HUAWEI

Striding Towards an Intelligent World 2023

Mobile Network

Bring 5.5G into Reality

Building a Fully Connected, Intelligent World

Abstract

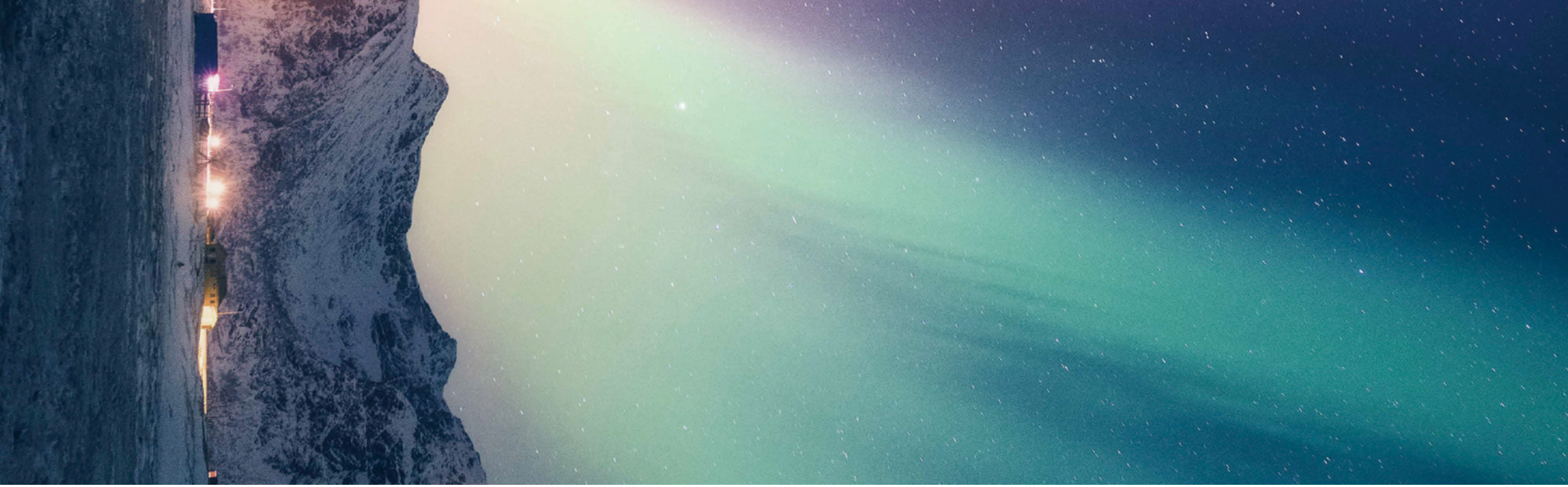
Of all the generations of mobile communications technologies, 5G has had the fastest development. The speed of 5G development has far exceeded expectations. After entering commercial use in 2019, 5G has spread rapidly around the world. More than 260 networks in more than 90 countries and regions have started providing 5G services. User experience has been drastically improved with 5G. The proportion of HD videos on mobile networks has increased from 40% to 60%. 5G has also accelerated the digitalization of diverse industries, with more than 65,000 5G industry applications deployed worldwide.

5G is creating more monetization opportunities for operators. It has become the major mobile traffic bearer, brings new traffic dividends. In addition, operators have begun innovating in new business models. Operator business growth has been boosted by multi-dimensional 5G experience monetization based on capabilities such as speed, uplink, and latency.

The success of 5G enables new applications, incubates new business forms, and opens up new spaces. There is massive growth in new services for people, homes, vehicles, things, and industries. In 2023, there were breakthroughs in technologies such as glasses-free 3D, immersive extended reality (XR), and AI Generated Content (AIGC) that elevated immersive personal experience to a new level. Home services become smarter and more diverse, accelerating the maturation of 10 Gbps fixed wireless access (FWA). The number of cellular Internet of Things (IoT) connections already exceeds the number of human connections. Diversified IoT types will be needed to realize hundreds of billions of IoT connections. Because 5G industry applications have become critical components of core production processes rather than just helpful tools, low latency and high uplink experience are now necessities. 5G vehicle connection capabilities needs to be further enhanced as vehicle moves towards highly reliable smart transportation. Besides, there are other industries needing sensing capability from 5G, instead of mere connectivity.

The first standard version of 5.5G (Release 18) will be frozen in Q2 2024. 5.5G improves existing capabilities 10 times and bring many new capabilities. it helps protect 5G investments on existing networks and meet the growing demands of consumers and industries for communications networks.

All of the society is moving towards an intelligent world, in which 5G and 5.5G wireless networks are important technical pillars. Huawei will continue to work with industry partners to promote 5G industry development. This report, summarizes seven major trends of the mobile industry as follows based on the status quo and change trends in industries:



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Trend 1

5G Five-Dimensional Experience Monetization Brings New Growth

After four years of development, 5G is developing faster than ever. After commercialization, the global deployment scale of 5G in three years has exceeded that of 4G in five years. Within the same time frame, the number of 5G users exceeds 1 billion, seven times that of 4G; there are now 260 5G networks around the world, twice the number of 4G networks; 5G terminal shipments account for more than 60% of total shipments, three times that of 4G.

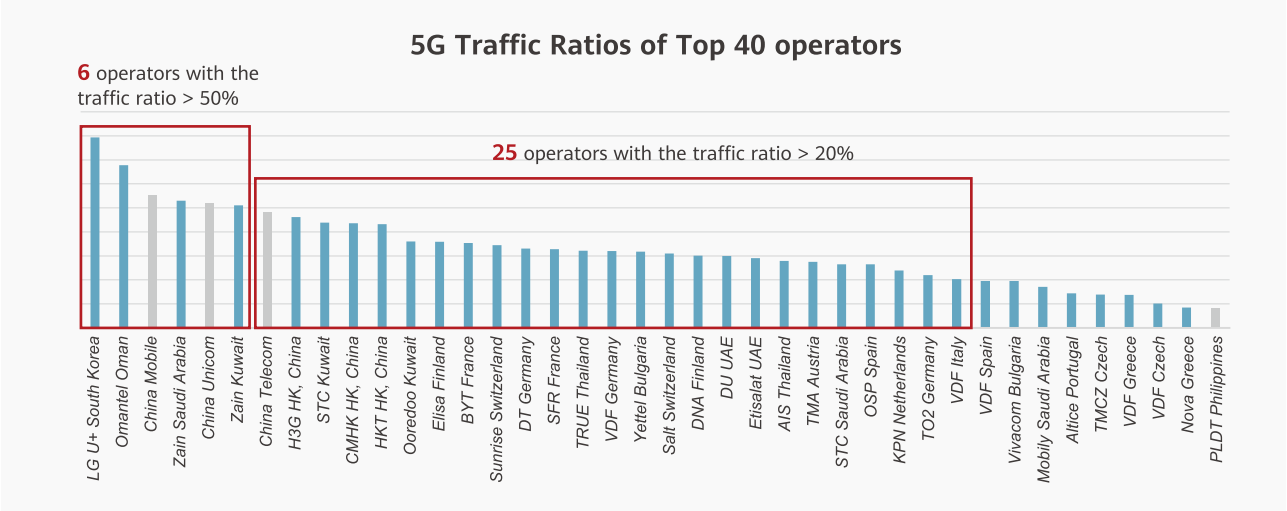
The large-scale development of 5G has driven up the average revenue per user (ARPU) and revenue growth of leading operators. According to Omdia, the revenue growth of leading 5G operators exceeds their regional averages.

Over the past four years of commercial use, 5G has continually created business, industry, and social value. During this process, new forms of experience, capabilities, and applications of 5G have matured, enabling operators to carry out business model evolution and innovation. Operators have shifted from traffic monetization in the 4G era to five-dimensional (data, downlink, uplink, latency, and reliability) experience operation, which in turn promotes business model innovation.

1.1 5G has become the major mobile traffic bearer, and brings new traffic dividend.

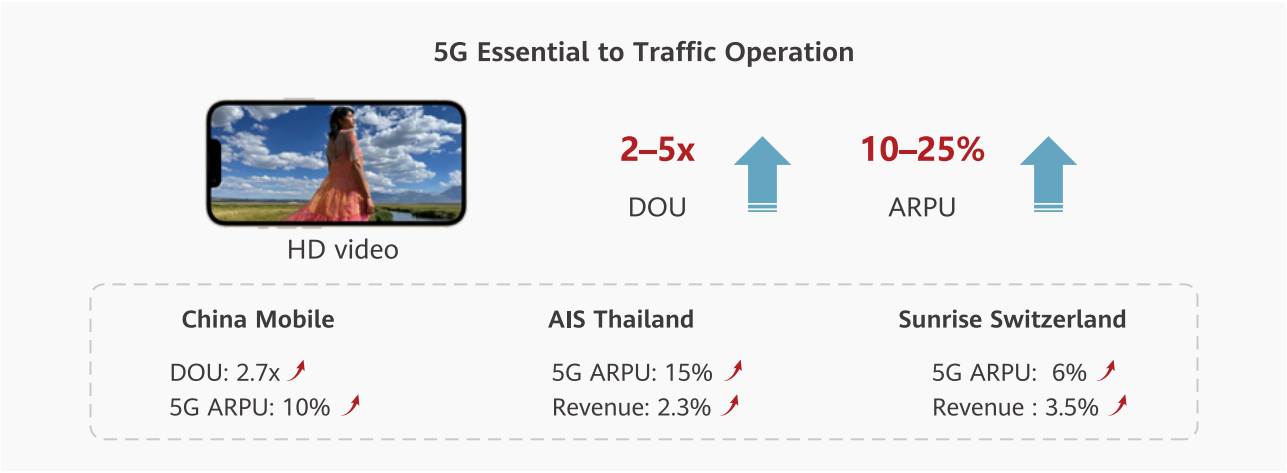
5G is developing rapidly. 5G traffic ratio of the first wave markets, including China, South Korea, and a number of Middle East countries, has exceeded 50%. 5G has become the major bearer network for mobile communications in these countries. The second wave is made up of markets in Europe, where the 5G traffic ratio has exceeded 20% and is increasing rapidly.

5G has significantly improved user experience over 4G. Heavy-traffic applications, such as HD short videos and HD live broadcasting, have become part of the mobile Internet. Taking shopping as an example, consumers have transitioned from browsing web pages to viewing video shopping channels that offer live videos and video promotions. According to the statistics from short video platforms in China, HD short videos now account for 60% of all short videos.



Thanks to 5G's lower cost per bit, 5G operators can explore more appropriate business models for new jobs emerging with the mobile Internet. Employees in vertical markets, such as express delivery, takeout service, logistics, and online car-hailing, require service packages with large traffic and voice volumes, because they need to receive orders, navigate, entertain, and contact customers in real time. Operators in China have launched packages with 60 GB monthly traffic (4 times the DOU) and 2000 minutes of call time, increasing the ARPU to twice the average value. DOU refers to data of usage.

According to the statistics of global 5G commercial networks, the DOU of 5G users is two to five times higher than that of 4G users. This increased 5G DOU further enables ARPU growth. The ARPU has increased by 10% to 25% for users who have switched from 4G to 5G packages. This growth in 5G users and ARPU in turn boosts revenue growth for operators.



1.2 Speed monetization has become a reality, with experience assurance further improving the ARPU.

In addition to the traditional traffic-based charging model of 4G, leading operators have explored a rate-based charging business model by making full use of the superior experience provided by 5G networks. The proportion of operators launching speed-based tariff packages has increased from 5% in the 4G era to 25% in the 5G era, a four-fold increase.

Using the downlink speed as the charging unit is the most common method of speed monetization. For example, Swiss operators divide 5G packages into three levels by rate. The rate is four times higher for the highest level than the lowest one, and the package price is 1.5 times higher. Many other operators have added speed-based hierarchical charging to their traffic packages to explore new growth dimensions in addition to the existing traffic-based charging model.

