Strategic Settings for 6G: Pathways for China and the US

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Executive Summary

6G wireless telecommunications is a key emerging technology that has already become a field for international strategic competition, most notably between the United States and China. By dramatically increasing capacity and lowering latency for wireless-data transmission, 6G promises to enable applications on new orders of magnitude or which are qualitatively new. These effects will translate into comparative national economic performance and into military capabilities available to states.

6G's performance parameters are still being defined, and its enabling technologies are still in relatively early stages of research and development (R&D). However, both the US and China, motivated by their intensifying strategic rivalry, are already prioritising the technology's development and exploring its potential for military uses.

Whereas national-security concerns around 5G are focused on its potential for espionage or sabotage through the presence in networks of equipment from politically untrusted actors, 6G will directly impact the international balance of military capabilities. For example, one of 6G's expected military uses is rapid, reliable and secure transmission of much higher volumes of data between fast-moving military platforms, including in outer space for ballistic-missile early warning.

To date, Washington has not prioritised development of next-generation telecoms to the extent that Beijing has, notably in deployment of 5G infrastructure and services. The upshot is long-term erosion of the US telecoms equipment industry. At the same time, the US still has strengths in its innovation ecosystems and in that US firms are well-positioned in key enabling technologies for next-generation telecoms, for example capabilities in software and semiconductors. The US is now shifting towards a more active government role in development of strategic emerging technologies, including 6G. Washington is also pursuing partnerships with allied and partner nations to accelerate as well as coordinate technological developments in ways that increasingly exclude China and capitalise on US strengths.

China's approach to technological development is state led, and it seeks to channel all the nation's resources under direct government influence and to manipulate markets and global standards setting in Beijing's favour. This statist approach has helped Chinese firms and research institutions immensely. From a negligible role in the global telecoms industry in the 1980s, China now holds advantageous positions in many aspects of 5G wireless telecoms, providing a strong foundation for further progress. This is reflected in metrics for 6G development such as patent filings and real-world implementations of relevant enabling or precursor technologies. However, China's capacity to develop 6G faces major constraints from continuing reliance on foreign technological inputs and US targeting of these dependencies through export controls as well as other measures.

Given the potentially significant effects of 6G on national security and economics, coupled with increasingly diverging geopolitical interests between the US and China, competition in this field among the two powers alongside other technologically capable states is expected to intensify. This contestation will increasingly extend to third-party markets as more countries build next-generation telecoms infrastructure – with implications for international technological ecosystems and the global balance of technological power.

Specification of 6G parameters and technical standardisation is still several years away with commercial availability of 6G technologies expected by the late 2020s. The coming years thus provide a window to frame policy-research agendas for 6G and to examine the underlying drivers of innovation ecosystems for future wireless-telecoms development. This requires a grasp of the basic nature of the technology and its applications, the relative positions of the US and China in its development and the way these two states' intensifying rivalry will shape evolution of a global telecoms industry that has become highly transnational and commercially driven.

This report first outlines the technological basics concerning 6G and its envisaged applications. It then reviews how the US and China have arrived at their current positions in the development of wireless telecoms. Next, the report examines academic collaboration and knowledge networks between the two countries and third parties, the role of government in the US and China in 6G development, and the role of industry in each power. The study then looks at international standards setting as an aspect of this national competition and at the broader international politics of 6G. Finally, the report assesses the defence and security implications of 6G.

Chapter One: 6G: Technical Fundamentals, Enabling Technologies and Envisaged Uses

6G is expected to deliver major boosts to various telecoms performance metrics such as capacity, latency, reliability and efficiency (in terms of both spectrum usage as well as energy usage).[1] Networks built to 5G specifications already promise significant capability improvements, but they cannot meet the requirements of various emergent applications like multi-sensory extended-reality applications, multi-way virtual meeting with holographic projections, remote surgery and autonomous robotics.[2] 6G wireless networks will exploit higher-frequency ranges of the electromagnetic spectrum that are not currently used by telecommunications. Development of 6G technologies is focused on the 95 gigahertz to 3 terahertz (THz) frequency range: the US government began licensing this spectrum range for experimental development in 2019.[3] The table below shows a selective representation comparing technical parameters of 5G and 6G.

Technologies commonly cited as potential applications of 6G include pervasive artificial intelligence (AI), 3D communications infrastructure and terahertz communications technologies.[4] Although AI is already being used in 5G networks, current techniques still rely on centralised learning and have yet to realise a truly distributed learning mechanism at the edge of networks, with significant intelligent functions residing in terminal devices rather than the network core.

Table 1: **Comparison Between Key Performance Indicators (KPIs) of 5G and 6G***

KPIs	5G	6G
Data rate (download)	20 gigabytes per second (Gbps)	One terabytes per second (Tbps)
Data rate (upload)	10 Gbps	One Tbps
Latency (radio-interface)	One millisecond	0.1 millisecond
Traffic capacity	Ten megabytes per second (Mbps)/m^2	1–10 Gbps/m^3
Reliability	10^{-5}	10^{-9}
User experience	50 Mbps 2D everywhere	10 Gbps 3D everywhere

*Emilio Calvanese Strinati et al., '6G: The Next Frontier', *arXiv*,16 May 2019, p. 5, http://arxiv.org/abs/1901.03239

Given the propagation characteristics of the short wavelength frequencies 6G is likely to use, networks based on existing cellular architectures may not be commercially viable, meaning that 6G may instead use more distributed and dynamic (cell-free) network architectures that will be enabled by intelligent end-point devices.[5]

Further progress in AI will be required to realise self-sustaining 6G networks capable of adapting their functions, resource usage and spectrum management according to strict requirements of differing applications.[6] Regarding 3D communications infrastructure, research on the 3D-propagation environment, frequency and networking planning would be required to effectively integrate terrestrial, airborne and satellite networks.[7] Terahertz communications face challenges from susceptibility to high propagation loss and molecular absorption, necessitating further study on antenna and circuitry technology.

Other 6G-enabling technologies currently under research include communication with large intelligent surfaces, data transmission using the visible light spectrum as well as technology and quantum communications.[8] Continued advances in microprocessors will be needed to deliver the processing power and energy efficiencies required by 6G devices.

Beyond improving 5G functionalities and user experience, 6G is envisioned to introduce revolutionary applications with wide-ranging economic, security and socio-economic impacts. Three commonly cited 6G use-cases are outlined below to give an impression of the technology's potential.

6G is expected to enable extended- or augmented-reality services integrated with sensory inputs, holographic projection and haptic communication.[9] For example, 3D representations of a person could be accurately replicated across the world, and human sensory data could be transmitted to provide a truly immersive user experience. Such 'multi-sensory holographic teleportation'[10] has many applications such as remote surgery and military uses like virtual reality-enabled personnel training and enhanced battlefield situational awareness.[11]

6G could also greatly enhance the performance of connected robotics and autonomous systems.[12] Automating industrial-control networks in high-precision manufacturing requires extremely low delay jitter and high reliability.[13] With 6G-enabled levels of reliability, low latency and high data-transmission rates (measured in terabytes per second), fully autonomous vehicles equipped with advanced AI and sensors could share traffic and hazard data in real time so as to ensure passenger safety.[14] The same capabilities could also be applied to autonomous robots and other networked systems and platforms in military scenarios.[15]

In addition, 6G connectivity would enable new wireless brain–computer interactions (BCI) scenarios. Microdevices implanted in the body could monitor biological processes to detect developing diseases and allow for remote analysis.[16] BCI has obvious e-health applications, but is also useful for defence purposes, such as enhancing cognitive capability in military personnel and deploying mind-controlled drones.

