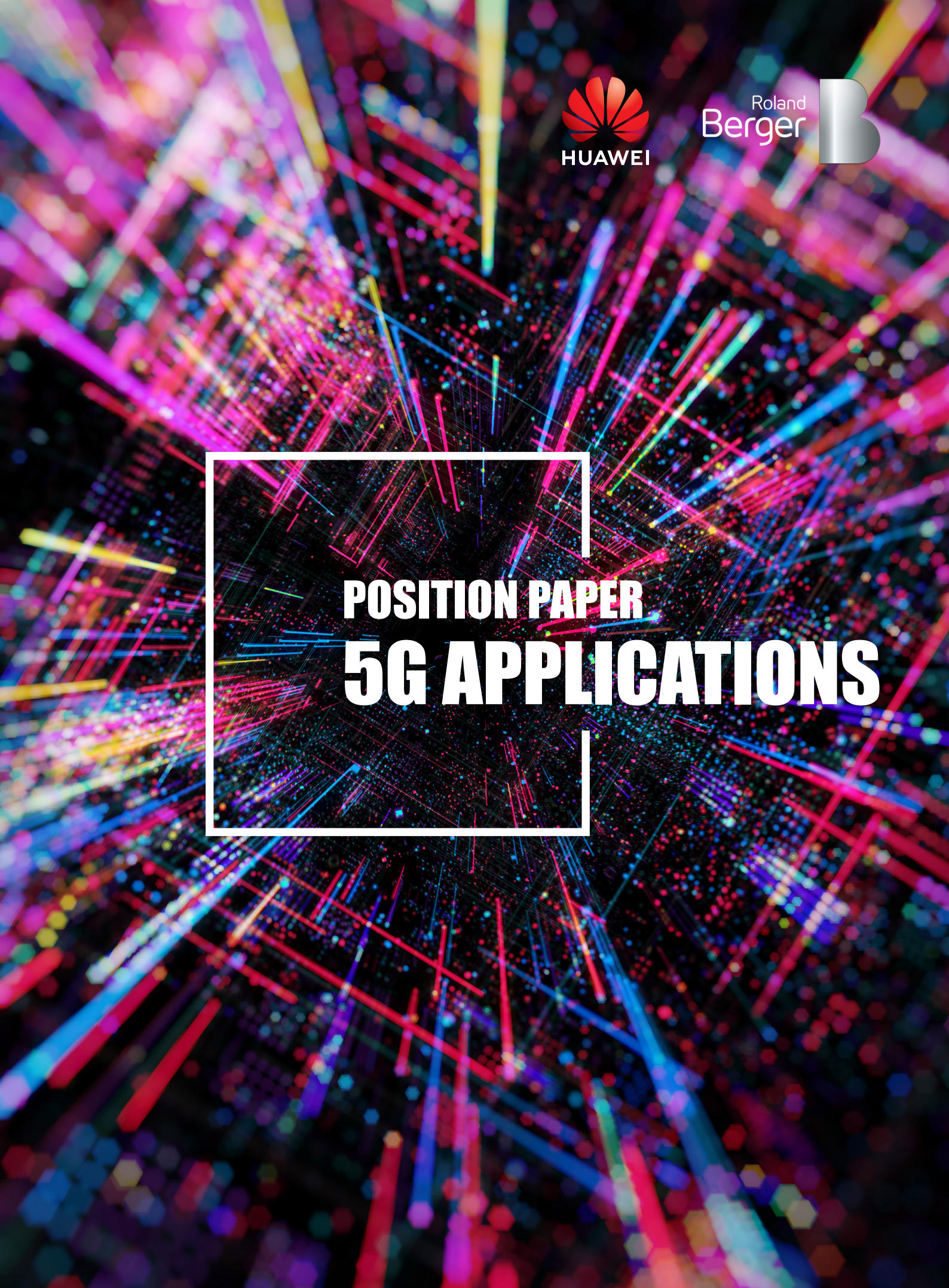
HUAWEI
Roland Berger
POSITION PAPER
5G APPLICATIONS

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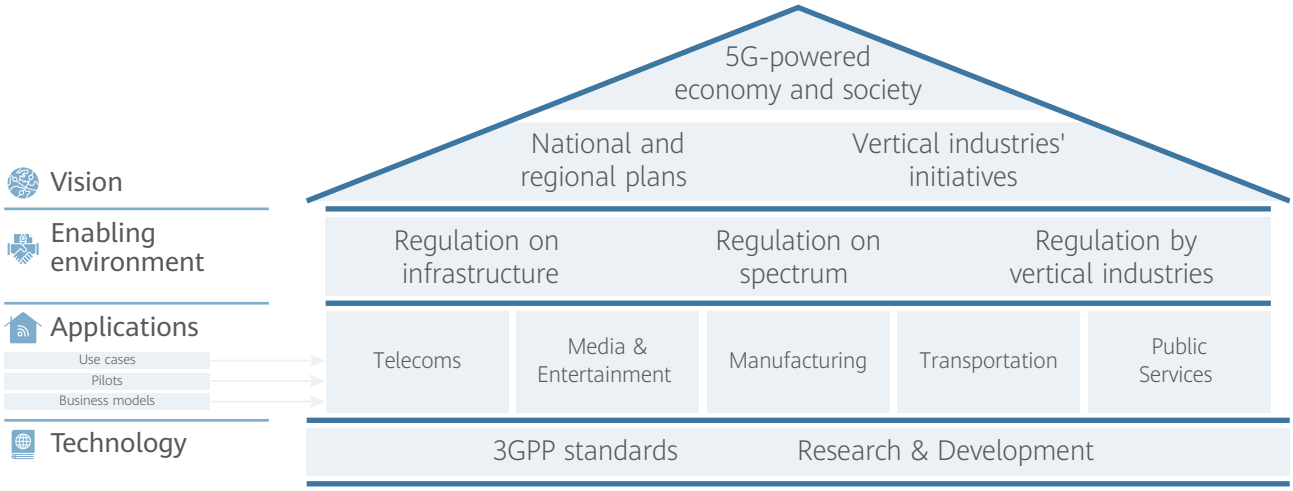
Executive Summary



5G is a new paradigm

Delivering Enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low-Latency Communication (URLLC) and Massive Machine-Type Communication (mMTC), 5G applications represent tremendous opportunities for consumers, homes, businesses and communities.

- 5G is expected to generate USD 12 trillion in revenues in 2035.
- 80% of telecom revenues (broadband, hardware, and services) will be linked to 5G in 2035.

Furthermore, 5G will help reduce inequality by increasing access and lowering the cost of essential services, such as healthcare and education. By expanding the scope of wireless technologies and making devices more autonomous, 5G will help to reduce our carbon footprint and conserve natural resources. Last, economic growth will boost direct and indirect employment in all economies.

Telecom operators, equipment vendors, and industry stakeholders are transforming their respective industries using 5G applications, supported by national strategies

New 5G applications are emerging, supported by national strategies:

- **Telecom** 5G for home (e.g. Fixed Wireless Access) and mobile
- **Media** AR/VR gaming, and advertising, multi- broadcasting
- **Manufacturing** Smart factories & connectivity over the full product lifecycle
- **Transportation** autonomous driving, in-car infotainment
- **Public services** healthcare (e.g. telemedicine), education

International standards drive cost efficiencies and speed 5G adoption

The first standards have been released, supporting the deployment of non-standalone and standalone 5G and the first applications. Next steps are focused on enhancing the 5G ecosystem and expanding the potential for applications in the coming years, notably with Release 16 (2020) and Release 17 (2021).

- 3GPP is leading the standardization of 5G. As 5G involves operators, equipment vendors, and industry stakeholders, broad-based cooperation is needed to create consensus.

Spectrum allocation is a critical regulatory and technical issue

5G requires multiple layers of spectrum to address a wide range of use cases.

- A global harmonization of frequency bands would reduce complexity and costs for vendors, operators, their industry partners, and end-users.
- National licenses should remain the main and preferred authorization model.
- Network synchronization should be considered to mitigate harmful interference.

5G requires a stable and transparent ecosystem to perform

As well as the quality and cost efficiency of the technology itself, the long-term success of 5G will also depend on a supportive business environment.

- Sustained infrastructure investment should be accompanied by precise and reliable national roadmaps that offer sufficient transparency for all stakeholders.
- Cooperation between stakeholders with common interests should be led by industry associations, such as 5GAA, 5G-ACIA, 5G AIA.
- A supportive regulatory environment should be provided for telecommunications and other industries, accompanied by government initiatives to stimulate new business.

5G uptake will depend on the engagement and investment of operators, vendors, and industry stakeholders

Operators are expected to be the natural investors for 5G. Strong engagement by equipment vendors and industry stakeholders will help drive economies of scale, benefiting the whole 5G ecosystem.

- 5G adoption will be progressive, as performance and economies of scale materialize.
- New businesses will take advantage of previous investments as appropriate: The first national licenses have been granted to MNOs, who will provide network access and solutions to vertical sectors using network slicing technologies.