Downlink experience assurance has become a new method of rate monetization and has seen successful application in FWA. In Finland, the packages for FWA have changed from speed-based (up-to model) to experience-assurance (guaranteed model), increasing the FWA ARPU.

1.3 Uplink capabilities enable new business forms and become new gold mine.

The uplink capabilities of 5G have enabled new applications to emerge and become a foundation for 5G innovation. Live broadcasting has become a new development opportunity in the mobile Internet industry. There has been massive growth in the number of streamers for e-commerce, gaming, reality show, concert, and sports event live broadcasts. 5G, with its large uplink capabilities, ensures smooth HD content production, making HD live broadcasting possible anytime, anywhere.

China Unicom Guangdong and Hong Kong 3HK have launched 5G live broadcast packages to provide more traffic, ultra-high uplink rates, and live broadcast assurance services for live broadcasters and viewers. Since the release of its live broadcast package, China Unicom Guangdong has attracted hundreds of thousands of users. Austrian operators include uplink in their rate-based hierarchical packages, further opening up the space for growth. These packages with doubled uplink rates have 30% higher prices than the baseline.

The uplink capabilities of 5G also enable 5G new calling, which, in addition to traditional voice call services, provides new functions, such as intelligent translation, fun calling, intelligent customer service, content sharing, and remote assistance. 5G uplink capabilities enable users to enjoy stable 720p+ HD video calls anytime, anywhere through the native call function.

Year	2022	2023 (Plan)
Package Subscriber (1000)	130	**600**
Price Increase After a Package Upgrade	70 CNY (from 129 to 199 CNY)	

Uplink live broadcast package of China Unicom

1.4 Cloud gaming/phone turn latency a monetizable dimension.

The low latency of 5G networks significantly shortens the latency of cloud services. Cloud phones and cloud gaming will witness an explosive development and become landmark 5G applications.

The end-to-end latency of traditional mobile phones is generally within 50 ms. For cloud phones or phones in cloud gaming mode where signaling and data are transmitted through video streams, the latency exceeds 100 ms on 4G networks, which results in lag. 5G cloud services reduce the latency to 100 ms, which enables cloud phones to run high-performance applications non-stop. It also enables cloud gaming to go from idle games to enhanced levels of interactivity. It is estimated that by the end of 2023, the number of paid cloud phone users will exceed 10 million, and the number of paid cloud game users will exceed 40 million.

Cloud Phone: Inclusive Cloud-end High-Performance Experience

E2E 60 ms@90%

10 million
paid users in 2023

Cloud Gaming: Download Not Required, Smooth Experience at the Cloud end

E2E 50 ms@90%

40 million+
paid users in 2023

- 5G cloud gaming services launched in Saudi Arabia and Europe use the ultra-low latency of 5G to provide high-speed services, driving growth in home broadband users and ARPU improvement.
- The cloud phone service of China Mobile provides users with cloud phones, sponsored traffic, and app binding in one package, promoting the fast spread of cloud phones. Cloud services have higher requirements on user experience, which can be guaranteed through 5G QoS Identifier (5QI). Cloud services significantly stimulate mobile network traffic. In China Mobile' beta test, the app traffic of cloud phones is 30% to 100% higher than that of physical phones.
- The 5G game acceleration packages launched by Hong Kong operators provide sponsored game traffic and 5G acceleration services. The QCI value of the gaming services is increased to ensure differentiated gaming experience.

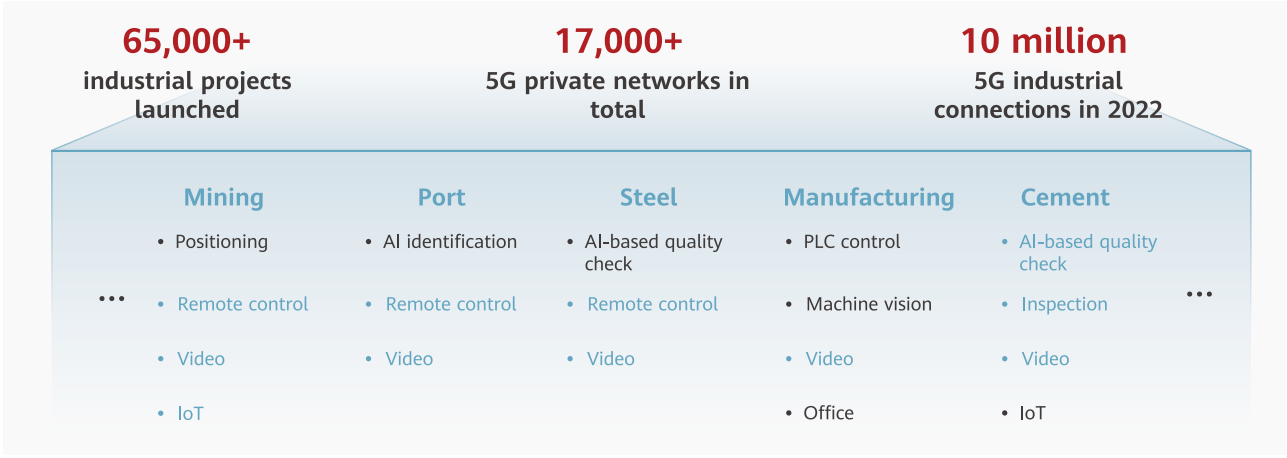
1.5 Deterministic capabilities brings new growth from industry connections.

5G private networks and virtual private networks (VPNs) provide the deterministic capabilities required by enterprises, such as low latency, high reliability, and slicing. These capabilities have become an important engine for the convergence between vertical industries and digital technologies. There are now more than 65,000 5G private network projects globally. The revenue of these networks and the number of industry connections have both tripled. Revenue generated by 5GtoB private networks is in the tens of billions, resulting in DT, IT, and CT revenue growth for operators in the hundreds of billions in the fields of cloud, storage, and platform.

In smart manufacturing, 5G deterministic capabilities are the foundation of fully connected factories. In Midea's factories, applications such as 5G + MES and 5G + industrial computers deployed on a 5G private network implement data extraction and intelligent analysis and prediction. This enables prompt adjustment of robot production behavior and optimizes the control over the entire manufacturing process in a closed-loop manner.

Electric power systems have strict reliability requirements. This is because precise load control requires millisecond-level latency. In addition, due to the critical importance of the electric power industry, power grid companies must ensure the security and stability of the entire system. The 5G power VPN slices enable faster, finer, and more accurate load control on the power grid. With the slices, power distribution line faults can be isolated quickly and accurately, shortening power outage durations to seconds.

In the railway industry, German operators have launched QoS-based slicing or dedicated resource slicing based on the existing communications infrastructure to deliver 100 Mbps uplink and 20 ms at 99.99% network performance. This enables train status monitoring, track defect detection, and intelligent passenger information systems.



1.6 Recommended actions

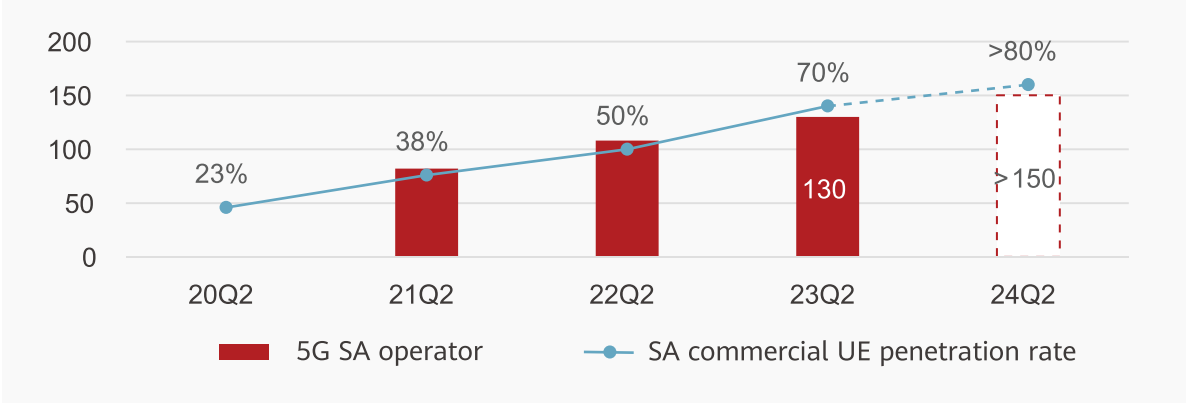
Build high-quality 5G coverage in all scenarios to ensure ubiquitous multi-dimensional experience

The depth and breadth of 5G network coverage must be extended to bolster the digital foundation for multi-dimensional 5G experiences. For example, the network coverage required for pushing HD short videos is 5 dB higher than that for non-HD videos. Cloud phones, cloud gaming, new calling, and other new services require a latency of 50 ms at 90% performance. This poses higher requirements on the network coverage rate and edge coverage quality.

The 5G network coverage rate has reached 90% for arterial roads and other common outdoor settings. However, the coverage rate is less than 70% for indoor areas, such as underground parking lots, elevators, and staircases. In addition, 5G needs to be extended to towns and rural areas to achieve equitable user experience for users in rural and remote areas.

Transform 5G from NSA to SA to provide new services and user experiences

As the 5G target network, the 5G standalone (SA) network is the basis for new services such as Voice over NR (VoNR), low-latency services, reduced capability (RedCap) IoT, and slicing. The 5G SA industry is maturing. Deloitte estimates that the number of mobile network operators investing in 5G SA networks at the end of 2023 will be twice that at the beginning of the year. 5G should be deployed on more frequency bands to realize high- and low-frequency coordination, so as to provide better user experiences and improve 5G SA coverage and capacity.

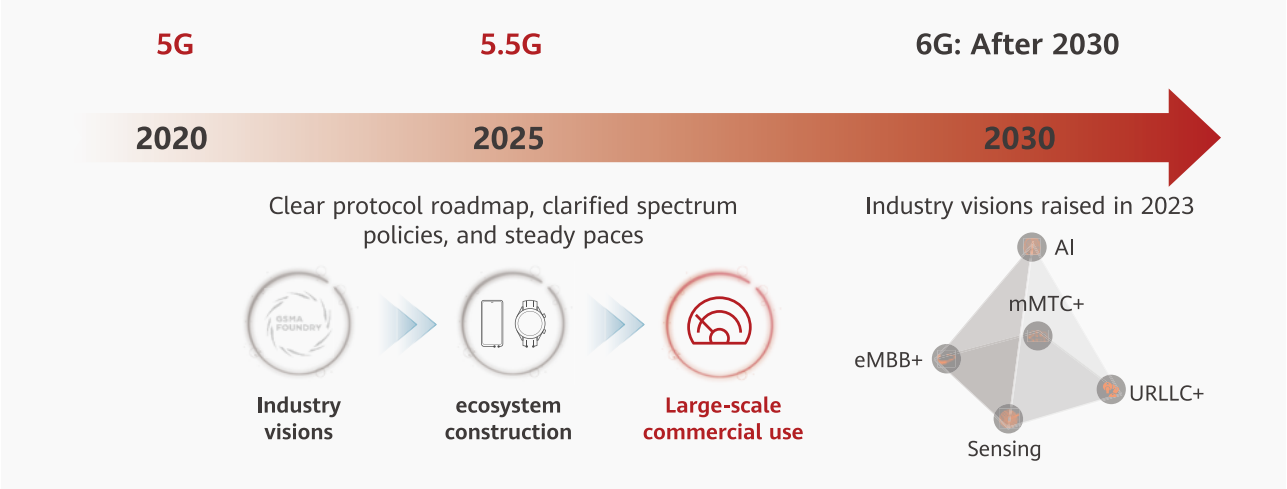


Trend 2

5.5G, with its First Standard Version to Be Frozen, Has Become a Deterministic Industry Trend.