An idea of the potential enhancements to military performance is provided by a 2020 commentary in a Chinese defence media outlet, which claims that 6G will enable:

- uninhabited intelligent reconnaissance with powerful sensing platforms able to intelligently process and disseminate the information they collect.
- more efficient command and control, through a system capable of 'intelligent learning, mining, analysis and application of big data on the battlefield'.
- real-time visualisation of combat operations, and thereby control of the battlefield through superior situational awareness.
- an integrated and adaptive security-information system that can better protect deployed forces and force generation resources in real time.[17]

Various commentators argue that 6G connectivity promises to achieve paradigm changes in effective integration of the physical, digital and biological worlds.[18] The potential of 6G as a pervasive public good also means that indicators representing sustainability and societal needs (for example, those relating to the United Nations Sustainability Goals), transparency, ethics and inclusiveness would ideally be incorporated in the design of 6G systems.[19]

Chapter Two: Development of the Wireless Telecommunications Sector

Modern telecommunications derive from the convergence of a long list of separate technologies.[20] During the second half of the twentieth century, telecoms technology became a global industrial enterprise led by firms from various industrialised countries, with global economies of scale and technological diffusion resulting in the worldwide adoption of wireless telecoms. With the spread and development of the internet, the range of components and contributors in the global telecoms technology ecosystem has diversified further. Wireless telecoms is now based on a sprawling network of technologies and actors, which is internationally distributed and extremely complex. An idea of this complexity is conveyed in a 2021 study that listed ten different sets of stakeholders divided between developers, researchers, law makers, standards bodies, consumers, vendors, telecoms manufacturers, internet providers, business consumers and private consumers.[21]

The umbrella grouping for global standards-setting activity for wireless telecoms, the 3GPP (Third Generation Partnership Project), embodies the multinational character of this technological ecosystem. The group has seven regional and national organisational partner bodies spanning the US, Europe and Asia. Its individual members include 439 entities from Europe (including the United Kingdom), 171 from China, 145 from India, 95 from the US, 46 from Japan, 15 from Finland, 18 from Sweden, nine from Taiwan and two from Russia.

Many of these actors are now engaged in 'pre-positioning' for 6G in anticipation of standardisation over the next few years and commercialisation from the late 2020s.[22] 6G development can currently be described as at a pre-competitive stage, with research being conducted into potentially profitable avenues for 6G applications, their associated requirements and key enabling technologies. Given the capital-intensive nature and technical complexity of these activities, many actors have entered research-and-development collaborations on various technologies behind 6G networking. These actors include major US, European and North Asian firms as indicated in Table 2 above. Not only do such open collaborations in the pre-competitive phase spur and sustain research momentum in 6G through close collaboration within industry and with academia, they also create breadth and heft for tech and telecoms firms to attract funding from various governments.

At 3GPP meetings, firms from the leading countries in telecoms technology are represented: notably South Korea (Samsung, LG), Japan (Fujitsu, NTT Docomo[23], NEC), the US (Cisco, AT&T, Qualcomm, Verizon), Europe (Nokia, Ericsson, Orange) and China (Huawei, ZTE).[24] By contrast, 6G Hexa-X is a solely European initiative. IOWNGF and the Next G alliance appear to be generally excluding Chinese companies like Huawei,

Table 2: **Selected 6G Collaborations**

US-initiated Next G Alliance	Headed by AT&T and Ericsson, comprising mainly US companies but also convening a host of leading ICT companies from Canada, Finland, Germany, Japan, South Korea and Taiwan. These include Qualcomm, Intel, Bell, Nokia, Samsung, NTT Docomo and MediaTek.
EU-funded Hexa-X project* and European 6G Industrial Alliance (6G-IA)**	Hexa-X is led by Nokia and Ericsson involving 25 organisations from France, Germany, Greece, Hungary, Italy, Spain, Sweden and Turkey. This initiative encompasses multinational firms such as Siemens, Atos, Intel Deutschland, Telefónica Orange as well as smaller ICT companies like Wings ICT Solutions and Nextworks. 6G-IA represents European private industry in partnership with the EU.
Global initiative – Innovation Optical and Wireless Network Global Forum***	Founded in January 2020 by NTT, Intel and Sony, the entity consists of more than 90 member companies from the US, Europe, Japan, South Korea and Taiwan, including Dell, Oracle, Chunghwa Telecom, Wistron, Fujitsu, NEC, Telefónica, Nokia, Samsung and Orange.**** Apart from business companies, academic and research institutes also form part of the network.

*See Hexa-X, 'About Hexa-X', https://hexa-x.eu/about/.
**See 6G-IA, 'About the 6G-IA', https://6g-ia.eu/about/.
***IOWN Global Forum, 'Members', https://iowngf.org/members/.
****Business Wire, 'Innovative Optical and Wireless Network Global Forum (IOWN GF) Triples Membership', 15 October 2020, https://www.businesswire.com/news/home/20201015005052/en/Innovative-Optical-and-Wireless-Network-Global-Forum-IOWN-GF-Triples-Membership.

China Telecom, China Mobile, China Unicom and ZTE, which are all pursuing 6G research and development. An exception is Futurewei Technologies,[25] a US-based research arm of Huawei, which is a member of the Next G alliance. Even as industry players advocate for cooperation in this pre-competitive phase of 6G development, the faint lines of geopolitical competition are emerging in these technology alliances as nations vie for superiority in this strategic technology.

Besides these large transnational coalitions, there are also smaller-scale 6G partnerships established across and within national borders. For example, SK Telecom has signed agreements with Ericsson, Nokia and Samsung to conduct R&D in 6G business models and technical requirements.[26] Chinese firms like China Unicom and ZTE have formed joint research programmes in 6G-related fields.[27] Smaller partnerships also facilitate targeted research in specific areas of 6G technology. In June 2022, Nokia announced partnership with Docomo and NTT to focus on two proof-of-concepts, namely the AI-based air interface for 6G and sub-THz radio access.[28]

It is evident that firms leading development and implementation of 5G technologies are currently the dominant actors in 6G development. Because 6G is an evolutionary progression from 5G, telecoms industry leaders can build on their existing capabilities in the transition to 6G networks.[29] The following section briefly reviews how the wireless telecoms sectors in the US and China respectively arrived at their current positions, and the foundation this has provided for 5G and 6G development.

The US Path Towards 5G and 6G

Although the US remains a world leader in many ICT fields, this is not the case in terms of telecoms network equipment. As the transition to 5G and 6G depends on network functionality, the loss of domestic capacity in this industry has made the US dependent on a shrinking number of foreign equipment vendors. By the late 2010s, this market had consolidated to be heavily dominated by Finland's Nokia, Sweden's Ericsson as well as the Chinese firms Huawei and ZTE.[30] As discussed below, technological trends favour US firms recapturing some of this market share over the coming decade. In recent years, however, the prominence of Huawei and ZTE as network equipment vendors has hampered US efforts to persuade other countries not to use Chinese equipment in their new 5G networks.

In the 1970s, the two largest manufacturers of telecoms equipment globally were US companies.[31] Subsequently, the negative effects of federal anti-trust policy were aggravated by poor investment decisions and US government failure to counter measures by foreign governments that supported their own companies.[32] Exacerbating matters was a focus by US firms on cost cutting and shareholder returns. By the end of 2000s, the US telecoms equipment industry had been almost completely displaced or bought out by foreign competitors, with even the famous Bell Labs now owned by Finland's Nokia. The notable exception was Cisco, a Silicon Valley firm founded in the mid-1980s that prospered by providing networking equipment (routers) for the expanding global internet.

From 2011 however, the US led the world in rapidly deploying 4G wireless technology domestically and in leveraging 4G capabilities into global leadership in market share and technical capabilities. This effort was spearheaded by US firms such as Apple and Qualcomm. The benefits that accrued to these firms and the wider US economy – by one estimate, US annual GDP was USD100 billion higher by 2016 due to the 4G transition[33] – were noted by policymakers elsewhere, especially in China, which began accordingly to prioritise development of next-generation wireless-telecoms technology.

Recognising that the US would face intensified foreign competition in capturing the 'commanding heights' of 5G, the Barack Obama administration took measures to accelerate development and deployment of 5G networks domestically. These included making a new electromagnetic spectrum available for commercial wireless broadband services and funding targeted R&D through the National Science Foundation (NSF).[34]

Ex-president Donald Trump replaced these measures by instructing the federal government to develop a national strategy that would make the unused electromagnetic spectrum available to the private sector.[35] At the same time, a proposal by national-security staff in the Trump administration called to build a state-owned 5G network to exclude Chinese 5G providers, as opposed to allowing the private industry to build, own and operate next-generation telecoms networks. Generally, however, US policy for telecoms lacked coherence during Trump's presidency. This incoherence reflected divisions between government agencies, legislators and industry over basic regulatory issues and policy priorities, especially the privileging of national-security considerations.[36]

The Trump administration consistently highlighted threats from China, attacking the role of Huawei and other Chinese firms in the global telecoms sector and other ICT industries.[37] Underlying these threat perceptions of China were universal concerns about the security challenges entailed by vastly enhanced connectivity brought on by 5G networks and the expanding Internet of Things (IoT).[38] Public debates over 5G security have helped technological competition with China become a high-profile issue in US domestic politics, and this has been accompanied by increasingly expansive US government efforts to exclude Chinese companies from telecoms networks entirely, not just within the US but worldwide.