01

THE WIDESPREAD ADOPTION OF 5G REQUIRES HIGH-PERFORMANCE, LOW-COST TECHNOLOGY; IT NEEDS ENGAGEMENT AND INVESTMENT ACROSS THE WHOLE INDUSTRY

The adoption of 5G will be progressive, as performance improves and economies of scale continue to materialize. Achieving significant economies of scale is a common goal pursued by operators, equipment vendors, and other industry stakeholders. Operators will contribute significantly to economies of scale by building out 5G networks with national coverage. In parallel, the whole ecosystem will invest in 5G applications for various sectors of the economy, leveraging operators' networks when appropriate.

1.1 5G is not just faster, but a new paradigm

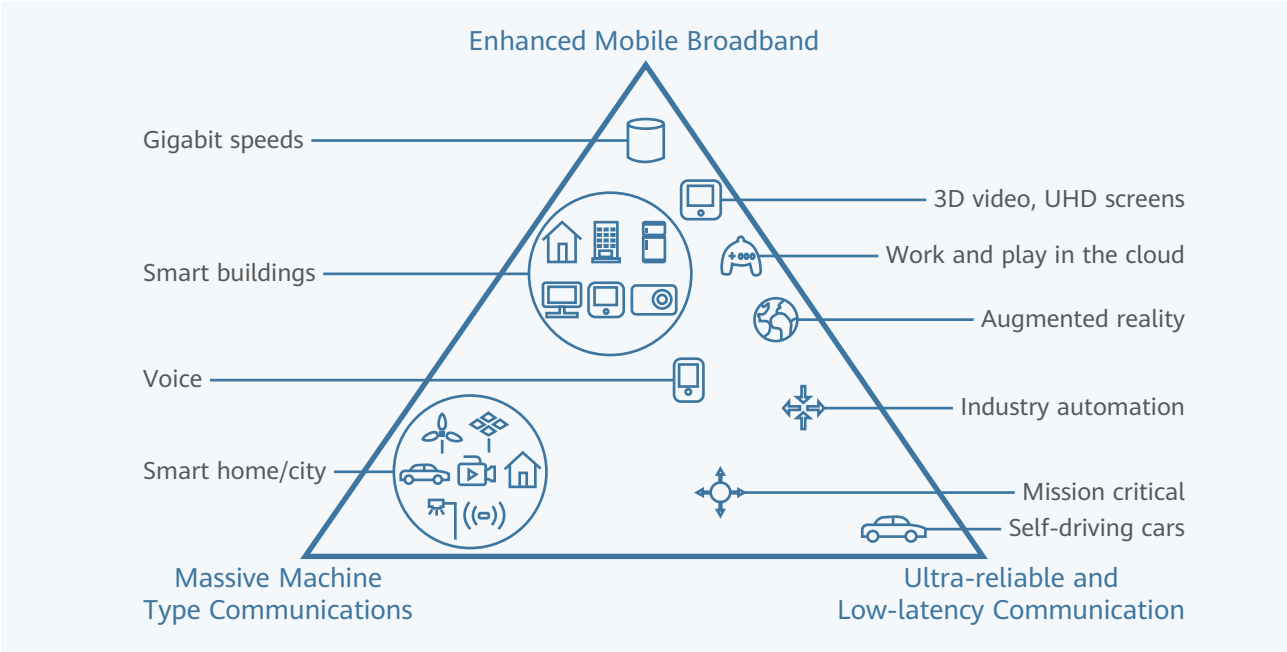


Figure 1: Three pillars of 5G and examples of related use cases

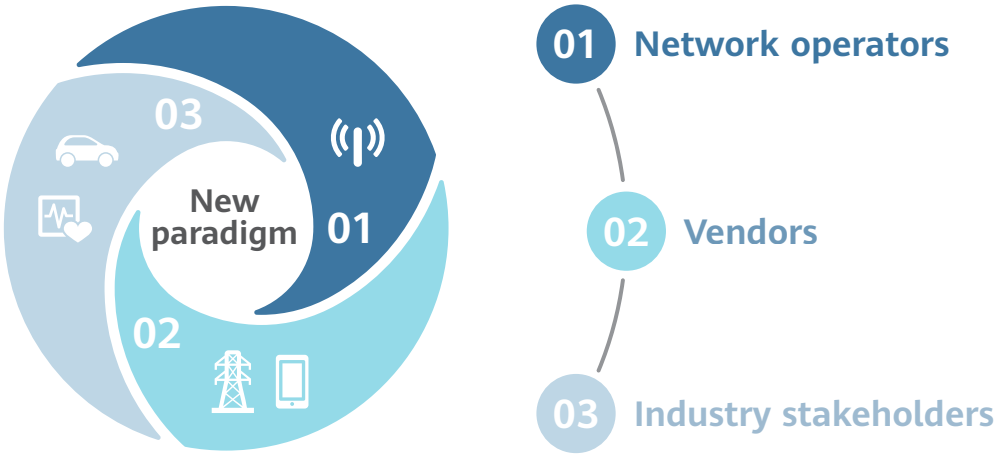
Source: ITU

Built on 3 main pillars, 5G will create tremendous opportunities:

- Enhanced Mobile Broadband (eMBB) will provide mobile network customers and industrial users with enhanced capacities, benefiting B2C, entertainment and media, and other service sectors.
- Ultra-reliable and Low-latency Communication (URLLC) will support new use cases in mission critical applications (e.g. autonomous driving, remote surgical operation, industry automation).
- Massive Machine-type Communications (mMTC) will enable industry players to connect massive numbers of devices with specific connectivity requirements, in sectors such as manufacturing, utilities, and logistics.

Much more than any previous generation of technology, the 5G paradigm brings together mobile network operators, equipment vendors, and other industry stakeholders, due to the broad range of technical and business opportunities opened up by 5G.

- Network operators have a central role in 5G deployment as they will run the 5G networks. They will commit in the greatest part of the necessary CAPEX and OPEX.
- Equipment vendors develop 5G technologies, define and introduce 5G products (RAN, core network, services, handsets).
- Industry stakeholders are brought into the paradigm by the new opportunities with 5G. Many sectors are involved because 5G will enable massive innovation both on the product side (e.g. connected vehicles) and on the productivity side (e.g. industrial IoT).



Source: Roland Berger

1.2 Investment by all stakeholders – not just operators – will drive growth and economies of scale that benefit the whole 5G ecosystem

Mobile network operators are the natural investors in 5G. Projected investments will reach USD 1 trillion between 2018 and 2025[1]:

- From an internal development standpoint, operator business models will be stressed by the exponential growth in demand for data (x6 between 2017 and 2024[2]), which will increase the costs of network management and the level of risk.
- Operators also have external incentives, such as users demand for better services and new applications, changes in the global competitive landscape, and their home nation's infrastructure needs.

Growing demand for 5G will trigger investment from other industry stakeholders as well.

These massive investments will result in important scale effects. The cost of production and maintenance for 5G networks will fall, and the value of the networks will increase in the eyes of network users. These outcomes are supported by theories of network externalities (e.g. Katz and Shapiro[3]) or Metcalfe's law:

- When more 5G products comply with the same technical standards, customers will benefit more from affordable devices and high-quality services.
- As more vertical industries adopt 5G technologies, end users will receive more value from these industries, as broad adoption of technologies increases the potential for interoperability and cooperation and drives the creation of new services.

Investment and engagement by all stakeholders will lower the costs of 5G deployment and help to fulfill the potential of this new technology. The result will be better economies of scale and enhanced value creation throughout the whole 5G value chain, both of which will be key levers for 5G adoption.

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[1] Investing in 5G, GSMA Intelligence, June 2019

[2] BuddComm, Roland Berger analysis

[3] "Network Externalities, Competition, and Compatibility," Michael L. Katz and Carl Shapiro, The American Economic Review, Vol. 75, No. 3. (Jun. 1985), pp. 424-440.

02

INTERNATIONAL STANDARDS DRIVE COST EFFICIENCIES AND ADOPTION

2.1 Standards benefit consumers and companies as they lower investment and deployment costs, facilitate connectivity and foster interoperability

5G standards will ultimately be required for microprocessors, devices, and device modules, as well as the 3 main layers of network infrastructure:

- Core network, the backbone of network exchanges, gathering and dispatching data packages
- Radio Access Network, made up of equipment that links the core network to user devices
- Services and systems, overall architecture and service capabilities

Each of these layers requires the coordination of multiple hardware and software elements that were developed by independent technology vendors. Interoperability amongst them is necessary to ensure good network performance and economic efficiency in production. Technical standards aim at ensuring interoperability.

As 5G involves stakeholders from other industries, the standardization process is broader than for 4G: it includes standards for specific application interfaces. For successful, universal 5G, it is vital to produce hardware with a general design based on common standards with flexible network capabilities. If modules and user devices have standardized interfaces and specifications, the industry will benefit from better scale effects and faster 5G adoption.