In the consumer field, new service forms and content types are developing rapidly. Breakthroughs in technologies such as glasses-free 3D and virtual reality (VR) elevate immersive personal experience to a new level. These new services pose higher requirements on 5G network capabilities. In industries where digitalization and intelligent transformation is underway, new applications and scenarios have stringent requirements on uplink large bandwidth, deterministic latency, high reliability, and precise positioning, making 5G technology evolution and upgrading a must. The integration of 5G into diverse industries in turn creates new requirements for 5G capabilities. New 5G technologies, such as RedCap, passive IoT, and Harmonized Communication and Sensing (HCS), will open new opportunities for the mobile industry.

5.5G is an enhancement to 5G with stronger capabilities and a wider scope of application. 5.5G can be applied to glasses-free 3D, IoV, intelligent IoT, and high-end manufacturing. Moreover, it helps protect 5G investments on live networks, allow for smooth network evolution with new technologies, and meet the growing demands of consumers and industries for communications networks.



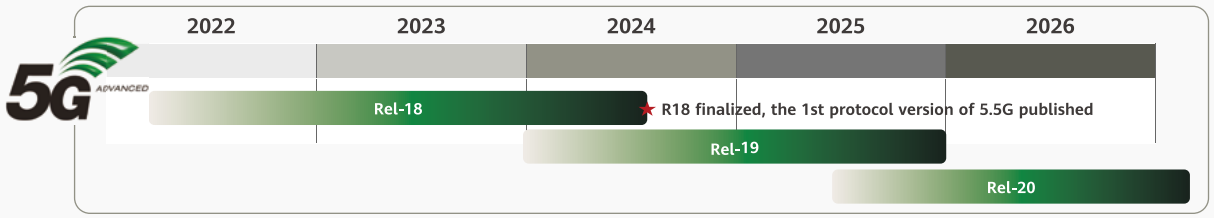
2.1 The 5.5G E2E industry chain is ready, preparing 5.5G for commercial use.

A consensus has been reached across the industry that the next step in the development of 5G networks is to upgrade and evolve towards 5.5G. 3GPP R18 is currently being formulated and will be frozen in the first half of 2024. At present, all R18 subjects have been initiated, and detailed formulation involving extremely large antenna array-massive MIMO (ELAA-MM), enhanced mmWave, energy saving, multi-band serving cell (MBSC), flexible spectrum access (FSA), XR layered QoS, low-power high-accuracy positioning (LPHAP), E2E deterministic experience, and enhanced RedCap is in full swing. In the face of the continuous enhancement required for new 5.5G services and scenarios, R19 research has also begun, with the aim of promoting cross-industry collaboration and implementation of key technologies.

The spectrum strategy for 5.5G has also become clear. New spectrum bands, such as mmWave and U6 GHz, are gradually maturing. More than 25 countries have allocated mmWave spectrum and most operators have obtained 400 MHz to 800 MHz high-band spectrum. The 6 GHz frequency band will be identified for IMT during WRC-23 to be held in November 2023.

The availability of dedicated terminal devices has historically been considered as the sign that a network technology has attained mature commercial use. One of the advantages of 5.5G is that its network capability is 10 times that of the current network. For example, with 5.5G, the peak download speed of mobile users increases from 1 Gbps to 10 Gbps. Leading chip companies have all released modems and RF systems that are prepared for 5.5G, which are capable of 10-carrier aggregation and delivering the ultimate user experience of 10 Gbps. In addition to the 10 Gbps chips, RedCap chip modules have also been put into commercial use, and new passive Internet of Things (P-IoT) devices will also be ready for commercial use shortly.

5.5G Standards: First Release R18, Enhancement R19, Continuous Optimization R20



2024 Q2
R18: mainly focusing on 10X improvement in network capability

2025 Q4
R19: exploring new services and scenarios

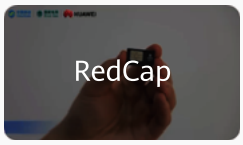
After 2026
R20

2.2 Global operators are actively verifying 5.5G on commercial networks.

Global operators are also actively engaged in 5.5G innovation. For example, more than 20 operators in China, Kuwait, Saudi Arabia, UAE, Germany, Türkiye, France, and across the world are verifying key 5.5G technologies.

» 10 Gbps downlink has been verified for commercial use and is ready for large-scale deployment: The mmWave, sub-6 GHz, and U6 GHz spectrum bands are flexibly combined for use and have been verified in multiple cities in Europe, the Middle East, and the Asia Pacific. Together with key technologies such as ELAA, the 10 Gbps capability of 5.5G enables ubiquitous high-speed mobile Internet experience in high frequency bands.

» 100 billion-level IoT connections accelerate verification for commercial applications: The RedCap industry chain of chips, modules, and devices is mature. It is ready for large-scale commercial use and has been verified in power grid and manufacturing scenarios. Maturation of the p-IoT industry chain is accelerating, and its technical verification in factories and logistics-related industries has been completed.



Technical tests and verifications completed in many places including UAE, Saudi Arabia, Kuwait, Germany, France, Spain, and China.

2.3 5.5G Is Necessary for Bridging 5G to 6G.

In June 2023, ITU officially released the 6G vision. In general, it takes at least 10 years for a new generation of mobile technology to go from vision to large-scale commercial use. However, faced by the emerging requirements of consumers and various industries, merely waiting for 6G to come is no longer a wise choice. The requirements for the development of a digital and intelligent society in the 5.5G era must be actively met.

The potential technological direction of 6G is 100% a natural continuation of 5.5G: Six typical 6G scenarios have been defined in the proposal for the IMT-2030 6G vision. These include immersive communication, ultra-large-scale connection, ultra-reliable low-latency communication (URLLC), convergence of AI and communication, Harmonized Communication and Sensing (HCS), and ubiquitous connection. The development and research of such scenarios have already been initiated in 5.5G.

5.5G is the necessity for achieving 6G. On one hand, 5.5G will enhance the existing 5G capabilities and provide diversified new capabilities to meet consumer and industry requirements in a timely manner. On the other hand, 5.5G will promote industry collaboration, help technology to become mature, and provide the latest direction for future development of 6G. 5.5G serves as a transition and connection between 5G and 6G.

Trend 3

The Turning Point for Immersive Applications Such as Glasses-free 3D and XR is Here and Drives 10Gbps Upgrade.

Even though the year is not over yet, it is certain that 2023 is the turning point for immersive applications. Breakthroughs have been made in XR, glasses-free 3D, and AI generated content (AIGC). With the continuous upgrade of hardware devices and the continuous enrichment of software content, people's expectations for immersive experiences are becoming higher and higher. XR and glasses-free 3D services can provide richer, more realistic, and more personalized experience to meet users' diversified requirements. The increase in such demand not only transforms entertainment but also brings new business opportunities and creates new values for society.

The turning point of immersive applications has come, pushing the network experience requirements to improve from 1 Gbps to 10 Gbps. Immersive applications require the transmission of a large amount of data and video information, which poses high requirements on network speed and stability. 1 Gbps networks are the current mainstream standard, since they are able to meet the requirements of most immersive applications. However, such networks may encounter bottlenecks as immersive application technologies continue to improve and user requirements continue to grow. Therefore, there is an urgent need for 10 Gbps networks.

3.1 Key breakthroughs have been made in glasses-free 3D and XR.

Breakthroughs in glasses-free 3D technologies enable natural and comfortable 3D experiences.

- E2E-mature glasses-free 3D devices: In terms of technology, glasses-free 3D devices generally support a resolution higher than 2K, allowing a single user to experience high quality 3D. AI-based real-time eye movement tracking (latency < 20 ms) and proactive screen adjustment technologies ensure a stable and consistent 3D experience when the user moves. (The 3D field of view ranges from –45° to +45°, covering left/rightward head-turning.) 2D and 3D images are automatically switched, guaranteeing a high quality 2D as well as 3D experience. At present, glasses-free 3D technology is featured on a variety of products, including smartphones, tablets, TVs, and monitors. In terms of additional cost, devices that support glasses-free 3D display are only a few hundred CNY more expensive on average.
- Reduced costs of glasses-free 3D content production: AI-based 2D-to-3D automatic content conversion enables a large number of existing 2D videos to be converted into 3D ones. Such conversion technology can also be used in live broadcast applications, converting 2D livestreams into 3D ones in real time with a latency of less than 5 seconds.

Number of terminals @2025

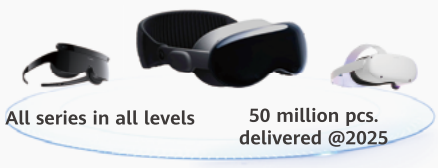
30-50 million

The XR industry ushers in a turning point, entering a rapid-development phase.

Recently industry giants such as Apple have entered the market, injecting new momentum into the XR market. New devices, such as Vision Pro, that integrate VR and AR functions enable users to enjoy high-definition 3D visual effects and spatial audio, providing them with a level of immersion that was previously impossible. Currently, there are various types of XR devices available on the market, including high-end, mid-range, and low-end device with prices raging from US$200 to US$3000.

- Breakthroughs in XR hardware: The 8K@90 fps capability meets the requirements of 12K or higher resolution for panoramic videos. The hardware now supports real-time 3D, multi-channel 8K, and dual-eye 4K cloud rendering, while achieving a video see-through (VST) of less than 12 ms to provide the ultimate immersive interactive experience.
- Breakthroughs in XR interaction: From controller-based to eye- and gesture-based interaction, interacting with the virtual world feels more natural and seamless than ever. Users can also freely and effortlessly switch between interacting with the virtual and real world, which is like under manual control in the physical space.
- Prosperous XR application ecosystem: From custom XR applications to an open application ecosystem, XR applications are now compatible with existing device ecosystems, opening up the potential for tens of millions of existing applications to become XR-empowered. The upgrading of developer platforms to support 3D further helps usher in a new era of truly immersive applications.

Glasses-free 3D and new XR devices are driving the continuous improvement of network capabilities. Large-scale, real-time XR rendering, and 3D reconstruction are transmitted to the cloud for processing through a 5G-enabled ultra-broadband, low-latency, and reliable network. To support smooth and immersive XR experiences, ubiquitous gigabit bandwidth and 10 ms-level latency are required. In the future, 8K multi-view 3D and 8K@120 fps XR will pose higher requirements on networks. Therefore, bandwidth expansion from 5 Gbps to 10 Gbps is a must for popularization of such services.