In 2018, US federal agencies were prohibited by law from procuring equipment from Chinese companies including Huawei and ZTE, which were later designated by the Federal Communications Commission (FCC) as national-security threats.[39] Trump in 2019 signed an Executive Order giving US authorities wide discretion to prohibit the procurement of ICT equipment – by any actor within US jurisdiction – from entities deemed to be 'under the jurisdiction or direction of a foreign adversary'.[40] The Trump administration pursued a global campaign against Chinese firms and Huawei in particular under the 'Clean Network Program' rubric, aiming to exclude Chinese businesses from telecoms networks and digital services markets, on top of cajoling other countries to follow the US lead.[41] As described below in the section on China, the Trump administration also introduced export controls on Huawei and other Chinese ICT firms that have had quantifiable impacts, and the Joe Biden regime has maintained and expanded these restrictions.

The Biden administration has also moved quickly to engage with allies and partners to reduce the clout of Chinese digital infrastructure globally. The EU-US Trade and Technology Council is reportedly discussing joint funding of digital infrastructure in developing countries, with a view to competing with Chinese companies like Huawei. President Biden, with the support of G7 leaders, also announced the Partnership for Global Infrastructure and Investment in June 2022, aiming to mobilise government and private capital to fund global infrastructure.[42]

The lack of US telecoms equipment vendors has hampered these efforts to advocate abroad against Chinese vendors. Consequently, both the Trump administration and US legislators began promoting Open Radio Access Network (ORAN) architectures as an alternative to integrated-equipment offerings from Huawei and ZTE, or even Nokia or Ericsson.[43] The basic concept behind ORAN is to develop technical solutions to 'open up' interfaces between elements of the radio-access network which are currently under proprietary control of the major vendors and thereby underpin their dominance of the equipment market.[44] In theory, this will facilitate a larger vendor ecosystem and result in lower equipment prices, making ORAN commercially attractive to telecoms-network operators such as AT&T, Verizon and T-Mobile. As telecoms networks become ever more complex and software enabled with the transition to 6G, network operators are also incentivised to be involved in the development of ORAN and future technical approaches so as to ensure that they do not become mere providers of 'dumb pipes' for technology owned by other companies.

An ORAN ecosystem would likely give advantage to US firms given their existing positions in relevant technologies, notably design of software and processors to enable the network virtualisation that will be integral to ORAN architectures.[45] Unsurprisingly, the system has aroused some suspicion amongst US allies. For instance, the European Commission's mid-2021 report on 5G supply market trends warned that ORAN could lead to a new oligopoly by US firms to the detriment of European firms and consumers.[46] Though it is unlikely to be adopted by most countries as a basis for their 5G-network rollouts, the political and commercial incentives driving ORAN's development mean that it might provide the foundation for 6G from the mid-2020s.[47]

Moves towards ORAN by large US-allied economies and increasingly aligned partner-states will influence this outcome. India is likely to take the ORAN route in its 5G infrastructure rollout.[48] Japan, home of the first company (NTT Docomo) to commercialise ORAN-based 5G, will trial 5G ORAN networks at scale in 2022.[49] And the UK recently awarded numerous R&D grants to support its '5G Supply Chain Diversification Strategy' that expressly promotes ORAN.[50] The US also now has a homegrown ORAN industry group which – unlike the leading ORAN specifications body, the O-RAN Alliance – does not include any Chinese firms.[51] However, absent politics, ORAN's technical and business drivers would make exclusion of Chinese firms from involvement in standardising the next generation of wireless telecoms very challenging. This would be further elaborated below.

China's Path Towards 5G and 6G

China's policies for its telecoms infrastructure and domestic development of wireless-telecoms technology reflect its latecomer situation that has shaped the nation's participation in the larger global ICT sector. As the People's Republic opened up its economy in the 1980s, it reformed its state-run telecoms sector. With expansion and technological upgrading of the telecoms network being a national development priority, Beijing allowed the import of telecommunications equipment from foreign firms. As a condition for entering Chinese markets, foreign vendors were required to enter into joint ventures (JVs) with Chinese partners, which established local equipment manufacturing facilities and R&D centres.[52]

The government encouraged these JVs to raise the proportion of domestically produced components, and this helped to reduce costs. The JVs also facilitated technology and skills transfers from the foreign firms to their Chinese partners. Moreover, state ministries organised training or job rotations at joint ventures for staff from Chinese companies not directly partnered, thereby helping to develop a larger ecosystem of domestic firms. Foreign vendors were subjected to import quotas linked to their willingness to localise production and transfer technology to Chinese companies.[53]

In the 1990s, as Chinese firms' capabilities matured and JVs expanded their business within China, they began to dominate the local telecoms equipment market. As was true across China's ICT industries, privately run companies like Huawei were generally more successful than state-owned enterprises (SOEs), although ZTE, a company that originated as an SOE joint venture and retains a dominating SOE presence in its ownership structure, also gained significant market share.[54]

Though self-portrayed as a privately owned and privately managed company (私有私营), Huawei's relationship with the state has played a significant role in its success. The symbiotic relationship between the company's rise and the Chinese state's policy goals was epitomised in a reported comment by Huawei's CEO Ren Zhengfei to Chinese leader Jiang Zemin in 1994 that 'a nation that did not have its own (telecoms) switching equipment was like one that lacked its own military'.[55]

By 1996, China's government had stopped special import policies for telecommunications equipment. In the late 1990s, the then-Ministry of Information Industry (MII) directed Chinese telecoms operators to buy domestically manufactured equipment instead. By 2000, the percentage of China's telecoms equipment market provided by imports had fallen to zero, with 60% now provided by foreign-Chinese JVs and the rest from indigenous suppliers.[56]

During China's negotiations for World Trade Organization entry in the late 1990s, US government pressure led to China granting market entry to the code-division multiple-access standard for 2G wireless telecoms, where the US firm Qualcomm was the dominant patent holder. The lucrative royalties Qualcomm derived from use of its intellectual property (IP) by Chinese businesses – the China market accounted for over a fifth of Qualcomm's global revenue by 2008 – spurred Beijing's efforts to promote a competitive home-grown 3G standard that proved unsuccessful.[57] But this experience led Chinese authorities towards more effective approaches, such as anti-monopoly regulatory decisions against Qualcomm that reduced costs for Chinese businesses using its IP and supporting participation by Chinese firms in international standards-setting processes for telecoms. This contributed to a rapid rise over the last decade in the proportion of 4G- and 5G-related patents held by Chinese firms, notably Huawei.

As its market share and resources grew, Huawei entered the expanding market for internet-data networks and associated use-cases such as IoT applications with cooperation from local governments and China's state-owned telecoms operators.[58] Huawei has been able to consistently undercut its competitors' prices, for example pricing its routers in the early 2000s at around half those of the US firm Cisco, which at the time had an 80% share of the Chinese market. By the time Cisco settled a lawsuit with Huawei over claims that the latter had stolen Cisco's router source code, Huawei had accounted for a third of China's router market.[59]

A 2019 investigation by the *Wall Street Journal* estimated that Huawei had received up to USD75bn in various kinds of assistance from the Chinese state spanning grants, loans, credit lines, tax breaks and land discounts, and this allowed the firm to undercut competitors' prices by around 30%. This significantly assisted Huawei's ability to compete in telecoms markets abroad. The *Journal* also estimated that over the previous two decades, China's policy banks had made up to USD30bn in credit lines available to Huawei's customers, with clients in developing countries receiving favourable interest rates in relation to China's own five-year benchmark rate.[60]

In recent years, the Chinese government has published various policy documents that emphasise indigenous development of advanced technologies, including in the area of future telecommunications. For instance, the 'Made in China 2025' industrial plan released in 2015 conveyed China's ambition to be globally competitive in ten industrial sectors by 2025, including next-generation IT in wireless networks. [61] Similarly, the 13th Five-Year Plan (2016–2020)[62] called for supporting innovation and driving growth in next-generation IT industries, including AI, smart mobile terminals and 5G networks. In 2020, the National Development and Reform Commission, China's peak macroeconomic management agency, identified satellite internet, IoT and 5G telecoms as 'new information infrastructure', development of which is a priority.[63]

