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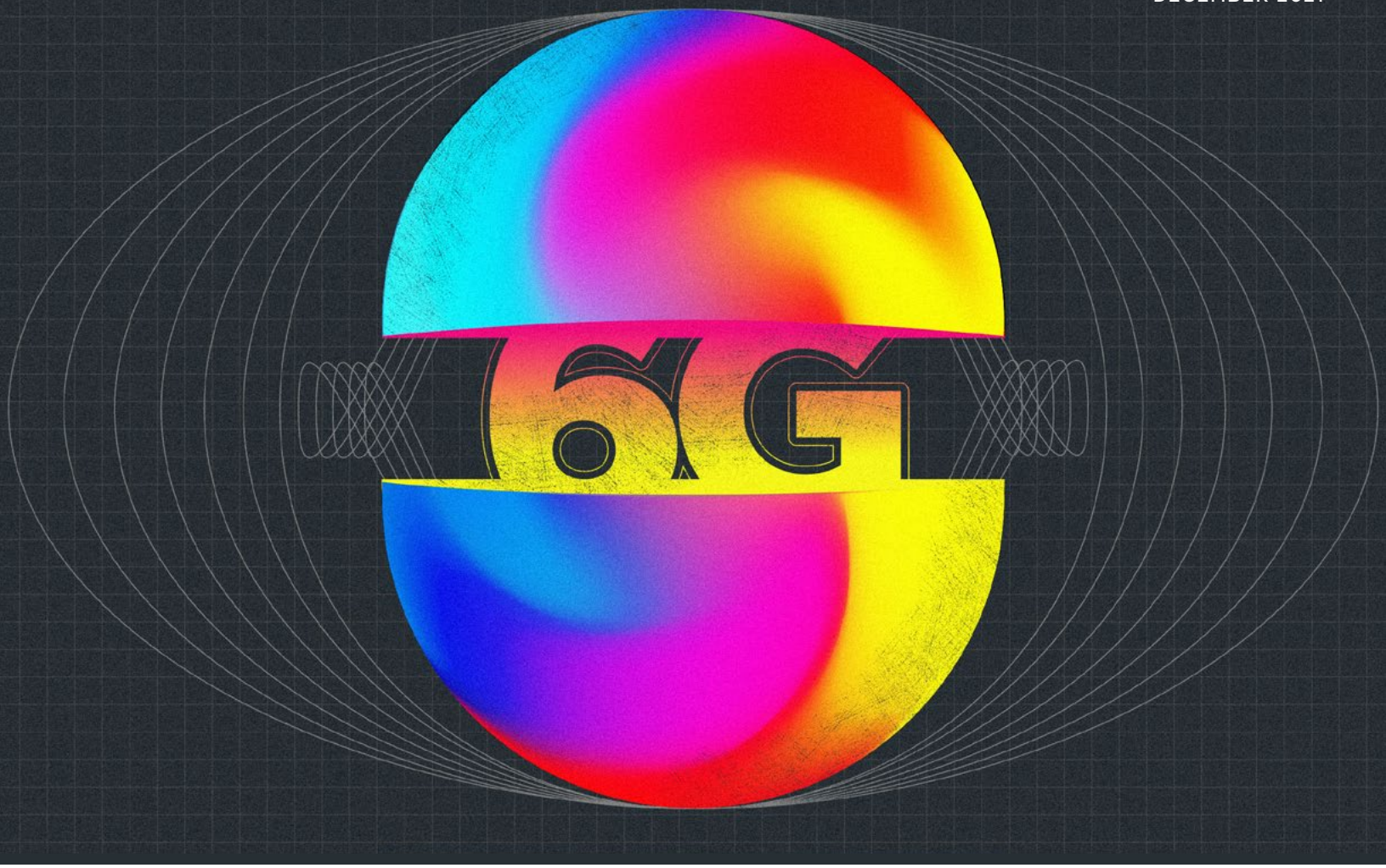

Edge Networks, Core Policy

Securing America's 6G Future

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CNAS

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About the Technology and National Security Program

Technology is changing our lives. Rapid developments in artificial intelligence, autonomy and unmanned systems, digital infrastructure, networking and social media, and disinformation are profoundly altering the national security landscape. Nation-states have new tools at their disposal for political influence as well as new vulnerabilities to attacks. Authoritarian governments are empowered by high-tech tools of oppression and exploit radical transparency. Artificial intelligence and automation raise profound questions about the role of humans in conflict and war.

CNAS' Technology and National Security program explores the policy challenges associated with these and other emerging technologies. A key focus of the program is bringing together the technology and policy communities to better understand these challenges and together develop solutions.

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Executive Summary

Technological leadership by the United States requires forethought and organization. The plan necessary to maintain that leadership—a national technology strategy—should be broad in scope. Its range includes investments in research, nurturing human talent, revamping government offices and agencies, and ensuring that laws, regulations, and incentives provide private industry with the ability and opportunity to compete fairly and effectively on the merits of their products, capabilities, and know-how. Given that key inputs are diffused globally, this plan must also carefully consider how the United States can effectively partner with other tech-leading democracies for mutual economic and security benefit. This includes taking measures to promote norms for technology use that align with shared values.