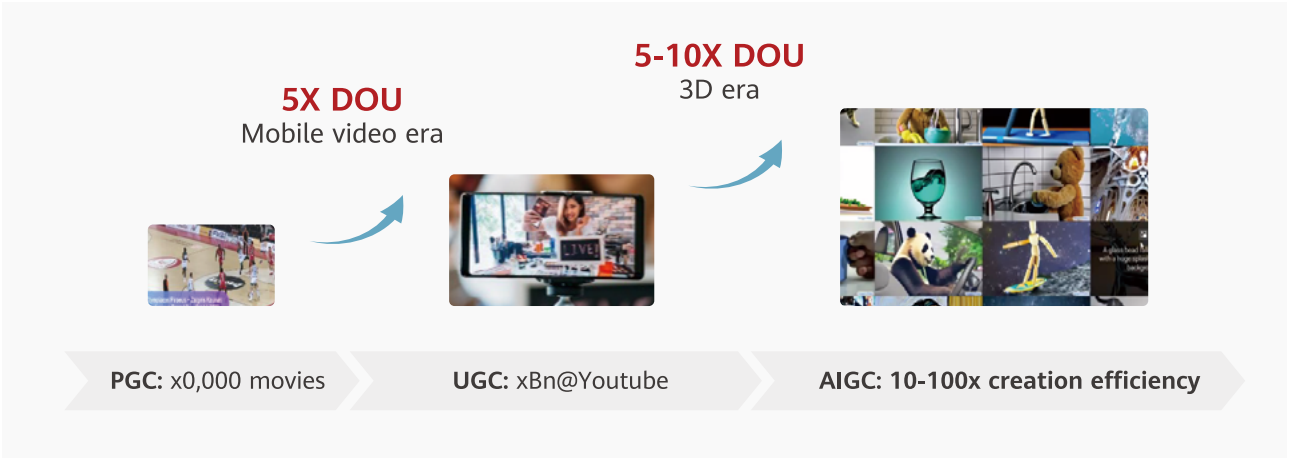


Typical Experience	2K@60fps	4K@90fps	8K@90fps
Bandwidth (Mbps)	90	240	960
Latency (ms)	50	30	20

3.2 AIGC reduces content production costs and accelerates immersive content popularization.

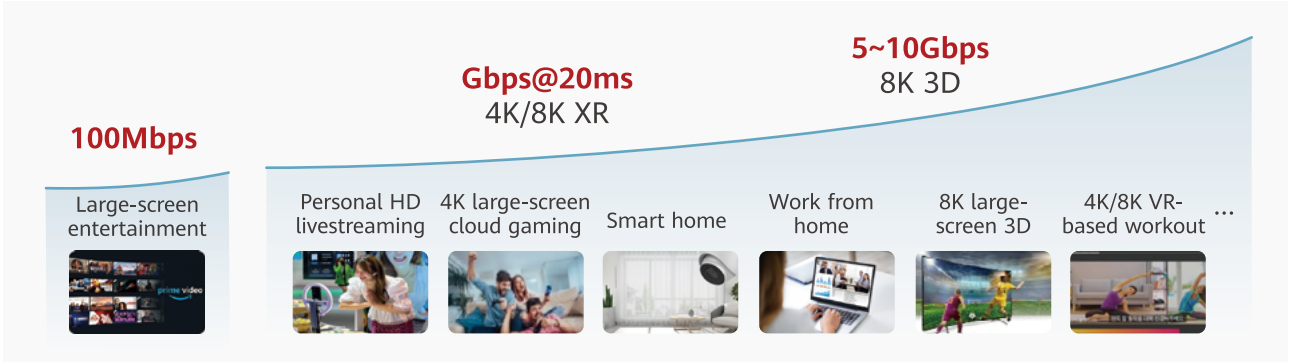
AIGC is a technology that uses artificial intelligence technologies to generate content. It is an all-new method of content creation that differs fundamentally from professionally-generated content (PGC) and user-generated content (UGC).

In recent years, AIGC has made significant progress in the field of 3D data generation. With AIGC, realistic and complex 3D images can now be generated from random text prompts. 3D immersive content production requires a large number of 3D models that take a large amount of time and labor to make. Traditionally, it takes several weeks or at least a few days to produce a 3D model. However, using AIGC, it takes only a few hours to generate a 3D model through text, photos, and videos. AIGC makes 3D production available to everyone. Through 5G networks, 3D modeling or conversion can be completed within 5 seconds, because 2D images and videos shot on mobile phones can be quickly uploaded to the cloud after which ultra-powerful computing resources can then used for reconstruction.



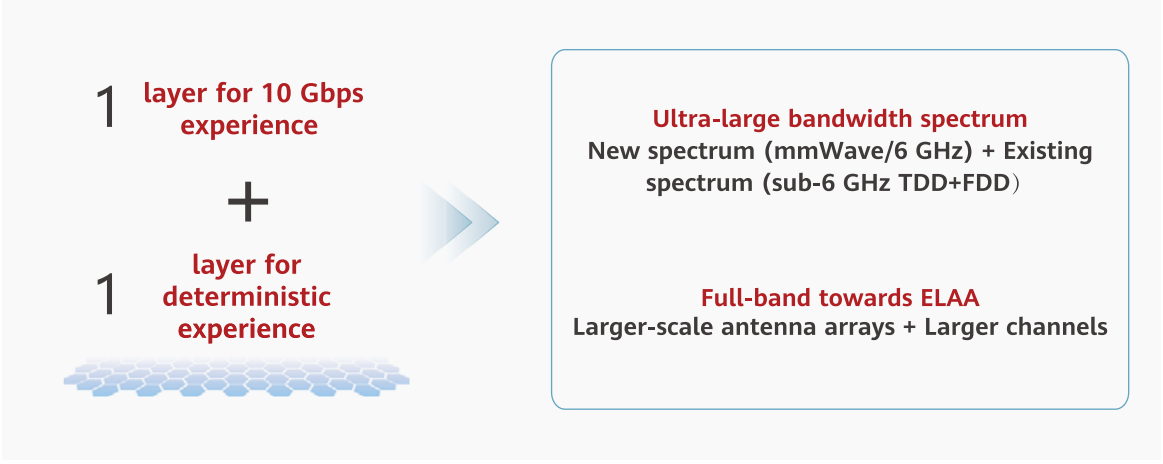
3.3 Immersive experiences have reached homes and drive home broadband experience upgrade.

Nowadays, people no longer consider their homes as merely a place to stay, but instead expect their homes to be a place that can provide a better living experience. The rapid expansion of home services has transformed from simple large-screen video experiences to smart home, home office, cloud gaming, and optical field/glasses-free 3D immersive experiences. Today, the price of 8K UHD TVs is around US$1500, a price decrease of two-thirds compared with 2019. Looking back on the development of HDTV, when the price of HDTV dropped to US$1500, more and more families were able to afford one. Therefore, it is foreseeable that the 8K era of home experience is just around the corner. The development of 8K UHD, glasses-free 3D, and XR will result in demand for home broadband to increase exponentially and will lead us towards the 5 Gbps to 10 Gbps era.

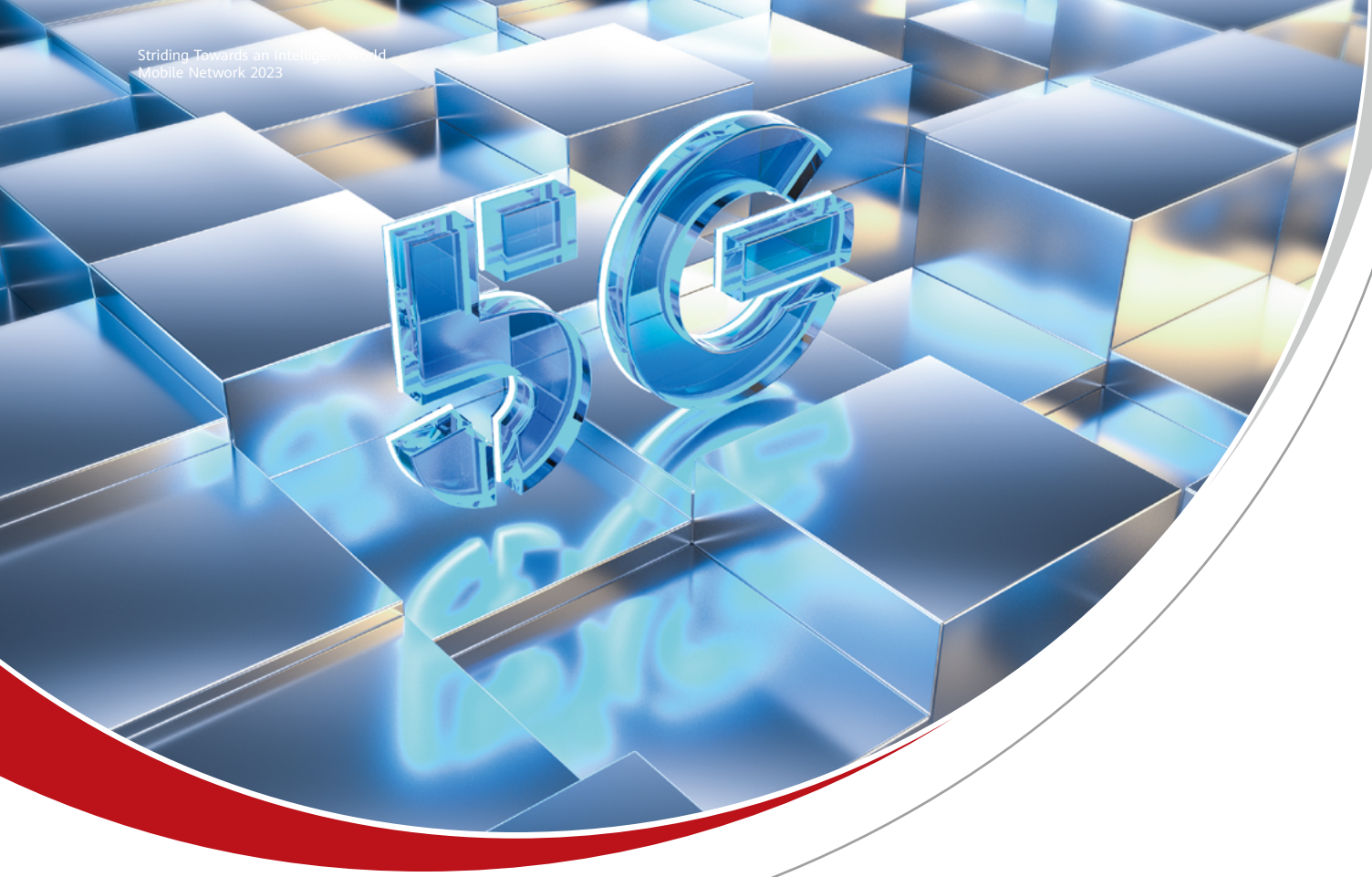


3.4 Recommended actions

- Service changes require network construction upgrade. Experience 1.0 marked by ubiquitous gigabit in the 5G era needs to be leveled up to experience 2.0 marked by 10 Gbps downlink, gigabit uplink, and deterministic experience in the 5.5G era.



- Ultra-high bandwidth spectrum serves as the basis of the 10 Gbps capability. The introduction of 5.5G makes more spectrum bands available. In addition to the existing near-100 MHz FDD and TDD bands, mmWave and higher-bandwidth 6 GHz are introduced to allow use of the 800 MHz and 200 MHz to 400 MHz spectrum, respectively. Flexible spectrum combinations of sub-6 GHz, 6 GHz, and mmWave can be used in different areas. As for the existing sub-6 GHz spectrum, ultra-high bandwidth can be achieved through spectrum reconstruction.
- Full-band evolution to ELAA enables efficient 10 Gbps network construction. The development direction for key technologies of the 10 Gbps capability is to maximize spectral efficiency by integrating larger-scale antenna arrays and channels. ELAA can enable its higher frequency band to achieve the same coverage as C-band, making it possible for users to enjoy a ubiquitous 10 Gbps experience. The ELAA-driven MetaAAU (3.5 GHz/2.6 GHz) has been put into large-scale commercial use in more than 30 cities. The ELAA 6 GHz band has been verified in field tests, where C-band-level coverage can be achieved in both O2O and O2I scenarios. Additionally, mmWave also adopts ELAA to address the issue of high penetration loss. A Gbps-level experience can also be achieved in 5 km away in addition to a peak experience of 10 Gbps. The sub-3 GHz band has obvious advantages at the cell edge and plays an important role in enabling a deterministic experience in terms of uplink and latency. Full-band beamforming is used on the sub-3 GHz band to achieve deeper coverage with better experience, which further contributes to the realization of a deterministic experience. However, this upgrade also poses higher requirements on coverage.



Trend 4

Accelerating of Industry Digitalization Needs Enhanced Connections and New Capabilities.

The 10% of enterprises that were early embracers of digitalization enjoy a revenue growth rate five times faster than that of the 25% of enterprises who embraced digitalization later on. Accelerating digitalization has become an inevitable choice for leading enterprises to achieve leapfrog-like development. As 5G technologies continue to develop and become more popular, more and more enterprises have come to realize the significant role that 5G plays in industry digitalization. However, there are huge differences in the pace that 5G is adopted for digitalization in different industries.

First level: 5G auxiliary production services are used in industries such as steel, mining, ports, manufacturing, and electric power generation. They are being replicated on a large scale and have started to be integrated into the core production phase. 5G implementation in such industrial enterprises have already reached a deeper level. Therefore, operators, equipment vendors, and industry solution providers are accelerating their cooperation with enterprises in these industries to better understand their pain points and requirements. This has become the key driving force for quicker industry digitalization, as industry leaders have already begun to realize the benefits of 5G technologies.