The 14th Five-Year Plan (2021–2025) called for accelerating large-scale deployment of 5G networks and increasing market penetration rates to 56% in China. This document also set out ambitions for 5G, stating that China would 'build up technology reserves for the future deployment of 6G network technology' and that it would also 'build high-speed, ubiquitous, integrated and interconnected, safe, and efficient information infrastructure that integrates space and earth (天地一体) and enhance data perception, transmission, storage and computing capabilities'.[64] China's National Informatisation Plan published in December 2021 prioritised clarifying the requirements of 6G mobile communications technology and developing key supporting technologies such as terahertz communications.[65]

Huawei's dominance of China's telecoms equipment market and increasingly of the global market owes much to the company's entrepreneurial nous and heavy investment in technological improvement. For over a decade, Huawei has poured an estimated 15% or more of its annual revenue into R&D, which by 2021 amounted to the equivalent of over USD20bn.[66] But as the above account indicates, Chinese government support – regulatory interventions against foreign competitors, mandatory technology transfers, subsidies of various types and cooperative development projects with state agencies and SOEs – has been critical to Huawei and other Chinese firms achieving their present position in wireless-telecoms technology. Numerous accounts of IP theft, one example being the Cisco case noted above, also suggest this has been a significant factor in the ability of Huawei and other Chinese firms to make rapid technological advances and keep their costs relatively low.

In recent years, China has made notable progress in rolling out 5G telecoms infrastructure nationwide. In mid-2020, the ICT hub of Shenzhen (a city of over 12 million) claimed to have achieved comprehensive coverage with 5G standalone networks, which is a progression beyond early-stage 5G deployment that builds on existing infrastructure. Such networks are expected to enable new applications like intelligent connected vehicles.[67] By late 2021, Chinese media was reporting that over 1.4m 5G base stations had been installed across the nation, making China the world leader by absolute number of 5G base stations, although not per capita.[68]

As US concerns about China's domestic political trend and foreign policy behaviour merged with those about its rising technological prowess, the Trump administration introduced export controls with national-security justifications that specifically targeted Huawei and other Chinese ICT leaders. These have had quantifiable impacts on Huawei's operations and on China's 5G infrastructure roll-out due to Chinese industry's continued deficiency in key technologies such as semiconductor manufacturing and consequent dependence on foreign vendors that are sensitive to US export controls with extraterritorial jurisdiction.[69] By late 2021, Huawei was projecting that it would lose due to US export controls 80% of its USD50bn global smartphone business. In addition, the company's stockpiles of foreign-sourced critical components like semiconductors were reportedly running out.[70] Over the first eight months of 2021, production inside China of 5G base station components, which trended similarly with base station installations, fell 53% year-on-year.[71]

The exposure of China's weaknesses in 'core technologies' like semiconductors and the implications for its continued progress in technologies such as 5G and 6G telecoms has induced much pessimism among Chinese industry and policy commentators about the nation's ability to endure a technology war with the US and its allies. A report published in early 2022 by Peking University's International Institute of Strategic Studies, which assessed China's innovative capacities and the impacts of decoupling from the US across a range of technology sectors, was apparently deemed too politically sensitive to remain on the university's website.[72]

Nonetheless, the June 2021 White Paper on 5G published by the Chinese Academy of Information and Communications Technology (CAICT) assessed that the coming two years will be a crucial period for commercialising uses of 5G within China, and this requires state and industry to cooperate in developing a 'relatively complete' (较为完备) innovation ecosystem that provides a foundation for the flourishing of 5G applications.[73] The 6G White Paper published in June 2021 by China's official 6G development association (the IMT-2030 6G Promotion Group) also stressed that successful commercialisation of 5G will lay the foundation for development of 6G.[74] This will expand and deepen the 5G-led transition in society's use of wireless telecoms from mobile internet access to the IoT and other qualitatively new applications, enabled by new technologies including AI.[75]

Chapter Three: Wireless Telecoms Innovation Ecosystems

Academic Collaboration and Knowledge Networks

The US

The US hosts several university-based research centres that are at the forefront of R&D in 5G and 6G technologies. These centres – notably at the University of Texas at Austin (UTA), New York University (NYU), on top of a joint initiative between Stanford University and the University of California at Berkeley – benefit from partnerships with US industry and from frequent exchange of personnel. For example, the current Director of NYU Wireless previously worked at Bell Labs, where he originated massive multiple-input multiple-output antenna arrays, a key 5G technology.[76] In addition, the Stanford–Berkeley Open Networking Research Center has 12 founding industry sponsors, including Cisco, Ericsson, Google, Huawei, Intel, Juniper, NEC, NTT Docomo and Texas Instruments.[77]

These university centres were involved in early 5G research projects and are now starting to advertise themselves as exploring 6G technologies and applications.[78] UTA established a 6G research centre in July 2021 with five affiliated companies (Samsung, AT&T, NVIDIA, Qualcomm and InterDigital) that have each committed to funding at least two projects at the centre for three years.[79]

The US government has also recently begun facilitating 6G development partnerships with allied states including Japan, South Korea and the UK.[80] Collaborations with Japan and South Korea include development of ORAN-based 5G/6G networks, reflecting the United States' desire to erode the China-dominated telecoms equipment market by diversifying the suppliers.[81] The US and Japan are also collaborating on global standards in uninhabited systems utilising 6G capabilities.[82]

China

The Chinese state has clearly structured mechanisms for steering and driving forward technological development, including through national-level policy statements such as the 14th Five-Year Plan and other documents mentioned above. For ICT-related sectors like telecoms, the lead state agency is the Ministry of Industry and Information Technology (MIIT), successor to the MII. A common means of state 'steerage' is through umbrella associations that bring together government, industry and academic stakeholders. National Technical Committee 260, for example, is responsible for national information-security standards that shape the design and implementation of telecoms networks.[83]

For developing 5G as a distinct body of technology, China's 'steering association' is the IMT-2020 5G Promotion Group, named with reference to the International Telecommunication Union (ITU) umbrella term for 5G technical requirements.[84] Public–private partnerships are not unique to China, with Europe's 6G-IA (see Table 2 above) being a Western example. But Chinese bodies like the IMT-2020 5G Promotion Group differ in being led by government agencies, providing a direct and institutionalised channel for state influence over decision making.[85]

China's association for 6G is the IMT-2030 6G Promotion Group, again named to correspond with ITU terminology. This entity was established in 2019 by MIIT, with involvement by other agencies including the Ministry of Science and Technology, Ministry of Education, Ministry of Finance, Chinese Academy of Sciences, Natural Science Foundation of China as well as the National Development and Reform Commission. Official reporting on the group's launch indicates that while its participants from industry and research institutes make proposals and provide advice, implementation decisions rest with the government agencies.[86]

The IMT-2030 6G Promotion Group operates 'under the guidance' of MIIT and its affiliated research institute CAICT, which is the Chinese working lead on international collaborations to develop 5G and 6G use-cases such as industrial internet applications like the Sino-German Industrie 4.0 Cooperation.[87] As noted above, in

June 2021, the group published a white paper outlining a vision for 6G and assessments about key technologies and use-cases. A selection of its membership, which includes several foreign firms, is given at Table 3 below.

Collaboration Between the US and China

Despite the growing political pressure to 'decouple' technology ties between the US and China, the two countries still engage in significant research collaboration on 6G. This section of the report uses Clarivate's Web of Science Core Collection database to identify 6G-related research papers authored by at least two distinct groups of researchers – one US-affiliated and one China-affiliated – that were published by the end of 2021.[88]

By inputting key words such as '6G networks', '6G mobile', '6G communications', 'beyond 5G', and scoping the search results to include 'US and China' and filtering the relevant Web of Science research categories, the database yielded 124 articles, with years of publication ranging from 2017 to 2021. The types of 6G-enabling technologies explored in these papers include reconfigurable intelligence surfaces, integrating artificial intelligence in networks, blockchain technologies, terahertz communications, space-air-ground networks and multiple antenna technologies. While the database is not comprehensive, it gives an indication of trends in 6G-related research collaboration between China and the US.