In the context of strategic competition with China, the need to craft new approaches to technology development and deployment is increasingly apparent to government leaders. Many lawmakers grasped the stark reality that U.S. technological preeminence was eroding when they realized that China had become a global juggernaut in telecommunications, a situation exacerbated by Beijing's push to dominate global fifth generation (5G) wireless networks. The state of play poses national and economic security risks to the United States, which, along with its allies and partners in the Indo-Pacific and Europe, has made notable headway in addressing and mitigating these risks. However, much work remains. Chinese firms continue to push for greater digital entanglement around the world, from Southeast Asia to Africa to Latin America. Given the fundamental importance to the digital economy of communications networks and the standards that govern them, the more successful Beijing's policies are, the greater the challenge for tech-leading democracies to maintain their economic competitiveness. There is also the specter of norms. If these are dominated by illiberal actors, their power to shape how networks are used and to manipulate data flows poses threats to liberal democratic values the world over.

It is time for tech-leading democracies to heed lessons from the 5G experience to prepare for what comes next, known as Beyond 5G technologies and 6G, the sixth generation of wireless. With telecommunications operators around the world still in the early stages of rolling out 5G, it is reasonable to ask why policymakers should focus now on 6G technologies that are not expected to be commercialized until around 2030. One reason is that governments of leading technology powers have already crafted various visions and strategic plans for 6G. Myriad research efforts, though nascent, are under way. Second, the 5G experience shows that belated attention to global developments in telecommunications resulted in vexing geopolitical problems that could have been better mitigated, or perhaps in some cases avoided altogether. Finally, because communications technologies are of fundamental importance to economic and national security, prudent and proactive policymaking in the early stages of technological development will help ensure that the United States and its allies and partners are well positioned to reap the benefits while countering the capabilities of adversarial competitors, most notably China.

To secure America's 6G future, the U.S. executive and legislative branches should act on an array of issues. First and foremost is setting a road map for American leadership in 6G. This framework will then inform the scope and scale of the actions needed to make that vision a reality. The necessary actions range from investing in research and development (R&D) to developing infrastructure to initiating novel tech diplomacy.

Promote American Competitiveness in 6G

The White House should:

- *Craft a 6G strategy.* The United States needs a strategic road map that lays out a vision for American leadership in 6G and the desired international and domestic telecommunications landscape of 2030 and beyond.
- *Expand R&D funding for 6G technologies.* The White House should explore opportunities for additional 6G R&D funding through research grants, tax credits, and financial support.
- *Leverage existing capabilities for testing, verification, and experimentation of 6G technologies.* The White House, working with the interagency Networking and Information Technology Research and Development Program, can establish government 6G testbeds (in the laboratory and field) to support and build upon 5G R&D.
- *Open additional experimental spectrum licenses to accelerate R&D efforts.*
- *Establish a U.S. 6G Spectrum Working Group.* The working group should identify spectrum needs for 6G rollouts and offer recommendations for spectrum access and management.
- *Promote the development of new 6G use cases by using the purchasing power of the U.S. government.*

Congress should:

- *Designate the Department of Commerce a U.S. intelligence community (IC) member.* Closer ties to the IC will improve information-sharing on foreign technology policy developments, such as adversaries' strategies for challenging the integrity of standard-setting institutions. This action will also integrate the Department of Commerce's analytical expertise and understanding of private industry into the IC.
- *Enact R&D funding to solve challenges for rural 6G development*. 6G offers an opportunity to develop alternatives to traditional hardware such as fiber-optic cables, for example wireless optic solutions or non-terrestrial platforms, that can fill network gaps to more readily connect rural areas.
- *Attract and retain much-needed foreign science and technology talent by initiating immigration reform*, such as by raising the cap for H-1B visas, eliminating the cap for advanced STEM degree holders, and amending the Department of Labor Schedule A occupations list so that it includes high-skilled technologists.

The National Science Foundation should:

- *Create an equivalent of its Resilient & Intelligent NextG Systems (RINGS) program for start-ups.* RINGS, supported by government and major industry partners, offers grants for higher education institutions to find solutions for NextG resilience.[1]
- *Expand the Platforms for Advanced Wireless Research Program,* a consortium of city-scale research testbeds, so that it includes software innovation hubs.[2]

Collaborate with Allies and Partners

Congress should:

- *Create a Technology Partnership Office at the Department of State.* A new office, headed by an assistant secretary for technology, is needed to initiate, maintain, and expand international technology partnerships.

The White House should:

- *Organize an international 6G Policy and Security Conference series.* U.S. policymakers should work with foreign counterparts of the techno-democracies to organize regular 6G conferences to discuss key issues including technology development, security, standard setting, and spectrum.

The White House, with the support of Congress, should:

- *Lead the creation of a Multilateral Digital Development Bank*. In partnership with export credit and export finance entities in allied countries, the United States should lead in establishing a new organization with the mission of promoting secure and fair digital infrastructure development around the world.

