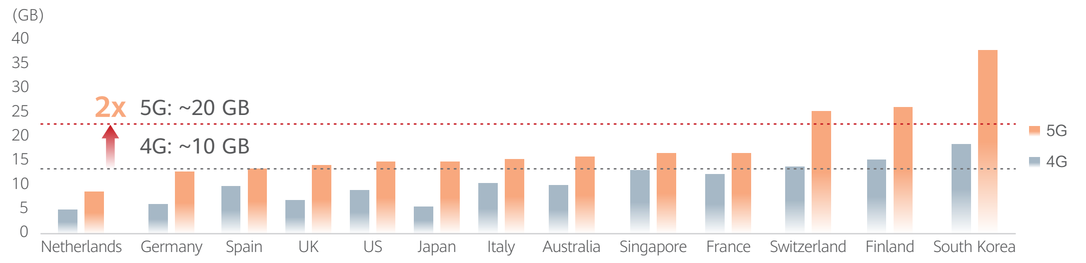


Figure 3 A comparison of 4G and 5G DOU

1.2 Upgraded 5G Tariff Plans Stimulate User Traffic Demand and Operator ARPU Growth

In commercial 5G rollout, global operators usually adopt a strategy of promoting users to upgrade their tariff plans. With 5G entry-level plans available at a higher price than 4G ones, 5G plans are marginally more expensive, but this slight increase can be offset by a far lower per-GB price, given that 5G provides higher speeds and capacity, and this will be a huge benefit for both users and operators.

- For operators, ARPU is increased. With mobile users switching from 4G to 5G, tariff plans are 20%–40% higher on average, compared with the 0–20% margin during the transition from 3G to 4G.

- For users, the cost per GB is lower, meaning more data traffic can be disposed. Statistics in China and South Korea indicate that the cost per GB is reduced by 40%–90%, and 5G mid-tier packages (including a data quota of over 150 GB) are the most competitive compared with 4G packages.

5G's high speeds encourage operators to provide tariff plans based on speed tiers, in 'speed-only' or 'speed + traffic' modes. After 5G enters

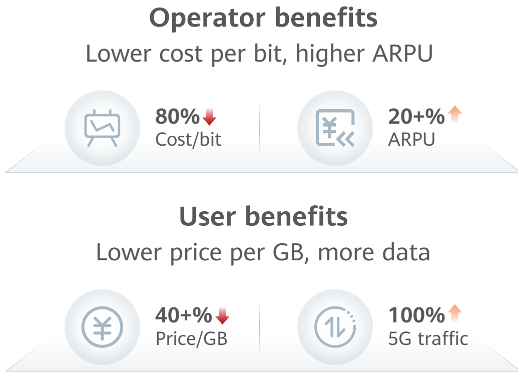


Figure 4 5G's benefits to operators and users

commercial rollout, 20% of operators have offered speed-based tariff plans. Compared with 4G's 5%, this number is already four times as high. 5G helps operators monetize networks based on speeds. In countries with abundant network resources, speed-based practices have already helped operators boost their revenue growth.

In Finland, for example, where speed-based tariff structures were first introduced, speed-based pricing means that users pay for mobile services only based on speed tiers without focusing on specific mobile technologies. As such, when introducing 5G services to users, operators could directly provide new higher-tier plans on top of existing ones to encourage package upgrades, realizing price premiums through 5G's amazingly high speeds.

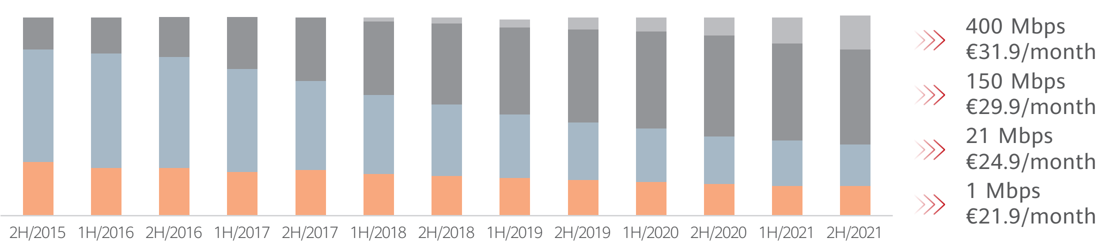


Figure 5 User tariff plan upgrades encouraged by the speed-based pricing approach of a European operator

1.3 5G is Making Mobile Video Experience Richer and More Immersive

Video services generate most data traffic on mobile networks. Globally, 70% of mobile data traffic comes from streaming video, a significant increase from 4G's 50%. This rapid increase is largely due to short videos that now make up about 40% of cellular network traffic.

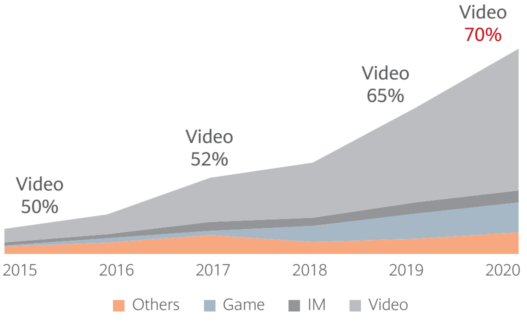


Figure 6 Proportion of the global mobile video traffic

The superb experience of 5G has had a transformative effect on video, evolving from standard definition to high and even ultra-high definitions. With 5G's growing adoption in video production, it is possible for content providers to produce long videos with a resolution of 1080p or higher. The high speeds of 5G make lightning-fast, interactive HD short videos a reality, eliminating the 4G practice of adjusting the bit rates based on network quality during short video playback. On 5G, users experience extremely short delay when switching between short videos, even with a fixed resolution of 1080p. In China, after 5G is already commercially available for mobile users, 720p or higher videos on mobile networks have seen their proportion step up from 4G's 40% to 5G's 60%.

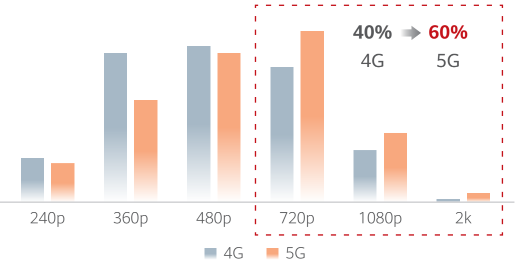


Figure 7 Video resolution on mobile networks in a major Chinese province

5G is changing the way users view video content, with a greater emphasis on interaction. The number of users who have used skipping and variable-speed playback has increased from just 5% in 2019 to 40% in 2021, and will likely exceed 60% by the end of 2022. Meanwhile, panoramic videos are increasing rapidly. According to the analysis of a major short video app platform, interactive panoramic videos are increasing by 30% a month, with a total scale exceeding 4 billion. A smooth viewing experience requires networks to support higher user-perceived speeds. For example, skipping requires a speed that is double the normal speed to ensure a zero-freezing experience, and the bit rates of panoramic videos will be five times that of common ones.

1.4 5G Boosts the Popularity of AR/VR and Many Other Innovative Services

Innovative 5G services, with common examples of VR/AR, have become the biggest driving force behind the growth of 5G public-user businesses. The fast availability of 5G networks is the basis to develop AR/VR. Considering such network dependency, operators are uniquely positioned to fully utilize the advantages of 5G's high bandwidth and low latency to reduce the usage barriers.

Following 5G's commercial promotion since April 2019, South Korea's three major operators have included VR/AR services into their 5G packages as a differentiation from 4G. Due to well-designed structures, such VR/AR services have enabled them to improve ARPU. For example, AR/VR is a privilege of their higher-tier tariff packages, attracting high-end 5G users to the packages priced at KRW75,000–85,000 (about US$52.7–59.7). This has attributed to an ARPU increase over their 4G provisioning with a common package pricing of KRW5,000–65,000 (about US$3.5–45.6).

A South Korean operator now provides more than 8,000 AR/VR contents. More than 60% of its 5G users are watching VR/AR contents for an average of more than 1.5 hours per week. VR/AR traffic continues to increase in South Korea, estimated to exceed 80% of overall service traffic by 2024.

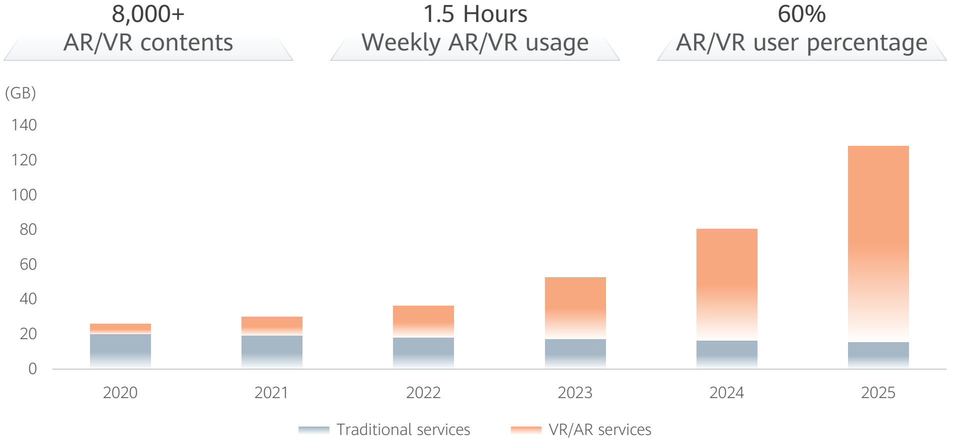


Figure 8 5G development driven by AR/VR growth in South Korea

Trend 2

5GtoB Emerges as a Major Driver of Mobile Industry Growth

4G has changed how we live, and 5G is changing society. 5G is taking the world by storm, delivering high bandwidth, low latency, and high reliability to open up a new era of fully connected intelligence and in-depth man-machine interaction. 5G will focus more on vertical industries, which is known as toB, with its data traffic following a 20–80 pattern: about 20% from people-to-people interaction and 80% from things-to-things communications.

After three years of exploration, 5GtoB has become a major driver of business growth for global operators. By adopting more high-quality connections, 5G private lines, and 5G private networks across industries, operators are reaping a rapid 5GtoB revenue growth and also enabling DICT (devices, platforms, applications, cloud, big data, intelligence, and integration) to realize a multifold increase in service revenue. In China, typical 5G applications are being practiced across 40 of the major 97 economic domains, including mining, ports, and manufacturing. In 2021, 5GtoB created more than US$3 billion of revenue for operators and contributed over US$20 billion to these DICT areas, becoming the fastest growing field for telecom businesses and attracting more investment over the next few years. With more investment coming on the way, 5GtoB is expected to see its revenue exceed US$30 billion while contributing hundreds of billions of DICT revenue by 2025.

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As its innovations continue to enhance uplink speeds and many other network capabilities towards the ambitious vision of 100 billion connections, 5G will enable operators to transform from merely a connection provider to a comprehensive service provider, mapping out a second curve of growth for operators.

2.1 Three 5G-centric Technologies Will Unlock 100 Billion Connections Over the Next Decade

Operators are currently developing IoT services, which will lead to a significant increase in the number of connections. In China, the number of Cellular Internet of Things (CIoT) users is increasing at 10 times the rate of the number of mobile phone users. By the end of May 2022, the number of CIoT connections had reached 1.59 billion, and it is estimated that IoT connections will surpass mobile user connections during the third quarter of 2022. According to operators' 2021 annual reports, IoT service revenue in 2021 of China Mobile, China Telecom, and China Unicom reached CNY141.4 billion, CNY2.859 billion, and CNY6 billion, respectively, with a year-on-year increase of 21.3%, 31.8%, and 43%. IoT services have become critical to operators.

In the 5G era, Narrowband-Internet of Things (NB-IoT), Reduced Capability (RedCap), and passive IoT technologies will support 100 billion connections, thanks to the scale economies effect of the wireless industry.