Second level: 5G technologies are taking deeper root in industries that related to people's everyday lives. The number of 5G applications in fields such as government services, media and entertainment, logistics, and healthcare has increased significantly, with the growth rate being much faster than in other industries.

Third level: Exploration and incubation of 5G has commenced in industries such as for IoV, drones, transportation, and financial services. In these fields, 5G faces security and technical challenges and needs to continue to improve its capabilities.

4.1 Industry core production process requires improved connection quality.

With the technological development of smart manufacturing and flexible manufacturing, 5G has become a must-have in the core production process, so as to meet the deployment requirements of more scenarios that require real-time control and high reliability. 5G capabilities, such as low latency, high reliability, and large uplink, are being improved comprehensively. This will enable factories to realize wireless connections for all procedures, reduce production line adjustment costs, and improve production efficiency. Core applications, such as cloud-based PLC and 3D visual detection in flexible production lines, require gigabit uplink and 4 ms@99.999% low latency capabilities.

Take an automobile manufacturing factory that needs to adjust 10 to 20 production lines each year as an example. Following the factory's adoption and verification of 5.5G enhanced URLLC, the time it takes to adjust production lines has been greatly reduced, resulting in an increase in production capacity of CNY800 million per year.

Another example is an equipment manufacturer that produces more than 10,000 product models and which can accept an order quantity as small as just a single item. The manufacturer often experiences several problems, including unbalanced production capacity, frequently changing production lines, and low effective asset utilization. However, after introducing 5G+PLC control and 5G+AGV reconstruction, the production line utilization rate is improved from 50% to 80%, and the adjustment time is reduced from weeks to just hours.

	Wired network connection	5G network connection
		
Time for adjustment on production lines:	x weeks	x days
Downtime due to cable faults:	60 hours/year	< 1 hour/year

- Cloud-based PLC
  4 ms@99.999%
- 3D visual inspection
  Gbps in uplink
- AGV collaborative operation
  Submeter-level positioning
- ...

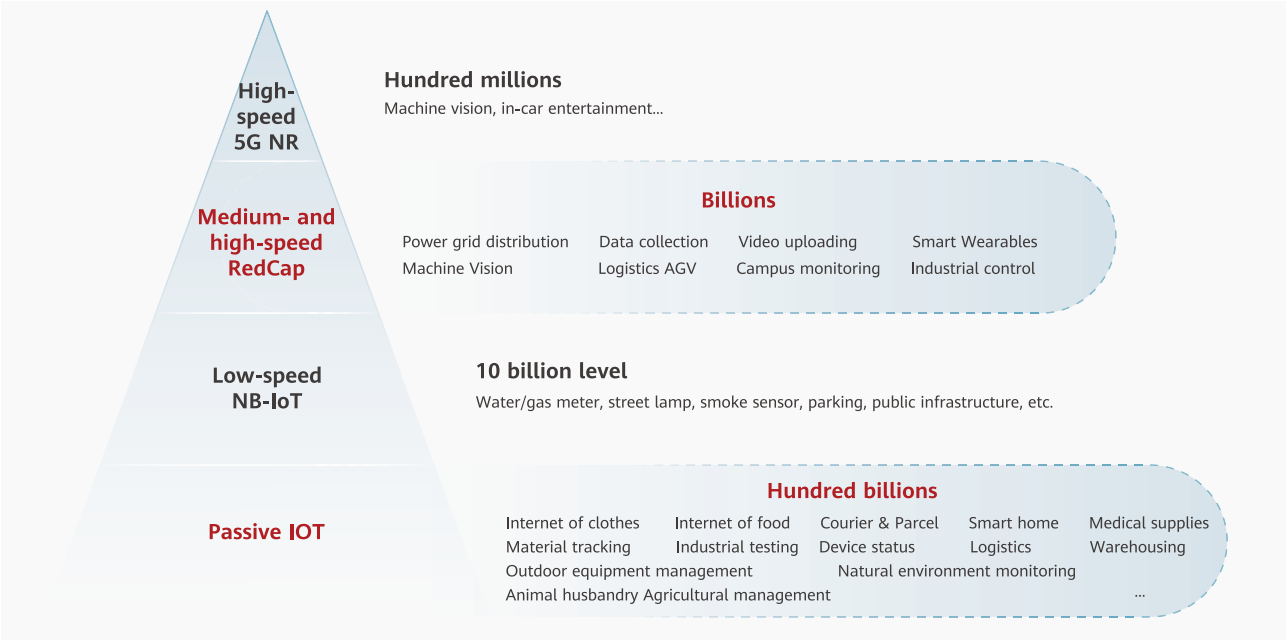
10-20 production lines are adjusted per year, costing CNY100 million+.
@Automobile manufacturing factory

4.2 With IoT integrated into all scenarios, more scenario-based capabilities are required.

In China, IoT is more common than Internet of People (IoP). The number of cellular-based IoT connections has reached over 2 billion, and "more IoT than IoP" is becoming a growing trend. 5G IoT has gradually become the main driving force of cellular-based IoT, with a compound annual growth rate (CAGR) of over 60%. From 2025 to 2026, 5G IoT is expected to surpass 4G IoT.

The application of IoT technologies has shifted from cost reduction to industry enablement and revenue increase. In the financial industry, the role IoT plays in data acquisition and asset management is becoming more and more prominent. It has become a new force to support the real economy as well as to promote the digital transformation of small- and medium-sized enterprises. For example, as part of Ping An Bank's Xingyun plan, the number of IoT devices exceeded 20 million, resulting in CNY650 billion worth of extra capital.

In the warehousing industry, IoT has become a necessity on par with electricity. ABI Research estimates that the amount of profit generated by traditional warehouses is US$79.33 to US$84.21 million while that of warehouses supporting 5G IoT is around US$146.75 to US$155.79 million.



The cost of IoT is key to its development. It is clear that 5G-enabled 100 billion-device IoT is the future requirement, and IoT capabilities are being further innovated to reduce connection costs as well as improve connection value. IoT will surpass IoP in terms of quantity, traffic, and value.

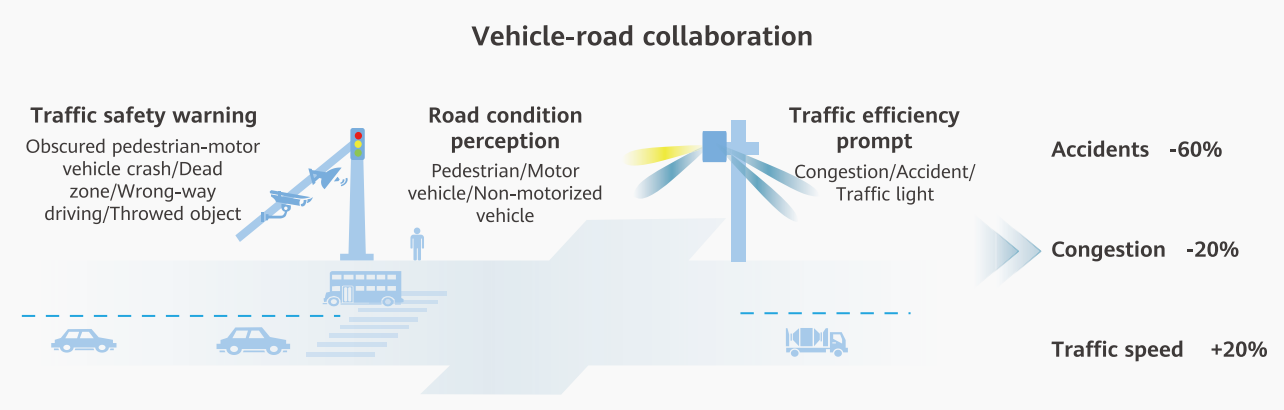
- RedCap will open a new blue ocean of medium- and high-speed IoT. Compared with traditional 5G IoT, RedCap has lower module costs and thus is more suitable for satisfying the extensive connection requirements in the electric power generation, industrial, wearable, and in-car device industries. RedCap chips and models have reached maturity, and it is estimated that more than 50 types of RedCap commercial devices in total will be launched in 2023.
- Passive IoT is a revolutionary technology, as it can use wireless signals to provide energy for P-IoT-labeled device without requiring a battery power supply. In addition, such devices are cheap, which helps satisfy the massive connection requirements in scenarios such as production, warehousing, and logistics.

4.3 vehicle-cloud and vehicle-road collaboration requires 5G V2X capability improvement.

There are around 1.5 billion existing vehicles in the world, which is comparable to the total number of households in the world. Today, the automotive industry is becoming intelligent and connected. Almost 100% of new energy vehicles (NEVs) are connected to the Internet and the average DOU of vehicles manufactured by new automakers reaches 28 GB, far exceeding the average DOU of individual users.

As the lifecycle of a vehicle is generally between 5 and 10 years, the lifecycle of a vehicle-mounted device is far longer than that of a handheld terminal. In the future, vehicles' requirements for cloud and AI will grow rapidly. Therefore, factory-installed 5G products have become a must for world-leading automakers. In China, new 5G-equipped NEVs make up almost 90% of all new 5G-equipped vehicles. It is estimated that more than 1.5 million passenger vehicles equipped with 5G smart cockpits will be delivered in China in 2023, with this figure rising to 5 million per year from 2025 onwards. Vehicle intelligence will continue to drive the 10-fold growth of vehicle-based Internet traffic and vehicle-cloud collaboration requires an uplink rate of over 100 Mbps.

In addition, smart transportation is also developing rapidly. Vehicle-road collaboration connects more than 400 million existing vehicles to millions of intelligent traffic lights and tens of millions of traffic cameras on roads, greatly improving traffic efficiency and management capabilities as well as reducing traffic accidents. According to the verification results of 5G commercial networks, IoV can prevent 95% of accident scenarios. To date, it has been shown that the implementation of IoV has reduced traffic accidents by 25% and improved vehicle flow rate by more than 20%. In Yizhuang, Beijing, self-driving distribution vehicles are now in widespread use and dispatch between 20,000 to 30,000 parcels every day. In terms of network traffic, the real-time video backhaul rate reaches 15 Mbps and the volume of the uplink traffic used for collecting assisted driving data is 20 GB to 30 GB per month. Use of self-driving vehicles in specific areas has entered the commercial stage. Trucks used for container transshipment are controlled in groups, improving traffic efficiency by 40% and reducing labor costs by 60%. In order to implement such technology, 100 Mbps uplink bandwidth and 100 ms end-to-end latency is required.



Trend 5

Wireless Intelligence Moves Surely But Smoothly Toward L4-level Automation.

With the diversification and rapid development of new mobile network application services, the introduction of glasses-free 3D video with their resultant bandwidth and latency requirements, and the rise in industry applications requiring large uplink bandwidth and precise positioning, operators have raised their expectations in terms of diversified service quality assurance. In addition, the introduction of new sites, frequencies, and technologies to wireless networks brings about structural challenges to such networks. More spectrums (sub-6 GHz, C-band, mmWave, and U6 GHz) and more site types (macro, pole, and micro base stations) further increase O&M complexity. In the face of such challenges and the commitment to achieving a "zero fault" vision, operators need to introduce intelligent fault prevention and prediction.

In addition, the rapid development of large model technologies will accelerate the convergence of 5G and AI and is expected to make "add-on" intelligence endogenous. The application of intelligence to networks will be generalized and upgraded from being case-centric to being intelligent capability–centric, facilitating the upgrade of services, experience, and network planning, construction, maintenance, and optimization.