The State Department should:

- *Spearhead a tech diplomacy campaign.* The United States and allied governments should craft clear and consistent messaging to the Majority World about the risks of using technologies from techno-autocracies, especially China.

Ensure the Security of 6G Networks

The Federal Communications Commission, with the support of relevant agencies, should:

- *Identify, develop, and apply security principles for 6G infrastructure and networks.* A proactive approach, with partners in industry and academia, should be undertaken to identify 6G security risks and ensure that international standards have cyber protections.

The White House and Congress should:

- *Promote and support the development of open and interoperable technologies.* Coordinated outreach, joint testing, industry engagement, and policy collaboration can build global momentum and communicate risks associated with untrusted vendors.
- *Create a 6G security fund, building on existing efforts to ensure 5G security.* This fund could be established in concert with the activities of the proposed Multilateral Digital Development Bank.

PRIOR REPORTS IN THIS SERIES

- "Securing Our 5G Future: The Competitive Challenge and Considerations for U.S. Policy," by Elsa B. Kania (November 2019)
- "Open Future: The Way Forward on 5G," by Martijn Rasser and Ainikki Riikonen (July 2020)

Introduction

Technology policy has profound geopolitical implications. Emerging technologies, as critical enablers for the creation and application of power, require sound strategy for their development and deployment. While the United States has enjoyed a seven-decade period of remarkable technological preeminence, the current global diffusion of scientific and technical capabilities is changing the dynamics of technology competition. A rising China—with distinct techno-nationalist policies centered on self-sufficiency, homegrown innovation, technology theft, and market distortions—poses a challenge that requires the U.S. government to change tack on how it promotes and protects its innovation ecosystem. Government leaders must take the helm and set course for a new strategic approach to technology policy. They must be engaged earlier and more deeply on crafting the contours and interconnections of the keystone technologies of the coming decades: artificial intelligence (AI), biotechnology, quantum science, microelectronics, and telecommunications technologies feature prominently.

This report focuses on next-generation telecommunications, generally referred to as 6G. As the physical and digital worlds meld ever more, how we communicate and connect increasingly impacts every facet of daily life. Digital infrastructure has become critical infrastructure, used to monitor and maintain the utilities and services needed to keep society running, and an enabler of almost every aspect of economic activity. As the dominant conduit for information, communications technologies can help foster and maintain free and open societies. They can also be used to suppress and oppress, sow discord and dysfunction, and push fragile democracies toward authoritarianism. How and by whom telecommunications infrastructure is deployed, and how resilient and secure that infrastructure is, at its core, a matter of vital economic and national security.

To articulate the best way forward, policymakers should heed the lessons of 5G rollouts—both specific technical developments and broader tech policy issues—and understand the scope of the 6G tool kit available to them.

After a review of what 6G networks are projected to be capable of and what key attributes these networks likely will have, this report describes the main concepts and technology areas that policymakers should understand. Next, the case is presented for why U.S. government leaders should focus on 6G policy. The United States cannot afford to be late to the game in understanding the implications of 6G network developments. To articulate the best way forward, policymakers should heed the lessons of 5G rollouts—both specific technical developments and broader tech policy issues—and understand the scope of the 6G tool kit available to them. As the section on 6G activity around the world shows, allies and adversaries alike are formulating visions and crafting strategies to reap the expected benefits of next-generation telecommunications networks. A critical mass of countries has comprehensive 6G research and development (R&D) efforts under way. This report concludes with a series of policy recommendations that the administration and Congress should implement to promote American competitiveness in 6G, engage with allies and partners, and ensure the security of 6G networks.

6G: A Primer

The next generation of wireless telecommunications technologies, 6G, promises to supercharge data transmissions and diversify the ways it can get from point A to point B, whether the points are humans or machines. If a "5G network is essentially a collection of microprocessors rapidly sending packets of data among themselves," as Tom Wheeler and Robert Williams describe, then 6G may be that collection distributed across not only land but also air, sea, and space, and able to autonomously optimize the pathways for sending data packets in ever-greater volumes, faster, and more directly.[3]

6G networks are projected to be up to 100 times faster than the peak speed of 5G, with further reduced latency, embedded AI-enabled capabilities, higher energy efficiency, and the seamless convergence of sensing, computing, and communications.[4] Its predecessor, 5G, has already made leaps and bounds over 4G by leveraging lucrative parts of the electromagnetic spectrum and leaning into opportunities afforded by increased digitization. The core—no longer a physical switchboard—consists of software running on multipurpose hardware. Similarly, software on generic hardware can manage radio units. Virtualization and software-defined networking are creating opportunities for flexibility and customization. They also open the

chance to disaggregate the network; cloud computing means that network functions can be more location-agnostic and dispersed to "the edge," rather than housed in the traditional core. These innovations central to 5G technologies set the foundation for 6G, which will lean into the strengths while addressing the weaknesses in 5G network capabilities.