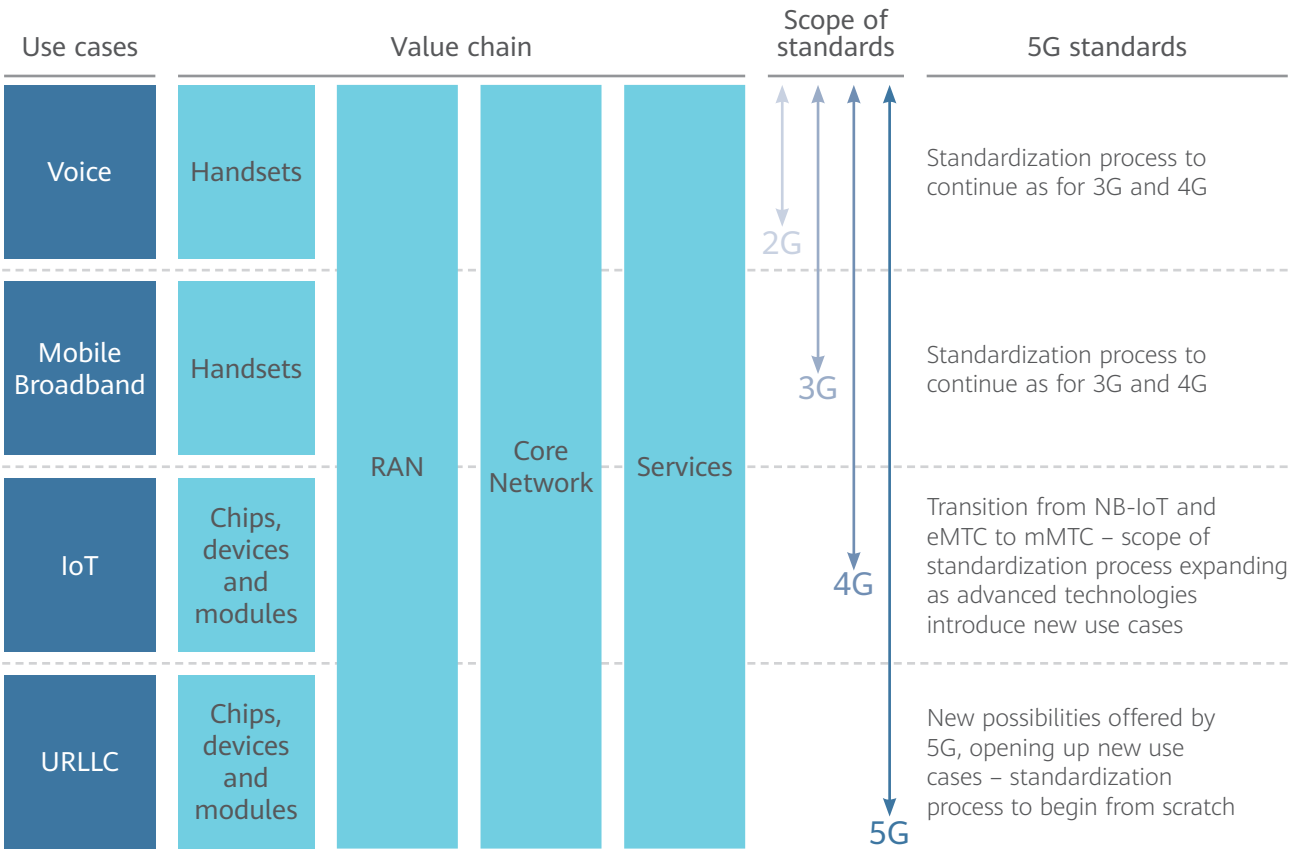


Figure 2: Expansion of standards 2-5G – Focus on 5G

Source: Roland Berger

2.2 Cooperation among standards organizations and all stakeholders has been expanded for 5G

Founded in 1998 by regional standards organizations, 3GPP produces the Technical Reports and Technical Specifications that define 3GPP technologies:

- Nature of the organization: "Non political" role in decision-making, but "a partnership" between Standard Development Organizations (SDOs); culture of consensus drives decision making process; focused on science and technology
- Structure and procedures: Technical specification groups (TSG) dedicated to Radio Access Network, Services & Systems and Core Networks & Terminals organized by tasks and items; clearly defined agendas, deadlines, and rules

5G standards are developed by 3GPP in multiple releases. Release 15 started in 2017. Release 16 is set to be completed in 2020. Release 17, expected for 2021, will bring more technologies for industry applications.

Release 15 is the first set of 5G standards including standalone 5G (5G RAN and the 5G new Core Network) and non-standalone 5G (a migration architecture helping MNOs to switch from a LTE to a 5G based system). Standalone 5G was frozen in June 2018 and non-standalone 5G was frozen in December 2017.

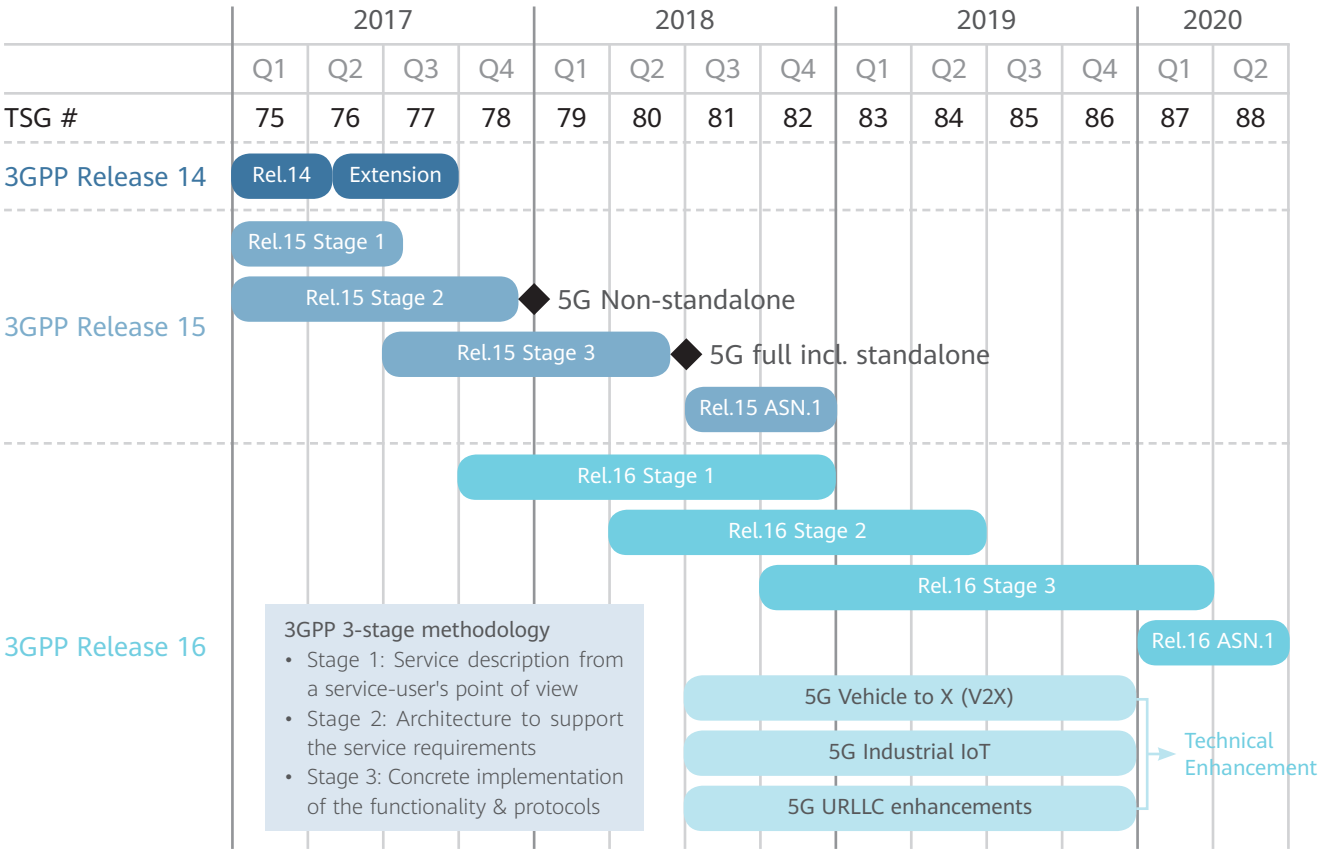


Figure 3: 5G standardization roadmap and milestones

Sources: 3GPP website, 3GPP Workshop October 23rd-24th 2018, Roland Berger

Release 16, expected to be published in mid-2020, will contain technical enhancements relating to general improvements in 5G and industry-specific topics.

Release 16 has 2 important vertical sectors: automotive and industrial automation.

- Automotive: Release 16 will include advanced V2X features primarily based on low latency, for use cases such as platooning.
- Industrial automation: Release 16 will support factory automation by defining time sensitive networking and high reliability. 3GPP's objective is to make 5G NR complement wired Ethernet connections in factories. URLLC enhancement are key advances in Release 16.