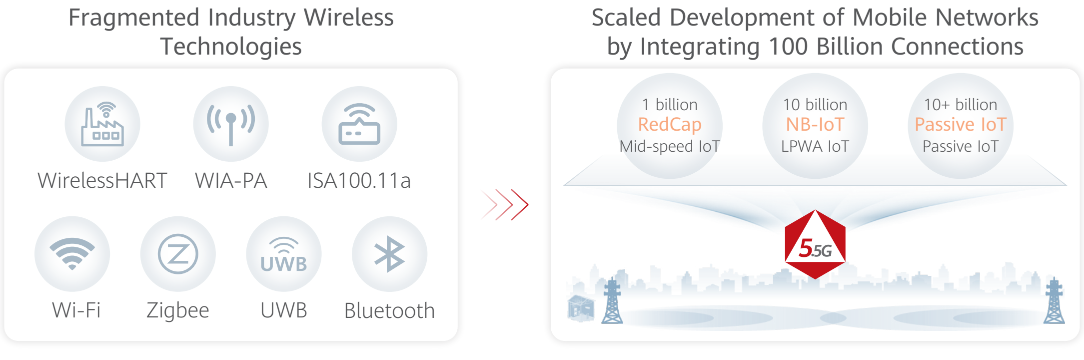


Figure 9 100 billion connections empowered by three 5G-based technologies

NB-IoT has become the mainstream technology in the Low Power Wide Area (LPWA) market and grown at a rapid pace.

Since 3GPP completed the standardization of NB-IoT in 2016, NB-IoT has been widely used to create applications, develop industry ecosystems, and build end-to-end industry chains. The technology continues to grow at a blistering pace, as it is now deployed in 126 commercial networks around the world. Operators like China Mobile, China Telecom, China Unicom, Vodafone, and Deutsche Telekom have put NB-IoT networks into commercial use. In terms of modules, the price of NB-IoT modules is equivalent to that of 2G modules; the price of a dual-mode (NB-IoT/GSM) module is as low as US$6, and that of a single-mode (NB-IoT) module is approximately US$4. This high degree of affordability lays the groundwork for the scaled development of NB-IoT. In addition, NB-IoT applications have been deployed on a large scale in numerous contexts, including gas meters, water meters, smoke sensors, and door status sensors, with the number of connections now in the tens of millions.

According to an industry report, in 2021, NB-IoT took the lead with a market share of 47%, and a growth rate and total volume in excess of those for unlicensed spectrum technologies, such as Lora and Sigfox. Therefore, NB-IoT is expected to become the go-to technology in the LPWA market. Since NB-IoT was officially incorporated into the 5G standards, NB-IoT connections will continue to grow, and come to replace 2G/3G IoT. It is expected that the number of NB-IoT connections will reach 10 billion by 2030, making it an LPWA technology in the 5G era.

The commercialization of RedCap has created new market spaces for billions of medium- and high-speed IoT connections.

At the 96th 3GPP plenary meeting held in June 2022, the 5G Rel-17 standard was finalized, indicating that the RedCap standardization for medium- and high-speed connections was completed. The growing RedCap maturity in industry standards, networks, devices, and applications could open up a new space of about 10 billion IoT connections.

RedCap mainly applies to smart wearables, industrial wireless sensors, and video backhaul, which all require a downlink and uplink transmission rate of 100+ Mbps and 10+ Mbps, respectively. These are lower than that of 5G eMBB services but higher than LPWA networks such as NB-IoT and LTE-M. As such, RedCap devices will be positioned as a lower segment than eMBB devices, but higher than LPWA devices in terms of technical features, achieving a balance between network performance and device costs.

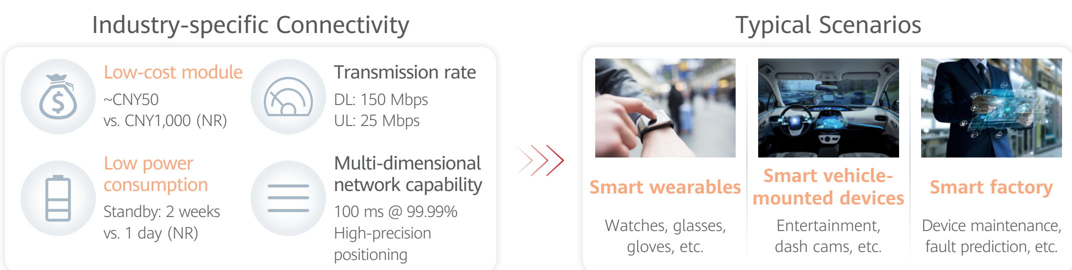


Figure 10 RedCap to create a new market with billions of medium- and high-speed IoT con-nections

Compared with NR, RedCap is simplified and customized.

Low cost: The maximum bandwidth requirement for a RedCap device in the sub-6 GHz band is 20 MHz. With fewer receive antennas and layers, RedCap supports 1R or 2R, lowering the cost of 5G device chipsets and modules. The cost of RedCap modules is estimated to be five times lower than that of eMBB modules, and the price of modules for large-scale commercial use is comparable to that of Cat 4 modules.

Large capacity and efficient coexistence: RedCap devices can run on 5G networks through separate initial BWPs and non-cell-defining synchronization signals and can coexist efficiently with eMBB devices, fully leveraging the advantages of 5G.

More optional functions are supported, such as low latency, slicing, positioning, and low power consumption.

Passive IoT combines cellular and passive tag technologies, providing an ideal option for connecting tens of billions of passive IoT devices.

Restricted by deployment scenarios, a large number of IoT devices cannot be powered by batteries or have low-cost requirements, such as fast-moving consumer goods (FMCG), logistics packages, and product packaging. These applications generate tens of billions of passive IoT connections. At present, battery-free passive tag technology is mainly used for such IoT applications. However, this technology can only be deployed at entrances and exits for local identification, which is too restricted for passive IoT. Therefore, using network technologies to improve the identification rate, coverage scope, positioning accuracy, and inventory efficiency of passive IoT become increasingly important.

Passive IoT combines cellular communications and passive tag technologies to significantly improve coverage capability. The outdoor NLOS reaches more than 100 m, while the indoor NLOS reaches over 30 m. It also provides stable network connectivity to effectively reduce interference between multiple readers, ensuring an inventory efficiency of over 99.9%. In addition, tags support energy collection, achieving extremely low power consumption of less than 10 μW. This way, tags can be widely used at an extremely-low cost.

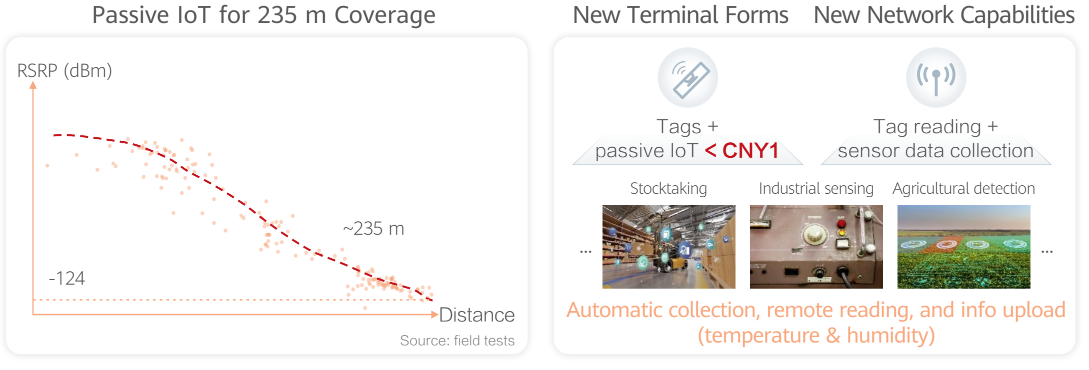


Figure 11 Passive IoT to enable tens of billions of IoT connections in various new scenarios

2.2 Continuous 5G Innovation Is Required to Improve Uplink Rate

Better connectivity is a must-have for 5GtoB services to create new value for industries, while innovation is critical for industries to address existing challenges and explore new market spaces.

5G has been applied in industries such as steel, mining, ports, and manufacturing. Services including 5G-based video surveillance, remote control, and machine vision require real-time upload of multi-channel HD videos, posing higher requirements on uplink capabilities. While the downlink peak rate of 5G networks has reached Gbps level, the growing demand of higher uplink rates for ToB services shows that improvements are still needed in this area.

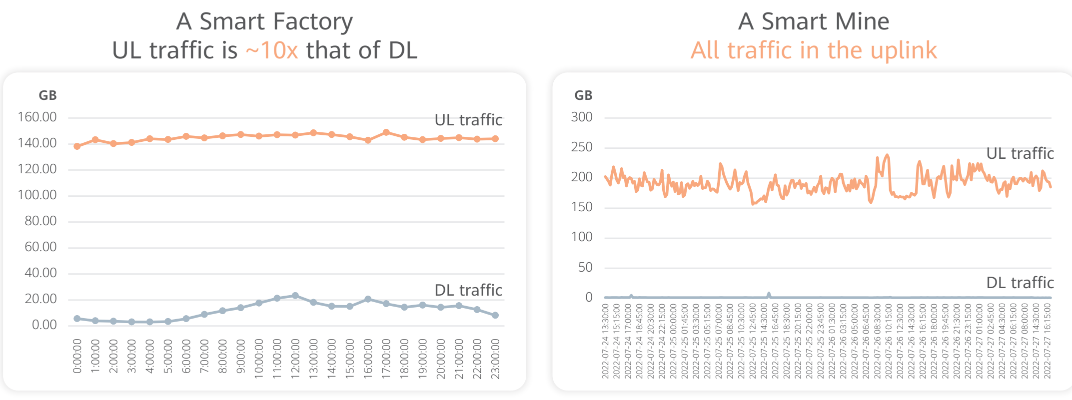


Figure 12 Uplink is essential for industry applications

The industry is exploring further methods of improving 5G uplink capabilities, including uplink-downlink subframe configuration (1D3U), Super Uplink, and uplink carrier aggregation.

Uplink-downlink subframe configuration (1D3U): As a large amount of downlink traffic is generated on the public network, the current mainstream 5G time division duplex (TDD) slot configurations are 8D2U and 7D3U, which prioritize the allocation of downlink resources over uplink. In closed local-area scenarios with high uplink requirements (such as underground mines), more resources can be allocated to the uplink by adjusting the slot configuration. For example, if the slot configuration is 1D3U, it can provide three times more uplink timeslots than 8D2U. Its peak rate of a single user approximates 750 Mbps, three times that of 8D2U.

Super Uplink: When a mobile phone is predominantly served by the TDD band, the Super Uplink solution can increase the uplink throughput and shorten the transmission latency by leveraging technologies like TDD and FDD coordination, high- and low-band complementation, and time-domain and frequency-domain aggregation. For example, when uplink data is transmitted in the TDD band, no uplink data is transmitted in the FDD low band. As such, the uplink throughput increases due to the naturally high TDD bandwidth and that two transmit channels are open for a device. Alternatively, when downlink data is transmitted in the TDD band, and uplink data is transmitted in the FDD band, the conversion between the FDD and TDD timeslots ensures uplink data is transmitted in all timeslots.

Uplink carrier aggregation: Carrier aggregation (CA) is a technology that bundles two or more carriers to aggregate scattered spectrums into a larger bandwidth, thereby providing higher network rates and spectral efficiency. Based on this principle, uplink CA aggregates the uplink frequency bands of different carriers to improve the uplink capability.

Not only that, the industry continues to explore technologies including slicing, low latency, high-precision positioning, and simplified O&M to provide technical support for the commercial use of 5GtoB services.

In a word, better connectivity will drive the emergence of new industries. Digitalization has become an inevitable step for various industries, while 5G network capabilities will continue to be enhanced to better serve whole industries.

2.3 Operators Are Reshaping Their Roles and Exploring E2E 5G Solutions

Operators are trying to reshape their roles from connection service providers to integrated service providers, creating excellent opportunities for their digital transformation.

Operators can undertake three roles in 5GtoB services according to their capabilities and industry requirements.

- Connection service provider: Operators mainly provide on-demand 5G network connection services of varying quality and prices to industry customers, including bandwidth, latency, positioning, and security. This can be done by themselves or via system integrators, that is, integrators integrate services sold by operators with other services, and sell them to customers.