Deployments of 6G are likely to be under way by 2030. Early R&D is taking place now, as is vision-setting for what next-generation telecommunications networks might look like. Many technical concepts may fail; others may emerge only with the passage of time. For these reasons, focusing on the key enabling capabilities anticipated for 6G will be more useful for policymakers than a deep dive into purely technical concepts. The advantages of 6G over 5G include more pathways for sending packets, more kinds of platforms to support those transmissions, and more flexible and scalable tools for managing these activities. In technology terms, these advantages are enabled by spectrum expansion and sharing, evolution of network topology enabled by diverse hardware nodes, and scalable network architecture managed by software. 6G use cases will likely entail a "merging of worlds" where sensor information has high enough fidelity to map the physical world to a virtual copy for transmission in near–real time for human-to-human, human-to-machine, and machine-to-machine communications.[5] In more detail, these key technology areas are:

Spectrum expansion and sharing. Electromagnetic waves are the physical medium that carries information in wireless networks. For next-generation networks, researchers envision making use of additional parts of the spectrum, including smaller wavelengths, to transmit signals. Different segments of the spectrum are optimized for different purposes. Smaller wavelengths can transmit higher volumes of data to more devices because they have higher frequencies—they oscillate much faster—and because they transmit as targeted line-of-sight beams rather than as an omnidirectional broadcast.[6] Yet these higher frequencies are prone to atmospheric attenuation, and so researchers are considering incorporating more parts of the spectrum, such as between 6 and 24 gigahertz (GHz), for wide area services to supplement more exquisite capabilities.[7] To increase efficiency of spectrum allocation, advanced spectrum sharing techniques will be required.[8]

Researchers are exploring the terahertz (THz) part of the spectrum, which lies between microwaves and infrared and has a wavelength smaller than millimeter wave (mmWave). THz is anticipated to carry potentially hundreds of gigabytes per second but shares some of the propagation limitations of mmWave due to atmospheric attenuation and its line-of-sight quality.[9] Because THz lends itself well to narrow beams, it will require radio units such as multiple-input multiple-output (MIMO) to direct these beams at user equipment, sensor equipment and modeling tools to understand where the beams propagate, and AI tools to anticipate the movement of user equipment.[10] To address propagation challenges due to the signal's line-of-sight transmission, researchers are also investigating intelligent reflecting surfaces to steer beams to their final destinations.[11]

In addition to radio waves, the optical spectrum is an area of interest for 6G, especially for wireless backhaul. In general, 5G networks require fiber-optic networks to transmit data from radio units to the core cloud infrastructure. But this fiber-optic infrastructure is expensive to deploy, so wireless backhaul capabilities, including wireless photonic connections or "optical wireless communication," may fill gaps in future network rollouts. The optical spectrum, including infrared and the visible light spectrum, consists of wavelengths even smaller than THz. This part of the spectrum is limited by the opacity of physical objects, but optical wireless solutions may facilitate 6G network deployment in rural communities and other environments where fiber-optic deployment is unfeasible or undesirable.

Evolution of network topology. In addition to terrestrial radio access technologies and backhaul infrastructure, researchers are exploring non-terrestrial network equipment to increase coverage and network reliability.[12] 6G will be more layered and more meshed, encompassing not only ground-based radio units but also unmanned aerial vehicles (UAVs), low earth orbit (LEO) and geostationary orbit (GEO) satellites, and high-altitude platform stations (HAPS).[13] The increased diversity of hardware nodes could expand service to maritime or airborne user equipment, leveraging new radio and antenna innovations along with wireless backhaul techniques to fill network gaps.

Scalable network architecture. With the implementation of cloud computing from core to edge, network management functions are dispersing in 5G, a trend expected to continue with 6G. This diffusion may create what the European Vision for the 6G Ecosystem calls a "single computing continuum stretching from user/IoT [Internet of Things] devices to centralized cloud."[14] Network management tools located at the edge, by virtue of physical proximity, will reduce latency and allow for pervasive network resource optimization—such as spectrum allocations—and overall scaling of network

architecture. Machine learning (ML) tools will be critical to automate network management for "touchless" decision-making and rapid machine-to-machine communications. Investments in all components of AI/ML, including hardware, will be necessary to support this function.

Application examples. 6G will support data-intensive applications for point-to-point communications and for connected autonomous platforms, among other use cases. Holographic telepresence, a mode of three-dimensional communication that may integrate physical interaction and haptic feedback, requires terabit data rates and ultra-low latency.[15] This tool can facilitate social interactions and tactile human-machine interactions, for example for telemedicine. In addition to enhancing interpersonal and human-machine communications, 6G will be essential for networking machines to machines.[16] The flexibility of 6G means that industry will be able to customize private networks for industrial IoT applications. Increasingly automated network management tools will also enable hands-off coordination of connected robotics. While these applications are data-intensive, privacy can be preserved if techniques such as federated learning are implemented to separate raw data from systems in the central cloud.[17]

The Case for 6G Policy Now

Communications networks are inextricably enmeshed in daily life. Telecommunications are integral to the everyday functioning of society, economic vitality and competitiveness, and the ability to safeguard national interests. Maintaining secure, reliable, and resilient communications networks is increasingly a matter of protecting U.S. sovereignty and security. Policymakers in the United States have focused on 5G, setting up a critical conversation around economic competitiveness and leadership in advanced technologies. While the competition over 5G is far from over, 6G development is already under way. U.S. policy must be developed now to define, incentivize, and support advances in 6G technologies.