Release 16 will also support other vertical industries such as Transportation (e.g. Future Mobile Communication System for Railways), and Media (e.g. 5G Mobile Broadband Media Distribution). Generic improvements that will benefit multiple industries are also to be delivered, such as advances in positioning, MIMO, and power consumption.

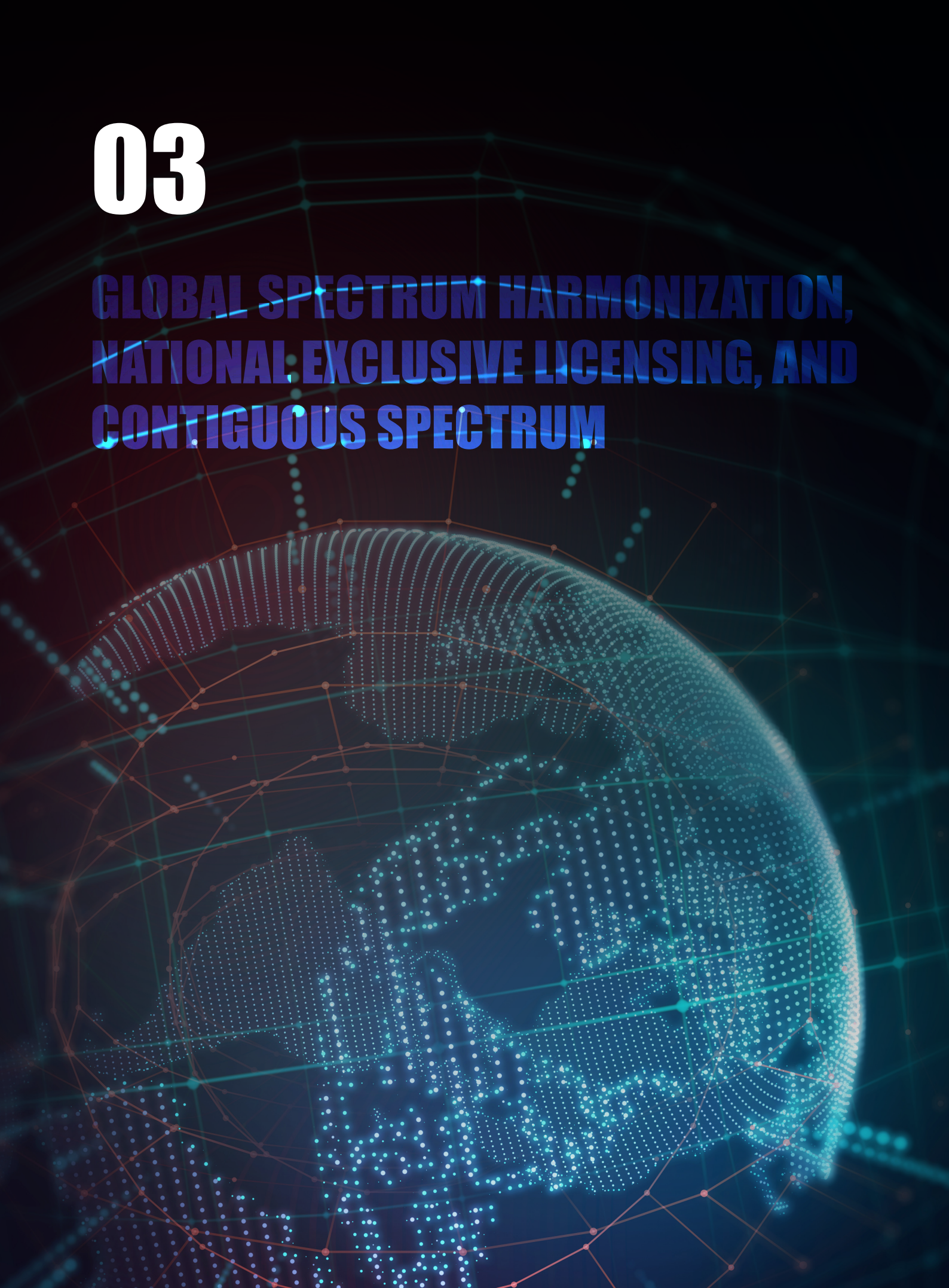
Regarding overall 5G improvement, Release 16 will specify the 5G Systems further, including Wireless Wireline Convergence,, Network Automation, Traffic Steering/Switching/Splitting, enhancements to Service Based Architecture, etc.

Later, Release 17 will add new features supporting more verticals and services enhancing the technical features specified in releases 15 and 16. An ambitious scope of work is under preparation and will be defined by the end of 2019. It may include:

- Transversal features: MIMO enhancement, coverage enhancement, small data transfer optimization, etc.
- Industry-specific features: Logistics, e-health, connected factories, etc.

03

GLOBAL SPECTRUM HARMONIZATION, NATIONAL EXCLUSIVE LICENSING, AND CONTIGUOUS SPECTRUM



3.1 Multiple spectrum bands are required to address the wide range of 5G use cases and applications

Spectrum harmonization between national regulatory authorities would support 5G development and the spread of 5G applications, as harmonization enables economies of scale and facilitates cross-border coordination and roaming for end users.

A multi-layer spectrum approach is required to address the wide range of 5G use cases:

- The "Coverage Layer" exploits spectrum below 2 GHz (e.g. 700 MHz) providing wide-area and deep indoor coverage. When used in combination with bands in the 3,300-3,800 MHz range, the pairing allows operators to benefit from their features, thus delivering enhanced capacity and coverage.
- The "Coverage and Capacity Layer" is spectrum in the 2 to 6 GHz range (e.g. C-band) that delivers the best compromise between capacity and coverage.
- The "Super Data Layer" is spectrum above 6 GHz (e.g. 24.25–29.5 and 37–43.5 GHz), used to address specific use cases requiring extremely high data rates (e.g. FWA and hotspot).

National governments and regulators should focus on making large blocks of contiguous spectrum available in these ranges (80 to 100 MHz per network in the Coverage and Capacity Layer, 800 MHz in the Super Data Layer), because fragmentation can impact spectrum efficiency and can drive up costs.

More medium-frequency bands will be required in the next wave of 5G development (i.e. in 5–10 years) in order to provide better 5G coverage and capacity. Spectrum between 5925–7125 MHz, within the medium-frequency range, is a good candidate, as it provides a good balance between coverage and capacity. As incumbent services already occupy this band in some countries, Huawei recommends creating a new WRC-23 Agenda Item to study the sharing and compatibility between IMT and incumbent services and to consider IMT identification based on ITU-R studies.

3.2 Regulatory frameworks need to be supportive of 5G deployment and applications

3 key points arise regarding regulatory frameworks:

- Regulatory frameworks should embrace the principle of technology and service neutrality for the smooth introduction of the latest technologies and services in existing and new bands. They should allow uplink spectrum sharing between LTE and NR.
- National licenses should remain the main and preferred authorization model for access to 5G spectrum, as they give operators the confidence to invest, and support predictable network performance and service quality.

National licenses as the main and preferred authorization model for accessing 5G spectrum

Huawei recommends a consensus approach to spectrum authorization, involving all stakeholders at the national level. Consensus should be based on ample discussion and studies, especially on market demand and spectrum supply. In the first wave of spectrum awards worldwide, most regulators granted national licenses in priority or exclusively to MNOs, with MNOs providing network access and solutions to vertical sectors using slicing technologies.

These licenses are allocated through auctions in most countries. Keeping prices reasonable is key to protecting MNOs' capacity to invest in technology. Coleago Consulting analyzes the sustainability of spectrum cost by comparison with the expected revenues generated by the future network. A spectrum cost lower than 5% of the expected annual revenues is considered likely to be sustainable; spectrum costs higher than 10% of expected annual revenues may harm network sustainability. In some markets, spectrum is allocated using alternative models. For example, in Japan, frequencies were allocated to MNOs after an application process (beauty contest).

- Network synchronization should be considered to mitigate harmful interference.

Network synchronization need to be incentivized and supported
Network synchronization plays a critical role in spectrum efficiency, interference mitigation, and the simplification of filters. National regulators may verify and study the appropriate technical specifications, such as the uplink/downlink ratio, and mechanisms to control harmful interference.
Network synchronization has been successfully implemented in 4G TDD networks, ensuring efficient use of spectrum resources by eliminating the need for guard bands between operators' spectrum blocks. Inter-operator synchronization and the alignment of uplink/downlink transmissions (slot and frame synchronization) will also be necessary for the efficient deployment of 5G-NR networks. Therefore, regulation should facilitate synchronization to make the best use of the valuable 5G spectrum resources.