A strong upward trend in the number of research articles is observed since 2019 (2017: one; 2018: one; 2019: ten; 2020: 41; 2021: 71), signifying a sustained increase in 6G-related research involving US–China collaboration. Out of 124 articles, 37% were produced by authors exclusively affiliated with US and Chinese organisations, while the remaining papers include authors from other countries apart from China and the US.[89]

Among all authors of selected articles, nearly half of them (48%) have affiliations with Chinese organisations, while 23% have US affiliations. A small number (eight authors) have affiliations with both US and Chinese entities. These figures are unsurprising given that 67% of the papers (83 out of 124 papers) had funding from the Chinese government, while only 18% papers had funding from the US government, leading to the higher proportion of Chinese researchers. Besides government funding, a few papers were also funded partially by US and Chinese corporations, among them Huawei, ZTE and Qualcomm.

Table 3: **Members of China's IMT-2030 (6G) Promotion Group***

Research institutes	Operators	System equipment providers	Chipset terminal providers	Universities
• Institute of Information Engineering, Chinese Academy of Sciences • Institute of Computing Technology, Chinese Academy of Sciences • Zhejiang Lab • China Academy of Information and Communications Technology • Telecommunications Development Industry Alliance • Guangdong Communications and Networks Institute • Shanghai Research Center for Wireless Communications	• China Mobile • China Unicom • China Telecom • NTT Docomo	• Huawei • China Information and Comunications Technologies Group Corporation • ZTE Corporation • Ericsson • Nokia Shanghai Bell • Samsung	• HiSilicon • Lenovo • Unisoc • Xiaomi • Vivo • Oppo	• Tsinghua University • Beijing University of Posts and Telecommunications • Southeast University • Zhejiang University • University of Electronic Science and Technology of China • Beijing Jiaotong University • Beihang University • Fudan University • Tongji University • Nanjing University of Aeronautics and Astronautics • Huazhong University of Science and Technology • Nanjing University of Posts and Telecommunications • Xidian University • Shanghai Jiao Tong University • Xiamen University • Fudan University • Peking University • Beijing Institute of Technology • Xi'an University of Technology • Dalian University of Technology

*IMT-2030 (6G) Promotion Group, 'Introduction of IMT-2030(6G) Promotion Group', undated, http://www.imt2030.org.cn/html/default/yingwen/Introduction/Members/index.html?index=1.

Author affiliations with US organisations comprise mainly US universities and companies, with the exceptions of an independent research institute and two government agencies. Authors affiliated with US universities stand at the largest proportion (87%), while a significantly smaller fraction (11%) are affiliated with US-owned or US-based entities such as Nokia Bell Labs, Intel and Qualcomm. Among US organisations, the University of Houston contributed the greatest number of articles (16 papers), followed by Princeton University (13) and Georgia Institute of Technology (seven).

Similarly, authors affiliated with Chinese organisations are mostly based in universities (85%), while the rest are affiliated with Chinese research institutes and companies. Beijing University of Posts and Telecommunication and Southeast University are the largest contributors among Chinese organisations, and each was involved in 13 6G-related research papers. The University of Electrical Science and Technology of China, Beijing Jiaotong University and Xidian University contributed nine papers each, with Peking University and Purple Mountain Laboratories contributing seven papers each. While the bigger contributors are mostly Chinese universities, Purple Mountain Laboratories is a state-backed research institute. Just recently, it achieved a world record for real-time wireless transmission of up to 206.25 GB per second within the terahertz frequency band (300 GHz to 3 THz) in partnership with Fudan University and China Mobile, one of China's three state-owned telecoms operators.[90]

Given the large proportion of university-affiliated authors, most of the US–China collaboration in 6G-related research involves university researchers. For papers involving authors from state-backed Chinese research institutes (17 out of 124 articles), most include co-authors based in the US universities, while a few others include co-authors from a US government agency (the National Institute of Standards and Technology) and US firms.[91] In terms of university–company collaboration, 18 research papers are found to involve authors based in US universities and authors based in Chinese companies and vice versa.[92] Research papers involving both US and Chinese companies are much fewer (five in count).

Moreover, three of these five papers are editorials which present opinions or viewpoints of 6G-related issues rather than investigate specific 6G-related technologies.[93] Overall, the small number of research papers involving authors from companies or stated-backed research institutes relative to university-based authors may be due to classified research projects which are not published to protect industry trade secrets or national competitiveness. In particular, the hostile political climate in the US towards Chinese technology companies arising from economic and national-security concerns also restrict opportunities for companies from both countries to collaborate in research and development of 6G-related technologies.

Finally, papers that involve both US- and China-based authors appear to have a higher citation impact among all China- or US-associated papers. Considering all 6G-related research papers[94] with at least one China-affiliated author in 2021, only 16% involves both US and China collaboration, but these papers account for 80% of the top 1% most cited China-associated papers. The same trend is observed in the top 5% most-cited China-associated papers, of which 35% are made up of studies with both US and China affiliations. Similarly, among all 6G-related publications that involves US affiliations, 35% includes US–China collaboration, but these papers make up 67% and 58% of the top 1% and top 5% of the most cited US-associated papers respectively.

Role of Government

The US

The Biden administration seems not to have prioritised policy for next-generation telecoms, despite its attention to securing US supply chains in critical technologies and the domestic ICT industrial base.[95] In September 2021, to guide the national transition to 5G, the FCC's acting chair articulated 'key principles' including supply chain security and resiliency, US industry leadership in a diversified telecoms-equipment market – based expressly on ORAN – and US leadership in international technical standards setting processes.[96] The FCC's acting chair and the US Commerce Secretary also highlighted the need for a more organised and unified approach towards national radiofrequency spectrum management.[97]

Since then, there have been efforts made to improve spectrum management. In March 2022, the FCC, along with the National Telecommunications and Information Administration – two entities in charge of spectrum management in the US – established monthly coordination meetings and a joint task force to discuss a new Memorandum of Understanding between the two agencies, 20 years since the old agreement was created.[98] As of May 2022, the administration and Congress were reviewing whether the US government should change how it manages allocation of electromagnetic spectrum, with industry and the think-tank community warning that failure to move on this issue will hurt US competitiveness in 5G and 6G.[99]

Washington has continued the general trend since Trump's presidency towards an increasingly adversarial stance against China in telecoms networks and their underlying technologies. The Biden administration has maintained and added to Trump-era export controls targeting individual Chinese digital-technology companies, while the FCC recently revoked on national-security grounds the licence held by one of China's three state-owned telecoms operators to provide services in the US.[100] However, the Biden regime has not followed its predecessor's high-profile campaigning overseas against Chinese firms' participation in other countries' 5G-infrastructure rollouts.

Biden's Infrastructure Bill, passed by Congress in November 2021, includes USD65bn for broadband and 5G connectivity.[101] The NSF funds various initiatives on advancing wireless telecoms, and has recently trended towards more directive research funding in line with the general turn in the US towards state-led industrial policy for emerging technologies.[102] For example, the Platforms for Advanced Wireless Research programme, a public-private partnership (PPP) between government, industry and academia, supports large-scale test beds.[103]

In April 2021, the NSF initiated a new PPP, the Resilient and Intelligent Next-Generation Systems (RINGS), which focuses on promoting resilience in next-generation telecoms networks under varying conditions, and is intended to enable closer collaboration with industry than was the case with past NSF-funded 5G research.[104] As of April 2022, 37 grants featuring a wide range of 6G-related research have been awarded to US academic institutions.[105]

The Defence Advanced Research Projects Agency also funds telecoms research with a national-security orientation, though these are currently limited to 5G projects. For instance, the Open, Programmable, Secure 5G Program aims to develop a technology stack for 5G networking that is both portable and secure.[106] In December 2020, the US Department of Defense (DoD) published a 5G strategy-implementation plan that includes ambitions to expand its activities (in cooperation with other government agencies) in international standard-setting bodies like the 3GPP. And two months prior, the DoD awarded USD600m to private industry for testing and evaluation of 5G services at five military sites, with a second tranche of 5G-related requests for proposals issued during 2021.[107]

In line with the government's push for an open telecommunication architecture, the DoD announced in early 2022 a competition to accelerate the development of an open 5G ecosystem, awarding up to USD3m to participants with hardware or software solutions.[108] To better address the needs of the DoD in adopting 5G technologies and beyond, the US industry also hosts dialogues with defence officials. For instance, the '5G to XG US Defense Symposium' convenes leaders from government, academia, and industry to help understand the technology and policy challenges the DoD faces in adopting 5G wireless telecoms for future warfighting.[109] The military is now the largest purchaser of 5G equipment and services in the US.[110]

China

As described above, Beijing takes a directive approach towards technology development. While China's 14th Five-Year Plan published in 2021 was the first to state the nation's ambition to lead 6G development, the government had already initiated pre-research in 6G technology in 2018.