The pace of evolution between generations of telecommunications technologies is accelerating. For 3G, it took 15 years from the illustration of an initial vision and technical standards to the deployment of mature technologies. Next, 4G took 12 years, and 5G rollouts began within 8 years. Industry estimates suggest that the first commercial deployment of 6G could occur as soon as 2030, following the completion of technical specifications in 2028.[18] The development-to-deployment timeline is shortening with each generation and industry experts expect this trend to continue.

It would be a mistake to wait until deployment of 6G is imminent to craft policy and design regulatory frameworks, because theoretical research and prototyping is well under way. Since 2020, standardization authorities such as the International Telecommunication Union (ITU) have sought to identify potential 6G use cases and requirements.[19] In the United States, in 2019 the Federal Communications Commission (FCC) opened experimental spectrum licenses to test and verify potential new 6G services.[20] Policy should be proactive and anticipatory. Decisions around standards, spectrum licenses, and federal R&D spending will shape the future of 6G technologies.

There are two key realms of information for policymakers to consider when formulating 6G initiatives. One is lessons learned from the 5G experience. That knowledge previews the way forward and provides the necessary context for evaluating the second consideration: 6G developments taking place around the world.

Lessons from 5G

As 5G network deployments continue, the United States and its allies must devote attention now to what comes next: 6G. Looking forward to 2022 and beyond, policymakers need to heed lessons from the advent of 5G around the world. They should devote attention early to the promise and perils of a new generation of wireless communications technologies. This section covers the main issues of concern with 5G—R&D investments, spectrum, standard setting and interoperability, intellectual property, vendor diversity and supply chains, untrusted vendors, security, the demand for network modernization, and the illiberal use of communications technologies—to frame how U.S. policymakers should plan for the future.

Three overarching themes from the deployment of 5G stand out in terms of their application to next-generation communications systems: first, the need for a unified, coordinated, and timely policy framework; second, the necessity of working with private sector partners; third, the importance of multilateral engagement.

The biggest obstacle to effective U.S. policy for 5G was the lack of a coherent vision and coordination. Tom Wheeler, who served as FCC chairman from 2013 to 2017, described the 5G policy discussion as "an elementary school soccer game where everyone chases the ball, first in one direction, then another."[21] To prevent a 6G soccer game, there is an immediate need for a unified policy

A worker installs 5G equipment in Orem, Utah, in 2019. While 5G's rollout is only beginning, 6G development around the world is well under way. (George Frey/Getty)

framework, including coordination and cooperation among U.S. partners and allies, federal agencies, private sector stakeholders, as well as city and state governments. Local and national authorities need to determine the right conditions, address bureaucratic and regulatory hurdles, and engage with private sector partners. Policy should not differ between the local and national levels. Of course, that is easier said than done—in reality, local policymakers might approach 5G with an entirely different set of priorities (such as infrastructure siting restrictions), and federal attempts to streamline the process have faced litigation.[22]

The strategy for 6G needs to be timely to set the direction for an effective policy framework. In short, the right strategy at the wrong time is the wrong strategy. A seven-page *U.S. National Strategy to Secure 5G* was released in March 2020, while the more comprehensive *National Strategy to Secure 5G Implementation Plan* was only released in January 2021.[23] In contrast, China pursued first-mover advantage in 5G rollouts and has sought to lead international standard setting on 5G.[24]

The patchwork of federal, state, and local regulations affecting telecommunications infrastructure necessitates better and earlier engagement with industry. While 5G deployments can involve existing infrastructure assets, advanced base stations and antennas are often needed for critical use cases. Installing new equipment often requires identifying an optimal signal site, gaining the appropriate permitting, and sometimes constructing in dense urban areas.[25] Government coordination with commercial partners can not only ensure efficient rollouts but also mitigate risks to national security to avoid the current situation: Equipment from untrusted vendors, such as the Chinese firm Huawei, must be removed from U.S. networks—an expensive and avoidable predicament. For 6G, creative and flexible approaches to research and develop technology with trusted vendors, for example through a proposed 6G public-private partnership, are needed to ensure vendor diversity and the security of next-generation networks.[26]

Finally, multilateral engagement is critical and encompasses safeguarding the 6G standard-setting process, promoting a shift to Open Radio Access Network (Open RAN), working with partners to ensure supply chain security, countering predatory trade practices, and preventing untrusted vendors from gaining dominance. The Biden administration is already pursuing multilateral 5G cooperation, as policymakers recognize the necessity of international engagement to secure domestic networks.[27]

Within these themes, there are specific lessons for U.S. officials to consider when formulating policies for 6G. The takeaways from the 5G experience concern technical issues and broader implications of market dynamics and tech policy matters.