04

5G APPLICATIONS REPRESENT TREMENDOUS OPPORTUNITIES FOR THE ECONOMY AND SOCIETY

4.1 5G is more than just business: It will have an induced impact on key socio-economic issues

Traditional broadband, hardware, and services revenue for telecom operators is expected to grow at 1% p.a. between 2019 and 2035. 5G will bring new opportunities for mobile operators (c. USD 600 bn by 2035) and will drive an estimated growth of 3% p.a. for the telecommunications industry as a whole between 2019 and 2035. 5G will make up c. 80% of service provider revenues, due to new business opportunities (industrial applications) and substitution of current 2G/3G/4G mobile broadband revenues[4].

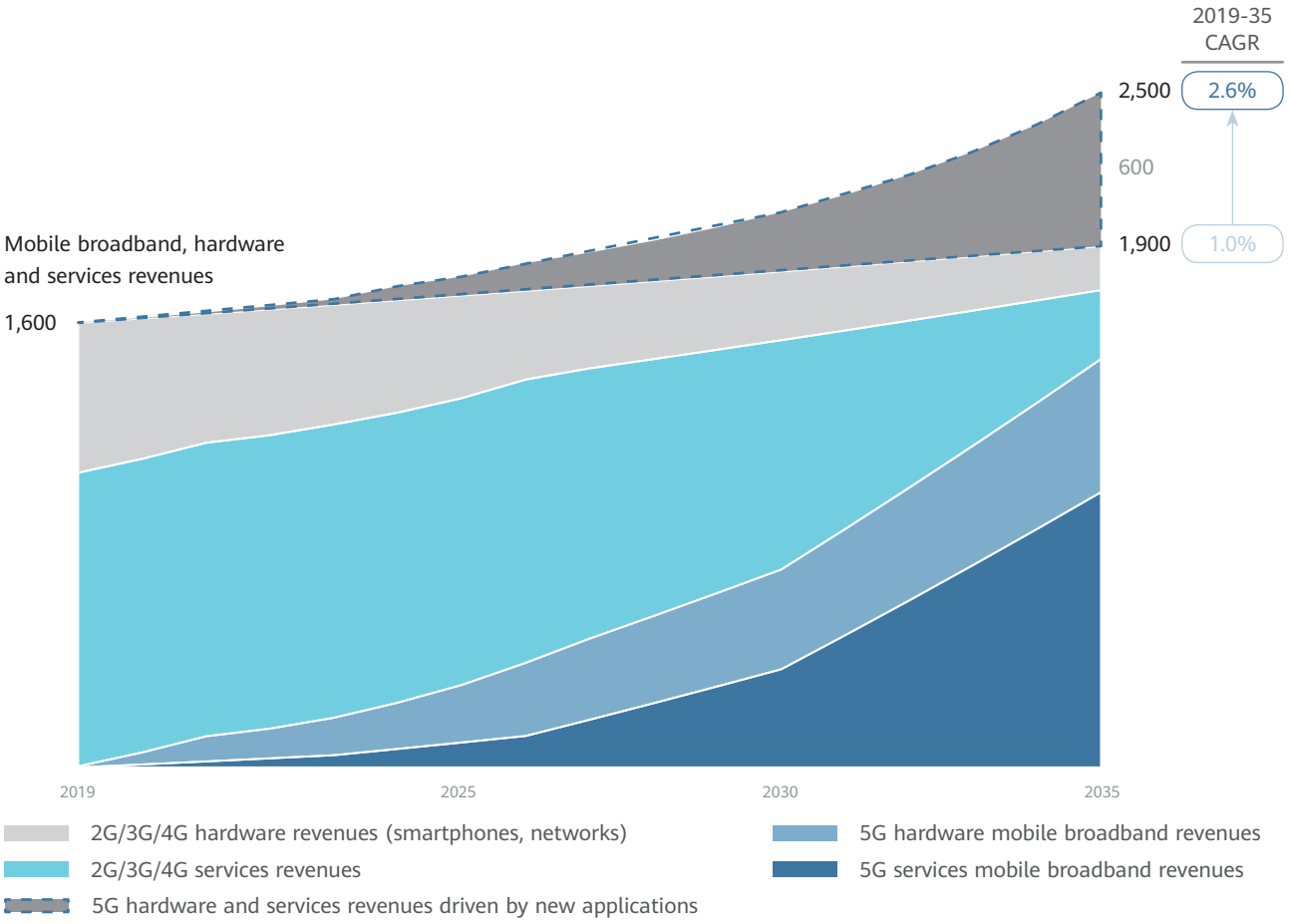


Figure 4: Hardware and services revenues for telecommunications companies (operators, vendors, infrastructure) generated by mobile broadband and new 5G applications [USD bn, 2019 - 2035]

Sources: The Business Research Company, Mason, Technavio, GSMA, expert interviews; Roland Berger analysis

The provision of 5G network and 5G application services with customized levels of service (slices) could enable new business models for operators and industry stakeholders. 5G is expected to enable up to USD 12 trillion of economic output in 2035, which will represent about 4.6% of the global output[5].

[4] Roland Berger analysis

[5] IHS Markit, The 5G economy: How 5G technology will contribute to the global economy, January 2017

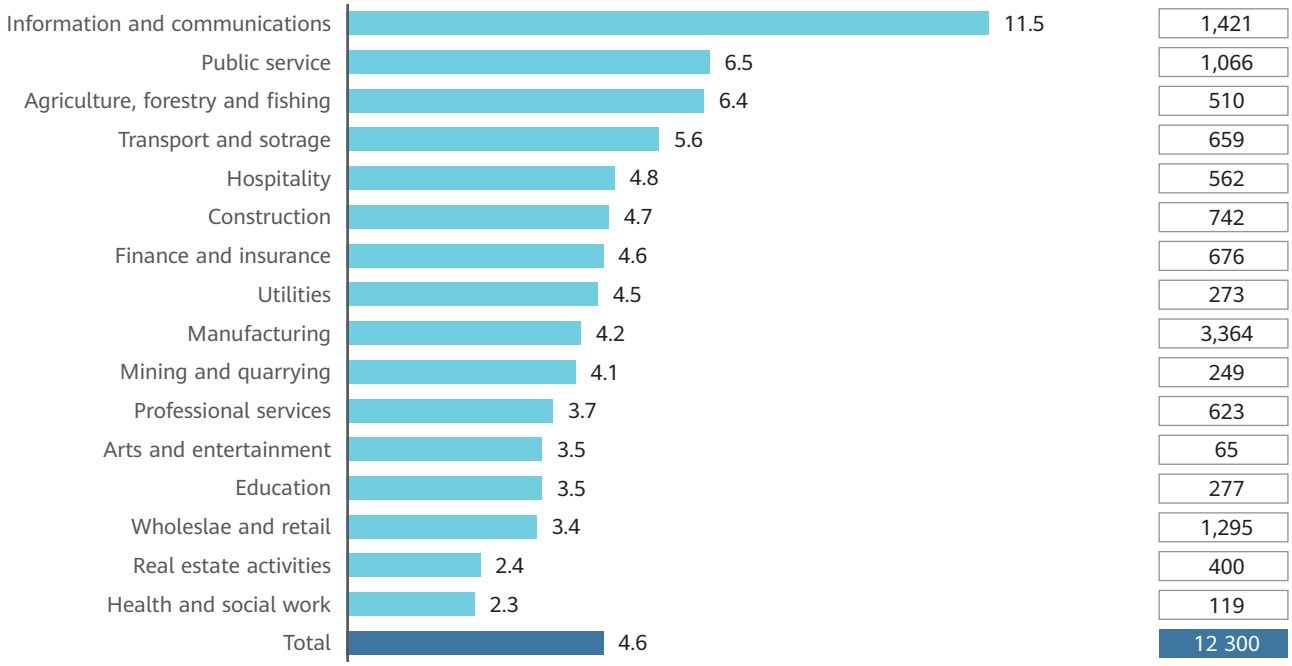


Figure 5: Global output of 5G in 2035 [% of total output; 2016 USD bn]

Sources: IHS Markit, Roland Berger

5G represents tremendous opportunities for the economy and all members of society: consumers, homes, businesses, and communities. The potential savings and improved efficiency of new technologies will trigger the democratization of many services. Connectivity will bring more information and education to all populations. New business opportunities across many different industries will boost investment and employment. By expanding the scope of wireless technologies and making devices more autonomous, 5G will help with the long-term objective of reducing our carbon footprint and conserving natural resources. 5G will be more inclusive, progressive, proven, and powerful than any previous generation of communications technology.