- Platform service provider: Operators provide enterprise customers with scenario-specific 5G network solutions. These solutions offer flexibility for enterprises in terms of coverage scenarios, local network deployment, customized NE resources, configurable network performance, controllable network O&M, and data confidentiality, providing stronger localization capability, better applicability, and easier controllability for enterprises.

- Integrated service provider: Operators provide E2E 5GtoB solutions and must therefore dive into industries to integrate resources and provide services such as business & construction consulting, top-level design, and planning. Moreover, they should handle overall solution design, SLA breakdown, pre-integration system test, and integrated delivery. This role can streamline networks, clouds, software development, and other systems, which can strain the capabilities of operators and requires long-term industry customer service experience.

5G will be widely applied in industry applications to deliver high bandwidth, low latency, high reliability, and wide connectivity. It will be integrated with cloud computing, big data, intelligence, and other technologies to evolve processes such as R&D design, production, manufacturing, market service, and operation management. E2E customized solutions such as 5G network slicing, enterprise information management systems, streamlined production and operation management processes, remote control, application platforms, data storage, and intelligent big data analytics are perfect for enterprises. Therefore, telecom operators need to cooperate with industry chain partners to build core competitiveness and grow their market presence.

System integration is an engine for developing the 5GtoB industry, 5G, and other communications technologies like cellular network technologies, and faces a bright future. However, the current IT infrastructure of operators, equipment vendors, and enterprises is unable to support scaled digital transformation. Integrators need to develop customized solutions for industries based on their communications capabilities. Along with new infrastructure investment in 5G, these capabilities will be the catalyst for the development of real economy.

In recent years, the overall investment and financing scale and quantity of industries have increased significantly. According to IHS Markit's research, 5G will generate US$13.2 trillion of economic output by 2035. Hence, there will be massive investment opportunities in 5G-based industries like transportation, manufacturing, video entertainment, education, and healthcare.

Recommended Actions

5GtoC and 5GtoB development trends show that 5G services and requirements are more diversified than 4G. A network with large bandwidth and continuous coverage is needed for connecting individuals, delivering cross-generation experience at a lower cost per bit, while a network with ubiquitous coverage is needed to connect massive IoT terminals. Furthermore, capabilities such as flexible high uplink, low latency, and high-precision positioning need to be deployed that are adaptable to different industries.

To fulfill these requirements, all bands need to evolve to 5G to build a wide-pipe foundation network with ubiquitous coverage based on large mid-band bandwidth. Other frequency bands are used to build differentiated advantages and implement additional on-demand N-dimensional capabilities.

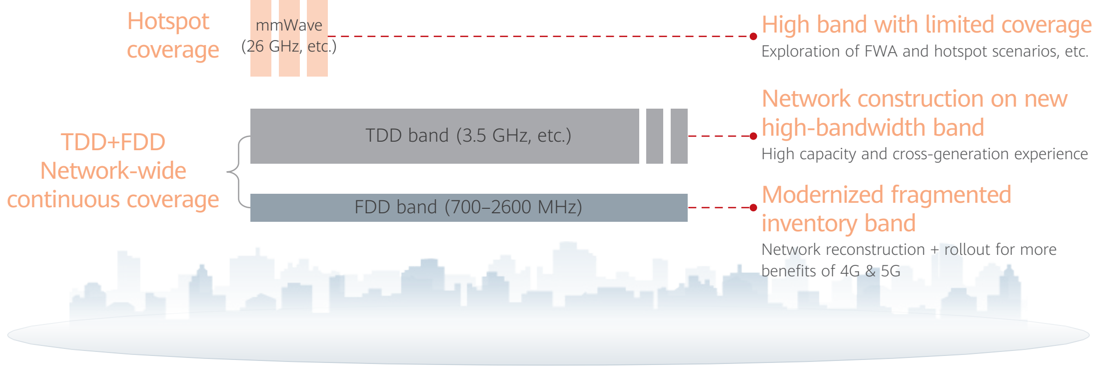


Figure 13 From band-varying 5G construction to multi-band convergence into one 5G network

Build a ubiquitous wide-pipe foundation network with large mid-band bandwidth as the core

Large mid-band bandwidth has become an industry consensus for providing a reliable cross-generation experience to users. It works with Massive MIMO to considerably reduce the costs per bit of 5G networks, which is the core of ubiquitous wide-pipe networks.

3.5 GHz, 2.6 GHz, 2.3 GHz, and 4.9 GHz are the four prime bands for 5G TDD. Regulatory authorities in various countries should provide continuous large bandwidths to maximize spectral efficiency, reduce deployment costs per bit, and improve cross-generation user experience. More than 80 countries have provisioned continuous large mid-band bandwidth (80–100 MHz), and it is anticipated that more than 35 countries will have provisioned new 5G TDD spectrum by the end of 2023.

By 2030, regulatory authorities need to release new 5G spectrum for International Mobile

Telecommunications (IMT) to meet the service experience requirements of IMT-2020, and each country will need 2 GHz mid-band spectrum to achieve sustainable development of mobile services.

6 GHz will be the only continuous large-bandwidth mid-band spectrum in 5G. By using advanced technologies such as Massive MIMO of larger scales, 6 GHz can significantly increase network capacity while achieving network coverage on par with 3.5 GHz. It is recommended that regulatory authorities allocate 6 GHz spectrum to 5G and its evolution technologies to maximize the potential of 5G.

Utilize extremely large antenna array (ELAA) for mid-/high bands

Propagation loss of radio signals becomes more severe in mid-/high bands, which poses challenges for base station coverage. To achieve co-site and co-coverage with C-band, extremely large antenna array Massive MIMO (ELAA-MM) is a must.

Introducing Massive MIMO in 5G has considerably increased network capacity while enabling co-site and co-coverage between TDD high bands and sub-3 GHz. Currently, Huawei has commercialized its ELAA-MM-capable MetaAAU (3.5 GHz/2.6 GHz) at scale in more than 30 cities, enhancing its coverage by 3 dB, improving indoor and outdoor experience by 30%, increasing 5G network users by 30%, and boosting site capacity by 40%. This realizes coverage and experience benefits while boosting rapid traffic growth.

Wireless base stations of the future will require larger antenna arrays to enable equivalent coverage between higher bands and C-band. Conventional 5G Massive MIMO AAUs have 192 arrays. To achieve the same 5G mid-band coverage, a base station will require more than 1,000 and 2,000 arrays on 6 GHz and mmWave, respectively.

Use ultra-wideband multi-antenna solutions on legacy spectrum

Operators generally have about 100 MHz of legacy spectrum on the FDD sub-3 GHz band. Thanks to its low-band coverage strengths, it is well suited for deep coverage in densely populated urban areas and continuous coverage in suburban areas. However, the FDD spectrum is fragmented. During spectrum refarming from FDD LTE to FDD NR, the per-bit cost of device reconstruction based on a single band shows only a slight decrease, resulting in a low ROI.

As such, innovations such as ultra-wideband and multi-antenna technologies are needed to significantly improve spectral efficiency, while simplifying site deployment and reducing deployment costs of legacy FDD site modernization, bringing benefits to both 4G and 5G.

Huawei's ultra-wideband multi-antenna products of the FDD Gigaband series, integrate multiple low and mid-bands of sub-3 GHz into one radio box and support 4T4R, 8T8R, and Massive MIMO. This series' weight and volume ease onsite deployment, while the unique power pool slashes power consumption by 30%. It flexibly adapts to operators' deployment scenarios, delivering optimal capacity, experience, and coverage.

Moreover, operators should follow the step-by-step principle to transform themselves from connection service providers to integrated service providers, and formulate 5GtoB development strategies based on an as-needed basis, as well as markets to achieve large-scale 5GtoB development, enabling 5GtoB success.

Clarify the 5GtoB development path and build tailored capabilities

First, target appropriate industry scenarios. Based on industry digitalization requirements, consider whether 5G is an immediate requirement, whether strong technical advantages are present, and whether deployment costs and SLA can meet industry requirements. Not only that, whether the application scenario has a certain market scale and whether large-scale replication is available are key to business success.

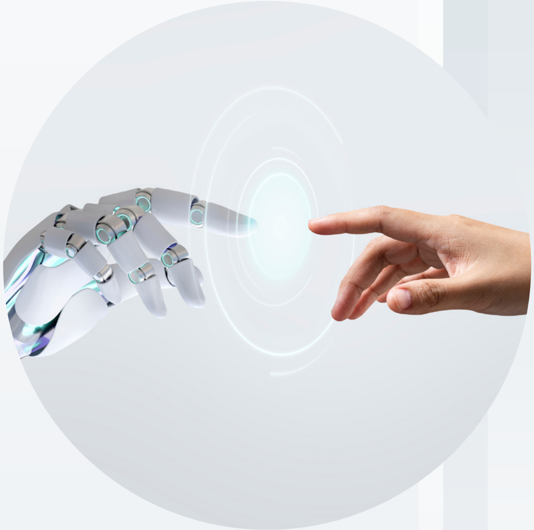
Second, clearly define roles. Many operators that focus on connectivity are actively transforming themselves. They can act as cloud service providers with cloud capabilities and even industry system integrators in industries they are familiar with. Therefore, roles depend on the boundaries of capabilities.

Third, design mature business models to achieve mutual benefits. A reasonable value-based pricing for 5GtoB services is prerequisite to drive innovation. Business models need to be simplified to boost efficiency. Benefits on the value chain also need to be distributed in line with responsibility, creating a positive cycle for the business ecosystem.

Fourth, continue to improve technical standards and industry specifications while promoting the implementation of industry policies. We should define 5GtoB network capabilities as well as promote and formulate standards and specifications for 5G target network construction in different industry scenarios to facilitate the large-scale development of 5GtoB services.

Trend 3

Intelligence Is Key to Addressing Growing Network Complexity



Integrating intelligence into wireless network services, experience, O&M, and green development is essential for operators to continuously explore new spaces and business forms of 5G/5.5G and implement digital and intelligent transformation. Industry-leading operators have proposed their own intelligent transformation strategies. One Chinese operator has proposed the autonomous network strategy, aiming to achieve network-wide autonomous driving network (ADN) L4 by 2025. Meanwhile, many operators outside of China have proposed the zero-touch operation (ZTO) strategy to build intelligent capabilities for simplified O&M, superior performance, and an ultimate experience.

3.1 Rising Network Complexity Drives Intelligent Transformation of Wireless Networks

As mobile networks evolve to 5G, network capabilities will be gradually upgraded, more services will be carried, and network complexity will increase significantly. This makes the three structural challenges of mobile networks more prominent.

Challenge 1: How to achieve simplified O&M against rising network complexity

Mobile networks have increasingly abundant spectrum resources, including low and mid-bands, and even high bands such as 6 GHz and mmWave in the future. A single operator will have more than 10 bands, and what's more, sites are evolving to multi-antenna forms, from 4T and 8T to Massive MIMO. Diversified scenarios also need to be considered, such as differences between indoor and outdoor environments, as well as peak and off-peak hours. All of these factors complicate operators' O&M, and as such, linear increase of manual O&M efficiency cannot cope with the exponential surge of O&M complexity.

To overcome this obstacle, intelligent space and time prediction and correlation analysis are needed to identify network O&M problems and provide solutions, for higher O&M efficiency.

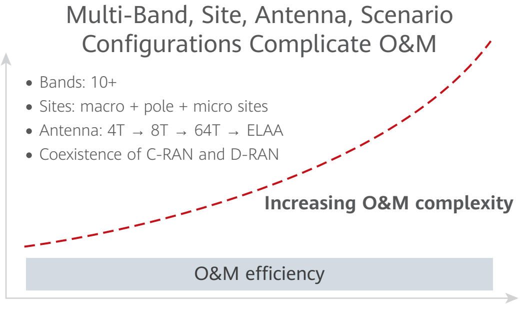


Figure 14 Increasing O&M complexity as a result of growing network complexity

Challenge 2: How to ensure optimal service experience against diversified services

As mobile networks penetrate all kinds of industries, application scenarios are soaring, including video, gaming, XR, wireless home broadband, as well as industry applications such as remote control and machine vision. Diversified services bring varying network requirements, such as high-speed uplink transmission, stable low latency, and high-precision positioning, making spectrum selection and network architectures more complex.