Technical Lessons

The technical lessons concern aspects of wireless telecommunications that impact how effectively a network can function and how secure and resilient it is. Inefficient and inadequate policymaking in these areas have impaired 5G rollouts in the United States.

SPECTRUM

One of the main challenges with existing 5G deployments is determining spectrum allocations to achieve the right balance between fast transmission speeds and signal ranges. Federal regulatory hurdles, including the difficulty of obtaining spectrum licenses, have significantly slowed the deployment of 5G in the United States. For example, the Department of Defense, which uses spectrum for sensing and communications, drafted a spectrum plan that conflicted with that of the FCC.[28] The 5G rollout shows that without proper top-level guidance from the National Telecommunications and Information Administration (NTIA), which has a statutory role for

managing federal spectrum uses, spectrum-dependent federal agencies will attempt to "take matters of spectrum management into their own hands" resulting in an "incoherent and erratic" approach.[29]

6G will likely operate on existing 5G frequencies along with new frequencies, ranging from 7 GHz to 24 GHz for wide area coverage and from 95 GHz to 3 THz for higher-speed communications. This expansion will allow for increased speeds, higher energy efficiency, lower latency, and improved spectrum sharing.[30] While the FCC has recently opened experimental spectrum licenses, interagency coordination and regulatory actions will determine the future of 6G in the United States. In addition to key technical achievements, the efficient rollout of 6G will require that policymakers, including the FCC and the NTIA, coordinate in auctioning off spectrum to private sector actors. Additional agencies with potential 6G interests, such as the Department of Defense, must also work collaboratively to address spectrum management. In this context, a first step could be research into best practices for spectrum management of 6G networks, including updating existing guidance.[31] Globally, spectrum auctions, one of the most prevalent ways of allocating spectrum licenses, have faced limitations, often a result of poor planning around the auction setup. In many countries, including India, Bangladesh, and Ghana, these auctions failed because the initial starting price was set so high that operators were not able to participate.[32] Poor auction design, rent extraction, and failure to publish a spectrum road map are all mistakes in policy that have slowed the rollout of 5G. Observing best practices for spectrum allocation, and supplying technical assistance to certain countries, can improve 5G's and subsequently 6G's rollout.

In June 2020, then–Federal Communications Commission Chairman Ajit Pai leaves a Senate Appropriations Subcommittee hearing on spectrum auctions for fiscal year 2021. Spectrum availability is key for next generation networks and will require interagency coordination to effectively auction it. (Chip Somodevilla/Getty Images)

Further research into the implications of 6G for spectrum management is also necessary to determine the unique challenges of next-generation communications technologies.[33] In the case of 5G, trends such as the increasing fragmentation of spectrum management approaches create additional challenges for policymakers.

INTEROPERABILITY

Interoperability in 5G networks offers an indirect solution to security risks by creating opportunities to diversify the vendor pool. It therefore offers an alternative pathway from continued single-vendor dominance, support to a narrow range of competitors, and the creation of a U.S. national champion.[34] While open interfaces and Open RAN may disrupt status quo vendors of network equipment, Open RAN is catching on. In late 2020, Deloitte identified 35 Open RAN deployments, which it anticipates doubling in 2021 and by 2025 growing from 1 percent to 10 percent of the RAN market.[35] Rakuten, a network integrator in Japan, has demonstrated so far that Open RAN is both feasible and ultimately more cost effective than traditional RAN setups.[36] Looking ahead, even status quo vendors such as Ericsson, with incentives to resist market disruption in the short term, have acknowledged that interoperability will be a key component for 6G.[37]

CYBERSECURITY

Debates about 5G security contend with a lack of consensus on the U.S. government's role and concerns over the expansion of the attack surface due to the diversity of components and vendors involved in these networks. The U.S. government's role has varied, from supporting efforts to implement security by design into 5G standards, to cutting out specific untrusted vendors, to a brief but controversial flirtation with nationalizing networks to oversee their security.[38] The latter was never a serious consideration, but the case illustrates the extent of disagreement about the government's role in ensuring network security.

The FCC had whiplash between the Obama and Trump administrations, when the latter canceled initiatives to require built-in cyber protections for international standards.[39] The administration canceled this initiative under the umbrella of its anti-regulatory position. In lieu of regulatory tools, the Trump administration implemented trade restrictions and launched a global diplomatic campaign to stamp out vendors

deemed untrustworthy. Quietly, it also solicited generalizable criteria for assessing vendor-based information security risks.[40] To address technical vulnerabilities and political risk–driven threats, the U.S. government has tool kits within several its departments and agencies. The White House should ensure that these organizations have license to support persistent 5G and 6G network security.