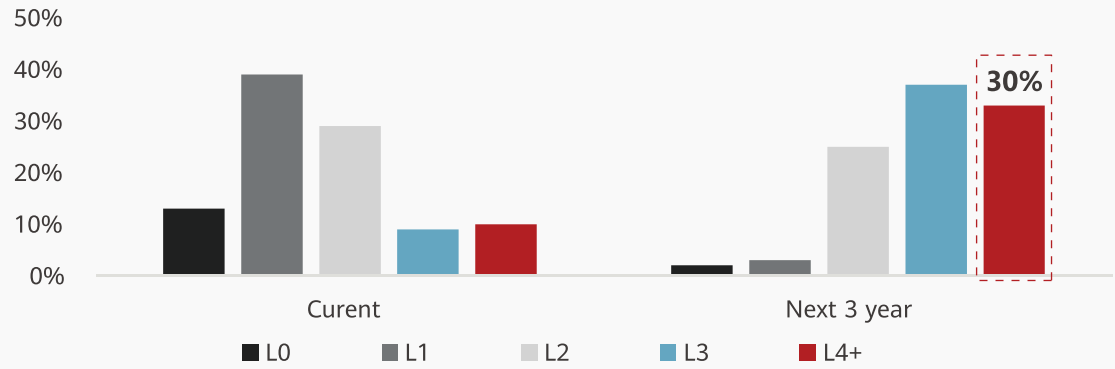
In the next three years, 91% of operators plan to incorporate network intelligence into their strategies and continuously invest in it. To that end, 5G+AI will accelerate operators' journey towards intelligence. Meanwhile, as technology front-runners, standards organizations and industry organizations, such as the 3rd Generation Partnership Project (3GPP), Global TD-LTE Initiative (GTI), TM Forum, European Telecommunications Standards Institute (ETSI), and China Communications Standards Association (CCSA), have already initiated standardization efforts in their respective technical domains. For example, new features in 3GPP Release 18 include the integration of AI and machine learning technologies, which offer data-driven and intelligent network solutions. RAN intelligence has become a significant research project within 3GPP Release 18. Releases 19 and 20 are currently under active development, with a focus on advancing autonomous networks within the industry.

5.1 Wireless networks moving towards L4 intelligence.

Autonomous network (AN) L4 standards focusing on intelligence are to be formulated in 3GPP Release 18. Operators, such as China Mobile, Vodafone Europe, and AIS Thailand, have incorporated L4 autonomous network in their strategic goals for 2025. Based on multi-party discussions in the industry, intent adaptation, multi-objective collaboration, deterministic experience, and prediction and prevention are key requirements of L4+.

The evolution of wireless networks towards L4 intelligence requires them to utilize more advanced intelligent technologies. For example, high-precision perception, device engineering parameters, and environment information. Additionally, L4 intelligence requires multi-dimensional analysis and decision-making capabilities (such as multi-objective and multi-method parallel optimization), easy-to-implement human-machine interaction with intent-driven capabilities, and efficient radio channel measurement capabilities. Mainstream operators and equipment vendors are actively involved in the commercial use of intelligent technologies in wireless networks. They primarily focus on improving energy efficiency, O&M efficiency, and user experience, and emphasize the applications of key technologies such as intelligent multi-frequency coordination, intelligent macro-micro coordination, intelligent network-level energy saving, network fault prevention and prediction, and live streaming service experience assurance. Further research and technical advancements in wireless networks are required, such as digital and intelligent awareness, digital twin, intent openness, and intelligent air interface.

Achieving L4+ by 2025 has become a common requirement of operators.



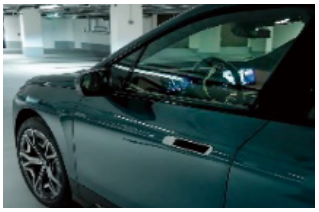
- Digital and intelligent awareness analyzes the channel data of wireless network users to perceive users, their environment, and the network status. It then builds a parameterized physical model that boasts high reliability. By obtaining these model-based feature descriptions, a digital representation of the radio environment can be effectively created, allowing accurate prediction of channel changes. This is important for optimizing communications systems and improving their performance.
- A digital twin network is a digital network system comprising a physical network entity and a virtual twin. The physical network entity and the virtual twin can interact with and be mapped to each other in real time. A simulation model of digital twin for wireless networks comprehensively considers evaluation dimensions, such as coverage, capacity, experience, errors, and energy consumption of networks. The model self-evolves dynamically and undergoes online iteration to continuously improve prediction accuracy. Digital twin–based network optimization eliminates the need for optimization iteration, resulting in zero service interruption and shorter optimization periods. Moreover, multi-method parallel optimization and multi-objective integration are supported, increasing the customization response speed.
- Intent openness achieves intelligent orchestration of user expectations into real-time network O&M intents through easy interaction between users and networks. Intelligent orchestration and evaluation enable the system to perform self-optimization based on user intents, formulate and adjust policies, cooperate with intent conflict management, and deliver policies to networks for automatic execution. Intent-driven technologies reduce service provisioning and delivery time, improve network performance, and greatly improve network availability and agility.
- Intelligent air interface introduces intelligent channel evaluation and prediction capabilities to enable precise beam management and real-time tracing in ELAA scenarios, thereby improving air interface performance. Enhanced intelligent receivers are better able to reduce scenario-level interference and noise and improve air interface coverage. Additionally, intelligent integrated channel design enables channel reconstruction across multiple domains and enhances interference resistance, thus increasing air interface capacity.

5.2 Capability openness has become a new focus point in the industry.

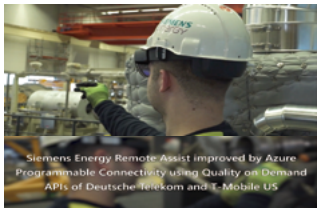
Over the past few years, the revenue growth of over-the-top services has surpassed that of telco services. In answer to this, operators aim to change their business models through network capability openness. Therefore, capability openness has become a new focus point in the intelligent industry as the focus shifts from cost reduction and efficiency improvement to quality improvement and revenue increase. At MWC 2023, CAMARA and GSMA's Open Gateway initiative garnered lots of interests from the industry. CAMARA, an open-source project initiated by GSMA, utilizes an open-source framework to achieve globally standardized Open Gateway APIs. This initiative is supported by 29 mobile operators. Some leading operators have started to explore the network as a service (NaaS) business model based on service APIs.

Intelligent technologies are leveraged to develop differentiated wireless network capabilities for operators, making network API development and service provisioning and assurance a hot topic in the industry. The QoD-based slice service experience assurance API and network status awareness API are the first two high-value applications using intelligent technologies. QoD stands for quality on demand.

- QoD-based slice service assurance API: Common applications such as cloud gaming, uplink live streaming, and self-driving have demanding requirements on network quality, latency, and reliability. An intelligent wireless network allows for SLA-based differentiated resource allocation, second-level SLA visualization, minute-level fault diagnosis, and dynamic RB adjustment for upper-layer applications over network APIs, thus ensuring optimal slice service experience. SLA stands for service level assurance.
- Network status awareness API: An intelligent wireless network can obtain the real-time cell congestion status and predict cell coverage. This enables upper-layer applications, such as TikTok and YouTube, to promptly detect the network resource status through network APIs and adjust video bit rate and resolution accordingly, thus preventing prolonged frame freezing and improving user experience.



Autonomous driving
@QoD API



Remote assistance
@QoD API

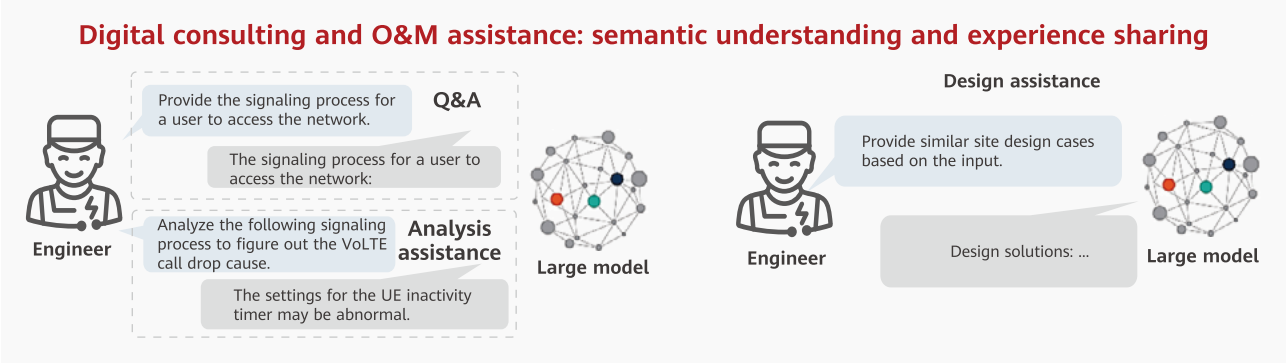
Unmanned aerial vehicle
@Device Location API

5.3 It's time to explore the potential of wireless large models.

AI has entered the era of large models, which may bring transformations in all aspects of mobile networks, including the network itself, marketing, and ecosystem, thus accelerating large-scale high-level intelligent engineering. Leading operators have already started to actively explore the application of large models.

The large amount of expertise and massive network data in wireless networks are used to train large models suitable for wireless networks, such as large language models, large multimodal models, prediction models, and decision-making models. Knowledge systems, which evolved from functional systems, are built for mobile networks, awareness and decision-making are made in closed-loop processes, and capabilities such as digital consulting, intent-driven O&M, and intelligent experience optimization are achieved. Man-machine interaction evolves to intent awareness and experience-based design evolves to intelligent design for complex projects. It is expected that the autonomous networks level of wireless networks will be upgraded to L4, reaching the intent-adaptive network-level intelligence.

O&M is a good example of the successful use of large models. O&M personnel can communicate with large-model AI through natural languages and perform fault analysis and solution design with assistance from AI, which greatly improves O&M efficiency. Furthermore, large models can break down tasks based on the intents delivered by O&M personnel and the perceived multi-dimensional network information, and provide network optimization models and simulation results.



5.4 Recommended actions

» **The industry collaborates with standards organizations in order to define the value directions and key technologies of intelligent wireless networks.**

Since the concept of autonomous driving network (ADN) was proposed by the TM Forum in 2019, the industry has reached a consensus on the vision, architecture, and level standards of autonomous networks through collaboration with standards organizations. The participation of standards organizations in discussions can help identify the optimal path for intelligence evolution, assist operators in effective collaboration with partners during network digital transformation, streamline end-to-end processes in multi-vendor environments, and enhance the competitiveness of rapid service deployment. The industry needs to accelerate its pace and participates in defining the key technologies and value directions of L4+ wireless networks to help wireless networks accelerate evolution to high-level autonomous networks.

» **The full application of large models is a long-term process and needs to move surely but smoothly.**

Although AI technologies are developing rapidly, the application of AI in various industries takes time. The application of large models still faces multiple challenges, which need to be addressed. For example, how to design an AI large model that enables networks? How to cope with corpus fragmentation and improve corpus quality? As communication networks are critical infrastructure, how to avoid misunderstanding or even dangerous instructions if factual questions may be incorrectly answered in the case of the use of large models?

The convergence of AI and mobile networks needs to be carried out in an orderly manner. Typical operation phases and automation requirements defined by 3GPP, such as self-configuration, fault prediction and prevention, multi-objective network optimization, and multi-objective energy saving, should be focused on first. The industry needs to participate in discussing the definition, training, and deployment of large models for wireless networks in this process so that endogenous network intelligence can finally be achieved based on large models and twin networks, driving ADN towards the network intelligent twin era.

Trend 6

5G Has Already Improved Energy Efficiency for Mobile Network and Full-Lifecycle Low Carbon Is a New Focus Point.

The road maps released by major global economies emphasize that green development has become a global mission and a common goal for these economies, in the same vein as the digital economy. 136 countries covering 88% of global emissions, 85% of the global population, and 90% of global GDP have made commitments to net zero emissions.