Therefore, intelligent technologies are required to form flexible policies based on expertise and real-time network sensing and proactive prediction, ensuring user experience of diversified applications.

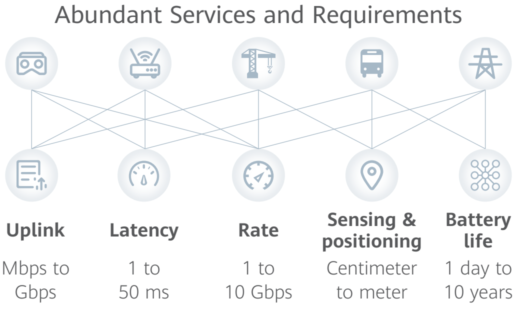


Figure 15 Diversified experience of varying services

Challenge 3: How to achieve optimal performance and energy saving against 100-fold traffic growth

Users' requirements for mobile network traffic keep surging. It is estimated that the DOU will reach 600 GB by 2030, which will drive the addition of sites, spectrum, and channels while increasing the power consumption of wireless networks. However, operators only expect a slight increase in network power consumption as the network traffic surges.

In this regard, real-time multi-intent optimization can be introduced on the network side to intelligently adjust resources such as sites, spectrum, and carriers based on service changes, for optimal performance and energy saving that do not compromise user experience.

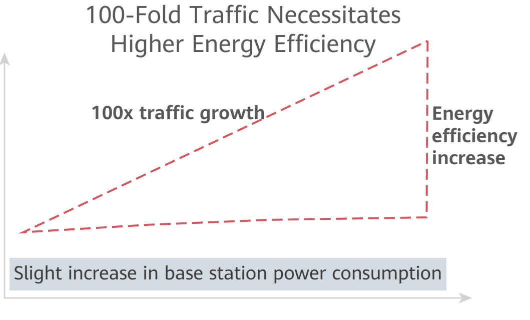


Figure 16 Increased energy consumption as a result of 100-fold growth in traffic

3.2 A Hierarchical Distributed Intelligent Architecture Ensures Optimal Performance

Over the past decade, with the evolution from machine learning to federated learning, intelligence technologies have been developing rapidly. Some of the latest intelligence technologies have been utilized in mobile communications, such as simplified site parameter configuration and NE-level algorithm optimization. As mobile networks scale up, how to leverage the data and computing power generated by millions of sites and apply intelligence technologies into the entire network life cycle, including network design, implementation and construction, O&M, and service planning, provisioning, and assurance, should be prioritized to achieve mobile intelligence.

Latency and bandwidth should be considered when building an intelligent architecture:

- To achieve millisecond-level and 100-ms-level (near-real-time) closed-loop control requires built-in inference capability at the NE layer and local deployment at the network layer, respectively. Therefore, the intelligent inference capability can only be locally deployed in distributed mode to fulfill low latency requirements of closed-loop control in mobile communications.

- Mobile network devices are distributed in different areas. If their data is aggregated and centrally processed, a large amount of transmission bandwidth is consumed. Therefore, local processing of training and inference is the most cost-effective way.

An intelligent architecture should be designed with top-down collaboration to implement layered distributed intelligence and fast local service processing for optimal performance. With this in mind, Huawei proposes a three-layer intelligent architecture to implement domain-specific autonomy and cross-domain collaboration.

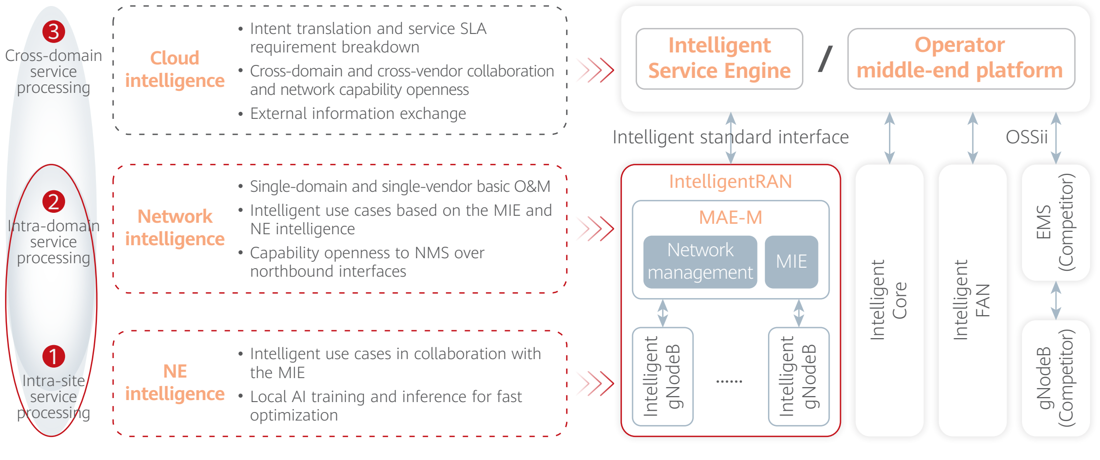


Figure 17 Hierarchical distributed intelligent architecture of mobile networks

Cloud intelligence: Translates service intents delivered from the application layer, breaks down service SLA requirements, handles cross-domain and cross-vendor collaboration, opens network capabilities, and exchanges with external sources.

Network intelligence: Implements single-domain and single-vendor basic O&M of the RAN based on the network management of the Mobile Automation Engine (MAE) and introduces the Mobile Intelligent Engine (MIE) to provide intelligent applications in collaboration with NE intelligence.

NE intelligence: Implements basic site O&M while conducting real-time optimization based on local training and inference; collaborates with network intelligence in terms of parameters, models, and decision-making; and achieves intelligent wireless networks throughout the entire process together with cloud intelligence.

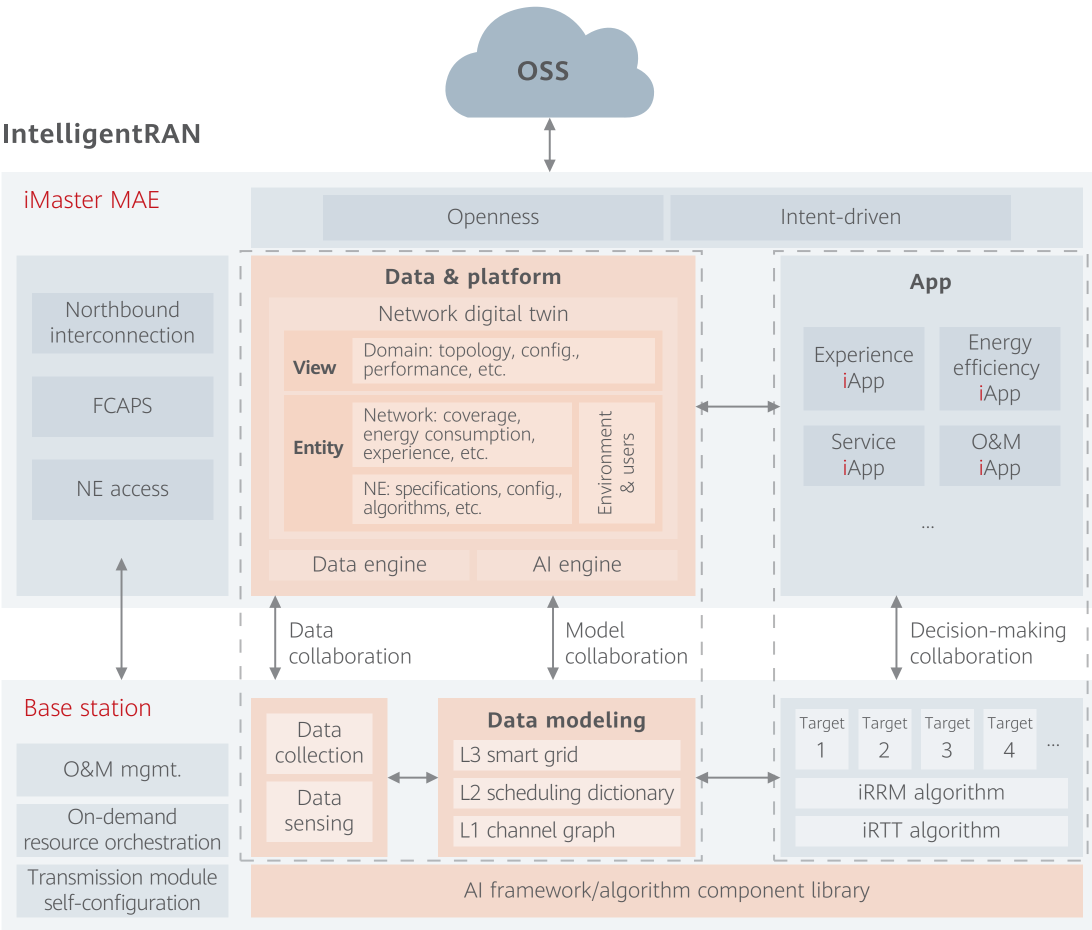


Figure 18 IntelligentRAN: AI-native wireless network

3.3 Intelligence Simplifies O&M, Optimization, and Service Operations

Based on the three-layer intelligent architecture, wireless networks can fully unleash intelligence for simplified O&M, network optimization, and service operations.

3.3.1 Intelligent Simplified O&M

Predictive fault management realizes faultless networks

To address complex wireless network faults and slow and inaccurate fault locating, operators and equipment vendors are developing innovative predictive fault management capabilities based on an intelligent architecture. This requires enhanced fault sensing capabilities to maximize management effectiveness and cross-layer, cross-site, and device-network collaboration to obtain the optimal automation outcome.

Take over-temperature prediction of devices as an example. Based on a three-layer intelligent architecture, base stations sense the temperature data of devices in real time, predict the NE-wide fine-grained short-period trend, and report it to the MIE. Based on long-period multi-site data, the MIE generates baseline intelligence models and generalizes them into site-level and area-level models. These models are then applied to single-site inference to carefully perform prediction and identify potential high-temperature risks in advance.

The prediction capability can also be used in scenarios such as optical module and path risks, where the long- and short-period sensing data based on the coordination between the RAN NMS and NEs is utilized to predict the subhealth status of optical components and paths.

3.3.2 Intelligent Network Optimization

Intelligent grid-based intelligent selection of multi-band carriers, maximizing network performance

Currently, all bands are evolving to 5G, but they have varying characteristics. FDD bands provide good coverage but narrow bandwidth, while medium and high bands provide large bandwidth but limited coverage. In addition, heterogeneous networking on different bands intensifies the impact on network performance, for example, the number of inter-frequency handovers increases. Multi-band coordination is critical to improving the spectral efficiency of the entire network.

Therefore, intelligent capabilities are necessary on multi-band networks to improve coordination efficiency, bringing together the advantages of different bands to achieve optimal performance of the entire network.

Smart grid technology is a typical form of intelligent technology used on multi-band networks. Without intelligence, the UE needs to perform inter-frequency measurement and then report the measurement result to the base station to select a proper band, which is a complex and time-consuming process. With intelligent capabilities, the coverage, spectral efficiency, and service experience can be predicted based on historical coverage, spectral efficiency grid data, and real-time information. Therefore, the optimal carrier can be quickly and accurately selected for UEs without relying on their measurements and reports.

Adaptive energy saving based on dynamic real-time optimization, ensuring performance and energy efficiency

Utilization of the energy-saving algorithm varies substantially across sites, as it is closely related to the software and hardware configurations, scenarios, and traffic models of the network. It is difficult to manually enable the energy-saving algorithm for thousands of sites. Moreover, energy saving on the network side is implemented by shutting down and waking up resources such as carriers and channels. However, the radio environment changes rapidly. Operators often worry that statically configured energy saving parameters cannot respond to TTI-level changes of UEs, services, and networks in real time, affecting KPIs.

Therefore, intelligence needs to be introduced into the network energy-saving algorithms to facilitate their use.

Based on the intelligent architecture, the MIE performs coverage modeling and parameter training on the entire network based on customers' KPIs and energy saving intent, generates initial energy saving policies through fast iteration, and optimizes the policies based on traffic and KPI prediction. This feature improves the activation efficiency of energy-saving features by more than 90%.