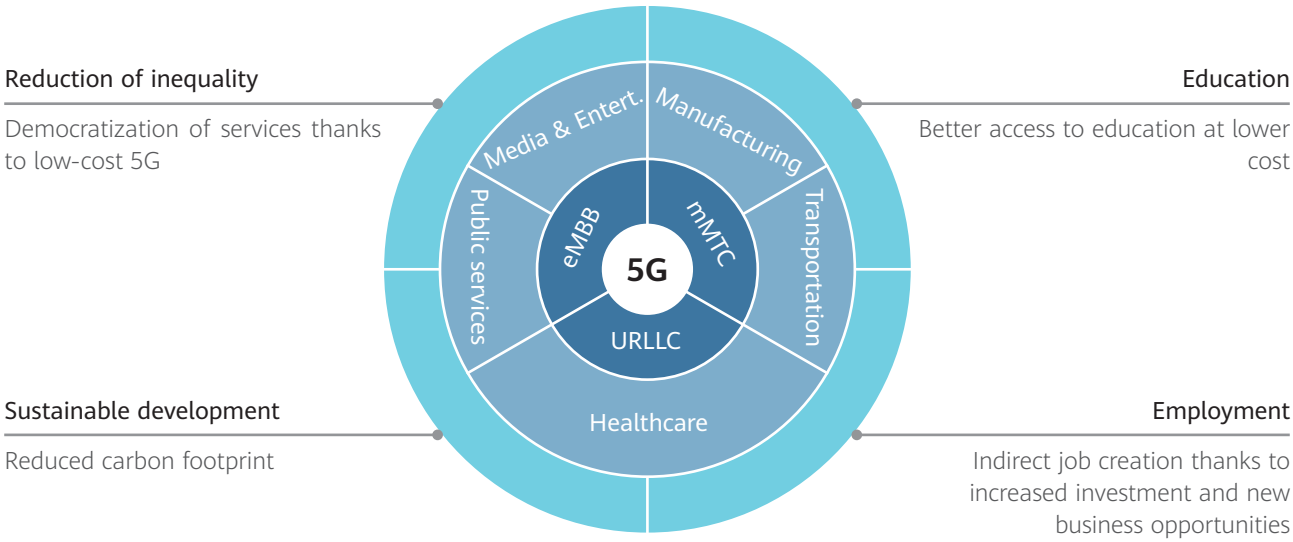


Figure 6: Socio-economic impacts of 5G

Source: Roland Berger

4.2 The industries that will leverage 5G to renew their business models and create more value

There are a number of industries with particularly intense dynamics and business opportunities around 5G: telecommunications, media and entertainment, manufacturing, transportation and public services. Each of these sectors has specific business issues linked to 5G and its potential use cases, some of which are already being explored in pilot projects.

4.2.1 Telecommunications

Telecom stakeholders are the frontrunners in pursuit of 5G opportunities, which will represent the majority of their revenues at the 2030–2035 horizon. 5G may be a solution to some of the problems the telecommunications industry currently faces, including the growth in data consumption. With 5G, mobile operators aim to improve the total efficiency of data provision to customers by building more capacity.

Main 5G opportunities

Currently, telecoms stakeholders are focusing on creating and expanding 5G coverage at a national scale, starting with local pilots. Superfast Fixed Wireless Access (FWA) is an opportunity to help governments to deliver on the promise of high-quality, universal broadband access to homes, especially in low density areas.
Edge computing as an evolution of cloud computing brings computation and data storage closer to the location where it is needed. It is expected that edge computing will play an essential role in the transformation of the telecommunications business: wireless carriers have a big advantage in the edge-computing race, as they control access to 5G high speed telecommunication networks.

5G network requirements

While 4G can reach speeds up to 100 Mbps, it is expected that 5G will enable speeds up to 1 Gbps, changing the scale at which telecommunications currently operates. With more power and improved efficiency, 5G may be the pathway towards connecting the world with greater ease.
Fixed wireless broadband networks using mainstream LTE-Advanced technology are proving capable of delivering fast, high-quality connectivity. 5G FWA will take fixed wireless to the next level, boosting speeds closer to 1 Gbps[6].
5G networks are a future environment for Multi-access Edge Computing (MEC) deployments. MEC applications interact with the 5G system to influence the routing of traffic for edge applications and to obtain notifications of relevant events, such as mobility events, for improved efficiency and a better end user experience.

Use case	Specific scenario	URLLC (ms/%[1])	eMBB (Mbps)	mMTC (density)
eMBB for smartphones	Smartphones enabling better connectivity and higher speed	<20	100	Low to medium
	Enhanced TV and video services	<20	100	Low to medium
Fixed Wireless Access (FWA)	Improved residential connectivity in less-densely populated areas	<20	1,000	Medium

[6] Ovum, Fixed Wireless Access: Changing the Face of Home Broadband Connectivity, 2018

Edge computing	Closer and faster link between data centers and customers	<20	1,000	Low

Sources: Ovum, Huawei, expert interviews

Market development insights

Commercial 5G network services and 5G hardware are expected to progressively replace current 2G/3G/4G offerings, and will make up c. 80% of the market by 2035.

FWA could become one of the major applications for 5G in the short term. The 5G Fixed Wireless Access market is expected to grow from less than USD 1 bn in 2019 to almost USD 50 bn by 2026 (annual growth of 97%)[7].

5G smart terminals

- Huawei and leading Swiss operator Sunrise announced the launch of 5G smart devices in Switzerland in May 2018. 5G coverage is available at the Sunrise Experience Store through Huawei's indoor coverage system
- Users can experience 5G network services using the Mate 20 X (5G) smart device for CHF 10 per month (CHF 997 for the phone)
- Sunrise uses Huawei's end-to-end 5G technology, including both networks and devices. The operator is leading 5G network deployment in Switzerland, with 173 towns covered already. Up-to-date information on 5G network coverage can be obtained on the Sunrise website. Sunrise plans to achieve 5G coverage of all of Switzerland by the end of 2019

Source: Huawei press release

4.2.2 Media and entertainment

Media and entertainment is one of the first sectors in which 5G will be widely used. Use cases will be deployed immediately. 5G can provide high quality audio-visual services and the ability to share live-videos over social media.

Main 5G opportunities

Thanks to the new network capabilities brought by 5G, annual mobile media revenues will double in the next 10 years to USD 420 bn in 2028. 5G will facilitate multicasting and HD mobile video: Image processing capabilities can be located on the cloud with secure, low latency connections that aggregate multiple image sources.

5G will enable augmented reality and virtual reality applications that will generate more than USD 140 bn in revenues between 2021 and 2028.[8] 5G will also unlock the market potential of volumetric 3D content and its ecosystem. Gaming will be at the forefront of 5G-led innovation, using AR technology. Fast responsiveness, high resolution, and real-time streaming will also help unlock gaming over mobile cloud. The revenues from 5G mobile games will exceed USD 100 bn per year by 2028.[8]

In the longer term, 5G will enable tactile feedback, thanks to highly responsive haptic suits combined with advanced VR capabilities. This new VR experience will flourish by 2025 and will generate over USD 5 bn annually by 2028.[8]

5G network requirements

With the increase in data consumption, 5G needs to accommodate enhanced mobile broadband and high density of devices. The seamless integration of different network technologies will foster mobility and consumption of services with zero interruptions.

Use case	Specific scenario	URLLC (ms/%[1])	eMBB (Mbps)	mMTC (density)
High definition streaming	Multicasting image treatment	<20	100	Medium to high
	HD mobile video	<20	100	Medium to high
Augmented Reality and Virtual Reality (AR/VR)	Augmented reality services in real time	<20	100	Medium to high
	Immersive gaming and/or training	<20	100	Medium to high
	Advanced VR capabilities (haptic touch, 3D holographic display)	<20	100	Medium to high

Sources: Wireless X Labs, EU BEREC, Huawei

Market development insights

5G will start to realize its full transformational potential from 2022 onwards with the adoption of AR and VR. Immersive and new media applications will reach scale at a later stage within the next decade.

5G rollout and fast adoption of VR & AR in South Korea

- South Korea is one of the most advanced 5G markets and among the first places to launch 5G AR/VR.
- In April 2019, 50% of the population had access to a 5G network built by one of the three national operators, and early versions of 5G VR/AR were already available. By June 2019, there were more than 1 million 5G users – faster than initial uptake of 4G. Meanwhile, the first cloud VR/AR solution using 5G (LG U+) went online.
- 1/3 of 5G users are VR/AR users, a very high adoption rate. 5G AR/VR business models have developed fast, inspired by mobile video models (traffic management, prime service content and exclusive headsets)

Sources: Huawei press release, LG U+, SKT, KT

[7] https://www.globenewswire.com/news-release/2019/03/21/1758742/0/en/46-36-Bn-5G-Fixed-Wireless-Access-FWA-Market-by-Offering-Demography-Application-and-Region-Global-Forecast-to-2026.html

[8] Ovum, How 5G will transform the business of media and entertainment

4.2.3 Manufacturing

Industry 4.0 is expected to be fueled by cyberphysical systems and the Internet of Things, which will require the support of 5G networks. This will enable the efficient, connected, flexible factories of the future.

Main 5G opportunities

Inside factories, 5G will facilitate manufacturing procedures, including more efficient production lines (e.g. with machine vision, and high definition video for managing processes), AGVs in factories (e.g. autonomous transportation) and machine control, with latency of less than 5 ms using URLLC.

Outside factories, 5G could help the manufacturing sector to improve product lifecycle management, for example by enabling predictive maintenance and bringing responsive design to products. Communication between companies can also be facilitated by 5G, enabling better end-to-end tracking of goods at lower cost, or data exchanges for simulations or collaborative design.