That year, the Ministry of Science and Technology (MOST) funded the first research projects to explore technologies underpinning 6G as part of the 'Broadband Communications and New Type-Networks Special Project'. The objective is for China to become 'a global leader in the R&D of Beyond-5G wireless mobile communication technology and standards'.[111] Five 6G-related sub-projects on highly efficient transmission technology were launched under this initiative in 2018.[112] The same year, also saw the launch of a 6G-related research project on space-ground integrated information network.[113]

From 2019 to 2020, 11 more 6G-related sub-projects were released under the Special Project.[114] These projects were awarded to universities and industry entities such as South China University of Technology[115] and Datang Mobile,[116] a state-owned telecoms company. Purple Mountain Laboratories, a state laboratory established by Jiangsu province, and Beijing University of Posts and Telecommunications were also awarded '6G overall technology'[117] and '6G all-scenarios, on-demand key technologies'[118] research projects respectively.

Following promulgation of the 14th Five-Year Plan in 2021, MOST released two 6G-related sub-projects under a new 'Multimodal Network and Communication Special Project'.[119] These two programmes explore fusion of communication, sensing and computing as well as ultra-low latency and ultra-reliable large-scale wireless transmission technology. In 2022, five sub-projects were released as part of the same Special Project, and they include AI-driven networks, security and privacy technology as well as ultra-low energy consumption mobile communication.[120] During 2022, MOST also began projects related to ensuring trusted access of multitudinous terminal equipment in a 6G collaborative-manufacturing scenario[121] and electronic chips for next-generation mobile communication base stations.[122]

Other sources of Chinese government funding in next-generation technologies are also likely to contribute to 6G development. In 2021 at the Fourth Session of the 13th National People's Congress, China increased its basic research expenditure by 10.6%. The 14th Five-Year Plan also stated that China would increase its annual R&D budget by over 7% every year for five years from 2021.[123] Concurrently, the government has also increased efforts in establishing national laboratories for the purposes of AI and quantum research.

Despite the focus on indigenous technology development, the Chinese government welcomes STEM collaboration between Chinese and foreign research institutes and companies, highlighting Beijing's continuation of a two-track technology development policy.[124] For instance, in 2019, Huawei established R&D hubs relating to 6G networks in Canada.[125] And in 2021, the China Academy of Information and Communications Technology is planning to cooperate with South Korea's Ministry of Science and ICT to develop core technology for 6G.[126] China also actively engages foreign industry experts in 6G discussions. In December 2019 for example, Ericsson and Nokia were invited to working group meetings of the IMT-2030 6G Promotion Group.[127] In addition, China organised two global 6G conferences in 2020 and 2022, and their participants include global academic and industry experts from the likes of Canada, Finland, Greece, Japan, Saudi Arabia, Singapore, Sweden, the UK, and the US.[128]

Role of Industry

The US

As noted above, US companies are well positioned to lead development of ORAN architectures and associated technical trends like network virtualisation (replacement of hardware-based functions with software-based ones).[129] Notably, Intel's software leadership in this field would synergise with its effort to re-establish itself in cutting-edge semiconductor manufacturing (if the latter is successful) to provide a foundation for broader US industry leadership in next-generation telecoms.[130] As in other ICT categories like semiconductors, US industry will increasingly benefit from domestic industrial policy, as US legislators and presidential administrations introduce more measures to promote supply chain 're-shoring' and technological competitiveness vis-à-vis China.

In December 2021, the US House of Representatives passed a bill (the FUTURE Networks Act) directing the FCC to create a 6G task force, which is to prepare for Congress within one year a comprehensive report on 6G wireless technologies.[131] Earlier in October 2021, the US Senate drafted a bill dubbed the Next Generation Telecommunications Act. The bill proposes to assemble a Next Generation Telecommunications Council that would be responsible for advising the Congress on 6G issues, including in the development and deployment of 6G.[132]

US industry's global leadership in space-based commercial telecoms – for example, through the internet service provided through SpaceX's StarLink constellation – may boost US prospects in international 6G competition, especially as Starlink constellation has demonstrated resiliency in cyber, electronic and information warfare during the Ukraine–Russia war.[133] The 3GPP has been working for some time on integrating satellites with 5G standards, and this work is being driven by ATIS, the US industry organisation that initiated the Next G Alliance.[134] The alliance has also published a 6G vision for the country, outlining the main priorities required for future 6G-related global standards, deployments, products, operations and services.[135]

An important factor in the US lead in space-based telecoms is the satellite-launch capacity provided by companies like SpaceX and Blue Origin, with China only recently starting to develop a private satellite-launch industry.[136] US-allied governments wary of relying on terrestrial 5G networks with Chinese connections have begun investing in space-based next-generation telecoms solutions. The Australian startup Myriota for instance, which provides satellite-based IoT connectivity, is expanding with Australian government funding to serve national security uses.[137]

China

Chinese companies are similarly active in the 6G space, and they are part of government-led knowledge networks. China's state-owned telecoms operators – China Mobile, China Telecom and China Unicom – and private ICT firms like ZTE, Huawei and VIVO have begun to explore their own 6G visions and enabling technologies.[138] For example, Huawei published its own 6G White Paper in 2021.[139]

In 2019, China Unicom led the formation of a joint research centre with 20 other companies and research institutes focusing on millimetre-wave and terahertz communication.[140] Chinese companies are also forming smaller groupings to cooperate on 6G development. In May 2020, China Unicom and ZTE announced they would form a cooperation pact to research and develop 6G technology, discussing trends and cooperate on standards.[141] In addition, Huawei, China Unicom and Galaxy Aerospace established a strategic partnership focused on air–space–ground integration technology in June 2020.[142]

By late 2021, Chinese stakeholders had filed the most 6G patent filings out of a global total of 20,000, ranking first with 40.3% of this figure according to a survey conducted by Nikkei and the Tokyo-based research company Cyber Creative Institute. The US ranked second with 35.5% of patents filed, and Japan ranked third with 9.9% of patents filed. Europe and South Korea ranked fourth and fifth, at 8.9% and 4.2% respectively.[143] This finding is consistent with a separate study published by the Chinese National Intellectual Property Administration (CNIPA) in April 2021, which found that China had the largest number of 6G-related technology patent applications globally (35%, >13,000).[144] However, while the Japanese survey reported that a large proportion of the Chinese patents were filed by Huawei, as well as state-run companies like the State Grid Corporation of China and China Aerospace Science and Technology, the CNIPA study found that universities and scientific-research institutes were the main contributors of 6G technology innovation.[145]

As a metric, patent-filing statistics can present only a partial picture depending on which patents are measured. Indeed, the quality of patents should be considered in addition to their quantity.[146] A study by Tokyo-based Patent Result assessed that of all patents filed by Qualcomm and Intel, 44% and 32% were 'high quality' and innovative respectively.[147] In comparison, the corresponding figure for Huawei was only 21%.

Nevertheless, Chinese media has been quick to publicise reported 6G R&D 'successes' and these came about mostly as the result of public–private partnerships. In 2022, Purple Mountain Laboratories, Southeast University, Pengcheng Laboratory, Fudan University and China Mobile reportedly achieved a breakthrough in 6G-oriented terahertz 100/200 gigabits/second real-time wireless communication, which could meet the needs of future applications such as the metaverse and holographic communications.[148] China reportedly also launched its first '6G test satellite', the *Tianyan*-5, from Taiyuan Satellite Launch Centre in 2020. This capability was jointly developed by the University of Electronic Science and Technology of China, Chengdu Guoxing Aerospace Technology and Beijing Weina Xingkong Technology.[149] However, the true functionality of this satellite is still indeterminable, given the nascent nature of 6G technology R&D.