In addition, intelligent base station energy saving is introduced to implement intelligent base station awareness. The precise perception capability is built, and the relationship between energy efficiency and KPIs is established to implement TTI-level resource shutdown management. This means, energy-saving resources can be hibernated and enabled to meet TTI-based resource scheduling requirements, fundamentally ensuring network performance, doubling energy-saving benefits, and reducing energy consumption by 25%.

3.3.3 Intelligent Service Operations

SLA-oriented precise network planning achieves fast service provisioning

5G networks are responsible for enabling digital transformation across industries. In recent years, 5G applications have developed rapidly in various industries, such as coal mines, ports, steel, manufacturing, and power grids. However, considering the variety of 5GtoB services, high SLA requirements, and complex application environments, the traditional network-planning mode that relies on individual expertise can no longer meet the deterministic network planning requirements of industries. Therefore, the SLA-based precise network-planning platform is critical to implementing large-scale commercial use of 5GtoB. It must provide the following key capabilities:

- Industry profiling: Build an industry profile library based on 5GtoB projects, translate "different industry languages" into a "unified network language", to enable automatic matching of atomic service models, and intelligently recommend network construction standards.

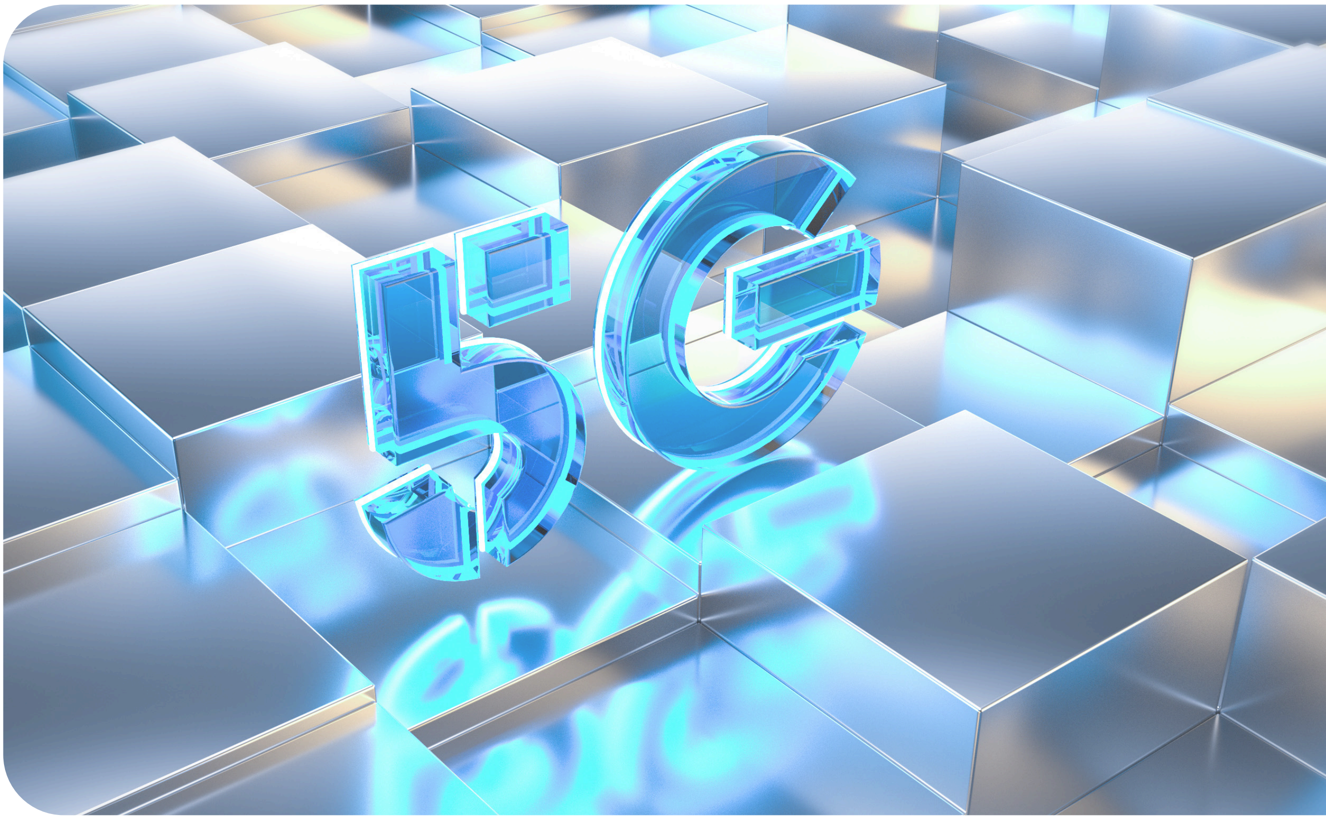
- Environment modeling: Based on environment surveying and mapping information such as the satellite map and point cloud, key technologies such as semantic identification are used to automatically complete refined environment modeling for oceans, ports, and factories, significantly improving the accuracy of network simulation planning.

- Adaptive propagation model: Build a scenario-based propagation model baseline li-brary based on 5GtoB projects, and automatically match the most appropriate propagation model based on application scenario characteristics (sector-level adaptive propagation models can be implemented on WANs).

- Multi-objective dynamic simulation: Based on service distribution and models (in-cluding toC, toH, and toB), use Monte Carlo simulation to simulate the receive level, rate, and delay of users at different locations and time, and collect statistics on SLA compliance.

- SLA planning: Based on multi-objective dynamic simulation, efficiently complete mul-ti-objective high-dimensional optimization such as coverage, rate, and latency in batches through graph coloring, and output the optimal site location, RF parameters (including patterns), and network resource planning results that align with 5GtoB service require-ments.

To fulfill the high SLA requirements of 5GtoB services, connection-level proactive and real-time O&M capabilities are key. Other capabilities such as visualization (of network topologies, device locations, multi-dimensional performance), minute-level exception detection based on machine learning, and fault prediction and prevention are also required.



3.4 Recommended Actions

Future wireless networks will bring smarter services to more and more industries. The mobile industry needs intelligent wireless networks to accelerate industry transformation and upgrade and promote the digitalization of society.

Establish a standard evaluation system for the intelligent architecture

Different vendors in the industry have launched their own intelligent architectures, which have personalized network capabilities. To address this, we need to establish intelligent evaluation standards, study key performance indicators of intelligent architectures and valued use cases, discuss evaluation standards in different service scenarios, and guide industry architecture and technology evolution. Intelligent evaluation standards can better guide the pace and direction of intelligent 5G network construction.

Jointly build an intelligent ecosystem and collaboration between applications and the intelligent architecture

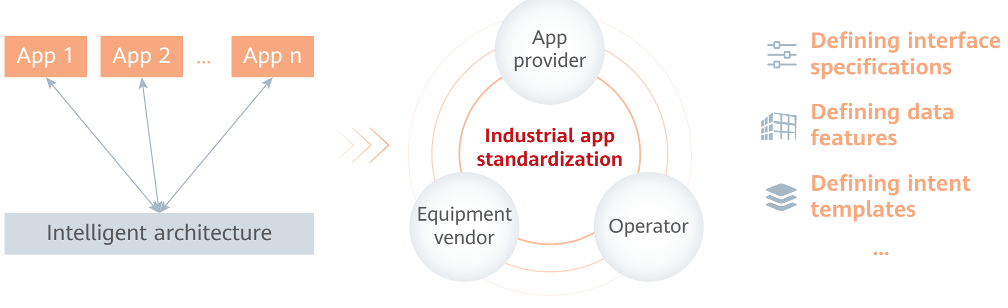


Figure 19 Jointly building an intelligent ecosystem

Besides equipment vendors providing intelligent applications, the intelligent architecture also supports applications of operators and third-party service providers. However, such applications need to be customized and can take time to develop. By building industry application specifications and defining interface specifications, data features, and intent templates, applications can be highly coupled with the intelligent architecture.

Trend 4

Green ICT Requires Hundredfold Traffic Demand to Align with a Slight Increase in Energy Use

These days, the majority of industries are focusing on development that is green and sustainable

First-rate 5G networks will be hugely beneficial to those who favor wireless connections, leading to rapidly increasing DoU, which is expected to reach 600 GB by 2030. If we maintain the energy efficiency of existing networks, the energy consumption of wireless networks will increase significantly, which counteracts the ambition of becoming sustainable. To help operators become green, we have established a network energy efficiency standard system and gradually improved network energy efficiency. By focusing on improving these two aspects, we can cope with 100-fold traffic growth without compromising too much on energy consumption, all while building wireless networks that deliver excellent performance and energy efficiency.

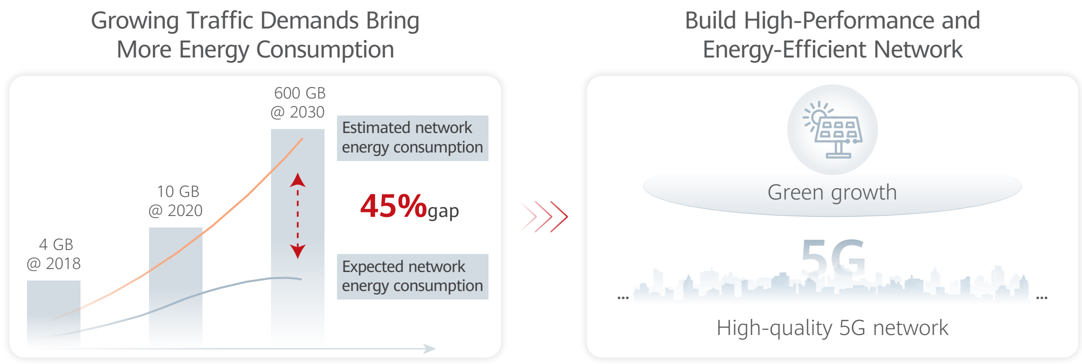


Figure 20 Green 5G for maximized network performance and energy saving

4.1 Shifting Focus from Energy Consumption to Energy Efficiency

As mobile technologies and networks develop, the main goal is to improve performance. Performance-related indicators are used to evaluate and measure networks, such as Gigabit network construction and ubiquitous 100 Mbps. To achieve the goal of constructing high-performance and energy-saving networks, a green evaluation mechanism is being introduced to aid mobile network construction.

Existing evaluation criteria focuses on the absolute energy consumption of a single 5G site. However, although a 5G site consumes more energy than a 4G site, its transmission rate and network capacity are also higher. Therefore, such an evaluation method is not objective enough. As the evaluation criteria evolves to be more comprehensive and objective, energy efficiency-based evaluation criteria have become a consensus in the industry.

Based on factors such as network development, network application scenarios, and network construction objectives, the energy efficiency-based evaluation system will continue to evolve in the following three aspects:

Telecom Energy Efficiency (TEE)

TEE = Equipment transmit power/Equipment power consumption

ITU standards define the transmit power efficiency of RF modules. Take RRU as an example. Under certain transmit power, the transmit power efficiency of a device is represented by dividing the transmit power by the power consumption of the corresponding module. A larger value indicates a higher rate of valid output power converted from transmit power. With the introduction of massive MIMO AAUs, considering that AAUs integrate RF modules and antennas, ITU defines a second type of device energy efficiency in EIRP scenarios. This method of representing equipment energy efficiency guides the industry to maximize the RF and antenna hardware capabilities of AAUs. It also prevents the industry from falling into the strange circle of continuously increasing the maximum transmit power of equipment and enables AAUs to develop towards green and efficient.