In 5G network architecture, virtualization and interoperability pave the way for more network components, more vendors, and ultimately more potential opportunities for attackers to exploit. In addition to diversity within the network itself, 5G will enable connectivity between masses of IoT devices—with their own potential security gaps. International organizations should prioritize decision-making on key 6G security features sooner than they did with 5G, and they should give special consideration to the integrity of AI/ML solutions for network functions. To address the increased attack surface, network operators will also need to boost supply chain security. Cyber operations are beginning further upstream through software supply chains, as exemplified by the Solar Winds hack and Operation Cloud Hopper, in which adversaries compromised third-party software sources to reach their final target.[41] In the latter case, the threat actor compromised a third-party cloud provider to conduct cyberespionage against its target.

Debates about 5G security contend with a lack of consensus on the U.S. government's role and concerns over the expansion of the attack surface.

Because 5G networks involve an increased number of parts and vendors, including cloud infrastructure, they will need information security solutions that can prevent or at least keep up with the increasingly complex threat landscape. 6G networks, even more dynamic than 5G, will require the U.S. government and private industry to understand and play their parts to enact effective policies and practices for security. This necessitates a set of broader policy actions not limited to 6G.

Policy Lessons

The policy lessons from 5G will inform proactive steps the U.S. government should take to enhance competitiveness in telecommunications technologies in the context of global industry dynamics and geopolitical developments. With some exceptions such as in the intelligence community, government officials paid little attention to technology developments and the growing clout and capabilities of Chinese firms in telecommunications.

R&D

The U.S. government, with the Office of Science and Technology Policy in the lead, should articulate a coherent vision and technology development road map for next-generation wireless telecommunications as soon as possible, because the lead times for relevant research are long. Early R&D, critical for the testing and verification of 6G technologies, will determine the future leaders in telecommunications technology. Researchers in key countries began this work several years ago, but the overarching guidance for research varies considerably. In China, Japan, and South Korea, government ministries have crafted planning documents. The European Union (EU) released its vision for the 6G network ecosystem in June 2021.[42]

The United States has no such plan yet, despite considerable activity. While the Biden administration is pursuing several collaborative initiatives with partner countries, there is no publicly announced 6G strategy with policy objectives to promote American competitiveness in the field.

GLOBAL DEMAND AND MARKET COMPETITION

Demand for network modernization is globally distributed—"Infrastructure Week" is not a uniquely American phenomenon—and generating affordable, sustainable means for states to make their upgrades will be as critical for 6G as it has been for 5G. The Global Mobile Suppliers Association has identified 443 operators in 133 countries and territories that have invested in 5G projects of various sizes and levels of maturity.[43] Countries and locales across the wealth spectrum, including in the United States, have cited cost as a motivator to acquire or retain equipment from untrustworthy vendors. But due to lavish subsidies and industrial initiatives such as the Digital Silk Road, China-backed options, which come with security risks due to systemic political factors, are likely to remain cheap.[44] In 2019, Huawei offered 5G equipment to a Dutch carrier at "a price that wouldn't even cover the cost of parts," according to *The Washington Post*.[45] To address the cost challenge, options include reducing prices and increasing the availability of funding. To reduce prices, Open RAN will likely create savings by improving market efficiency through widening competition, as described in a previous section. To increase the availability of funding,

states have begun to build new digital development resources and should expand upon these initiatives.

Funding initiatives for digital development and modernization are gaining momentum in the United States, among allies and partners, and in multilateral fora. The International Development Finance Corporation (DFC) and the U.S. Export-Import Bank have implemented a new focus on digital infrastructure. In May 2021, the DFC's low-interest loans paved the way for a Vodafone-led 5G-capable project to win an auction in Ethiopia, prevailing over a proposal backed by a Chinese investor.[46] ZTE had maintained a monopoly on Ethiopia's legacy networks until 2013, when Ethio Telecom, the state-owned monopoly, added Huawei as a vendor; the pivot from these companies represents a significant shift.[47] On the multilateral front, the Group of Seven (G7) announced multilateral public finance initiatives as part of its Build Back Better World (B3W) partnership.[48] The B3W statement specifies that the U.S. government will work to boost the impact of the initiatives and to mobilize more capital—both public and private—for sustainable infrastructure development. In terms of investment standards, it points to multilateral development banks and international financial institutions. This commitment carries forward the precedent set by other multilateral initiatives such as the Blue Dot Network, which certifies the financial sustainability of investments, to proliferate sound practices and funding for secure digital infrastructure.[49]

VENDOR LOCK-IN AND INEFFICIENCIES

In the lead-up to 5G deployment, telecommunications market consolidation generated market inefficiencies and potential lock-in to vendor-specific security risks. Due to high upfront costs of building networks, the industry is prone to a "natural monopoly."[50] For 5G, this tendency manifested in a small number of vendors being able to supply equipment, especially for radio access networks. In 2020, the top three companies—Huawei, Ericsson, and Nokia—accounted for 80 percent of the global market and the top five, which includes ZTE and Samsung, accounted for 95 percent.[51] Subsidies from China's government exacerbated this dynamic and tipped the balance of this already narrow playing field in Huawei's favor.[52] The result has been a small number of vendors to choose from, and, because of the status quo of hardware-based proprietary network solutions, the risk of vendor lock-in due to the high cost of replacing network equipment (so-called "rip and replace"). The systemic nature of the security risks behind China-based vendors such as Huawei means that screening code and trying to isolate equipment from the 5G core is not viable. However, alternative technology concepts can create conditions to widen the playing field, which will open the door to new vendors, more flexibility, and the cost efficiencies of open competition.