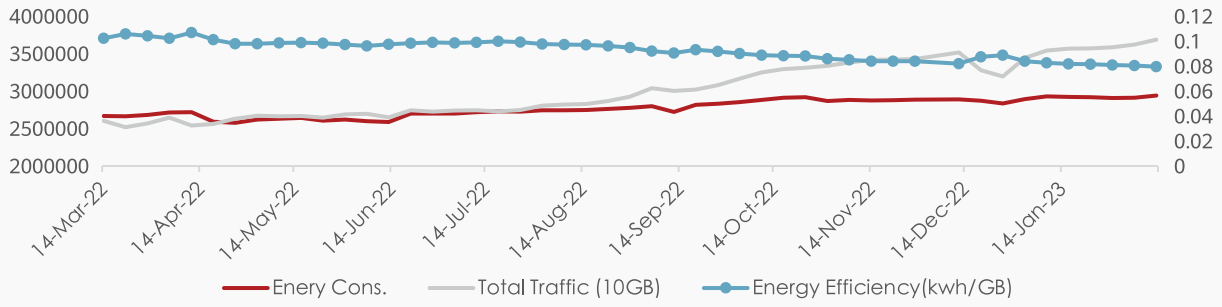
The emission reduction target of the ICT industry has long been determined. Greenness has become the core strategy of global operators and 63% of operators have promised to reduce carbon emissions, with 38% of them having set carbon neutrality targets. The balancing act between greenness and development is a long-term challenge. In the next five to ten years, operators will face conflicts between traffic and service growth on one hand and carbon emission reduction targets on the other. Energy efficiency improvement is the basis for reaching harmony between development and greenness. In addition, new industry directions such as full-lifecycle greenness have emerged.

6.1 5G traffic growth multiplies while energy consumption only increases slightly.

The global popularity of 5G has had the added effect of demonstrating the energy efficiency advantages of 5G on global networks. The power consumption per bit of a 5G base station is only about 1/5 of that of a 4G base station. According to GSMA data, more than 40 networks around the world have implemented energy efficiency improvement measures, including accelerating the migration of users to 5G. These measures have improved the core energy efficiency indicator of mobile networks from 0.24 kWh/GB to 0.17 kWh/GB.

According to data from some sites in the first countries to introduce 5G networks, such as Kuwait and China, the energy consumption of sites remained stable even when the network traffic carried by the sites tripled. In addition, on some multi-band 4G/5G co-sites where the 5G traffic ratio exceeded 60%, the site power consumption even decreased.

Traffic growth multiplies while energy consumption does not increase.

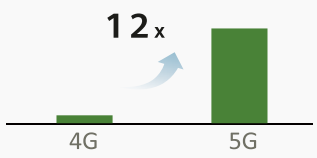


6.2 The industry promotes the multi-dimension energy efficiency evaluation standard.

The communications industry has shifted its focus from energy consumption to energy efficiency. This new modality is guiding the green development direction of the industry and has been adopted by multiple standards organizations such as EIST and NGMN. Energy efficiency (kWh/GB) is applicable to evaluation of the capability of a single product. However, for an entire wireless network, the impacts of indicators related to coverage and experience also need to be considered. Multi-dimensional energy efficiency introduces service quality and scientifically considers network development and energy saving requirements. It focuses on not only network energy saving and KPI assurance, but also user experience assurance.

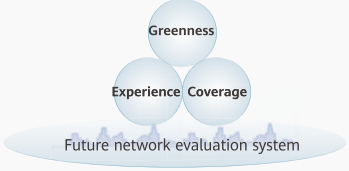
Multi-dimensional energy efficiency standards include multi-dimensional factors such as capacity, coverage, and experience in the energy efficiency evaluation system, thereby guiding the evolution of 5G network construction towards both greater performance and energy saving. It is recommended that optimal energy saving policies be orchestrated for different network scenarios. In low-traffic scenarios, only basic network KPIs are ensured, maximizing energy saving, whereas in high-traffic scenarios, user experience is also ensured. With multi-dimensional energy efficiency, policy orchestration shifts from being experience-driven to data-driven, achieving minute-level energy saving policy generation and millisecond-level optimization policy delivery.

Energy efficiency (bit/J):
Reflects greenness indicators to some extent.



$$NEE1.0 = \frac{Traffic}{Energy\ consumption}$$

Multi-dimensional energy efficiency:
Achieves harmony with performance indicators.

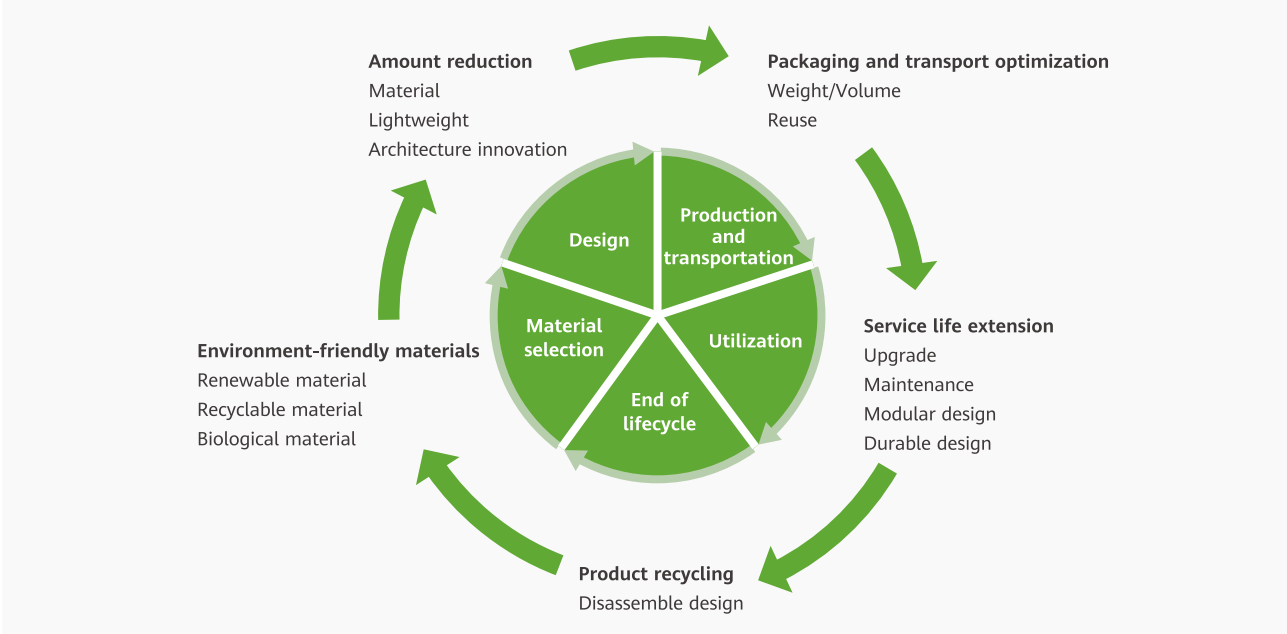


$$NEE2.0 = \frac{Multiple\ dimensions\ (traffic\ and\ experience\ factors)}{Energy\ consumption}$$

6.3 Low carbon has become a focus for the entire lifecycle.

To achieve carbon neutrality, operators need to greatly reduce network energy consumption, and further reduce carbon emissions by transitioning towards a circular economy in non-network running processes such as production, manufacturing, and transportation.

In the design of wireless products, people need to select environment-friendly materials, reduce the use of raw materials, and make products more durable and easier to disassemble. People need to improve product recycling systems and optimize the material efficiency of products throughout the lifecycle while consuming fewer natural resources. For example, people can use AAUs and RRUs with higher integration and adopt ultra-broadband technologies to reduce the number of devices needed, select appropriate digital supply chains, save paper by replacing paper labels with QR code labels, reduce packaging mass by using lightweight packages for AAUs and other devices, reduce the use of plastic packaging, use FSC-certified materials, and use 100% degradable environment-friendly materials.



6.4 Recommended actions

- **Take full advantage of advanced technologies and march towards "0 bit, 0 watt".**

  5G has significantly higher energy efficiency than 4G during peak hours and lower traffic volume during off-peak hours. However, the energy efficiency of 5G can be further improved. "0 bit, 0 watt" is the goal for energy efficiency for all applications at all times. Device shutdown capability is being continually improved to achieve millisecond-level dynamic shutdown and wakeup, which enables energy saving under all weather conditions and at all times. Super dormancy of devices is being implemented in ultra-low load scenarios. For example, new materials and techniques are being used to solve problems with condensation and low temperature when AAU hardware is shut down. As only power modules are running in standby mode, the power consumption of AAUs is reduced from 300 W to less than 10 W in ultra-low load settings.

- **Speed up in defining and implementing the multi-dimensional energy efficiency evaluation system.**

  The industry currently has no unified standard for evaluating and measuring green 5G wireless networks. A standard that balances user experience and energy consumption is urgently needed for both policy-based energy saving and AI-based intelligent energy saving. The industry needs to speed up in defining a multi-dimensional network energy efficiency evaluation method, which covers indicators such as traffic, energy consumption, and network performance. This will enable accurate measurement of the network energy efficiency and guide the development of networks towards greater performance and energy saving.

Trend 7

5G is enabling CT/OT/IT convergence and intrinsic security has become a trend.

7.1 Top 3 network security requirements: security compliance, threat prevention, and compliance with vertical industry requirements.

Telecom networks are critical national infrastructure. Security compliance is the top requirement for operators and a key cyber security challenge. This is reflected in regulations such as the UK's TSR, France's R226, and Germany's IT Security Act 2.0. In March 2022, the UK released the draft Telecommunications Security Regulations and the draft Code of Practice. The former defines security measures and specifies the aspects that operators must note to protect their public networks and services, covering 10 categories of security requirements for three layers of networks. The latter provides detailed technical guidance and explains how operators need to fulfill their legal obligations. In addition, the Vendor security assessment was referenced to define security requirements for vendors. The TSR is critical to the secure operation of carrier networks.

- **Infrastructure security:** third-party vendor security, CPE security, virtualization security, and network supervision module security
- **Network layer security:** management plane security, signaling plane security, monitoring and analysis, and user plane security
- **Enterprise security governance requirements:** services in line with processes, resilience at a national level

As telecom networks gradually converge with traditional IT networks, threat prevention is becoming a major challenge for operators. In February 2023, GSMA released the report GSMA Mobile Telecommunications Security Landscape 2023, which listed the top 10 threats and attacks in each threat in the industry in 2022. These threats are supply chain, ransomware, malware, spyware, smishing, critical national infrastructure attacks, fraudulent SIM swap, inter-connect attacks, attacks on virtualized and cloud-based infrastructure, and human threat. In these contexts, mobile network operators need to protect the confidentiality, integrity, and availability of the entire network communication by protecting critical assets (hardware, software, and data) and preventing unauthorized access to or intrusion into any constituent nodes and links. Using security control design, 5G enhances the defense capabilities against diverse threats faced by traditional 4G/3G/2G networks and provides higher security for situations such as roaming.

While 5G is pushing forward digital transformation of industries, operators are transforming from "telecom operators" to "digital service providers", and security needs to extend from "self-security" to "security for diverse industries". Using new security mechanisms, 5.5G will lead to secure, intelligent connections of all things for ToC, ToH, IoT, IoV, and ToB applications.

Mobile Telecommunications Security Landscape (GSMA 2023)

7.2 Intrinsic security of 5G equipment has become an important method of network security.

Operators need to take following measures to achieve resilient networks and sufficient security capabilities:

- Provide intrinsic security protection for network devices to minimize the threat surface and raise the threshold for attacks.
- Build an integrated in-depth defense system and use different security technologies and means for multi-layer security on the entire network
- Provide comprehensive adaptive security management solutions to coordinate risk and threat prediction as well as prevention, detection, and response measures. Create seamless workflows through end-to-end security coordination.
- Make vendors security capabilities open to enterprises and available to industries based on the enterprise 5G private networks and operators' security capability exposure platforms.