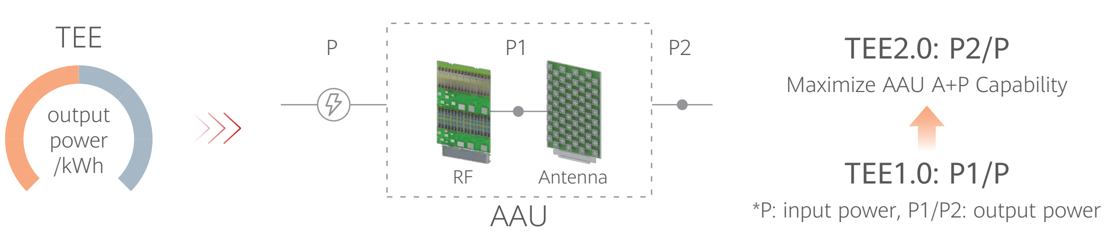


Figure 21 Telecom energy efficiency (TEE)

Site Energy Efficiency (SEE)

SEE = Base station energy consumption/Site energy consumption

The SEE indicates the ratio of the power consumption of the main equipment of the base station to the power consumption of the entire site. The lower the power consumption of the equipment room and cabinet, the higher the SEE. Operators can focus on reducing the energy consumption of site equipment rooms by reconstructing indoor sites, removing air conditioners, and improving power supply efficiency. In certain scenarios, operators can also improve SEE by removing diesel generators or adding solar power modules to sites.

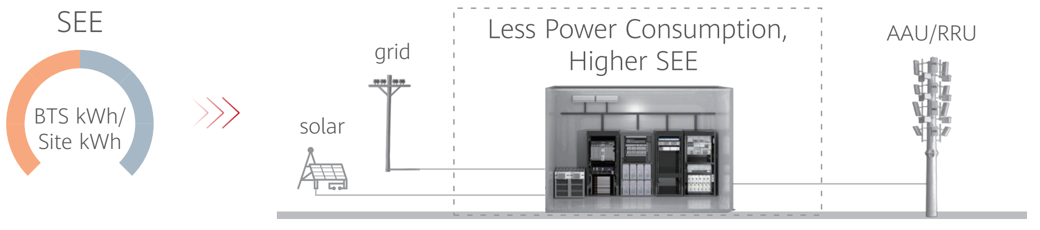


Figure 22 Site energy efficiency (SEE)

Network Energy Efficiency (NEE)

NEE = Network traffic volume x Experience satisfaction factor/Network energy consumption

NEE represents the relationship between network development and network energy consumption from the perspective of demand-energy consumption. For operators, the value of NEE lies in the introduction of a relatively fair and objective evaluation system to guide the coordinated development between service traffic growth and carbon emission reduction, and facilitate the evolution of green 5G target networks towards performance and energy saving.

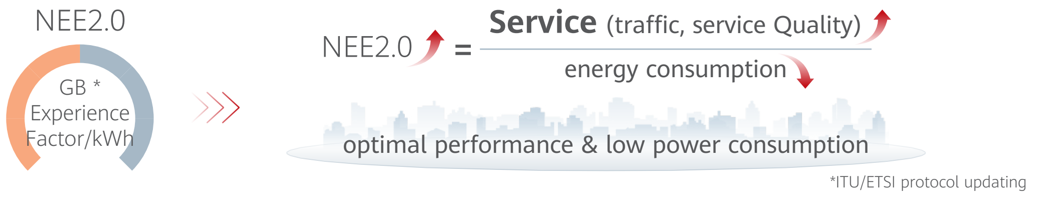


Figure 23 Network energy efficiency (SEE)

4.2 Device, Site, and Network Innovations Help Build a Foundation for Green 5G

How to reduce network energy consumption and achieve green network development while meeting network development requirements is a key driving force for wireless network innovation. Currently, the mobile industry relies on the three-layer energy-saving architecture of "device-site-network" to continuously innovate technologies and build a foundation for green 5G networks.

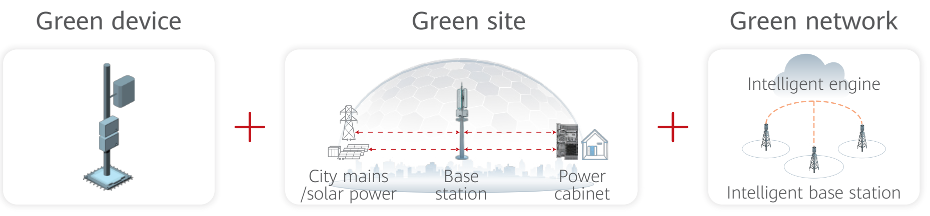


Figure 24 Three-layer (device-site-network) architecture for energy saving

4.2.1 Green Devices: Improve Equipment Energy Efficiency

Multi-disciplinary integration, continuously reducing hardware power consumption

As hardware techniques, materials and the application of new technologies evolve, hardware will leap forward every two to three years to consume less power while delivering more. Compared with RRUs, 5G AAUs are more complex and consist of more components, involving multiple disciplines, such as materials, thermodynamics, mathematics, electromagnetics, and structure. Naturally, AAUs need to reduce hardware power consumption through multi-disciplinary integration and systematic design.

High-efficiency power amplifier (PA): As a component with the highest power consumption ratio of RF modules, PAs are the starting point for reducing power consumption. The PA efficiency is improved based on GaN improvement, innovation of the PA architecture, and more advanced neural network DPD predistortion algorithm.

Innovative materials: Introduce high-performance dielectric filters, advanced materials and techniques, and active and passive joint design to improve RF module performance and reduce RF module loss. Compared with traditional metal cavity filters, new dielectric filters use new topology architectures and dielectric materials to greatly reduce the size, weight, and insertion loss. New high-performance resin materials help integrate and support lightweight and high-performance antennas. Through the joint design and evolution of active and passive devices, new dielectric materials with low insertion loss are introduced to reduce dielectric loss.

Efficient heat dissipation: When an RF module is working properly, the power it consumes is affected by the temperature. Simply put, the higher the temperature, the higher the power consumption. Heat dissipation technologies, such as RBC and bionic teeth, enable the module to work at a relatively low temperature for higher energy efficiency.

Energy-efficient antennas: Passive antennas do not directly consume DC or AC power, and therefore they are not particularly effective at saving energy. However, as a radio frequency energy and electromagnetic wave conversion unit, antennas transmit all radio frequency energy to mobile terminals. It has a huge impact on the energy conversion efficiency and the energy consumption of the entire RRU. With the same coverage, energy-efficient antennas can reduce cable loss and reduce RF energy output by RF units. This means that we can reduce the output power of RF units to save energy for base stations.

Introduce ELAA to AAUs to continuously improve bit energy efficiency

With multi-antenna and multi-channel design, 5G Massive-MIMO AAUs are ideal not only for improving system capacity through spatial multiplexing, but also for adjusting the amplitude and phase of multiple antennas to concentrate radio signal energy on narrower beams and accurately point to user locations. This improves energy transmission efficiency and bit energy efficiency. Test results show that the bit energy efficiency of 5G 64T64R AAUs is 20 times higher than that of 4G 4T4R RRUs.

Innovating extremely large antenna array (ELAA) is an important step for reducing AAU power consumption. By innovating software and hardware such as baseband algorithms and antennas, ELAA increases the number of dipoles, greatly improving the energy efficiency of devices while maximizing the antenna utilization. With on par user experience and coverage at the cell edge, the power consumption can be driven down by more than 30%.

Ultra-wideband enables multi-band RRUs to reduce energy consumption

Deeper integration has seen equipment's modules evolve from single-band capability to multi-band and ultra-wideband support. This changes the mode of 5G deployment, from allowing just one band on one RRU or AAU for a single RAT to integrating multiple bands and RATs into a single module, reducing the number of required devices, costs, and power consumption.

For example, an operator in the Netherlands used two RF modules for deploying its networks on the 800 MHz and 900 MHz bands, respectively. Now with Huawei's ultra-wideband RRU, it can deploy networks on the 700 MHz, 800 MHz, and 900 MHz bands using only one such RF module, which supports one more band without increasing power consumption.

4.2.2 Green Sites: Improve Site Energy Efficiency

The power consumption of a wireless site consists of two parts: one is the auxiliary system, such as the air conditioner, power supply, and transmission system in the equipment room; and the other is the main equipment, such as the RF and baseband units. Traditionally, energy could be saved by simplifying site construction. When wireless networks evolve to 4G and 5G, equipment rooms become combined or removed to boost site energy efficiency from 60% to 90%.

However, auxiliary equipment consuming 40% of site power, such as those for supplying and consuming power, is 'dumb' – it cannot sense or collaborate with each other or detect real-time service load and running status. Therefore, the power supply and consumption efficiency is low, resulting in huge wastage.

In this context, future efforts to build efficient and green sites will focus on achieving efficient linkage between services and power supply, storage, and consumption components. Solar energy, power supply, battery, power grid, and temperature can be linked with service load to enable flexible power, energy, and temperature control and adjustment, improving energy utilization and saving site energy.

Service-based power adjustment: Adjust the number of working power modules based on service load, and hibernate inefficient power modules to ensure high power supply efficiency of the entire site.

Service-based energy adjustment: Based on service load prediction, dynamically adjust the off-peak charging and depth of discharge (DoD) of lithium batteries at sites. Save electricity charged in off-peak hours for use in peak hours when the electricity price is high. Based on the tiered electricity price in Zhejiang province, the electricity fee can be reduced by around 17%.

Service-based temperature adjustment: Based on service load prediction and changes, dynamically and intelligently adjust the temperature to reduce the power consumption of air conditioners. Power consumption at typical sites can reduce more than 10%.

4.2.3 Green Networks: Double Energy Saving

In 5G, energy saving is becoming more dependent on intelligence. Intelligent technologies enable real-time shutdown threshold calculation, and network and spectrum resource allocation adjustment based on RATs, bands, coverage scenarios, service characteristics, and network running status. This improves energy saving without compromising network KPIs.

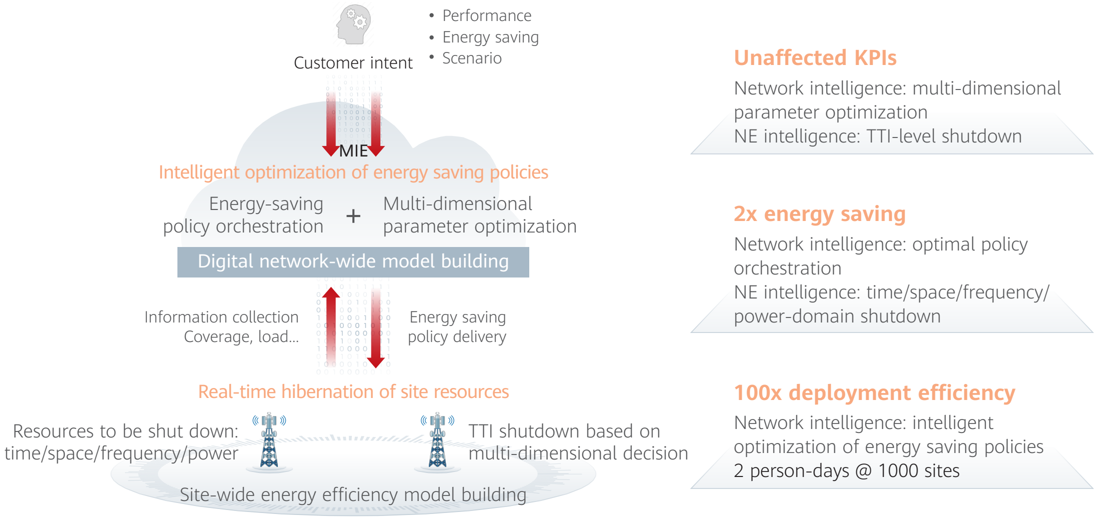


Figure 25 MIE for doubled energy saving gains

4.3 Recommended Actions

ICT technologies such as 5G are playing an increasingly important role in the global economy. Statistics from GSMA show that in Europe and North America, the contribution of mobile communications to social energy conservation and emission reduction reached 1:5 in 2015, which means that every kilowatt hour of electricity that mobile communications use will reduce 5 kilowatt hours of social electricity consumption. GSMA believes that this figure will reach 1:10 by 2025. The construction of green 5G networks requires the entire industry chain to come together, and not only operators and equipment vendors.

Establish energy efficiency evaluation standards to drive green network development

The key to assessing energy efficiency is to find appropriate indicators that measure network energy performance. Traditionally, energy efficiency is defined as the effective output of per unit energy consumption. In practice, service volume such as traffic, and more specifically, the ratio of traffic to energy consumption is used to evaluate energy efficiency. Traffic-based energy efficiency evaluation has been studied and put into practice in the industry.