China's 14th Five-Year Plan for Informatization published in 2021 prioritised developing space-based 5G and 6G telecoms.[150] In broad terms, China's growing private-sector space-technology industry – some estimate it to exceed 100 companies – could play a role in contributing to China's space-based communications technologies, which would form part of 6G networks.[151] According to Chinese media, some of these companies like Galaxy Space are already seeking to specialise in the satellite applications for communication, internet, navigation and remote sensing.[152] The state-owned China Satellite Network Group was established in 2021 and aims to expand China's satellite internet capabilities through LEO constellations.[153] Nevertheless, a caveat to the sustained competitiveness of these Chinese companies in the short to medium term lies in the ability of its private sector to catch up with foreign competitors in core technological components such as semiconductors.

Standard Setting

The US

Industrial- and technological-standards setting in the US has historically been decentralised with limited involvement by government. The US representative body at the International Organisation for Standardisation (ISO) is the American National Standards Institute (ANSI), a non-profit organisation with a membership that encompasses private businesses, civil society entities like trade associations and labour unions on top of government entities.[154] An important actor in the landscape of US technical standardisation is the National Institute of Standards and Technology (NIST), a federal agency tasked with promoting US innovation and industrial competitiveness.[155]

However, the escalating competition with China in strategic emerging technologies is creating pressure in the US for more state involvement in technological standardisation. The Future Networks Act mentioned above puts standards setting and the status of industry-led standards-setting bodies at the top of the list of subjects over which the new 6G Task Force is directed to report to Congress.[156]

In 2021, NIST issued a request for public comment on Chinese influence in standardisation of emerging technologies.[157] The institute is running a multi-year contest to select and standardise one or more post-quantum cryptography algorithms – an effort that undoubtedly looks to China's progress with quantum technologies and the implications for US communications security – and similar efforts concerning 6G can be expected in future.[158] Already in October 2021, NIST published a paper with international research collaborators proposing a 'cognitive' 6G network.[159]

China

China's approach to technical standards setting has been described as a 'state-centric variant' on practices not fundamentally different from those in the West.[160] Indeed, China's ISO representative body is a government agency, the Standardisation Administration of China that sits under the State Administration for Market Regulation. Although China's domestic entity for standards setting differs from Western ones, at the international level, Chinese actors participate in the same formal standards-setting processes and set de facto industry standards similar to their foreign counterparts. Furthermore, China's domestic standards-setting system has been undergoing a long-term reform process to loosen state control, allow market forces more influence and promote convergence with global standards. Nevertheless, state influence over standards setting is still more pervasive than is the case in any Western country.[161]

China's current National Standardisation Strategy published in October 2021 emphasises the importance of standards to economic development and supply chain security. It promotes synchronisation of Chinese and international standards, and this is consistent with policy guidance issued by Chinese national authorities in recent years.[162] However, this convergence is intended to take place on terms that accord greater influence to Chinese actors in shaping international standards.[163] The state and market are envisioned as playing equally important roles and working together towards an ambition of 85% of Chinese-developed standards becoming international standards by 2025.[164]

China's digital-economy development plan that was published in support of the 14th Five-Year Plan explicitly stated its goal to actively participate and promote 6G international standardisation work, signalling its intent to play a leading role in new wireless standards.[165] Given the foregoing discussion about how the global wireless telecoms sector has evolved, it is clear why these Chinese policy goals have become a lightning rod for the geopolitics of technological competition over 6G.

Chapter Four: Geopolitics of Wireless Innovation

Globalisation of many economic sectors over the last few decades, especially in electronics, has made international technical-standardisation processes highly significant to technological development and the international distribution of economic power. State involvement – even in mundane ways like financial support for participating in international standards-development organisations (SDO) meetings – can significantly influence technical-standardisation outcomes.

As such, international standards-setting organisations such as the 3GPP have attracted growing attention in Western policy debates in the context of the growing focus on technological competition with China and with particular focus on the prominence of Chinese firms (most notably Huawei) in terms of 5G technology. Coordinated voting behaviour of Chinese actors in some SDOs, particularly relating to development of 5G telecoms, has also unsurprisingly raised concerns.[166]

However, recent studies of the major global SDOs and the role of Chinese actors in them have shown that the latter are not dominant in any general sense.[167] In the specific case of 5G wireless, the influence of Chinese actors appears mixed when disaggregated across different elements of international standards setting. These elements include leadership of SDOs, participation in technical committees and 'standard essential patent' declarations (which can differ significantly from patent citation, the latter metric being a more objective indicator of 'essentiality').[168]

Moreover, the unified nature and cumulative technical precedent that characterise the body of 5G standards is unlikely to apply in many other technology categories. Standardisation of AI applications, for example, is likely to be far more diverse, ad hoc and tailored to local priorities.[169]

The key question for the geopolitics of 6G is whether the technology will develop along the same standardisation and technological pathways as 5G, or whether technical divergence will make it easier for the US and China to build separate foundations for next-generation wireless telecoms, avoiding the constraints of interdependence that have characterised recent tensions over telecoms technology. The general estimate that 6G standardisation will begin in the mid-2020s sets a short timeframe for this dynamic to play out before the 6G-technology stack begins to take shape. For example, there is the US NSF's RINGS programme (mentioned above) that funds three-year research grants in the expectation that these will deliver results as 6G standardisation starts in 2024–2025.[170]

Technical divergence is not as straightforward as it seems, however. ORAN is not a clean break with past generations of mobile wireless specifications and patents, but rather builds upon them. It therefore inherits an extensive list of contributions and intellectual-property holdings by Chinese companies.[171] The leading ORAN specifications body, the O-RAN Alliance, counts Chinese companies as the second-most numerous member nationality after the US, which is unsurprising as the body was established by merging a US-European industry group with a Chinese alliance set up by the state-owned telecoms operator China Mobile. Indeed, the latter's chief scientist is currently co-chair of the O-RAN Alliance's technical steering committee.

The current global standardisation framework for wireless telecoms frustrates attempts to exclude particular actors on the basis of nationality. One example is the Trump administration's rollback of export controls to allow US entities to take part in 3GPP processes despite Huawei's participation, since not doing so would have removed US influence from the 3GPP while the framework proceeded with contributions from Huawei.[172] Citing this example, ANSI's submission to the NIST request for public comment mentioned above advocates removing all export controls on standards-development activities, claiming that these impede US global competitiveness.[173]

Another example is Nokia's cessation in mid-2021 of participation in the O-RAN Alliance nominally for fear of violating US export controls given the participation of Chinese companies on the US Commerce Department's Entity List.[174] Nokia resumed cooperation with the O-RAN Alliance after the latter changed its procedures to ensure technical activities could continue in compliance with US law.[175] As Nokia is a founding member of the Next G Alliance and the emphasis on promoting ORAN among US policymakers and legislators, this shows that attempts to cut Chinese actors out of standardisation processes may not promote US policy goals for 6G.

US prospects for achieving international decoupling from China also faces obstacles due to the nature of the supply chains underpinning future wireless telecoms. Telecoms network equipment (like all modern electronics) relies on semiconductors that are produced through a globally distributed supply chain where many key actors are non-US companies. Despite efforts to repatriate offshored elements of this supply chain, the US (and every other nation) will remain dependent for years to come on Taiwan's TSMC, South Korea's Samsung, the Netherlands' ASML and various other specialist firms that are monopolies or oligopolies in their particular niche. Furthermore, the increasingly dense integration of China with many other Asian economies, which are key nodes in electronics supply chains, presents major obstacles to decoupling these supply chains from the People's Republic.[176]

The US has been setting up political frameworks to coordinate development of 6G and other emerging technologies with allied and partner states to compete with China. Washington is pursuing collaborative initiatives with Japan, South Korea and Taiwan on semiconductors.[177] It has also established a joint Trade and Technology Council with the European Union, as well as the AUKUS framework with the UK and Australia. In addition, the US is pursuing technology discussions with India in the context of the Quad framework. To date however, it is unclear whether such political efforts will keep pace with the speed of globalised technological development or overcome the reality that many of these US-aligned economies have conflicting interests.