5G network requirements

Indoor mission–critical processes have stringent requirements. In order to deliver ultra-low latency and ultra-high reliability in a heterogeneous environment, further enhancements to 4G and 5G technologies will be necessary.

Exploiting product lifecycle data from connected goods will also require new technologies, featuring minimal energy consumption, ultra-high autonomy, and low subscription costs.

Use case	Specific scenario	Availability	Cycle time	Typical payload size	# of devices	Typical service area
Motion control	Printing machine	>99.9999%	< 2ms	20 bytes	>100	100mx100mx30m
	Machine tool	>99.9999%	< 0.5ms	50 bytes	~20	15mx15mx3m
	Packaging machine	>99.9999%	< 1ms	40 bytes	~50	10mx5mx3m
Mobile robots	Cooperative motion control	>99.9999%	1ms	40-250 bytes	100	< 1 km^2
	Video-operated remote control	>99.9999%	10-100ms	15-150 kbytes	100	< 1 km^2
Mobile control panels	Assembly robots or milling machines	>99.9999%	4-8ms	40-250 bytes	4	10mx10m
	Mobile cranes	>99.9999%	12ms	40-250 bytes	2	40mx60m
Process automation(process management)		>99.99%	> 50ms	Varies	10000 devices per km^2	

Source: 5G-ACIA, ZVEI

Market development insights

The pioneer is Germany, which launched the 15-year "Industry 4.0" plan in 2011. The government is supporting research, the building of cross-industry networks, and standardization.

The U.S., which represents 17% of the world's manufacturing output,[9] released a national plan in 2018 to support "American leadership in advanced manufacturing". This leadership will be achieved notably through the development of and transition towards new manufacturing technologies.

Worcestershire 5G testbed

- The testbed in Worcestershire is exploring ways to increase productivity by using robotics, big data analytics and augmented reality with 5G in a manufacturing setting. Global experts and partners are involved in trials at the Worcestershire 5G testbed, a government-backed program.
- The Worcestershire 5G Consortia will explore:
  - Increased productivity in manufacturing
  - Detection
  - Remote maintenance
  - New models – manufacturing as a service ‘Security by design’
  - Training the next generation 5G engineers

Sources: gov.uk, uk5G.com, zdnet.com

4.2.4 Transportation

The automotive industry has been an early adopter of various connectivity technologies. There has been a major impetus by car manufacturers to develop connection-ready cars, taking small steps forward within a long-term vision of autonomous vehicle control using eMBB and URLLC.

Main 5G opportunities

5G will bring improvements to services in the automotive industry in the form of vehicle-to-everything (V2X) communications on the path to autonomous driving, but also in the form of improved in-car 'infotainment'. As cars become more connected and collect a larger amount of data (location, usage, performance, telematics), opportunities also open up for remote diagnostics, pay-as-you-drive insurance models, and driver assistance using 5G technology.

Such use cases can be transposed at a later stage to other forms of transportation such as rail, air transportation, ports, etc.

5G network requirements

5G may be helpful for use cases associated with autonomous driving and V2V telecommunications, and some in-car infotainment services. 5G can support real-time, low latency exchange of data in a mobile context.

The connected car concept extends beyond V2V communication. It also requires communication with infrastructure (V2I) and pedestrians (V2P). Taken together, these are referred to as V2X communication. An increasingly popular solution for V2X communication is Cellular-Vehicle-to-Everything (C-V2X), the C referring to 4G or 5G.

Beginning in Release 16, 5G-V2X will offer improved features for autonomous driving. Specifically, short range direct communications will rely on 5G capabilities (lower latencies and increased bandwidth). [10]

[9] OECD

[10] 5GAA, Timeline for deployment of C-V2X

Use case	Specific scenario	URLLC (ms/%[1])	eMBB (Mbps)	mMTC (density)
V2X communication	Collision avoidance and emergency braking	<5		Low
	Intelligent traffic systems (Vehicle-to-Infrastructure)	<5		Medium
Platooning	Truck convoy system	<5/ 99.99%	10	Medium
Advanced driving	'See through' the front vehicle In-dash junction cameras	3/ 99.999%	30	Medium
Remote driving	Multiple real-time HD video feeding remote driver Remote control	5/ 99.999%		Medium
In-car infotainment services	On-demand entertainment services Traffic management Enhanced GPS, weather and location-based services	10	>10	Low
Data collection	Pay-as-you-drive insurance		>10	Medium

Sources: Huawei, EU BEREC

1. Latency in milliseconds, reliability in %

Market development insights

Vehicle manufacturers forecast that they will begin production of vehicles with the C-V2X communications chipsets and communication modules in 2019 to enable them to be on track to hit the market in 2020–2021. BMW and PSA have already announced their plans. Ford announced that all new cars in the U.S. will be equipped with C-V2X from the beginning of 2022.

3GPP Release 16, which introduces additional features in 5G-V2X, is still in the specification phase. First deployments using R16 may be expected in 2021 at the earliest.

Market maturity will also be driven by commercial issues, as cost savings are highly tangible in the connected car case. For instance, truck platooning decreases fuel consumption by 10%.

5G remote driving

- A trial of 5G remote driving technology using an ordinary consumer car was held at the 2017 Mobile World Congress in Shanghai. Huawei provided 5G wireless solution connecting SAIC Motor's smart car (iGS), while China Mobile provided the 5G connectivity.
- The driver was located over 30 kilometers away from the vehicle and was able to maintain full control at all times. High definition video cameras installed in the vehicle sent multiple streams of real-time HD videos to the driver, providing him with a 240-degree view over 5G network.
- Control signals for the steering wheel, gas pedal, and brakes were also transmitted over the 5G network with ultra-low latency.

Source: Huawei press release

4.2.5 Public services

The global demand for better healthcare continues to grow, and costs are rising, up from 8.5% of total GDP in 2000 to over 10% in 2016[11]. As well as its positive economic impact, 5G can bring sustainable health benefits and improved quality of life.

Main 5G opportunities

5G opportunities in healthcare rely on a combination of massive IoT and enhanced broadband to support telemedicine. 5G will help to improve diagnoses requiring multiple connections at a remote site (e.g. patient dialysis at home, or remote control of medical equipment). Telemedicine and connected equipment inside hospitals will be possible using 5G.

5G network requirements

Smart emergency vehicles, remote sensor networks and other wearable devices all demand rapid data transmission and low latency to function effectively.

Use case	Specific scenario	URLLC (ms/%[1])	eMBB (Mbps)	mMTC (density)
Smarter medication	Remote therapies, connected medication	<10	<10	High
	Enhanced therapies: multiple connections, telemedicine	100	10	Medium
Wireless tele-surgery	Wireless telesurgery with a robot	<1/ 99,999%	10-15	Low
Asset management in hospitals	Tracking equipment location and usage inside the hospital	100	<10	High

Sources: Wireless X Labs, EU BEREC, Huawei, expert interviews

1. Latency in milliseconds, reliability in %

Market development insights

Based on projected timelines, 5G opportunities in public services are expected to scale up in 7 to 10 years. Most current pilots are extensions of telemedicine initiatives or connected devices that already exist and can be easily scaled up (e.g. video).

[11] World Bank: World Health Organization Global Health Expenditure database

5G remote surgery

- Huawei, China Unicom, Fujian Medical University Hospital and Suzhou Kangduo Robot Co. collaborated on a trial 5G remote surgery.
- The surgeon’s actions were transmitted in real time through 5G technology so that a surgical robot could perform hepatic lobectomy on the experimental animals. The remote control link and the two video links were all carried on the 5G network.
- The entire procedure took about 60 minutes and the lag was extremely small. The surgical wounds were neat, and there was no trace of blood throughout the whole process. The vital signs of the experimental animals were stable after surgery.
- The surgeon's feedback regarding the network was very positive: "Based on my experience using the 5G network, it delivered the same experience on the high-definition video as a fiber-optic connection."

Source: Huawei press release

4.3 New business models emerging in pilot programs, combining multiple stakeholders to deliver innovative services

The rise of 5G could lead to the changes within the connectivity industry, evolving the traditional business models of telecoms operators. Operators and industry stakeholders will collaborate to build new value models.