Evolving networks give rise to new services and scenarios. Different types of services require different network rates, and therefore operators need to focus on increasing both traffic demand and service experience requirements.

The current energy efficiency evaluation system that uses traffic as the only metric needs to evolve to a more comprehensive method of evaluation based on more metrics, such as user experience. Such metrics should be chosen based on the network development stages and service priorities of different scenarios. This will drive mobile networks to transmit more data and provide a better experience while consuming less energy.

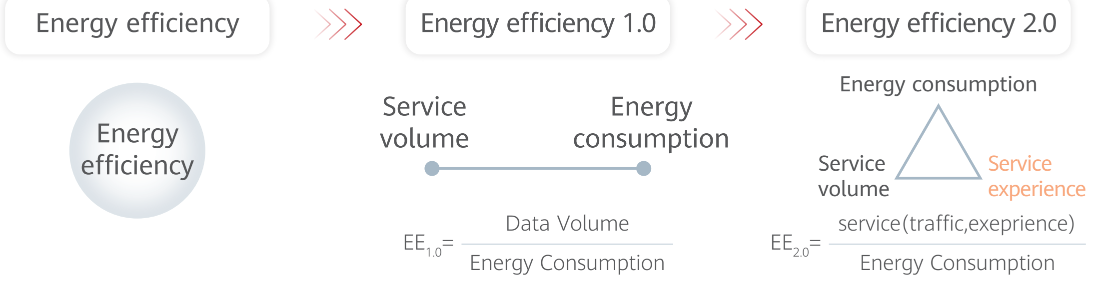


Figure 26 A multidimensional standard system for energy efficiency evaluation

Unleash 5G's energy efficiency potential by accelerating traffic migration through network construction and precision marketing

Statistics show that the energy efficiency of 4G is 7 to 10 times that of 3G, and that of 5G is 20 times that of 4G. In the future, 5G energy efficiency will be boosted even further through the introduction of new technologies, which means that 5G networks consume less energy when carrying the same amount of traffic.

Increasing network traffic makes it necessary to drive services towards higher RATs such as 5G. 5G's high energy efficiency, if fully leveraged, will reduce network energy consumption. According to the live network data of a city in China, from 2019 to 2021, 5G traffic ratio reached about 20% and the network energy efficiency improved by 3.5 times. To migrate traffic to 5G, operators can guide users to enable 5G function, improve the camping ratio, and promote service migration.

Trend 5

Evolution to 5.5G Provides 10 Gbps, 100-Billion Connectivity, and Native Intelligence

A new generation of mobile communication technology is launched every decade, and 5G, the most important mobile communication technology before 2030, is expected to be around until 2040. The development history of 2G, 3G, and 4G over the past 30 years has proved that each generation of mobile communication technology must undergo continuous evolution and enhancement to fully unleash its potential to promote sustainable industry development.

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

In April 2021, 3GPP officially named the advanced version of 5G as 5G-Advanced, and is now developing R18 standards. All parties in the industry have reached a consensus on the 5.5G business vision and standard technologies. In the next phase, they need to continuously innovate 5.5G technologies to enhance eMBB, mMTC, and URLLC capabilities, and build revolutionary capabilities, such as high-precision sensing, passive IoT, high-precision positioning, and intelligence. This will help realize 10 Gbps experience of wireless networks, 100 billion connectivity, and native intelligence, and prepare the industry for the commercial use of 5.5G in 2025.

Figure 27 5.5G for 10 Gbps experience, 100-billion connectivity, and native intelligence

5.1 Ultra-High Bandwidth and ELAA – Massive MIMO Is Key to 10 Gbps Experience

Massive MIMO is the most important technological innovation of 5G. By using a large number of passive antennas in base stations, Massive MIMO significantly improves spectral efficiency and coverage. It has become the first choice for 5G network deployment. Given the coverage challenges brought by high bands, the focus of 5.5G technology innovation is to improve the performance of extremely large antenna array – Massive MIMO (ELAA – MM) to fully leverage networks.

Furthermore, achieving native large bandwidth for single carriers on new bands such as 6 GHz and mmWave, together with 8R devices and HBF – ELAA CSI enhancement, can support downlink 10 Gbps. Enhancing broadcast channels to wideband and short-time can improve their coverage, thereby enabling ubiquitous access.

In TDD + FDD multi-band deployment, Multi-band Serving Cell (MBSC) implements integrated management of all bands, improving user experience by more than 50% and supporting virtual ultra-wideband and ubiquitous ultimate experience. Control channel integration minimizes the control overhead, and data channel integration enables more TDD + FDD component carriers (CCs). CSI-RS integration and multi-band CSI-RS channel estimation reduce the overhead while improving precision. Multi-band and multi-site combined with CSI reporting + SRS can improve user experience with the same overhead.

5.2 Multi-Band Convergence with Uplink-Downlink Decoupling Enables Uplink 1 Gbps

Industry digitalization has higher requirements for uplink rates over downlink rates. With uplink and downlink decoupling, the uplink and downlink spectrum on different bands can be flexibly adjusted based on industry requirements. To meet ultra-large uplink bandwidth requirements, existing FDD spectrum can be fully utilized and the uplink-only spectrum can be defined for SUL to implement multi-frequency convergence through uplink and downlink decoupling and provide Gbps-level uplink rates. Currently, uplink and downlink decoupling has been commercially and widely deployed in multiple scenarios, such as coal mine and steel to provide 1 Gbps uplink rate for multi-channel HD backhaul, panoramic remote control, and remote real-time quality inspection.

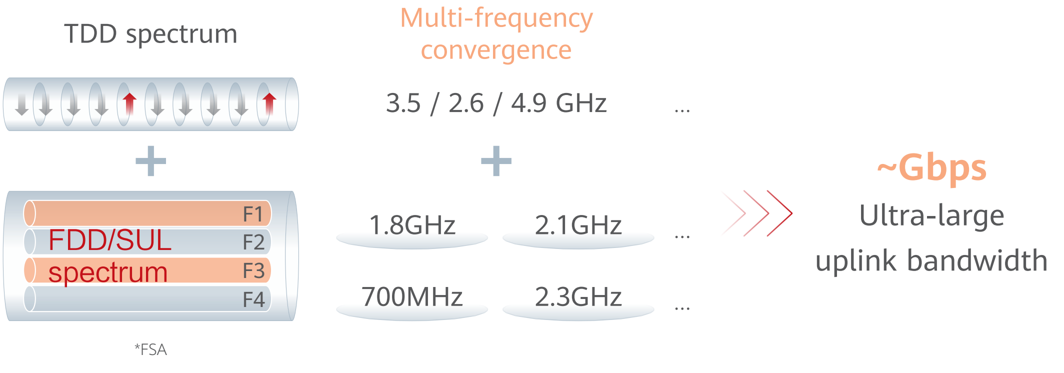


Figure 28 Multi-band convergence to support 1 Gbps uplink

- Flexible spectrum access (FSA) enables devices to implement full spectrum access in the uplink. In the traditional carrier aggregation mode, configuration and transmission bands are bound, with limited spectrum for access. FSA can replace layer 3 mobility management with layer 1 cell switching and symbol-level switching of uplink channel frequencies to decouple configuration and transmission bands and the pooling of both spectrum and transmission channels.
- The uplink-only spectrum, as the name implies, refers to the continuous uplink spectrum allocated with only 10 to 100 Mbps, such as the 1.4 GHz spectrum used in Europe, which is used for uplink transmission only. It needs to be used with existing TDD/FDD cells in network deployment to increase uplink transmission resources by several times and achieve higher uplink rates and larger capacity.

5.3 HCS Authentically Enables Everything to Be Sensed and Interconnected

HCS can nurture the growth of new applications that would not have been possible on traditional mobile networks. By using the real-time sensing function of radio communications signals to obtain environment information and using advanced algorithms, edge computing, and intelligence to generate ultra-high-resolution images, reality is digitalized and integrated with the virtual world to deliver more authentic experience.

Sensing is required in thousands of industries: vehicle, people, and object sensing in V2X; personnel intrusion detection in security protection; drone detection in aviation regulation; personnel falling, breathing, and heartbeat identification in healthcare; wind speed and rainfall sensing in weather monitoring. It usually requires new spectrum resources to build a new sensing network, which is slow and costly. 5G networks are widely deployed with wide coverage and large-scale antenna arrays, giving them significant networking advantages. They can be equipped with sensing capabilities through software and hardware upgrade.

HCS is the basis for wireless sensing. Multi-type target sensing capabilities need to be built on existing 5G networks to provide 24/7 wide coverage without having to change network architecture and increase site deployment density.

Communications and sensing resources can be multiplexed through time, space, and code division, so that sensing functions can be added to base stations as required at lower deployment costs. High-isolation antennas are full-duplex and have 5G TDD enabled, that is, supporting a co-frequency co-time full duplex (CCFD) sensing mode and co-coverage of communication and sensing while ensuring optimum communications performance. An integrated architecture for communications and sensing can help provide E2E sensing services across different industries and ensure data security.

Increasing sensing resolution is the key to expanding sensing applications. Ultra-wideband and multi-antenna can achieve centimeter-level sensing. Multi-site collaboration of cellular systems can add 3D multi-angle sensing with no blind spots to single-site sensing. Additionally, the machine learning-based target recognition algorithm can improve the recognition resolution with rich multi-domain (time, frequency, space, and code) 5G NR information.

5.4 Native Intelligence Improves 5G Network Capabilities

Network complexity increases as communications technologies become more advanced and 5G application scenarios expand, giving rise to serious challenges for traditional O&M modes. Multi-band multimode coexistence complicates networking and network collaboration, which hinders multi-band and cross-domain collaboration, fault locating, and unified resource scheduling and experience management in the context of dynamic user changes. 5G networks, as an enabler of various industries, need to support a diverse set of services and personalized experience, complicating user experience management and O&M.

By 2030, fully-automated, zero-wait, and zero-touch autonomous driving networks will be built by promoting all-round evolution toward intelligent air interface, network, and O&M. This constitutes one of the important capabilities that support the digitalization of various industries. Intent-driven and intelligence-powered wireless networks will keep moving up in the level of automation, from highly autonomous level-4 to a fully autonomous level-5.

Future networks will be capable of autonomous thinking and decision-making to deal with the different business intents of different industries. They can automatically, accurately, and efficiently identify the service objectives in telecommunication, agriculture, public utilities, oil and gas, logistics, and finance fields, convert them into network configuration languages, and orchestrate them. This achieves efficient adjustment and allocation of network resources as well as fast adaptation to service changes and requirements.

Not only that, level-5 autonomous driving networks will be capable of evolving by themselves and support zero-touch automated O&M. After the network receives an intent-driven adjustment policy, the base station reports information it detects about itself and its surrounding environment in real time and generates a digital twin model. Based on the environment and hardware information reported by the base station, the network automatically adapts parameters and scenarios. Intelligent fault monitoring supports fault detection and cross-layer collaborative diagnosis. And the spatiotemporal dynamic intelligent algorithm enables networks to warn and work around potential issues and conduct self-recovery. Network performance self-optimization will gradually replace empirical optimization. Machine learning and performance simulation can find the optimal network parameters and collaborate targets across sites automatically.

5.5 Recommended Actions

Great progress has been made in striding towards 5.5G over the past three years. While preparing 5.5G for commercial rollout in 2025, the whole industry needs to learn from the experience of previous generations of wireless technologies in promoting commercial use through technical verification and scale tests. All parties in the industry, including operators, equipment vendors, and standards organizations, need to work together to define the key features of 5.5G networks, network deployment strategies, and major product trends based on key requirements. They also need to verify functions of key technologies and multi-vendor interoperability based on unified frequency and specifications, and conduct pre-commercial field tests.

Push for industry consensus on accelerating 5.5G technological innovation

The industry needs to build a consensus on technological innovation from an industry and commercial perspective in order to fully utilize the future ultra-high-bandwidth spectrum, thereby providing a solid base for the commercial use of 5.5G.

Innovation should focus on spectrum usage mode, equipment form, and network architecture: First, reconstruct uplink and downlink spectrum to efficiently utilize ultra-high bandwidth; second, innovate the form of wireless network equipment to meet the requirements and challenges of 5.5G bands; third, given the different capabilities of 5.5G bands, develop intelligent network architectures to meet various requirements.