Traditional network security defense systems are limited by the outdated approach of "best effort and zero problems". The security protection "add-ons" cannot cope with new security risks. For example, DoS attacks may occur on air interfaces, but it is difficult to deploy traditional security "add-ons", such as firewalls, on a large number of base stations. In addition, patch-based protection "add-ons" have high requirements on security O&M personnel's capabilities, but O&M efficiency is low, which means huge costs for suppliers. Unlike traditional "add-ons", intrinsic security integrates network security capabilities with the information environment instead of using "add-ons" or partial security. In this way, ubiquitous "immunity" is achieved in the digital environment.

Intrinsic security of devices means that security capabilities are embedded in internal systems of NEs and security technologies are integrated into mobile communication services to make network protection more integrated, effective, and efficient. In this way, full-stack intrinsic security capabilities are built at the hardware chip layer, operating system layer, virtualization layer, and service layer from bottom to top based on service needs, keeping 5G devices trustworthy and secure. In addition, auxiliary security O&M and operation capabilities are provided for operators to build resilient networks.

From the perspective of 5G device services and internal structures, the software and hardware environments of 5G devices include the hardware and operating systems that support the running of 5G services, virtualization components in cloud scenarios, and service-related processes. The intrinsic security architecture of 5G devices is designed hierarchically according to these dimensions. A secure software and hardware environment is built to ensure service availability following the in-depth defense principle. In addition, dynamic defense is used to rapidly detect and respond to diverse attacks and abnormal behaviors.

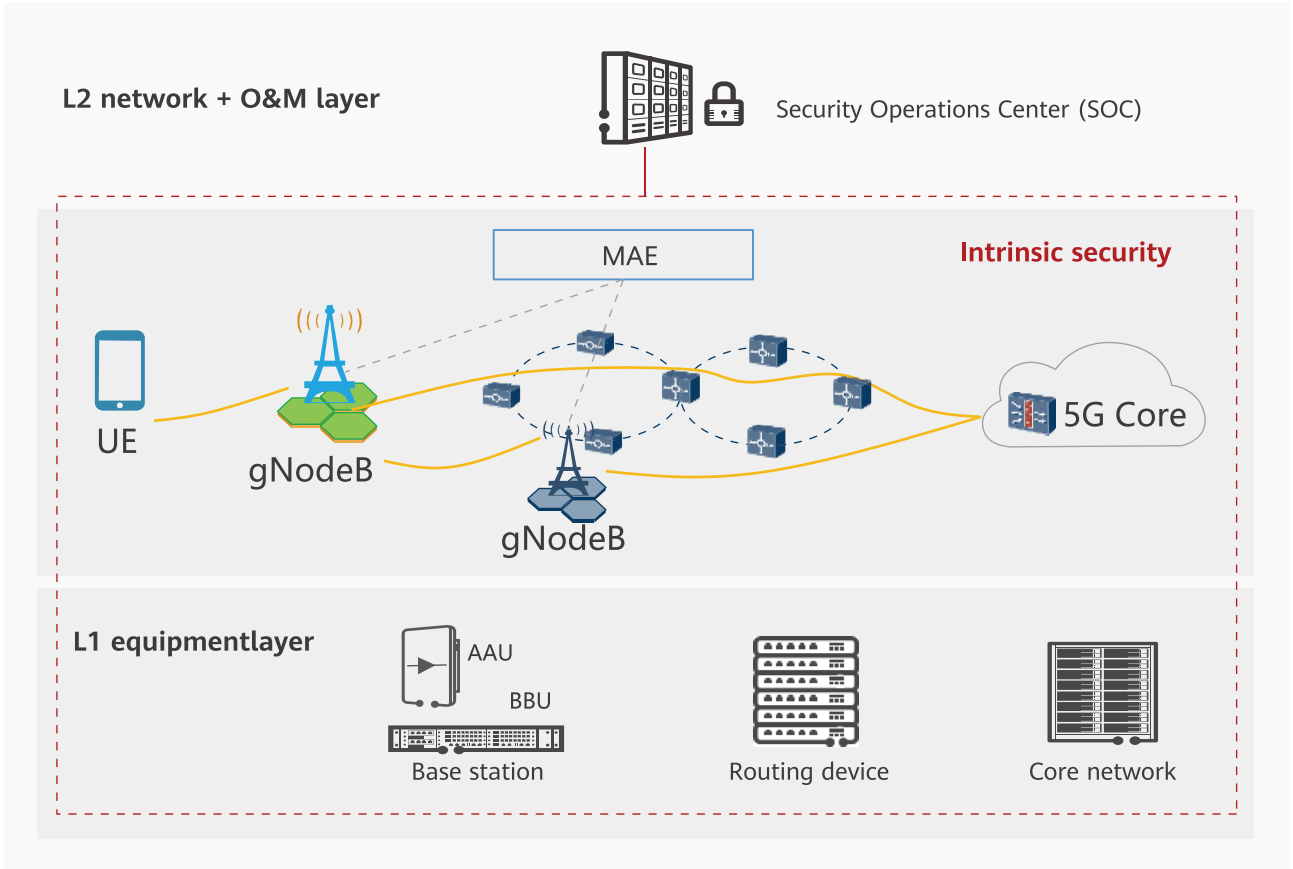
In-depth defense provides multi-layer security measures to protect internal critical assets from external threats. Different security technologies are used at different layers to prevent compromised single points from affecting the entire system. Intrinsic security of devices can make up for border protection shortages. Security is integrated into each NE. When an attacker breaks through the border, penetration attacks on any NE will be detected rapidly and reported to "NE security management" in real time. NEs analyze their service behaviors in real time from startup to running and detect irregularities based on a preset "service behavior whitelist". If an attacker penetrates an NE, any attempt to change the system will be detected rapidly.

The core of dynamic defense lies in real-time monitoring, quick response, adaptive detection response, and continual optimization. Intrinsic security capabilities enable 5G NEs to monitor attacks and threats in real time, block attacks, and

respond quickly to attacks through upper-layer management software. This minimizes risks and protects 5G NEs from diverse security threats.

Intrinsic security provides anomaly detection based on deterministic behavior. This detection is stable and reliable and occupies few resources of NEs, fulfilling the high reliability requirements of telecom systems. As this solution has been integrated into NEs, operators can build more secure 5G networks without additional investment.

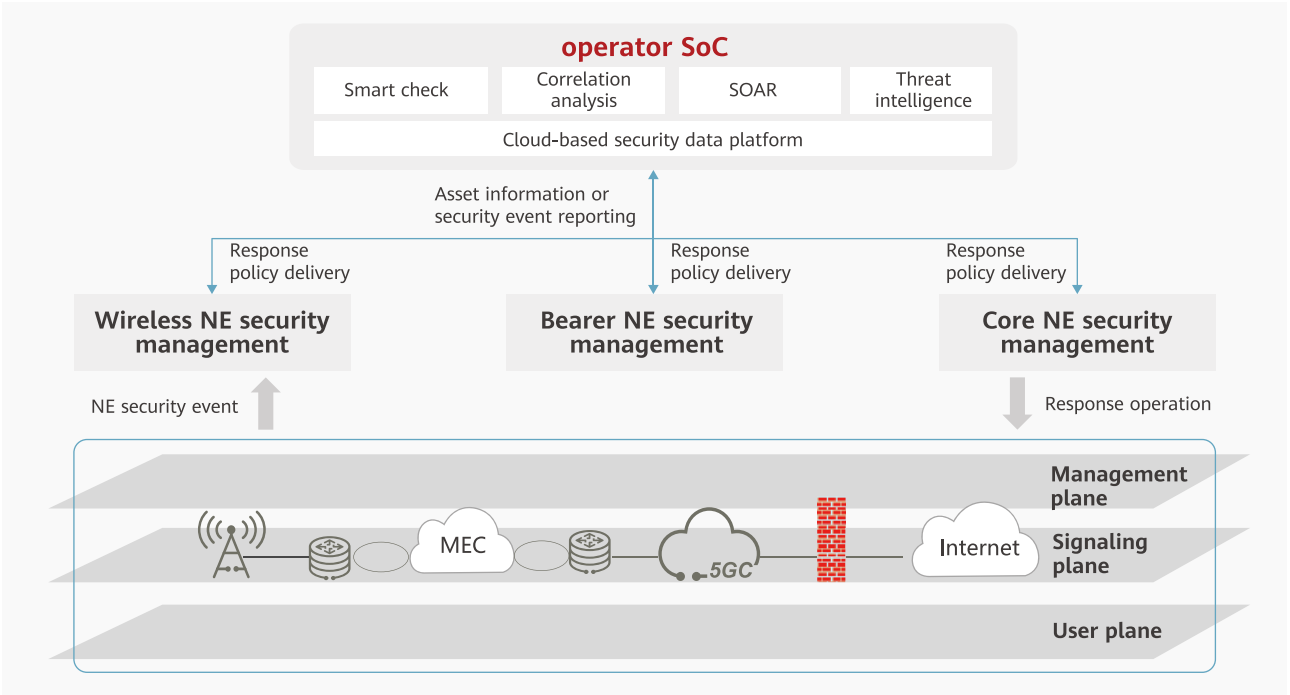
Intrinsic security provides more comprehensive, real-time, efficient, and continuous protection, reduces dependency on external components, and is more covert, easy to maintain, and scalable. Despite these advantages, however, traditional security solutions are still important means to defend against large numbers of low-cost pan-network attacks. Intrinsic security needs to be fully considered during design and continually updated to handle increasingly complex and diverse threats.



Intrinsic security capabilities built on 5G devices enhance device security and provide security detection and response capabilities for the upper layer. Intrinsic security capabilities can be associated with the security management system to help operators build and operate resilient networks based on end-to-end security, detection, and response.

The 5G network security operation architecture consists of three layers: Security Operations Center (SOC), single-domain security management, and NE security. The carrier's SOC is responsible for network-wide asset security management, vulnerability management, device configuration check, network-wide event analysis, and network-wide collaborative response. It aggregates diverse security data from network devices, security add-ons, and 5G terminals to build an automatic security operation platform and achieve network-wide situation awareness, notification and warning, and emergency response.

Single-domain security management is responsible for asset security management of a single NE on the wireless network, bearer network, or core network, including single-domain asset management, device security configuration check, vulnerability management, single-domain security event analysis, and single-domain analysis response. The single-domain security management platform connects to the carrier's unified SOC to enable unified security operation analysis, alarm reporting, and response for the entire network. It provides data collection interfaces and delivers security control policies to NEs. NEs support intrinsic core security capabilities, such as information collection, threat detection, and security response and handling, and connect to the single-domain security management platform. Intrinsic security capabilities and single-domain security management functions of NEs are provided by vendors.



7.3 Recommended actions

Based on intrinsic security of NEs, operators need to integrate security concepts into the entire process of network planning, network construction, and network O&M based on regulatory compliance requirements and industry customer requirements. In addition, operators need to integrate NE and external security product capabilities, build resilient networks, and provide industry customers with security capabilities.

- **Security planning:** During network construction, security needs to be considered and regulatory compliance requirements must be met. Based on the requirements of 5G private network industry customers, Huawei provides critical information infrastructure (CII) protection and classified protection solutions.
- **Security construction:** During network deployment and construction, a comprehensive security mechanism needs to be constructed. Different security solutions are deployed at different locations on the network to balance protection results and costs. The security capabilities of add-ons and intrinsic security capabilities of NEs complement each other and are deployed together.
- **O&M/operation security:** Modules such as asset management, compliance management, policy management, intelligence management, certificate/key management, security event management, operation security management, and emergency response management need to be deployed to support O&M/operation security. Using big data and AI models, service exceptions must be continuously monitored and quickly responded to and handled. Network O&M and operation security capabilities need to be continuously improved through iteration.

Currently, the entire industry is vigorously promoting 5G network construction. Stakeholders such as operators, telecom device vendors, research institutes, and regulators need to work together to promote research on intrinsic security of 5G networks and construction of key security capabilities, and form a best practice guide for intrinsic security.