China for its part remains vulnerable to technology blockades by the US, especially if Washington coordinates its effort with other advanced economies. This is so because of Chinese industry's deficiencies in certain fields and the technical difficulty of closing these gaps. The most critical gaps are probably in the manufacture of high-performance semiconductors that will be embedded in 6G infrastructure and across the larger ecosystems underpinning the new applications that 6G will enable.[178] Even if China can achieve certain levels of import substitution, indigenisation and associated lower performance levels will likely hurt Chinese firms' international competitiveness in wireless telecoms. Indeed, Huawei's need to redesign its products in response to US export controls is the public reason given by the UK government for changing its security assessment about including Huawei equipment in the UK's 5G networks.[179]

From the industry point of view, preferences in the US and China are generally in favour of continued integration, and this conflicts with the political imperative for technological decoupling. All firms face reduced economies of scale, markets and R&D resources from being confined to only certain parts of the world. Without the economies of scale provided by globally unified standards, it may not be economical to develop various technological applications that are putative goals for use of 6G.[180]

The private sector can also exploit technology politics without necessarily delivering the outcomes desired by policymakers. Just as Beijing's industrial policy has often proved wasteful, it is uncertain whether the financial support now being directed by Washington towards US business will be effectively utilised in supply-chain 'reshoring' or will it simply boost these firms' profitability and shareholder returns.[181]

Many multinational firms appear to be responding to political pressures by building different technology stacks between national markets tailored to the political and regulatory requirements of different jurisdictions.[182] A clean technological split between US and Chinese spheres of influence is therefore less likely than a messy situation – the so-called 'patchwork decoupling'[183] – where technology stacks and supply chains continue to straddle the US–China political divide, but politics constrains the benefit generated by these connections while raising the risks.

Chapter Five: Defence and Security Implications for the US and China

Both powers currently view emerging and disruptive technologies as vital areas of competition for civilian and defence technological supremacy. To date, there is no definitive picture as to how advances in 6G and its uses will be implemented in either nation's military capabilities. However, both are likely to view advancements that build upon 5G-like aspects of next-generation ICT to have defence utility.

Assuming that 6G will be developed over the next decade and that related technological applications will mature during that time period, it is likely that 6G applications would contribute to Beijing's ambition of fighting 'intelligentised'(智能化) warfare and systems confrontation.[184] By the former, Beijing seeks to leverage emerging and disruptive technologies such as AI for its concept of future warfare. Systems confrontation refers to the concept that outcomes in war will be determined by the relative resilience and performance of digitally networked systems.[185]

Warfare in the mid-2030s and beyond could include intelligence swarms, cross-domain mobile warfare, AI-based space confrontation and cognitive control operations.[186] Battlefield information processing and decision-making would be turbocharged in the future environment. 6G can enable these operations. It also has the potential to improve missile defence. Chinese scientists recently developed a device which could potentially effectively use 6G technology for communication and target detection, overcoming previous problems of signal blockage that occurs at hypersonic speed (five times the speed of sound or faster).[187]

In 2020, China's National Defence News articulated its vision of how 6G could be used in future operations.[188] This included cross-domain communication networks [陆海空天一体化通信网络] made possible through satellite, drone, and optical communications technologies. 6G could also potentially improve the surveillance and reconnaissance capabilities of the People's Liberation Army (PLA), particularly in space. Large-scale big data processing using 6G would be a step up from the same process with 5G. In the former, more devices could be connected across multiple frequencies and large bandwidths. Moreover, the integration of AI and machine learning across 6G applications would allow the military to leverage big data and its large number of data streams to continuously learn and improve decision making, defence mobilisation as well as command and control. Furthermore, the PLA could leverage 6G to provide virtual and extended reality training and education for its personnel. The China National Defence News article also expounds the benefits of 6G for real-time visualisation of combat.

US Department of Defense writing about future warfighting concepts and operations, while not mentioning 6G specifically, does not stray far from what is delineated in the China National Defence News article. This is not surprising as the PLA has a long history of learning from other militaries. The DoD is also focusing on aspirational challenges in future warfighting through its concept of expanded manoeuvre to deter China and Russia. The Pentagon is particularly interested in four areas: contested logistics, joint fires from all domains and services, joint all-domain command and control (both within permissive and contested environments) and information advantage.[189]

What is striking is the emphasis placed on downstream challenges posed by enhanced data-centric warfighting and future warfighting concepts, namely training and decision-making requirements as well as defence-related data strategies. The former deals with training warfighters to better cope with uncertainty as the battlefield may become less predictable in the future. While the Chinese article focuses on the benefit to decision-making, the DoD highlights the increased need for warfighters to 'be more understanding of the strategy underpinning the guidance they're given' and to be 'trained to become disruptive and innovative thinkers who thrive in chaotic environments'.[190] The human-centric approach to this line of thinking stands in contrast to the Chinese article.

As for defence-related data strategies, the DoD is not just considering the presumed benefits of data processing, but already implementing a Defense Data Strategy for joint operations in coordination with allies and partners in order to organise data in a manner that facilitates processing speed. As David Spirk, the DoD's chief data officer, stated: 'It's about speed. And if you don't organise your data, if you can't create repeatable, testable and trusted data workflows from the tactical edge all the way up to your senior-most, decision-making activities, then you will just lag behind.'[191] While it is entirely plausible that the PLA is also considering these issues, further information in open sources remains scarce.

Another indication that 6G would play a major role in future US warfighting efforts is found in the technology strategy published by the Office of the Under Secretary of Defense for Research and Engineering in February 2022. The strategy's overall aim is to reinforce the US military's technology superiority and calls for rapid fielding of opportunities arising from emerging science and technologies while creating new operational concepts and engaging in increasingly joint operations.[192] It identifies 'Future Generation Wireless Technology' (FutureG) as one of the 14 critical technology areas which is equivalent to 6G. Classified under the category 'seed areas of emerging opportunity', along with biotechnology, quantum science and advanced materials, FutureG is expected to build on the military's growing 5G capability by providing 'leap-ahead technologies'. The document also highlights the importance of US leadership in future wireless technology in maintaining economic and national security.

One month after the publication of the technology strategy, there were organisational changes to pursue this aim. In March 2022, the DoD announced the establishment of a 5G and FutureG cross-functional team comprising senior officials from the Office of the Secretary of Defense, Joint Staff as well as the Services and Combatant Commands.[193] The team aims to accelerate the adoption of 5G and future generation wireless networking technologies in the military through 'at-scale prototyping and experimentation' while collaborating with industry, interagency, and international partners.

Conclusion

The strategic implications of 6G for national economies and security will likely be substantial. This technology is expected to enable revolutionary applications that would be impossible with previous generations of wireless telecoms. Regarding military uses, the ubiquitous, high-speed mass data transfers promised by 6G are expected to support applications encompassing autonomous vehicles, virtual reality as well as AI-powered command-and-control systems. Such changes should be expected to have transformative effects on military doctrine, operations and battlefield outcomes.

However, whether 6G develops to its full potential will be heavily influenced by its commercial development. Wireless telecoms is an exemplar of a technology field where development is driven by civilian industry and built upon transnational supply chains, research networks and economies of scale. The growing burdens placed on this development model by technology geopolitics, in particular those driven by the US–China rivalry, will inevitably have negative effects on innovation.

While the Chinese leadership has long placed a high priority on developing future wireless telecoms through sustained policy and action, the US approach to date has been more laissez-faire and less coherent. However, this is changing as the US government moves towards activist industrial and technology policy, and seeks to build technology development communities that exclude Chinese actors by enlisting the cooperation of other producers of advanced technologies. Almost all such states are US security allies and/or partners, but the effectiveness of such coalition building remains to be seen.

The recognition of 6G's strategic value to national economies and security has spurred significant investments in research and development of 6G-related technologies in both the US and China. Both powers are leveraging private-public partnerships that coordinate efforts by research institutes, industry and government. Investments in 6G-related technologies in both countries will accelerate as both seek an edge in technological advances and international standards setting.

It is too early to judge whether the US or China will lead in developing and deploying 6G infrastructure and technologies. However, the US holds advantages in some enabling technologies and has relatively greater leverage over other countries that are major players in these supply chains. Unless China can effectively circumvent these technological chokepoints, its ability to develop next-generation wireless telecoms equipment is likely to be increasingly encumbered by actions from the US and its partners to restrict Chinese access to critical inputs. Conversely, China's relatively advanced deployment of 5G networks and applications that use them may provide some advantages towards 6G development.

Ultimately, much more divergence would be required to achieve global bifurcation of wireless telecoms systems between US- and Chinese-led spheres. While there are many voices in both the US and China advocating such bifurcation on national-security grounds, it runs against the sector's globalised nature and would inevitably have negative effects on economies of scale and innovation potential, to the point where experts question whether 6G's promise could be fully realised under such conditions.[194] The trade-off between these policy goals is the core challenge facing policymakers as the world moves rapidly towards a 6G telecoms-enabled future.

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