Accelerate integration of information technologies to upgrade the information industry

Ubiquitous 10-Gbps 5.5G networks will support cross-domain, all-round, and multi-level integration with intelligence, IoT, cloud computing, big data, and edge computing.

Integration accelerates the rapid expansion of information technologies. Take 5G and intelligence technologies as an example. Intelligence turns wireless networks into autonomous networks featuring intelligent service operation, network optimization, and simplified O&M. Wireless networks with ubiquitous wide-pipe capabilities, in turn, transform intelligence into an easily accessible public resource that is similar to water and electricity, which lays a foundation for making everything in the world intelligent.

Accelerate 5.5G-empowered industry transformation and technology development

By unleashing 5.5G across all industries, we can build an all-scenario and all-type hyper-connected platform. Based on the platform, we can bring innovative applications and an upgraded experience to individual and family users while supporting hundreds of billions of IoT connections. In this way, we penetrate information technologies into various industries and accelerate the large-scale replication of industry applications, thereby building a digital, intelligent society.

Operators should lead industry partners to verify 5.5G application scenarios such as RTBC, ultra-large uplink bandwidth, passive IoT, and HCS to ready them for commercial use, and consolidate the foundation for 5.5G to integrate into and transform vertical industries and technologies.

Trend 6

Native Security Ensures Full-Lifecycle 5G Security

The digital economy has entered a new stage of system innovation, cross-domain convergence, and intelligence-led development. This justifies the urgency of accelerating 5G development to match its role in transforming industries and building a digital society. For 5G to do this, security will be key to the digital ecosystem that can safeguard the sound development of the digital economy. To scale up 5G adoption, security is indispensable and will change from a quality attribute to an industry attribute. By combining security technology innovation with native security mechanisms of networks, security capabilities will be systematically enhanced for operators to streamline the construction of secure and resilient mobile networks and provide secure and reliable information services across industries, safeguarding industry digital transformation.

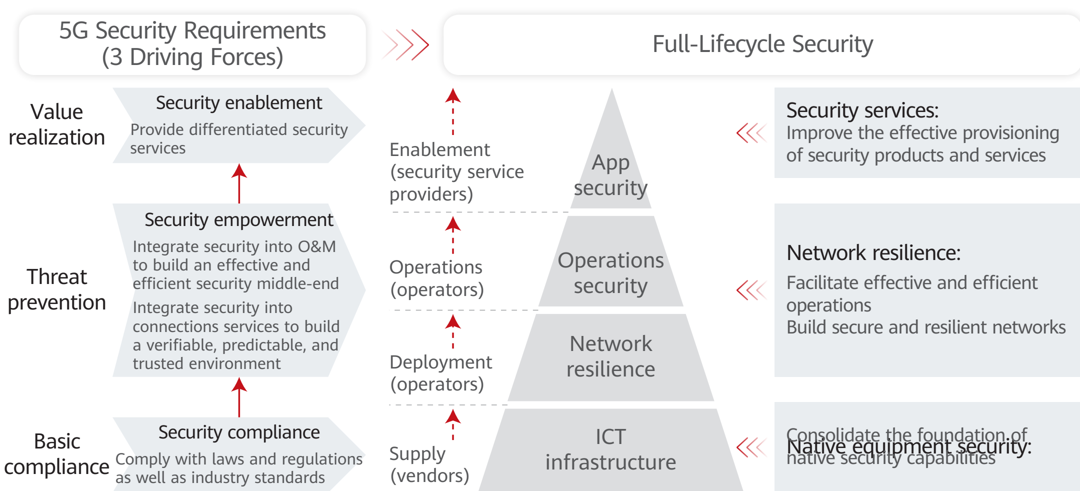


Figure 29 5G's full-lifecycle network security based on native security

Technically, the security architecture for 5G is essentially the same as those for 2G, 3G, and 4G. 3GPP also defines 5G's security model into three layers (from top to bottom): application security, network security (including network resilience and operations security), and NE security (ICT infrastructure).

For the NE security layer, the focus is on vendors, including their compliance, security development processes, and product security and anti-attack capabilities. Industry standards and methodologies mostly observed include Network Equipment Security Assurance Scheme (NESAS) and Security Assurance Specifications (SCAS); and the Secure Software Development Framework (SSDF) of the National Institute of Standards and Technology (NIST). NESAS/SCAS is a unified evaluation and certification mechanism, and is recognized across the industry as a global de facto standard for 5G security certification. NESAS already boasts a mature industry ecosystem. GSMA and 3GPP have developed NESAS/SCAS 2.0 and are still working on new releases.

For the network security layer, operators plan, design, and deploy networks based on vendor-provided equipment and security capabilities. This process ensures network compliance, O&M security, and network anti-attack capabilities. ISO 19600, NIST Cybersecurity Framework (CSF), and GSMA 5G Cybersecurity Knowledge Base (CKB) are common industry standards and methodologies. The 5G CKB was built by the mobile industry over the past 2 years to provide stakeholders with suggestions on risk management strategies, best practices, and threat mitigations. Therefore, it can help operators meet network security requirements and better plan, maintain, and optimize 5G network security.

For the application security layer, vertical industries are responsible for E2E service and application security. In addition to relying on operator-provided network security, they need multi-party collaboration to ensure 5G application security. Differentiated security services can be provided to realize the network value.

6.1 Network and Security Convergence Requires Enhanced Native Equipment Security

Conventional security industry chains separate IT and CT from security, with clear boundaries between stakeholders and their interests. However, deep integration between networks and security will require the boundaries to be broken to facilitate more efficient and effective IT, CT, and security solutions as a whole.

We need to review the security requirements of CT systems and build service-specific native security:

- Put security defense before attack source tracing and threat intelligence analysis by focusing on protecting systems from being cracked.
- Minimize exposed surfaces by isolating production systems from the Internet unless the interfaces are necessary for services.

- Develop lightweight security solutions with minimal resource usage to guarantee service SLA.
- Ensure existing systems remain stable and reliable when a new security software is introduced.

To achieve these goals, mobile communications equipment must be natively secure to ensure integrated protection with a minimum number of nodes required, thereby boosting protection efficiency and level. Basic network capabilities must be built through full-stack security hardening, verification, and detection to ensure architecture-level intrinsic security.

6.2 Security and Services Are Coupled for Building Network Resilience

In recent years, operators have called for specific network resilience requirements. These are elements of secure and resilient networks, which cover availability, reliability, robustness, security, and privacy protection; and key components of security capabilities, which include service availability, confidential computing, service agreements and identifiers, and security assurance and defense.

In either dimension, for mobile communications, it means to continuously build service-attribute-based security capabilities. Based on mobile communications service model libraries, industries can continuously perform adaptive detection and identity evaluation. This, together with security policy management, will help achieve quick response and build simplified, secure, and resilient networks to ensure trusted connections. Also, by promoting operators' best practices in 5G security risk management, industries can build secure and resilient networks for efficient operations.

In this process, we need to use the core methodology — Identify, Protect, Detect, Respond and Recover (IPDRR) — to build adaptability. The IPDRR concept for 5G networks aims to reduce the risk exposure period, shorten threat detection time, and prevent damage from escalating. Given 5G's service characteristics, layer- and domain-based adaptability requires all NEs to have intrinsic security capabilities (covering security information collection, analysis, and processing). These capabilities will form single-domain and cross-domain processing capabilities, which in turn will help strengthen network resilience.

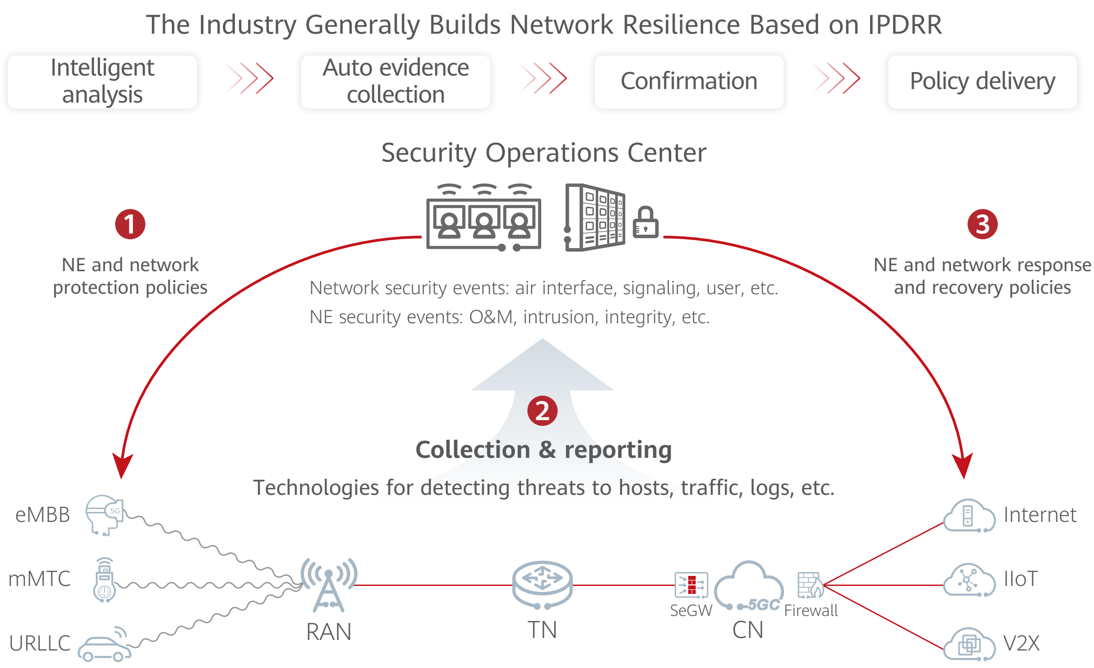


Figure 30 Common industry practice of IPDRR-based network resilience

6.3 Security Will Become an Indispensable Part of the Industry

Security changes can be reviewed from three aspects: compliance, threats, and value creation. These aspects help the industry think about the security requirements brought by structural changes in services and networks. Compliance drives regional markets to strengthen a unified security certification ecosystem. Threats force leading enterprises to focus on constructing systematic security systems, and small and medium-sized enterprises to focus on simple and integrated solutions. Value stimulates the shift of the security value chain from boxes to platforms and networks.

Figure 31 Network security emerging as an industry attribute

Currently, the value of base station services is relatively decentralized and controllable, whereas in the future, the value of base station and edge network services will become centralized and huge. As 5G is applied across industries, enterprises will face changing networks and IT infrastructure, which will place higher requirements on security. For example, security is critical to production continuity in the manufacturing sector, and to public safety in power grids and other public utility sectors.

First, 5G networks must comply with the security protection requirements of industries while being open to enterprises and serving as part of their infrastructure. Second, given the variety of industry applications, 5G must provide differentiated security capabilities. And lastly, 5G must enable enterprises to process their data totally within their campuses and guarantee application and data security.

For this reason, we need to focus on ICT network capabilities and work together to build standards, solutions, and value chain ecosystems, to guarantee the effective provisioning of security products and services.

6.4 Recommended Actions

The ICT industry should build secure and resilient mobile networks to ensure trusted connections. To achieve this, all parties need to:

- Collaborate and promote the evolution of GSMA/3GPP NESAS/SCAS (NE layer security evaluation) and best practices from GSMA 5G CKB (network layer security evaluation).
- Meet compliance requirements and prompt regulators worldwide to publicly recognize NESAS as a global 5G product security assessment standards.
- Based on market development and current capabilities, improve capabilities in terms of native security (native security capabilities of equipment from vendors), resilience and trustworthiness (network planning, construction, maintenance, optimization, and operations by operators), and industry supply (toB) to ensure main mobile communications services.
- Build native security capabilities into equipment mainly through white-box thinking. Based on three basic capabilities, including full-stack security hardening, verification, and detection, to native capabilities of CT networks, enable operators to build secure, resilient, and trusted mobile networks. This will be crucial to boosting CT security protection and O&M efficiency, as well as reducing customers' integration and O&M costs.

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