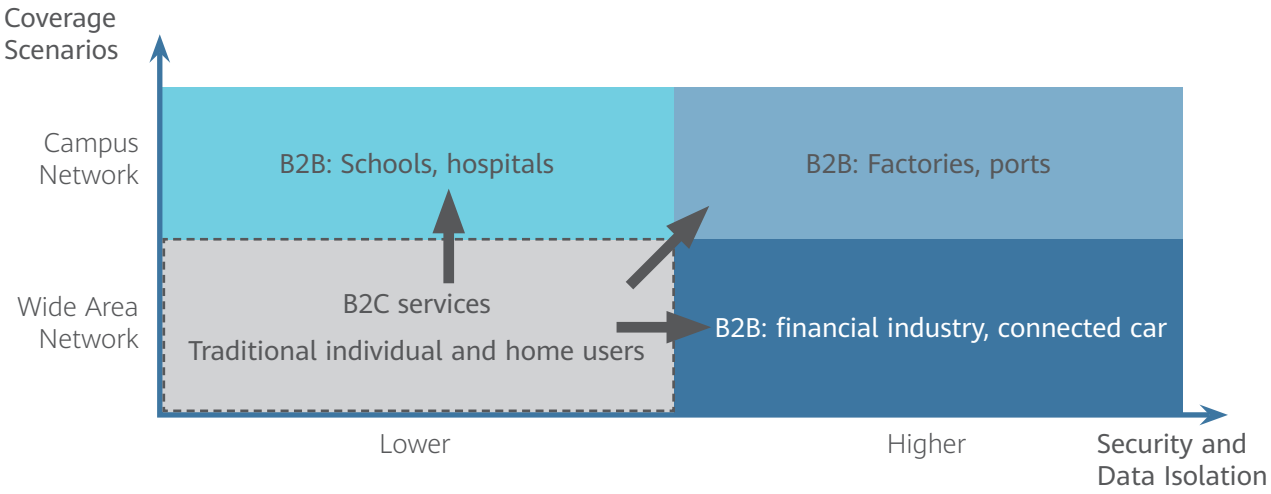


Figure 7: New service opportunities for operators

Sources: Huawei, Roland Berger

The diversity of services and end users brought by 5G technology has opened up new business models for operators and industry stakeholders. Today, operators face a more diverse range of demands: the need for increased security and isolation (e.g. data privacy in factories), more local and denser coverage of key areas. Collaboration with industry stakeholders will deepen so that operators and their partners can build networks customized to specific needs.

A model based on the public network could be efficient. The network can be owned by operators, or by new players offering network slicing and/or APN services in collaboration with the infrastructure owner. The industry stakeholders may typically leverage the public network via slicing technologies without having to bear the costs of a privately-owned network. The operators' networks would be so powerful that they could meet the end users' customized needs in terms of data isolation and management.

05

HEALTHY, PRODUCTIVE, AND SUPPORTIVE 5G ECOSYSTEM FOR SUSTAINABLE INNOVATION

The broad adoption and sustainable development of 5G applications will require more than just advanced technologies and sound business models. 5G also needs a supportive external environment.

5.1 Governments and regulators define 5G plans and initiatives, with greater transparency in regulatory policies

Most governments have invested time and effort into creating a supportive regulatory environment, through:

- Engaging with the international standardization process
- Streamlining procedures to allow timely infrastructure deployments and spectrum availability
- Adapting telecommunications and sectoral regulations to 5G needs
- Anticipating public infrastructure sharing
- Stimulating experimentations (e.g. economic incentives, bringing together stakeholders)

As infrastructure underpins the development for all stakeholders, regulatory efforts should focus on creating an adequate framework for 5G infrastructure.

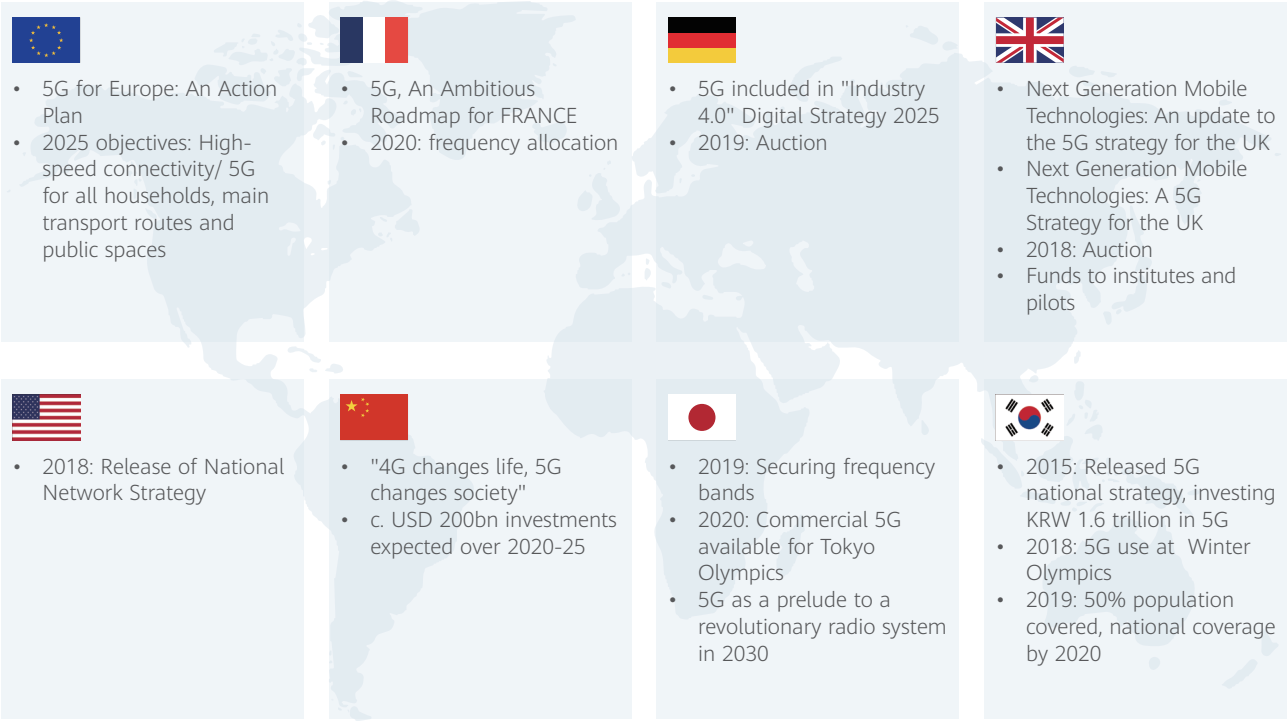


Figure 8: 5G national strategies

Source: Roland Berger

5.2 Regulation of other industries must evolve, which will require cooperation between institutions

With 5G involving many stakeholders in new use cases, industry regulation will need to be updated. Telecommunication regulators and the regulators of other verticals will need to collaborate closely to develop supportive regulations, and nurture business opportunities while ensuring safety at all levels.

For example, the use cases in transportation (e.g. autonomous driving) and healthcare (e.g. remote surgery) will need specific regulations on liability law. A collaborative approach involving multiple government agencies will be necessary.

5.3 Stakeholders should coordinate to build the capabilities required for potential applications, target business models, and the 5G ecosystem

Industry associations should work together with research institutes, operators, equipment vendors, and other industry players to achieve common objectives:

- Understanding and aligning on the needs of specific verticals
- Meeting the needs of verticals in standards
- Exploring commercial use cases and business models across verticals and fostering advanced research

Some sectors are leading the way in terms of collaborating and coordinating on 5G developments:

- 5GAA (5G Automotive Association) coordinates with the European regulator to promote C-V2X as a technology option. Industry stakeholders collaborated on the white papers concerning scenarios, roadmap, and key technical requirements.
- 5G-ACIA (5G Alliance for Connected Industry & Automation), was founded in 2018 with the goal of applying industrial 5G in the best possible way.
- 5G AIA, dedicated to the commercial development of industry use cases, encompasses 5 working groups from different verticals, which work to build coordinated value chains for their respective industries. There is also an Investment & Financing Group which is responsible for incubation funds to develop 5G industry pilot projects.

06

GLOSSARY

3GPP: 3rd Generation Partnership Project

5G-ACIA: 5G Alliance for Connected Industries and Automation

5G AIA: 5G Applications Industry Array

5GAA: the 5G Automotive Association

API: Application Programming Interface

B2B: Business-to-Business

B2C: Business-to-Consumers

CAPEX: Capital Expenditures

CAPIF: Common API Framework

C-V2X: Cellular-Vehicle-to-Everything

DSRC: dedicated Short-Range Communication

eCAPIF: Enhanced Common API Framework

FDD: Frequency Division Duplex

FRMCS: Future Mobile Communications System for Railways

FWA: Fixed Wireless Access

IMT-2020: International Mobile Telecommunications 2020 – requirement issued by the ITU-R for 5G networks, devices and services

ITS: Intelligent Transport Systems

ITU: International Telecommunication Union

ITU-R: International Telecommunication Union Radiocommunications sector

LGA: Land Grid Array

LTE-A: Long Term Evolution Advanced

M.2 / NGFF: Next Generation Form Factor

MC: Mission Critical

MEC: Multi-access Edge Computing

MIMO: Multiple-Input Multiple-Output

mIoT: massive Internet of Things

mMTC: massive Machine Type Communications

MNOs: Mobile Network Operators

NR: New Radio

OPEX: Operating Expenditures

PDC: Personal Digital Cellular

SDOs: Standard Development Organizations

TDD: Time Division Duplex

TSG: Technical specification groups

V2V: Vehicle-to-Vehicle

V2X: Vehicle-to-everything

WLAN: Wireless Local Access Network

WRC: World Radiocommunication Conference

WTTx: Wireless to everything

XR: Extended Reality

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