World leaders meet in Cornwall, England, in June 2021 for the Group of Seven (G7) summit. This year, G7 countries announced multilateral public finance initiatives as part of their Build Back Better World partnership, which could promote sound investments in digital infrastructure. (Japan Office of the Prime Minister)

The technology principle of open interfaces can offset the geopolitical risks of vendor lock-in by setting conditions for wider competition. For 6G, market diversification will be especially critical, given the heterogeneity of network components and opportunities for specialization. Open interfaces, which entail modularity and interoperability across generic hardware, lower the barriers of entry into telecommunications by reducing the timescales and costs required for vertically integrated solutions, especially because they include hardware deployments. Disaggregating network components can produce new non-traditional telecommunications stakeholders such as cloud service providers, traditionally enterprise-focused hardware companies, integrators, and AI start-ups with niche software specialties. For example, Microsoft and Amazon are providing 5G cloud infrastructure, Hewlett Packard Enterprise and Fujitsu offer network and other hardware components, and Rakuten has demonstrated that companies with virtualization expertise can enter the telecoms market.[53] Open interfaces have paved the way for new software-driven vendors as well, such as Altiostar, Parallel Wireless, and Mavenir. A report from Deloitte estimates that Open RAN may reduce capital expenditures on RAN by 40 to 50 percent, and operating expenses by 30 to 40 percent, in addition to disrupting the telecoms oligopoly.[54] Further, software-based interoperability offers

"future-proofing" because of the possibility of upgrading network features without needing to rip and replace hardware, and of swapping out vendors as well. Rapid software upgrades and reduction of vendor lock-in will boost network security by creating flexible conditions to stay ahead of security developments. As an amalgamation of technology upgrades, 6G will similarly benefit from principles that promote interoperability and innovation in a competitive market.

UNTRUSTED VENDORS AND SUPPLY CHAIN SECURITY

In addition to vendor lock-in, issues relating to supply chain security have featured prominently during the 5G rollout. While some of these issues are directly tied to China-based vendors such as Huawei, the risks associated with untrusted vendors include targeted disruption or manipulation of services, espionage concerns, and threats to critical infrastructure that rely on 5G networks. Given the 5G experience, two aspects of cost diffusion are, in hindsight, not to be overlooked. First, operators of mobile networks may not consider the *lifecycle* costs of untrusted hardware. These expenses, which occur after the initial deployment of 5G, might include unexpected cybersecurity costs or the possibility of rip and replace. Second, costs are also external, meaning they are borne by parties other than network operators.[55] It is crucial that policymakers engage private sector partners to communicate lifecycle costs associated with untrusted vendors. It is equally important to ensure that policymakers address external costs—one reason to start the 6G policy conversation early is to reduce the external costs of untrusted networks.

Initial research into specific security risks associated with certain vendors is an important step to identifying appropriate policy responses to 6G. There is not, however, a silver bullet solution to removing untrusted vendors from the global supply chain. While the U.S. government can and should promote open interfaces, diplomatic engagement is also necessary to disseminate risk mitigation approaches and adopt security principles. In the domestic context, the United States can coordinate with existing lines of effort, such as the Executive Order 14017 supply chain review of the information and communications technology industrial base, expected by early 2022.[56]

INTELLECTUAL PROPERTY AND PATENT PROLIFERATION

As standard-essential patents (SEPs) can be extremely lucrative for their owners, SEPs and patents more broadly represent an area of competition for 6G. In the case of 5G, one investment firm estimated that international standards bodies have already recognized more than 125,000 active SEPs.[57] Manufacturers that use SEPs must work with patent holders to determine license agreements, and the likely expansion and proliferation of patent use will add to the complexity of determining royalty and licensing fees.

China has filed more than 13,000 6G-related patents, more than a third of the world's total.[58] Research and development efforts, including to patent 6G-related technologies, will be critical for determining the major international players in next-generation networking.[59] As seen with 5G, states that exercise top-down industrial policy may be incentivized to influence international standards bodies to ensure that their relevant patents are recognized as essential. In doing so, countries such as China can provide lucrative licensing opportunities for domestic vendors. Indeed, Huawei's founder and CEO acknowledges that the competition over 6G and future telecommunications standards begins with patents.[60] The fight over intellectual property only underscores the importance of protecting the technology-focused integrity of international standard-setting bodies.

STANDARD SETTING

State interventions in standard-setting bodies threaten to create unfair advantages for some companies in 5G innovation. These bodies elect specifications based on technical merit; however, state actions toward participating companies and the bodies themselves can disrupt these traditionally "neutral" venues. The resulting unequal playing field can unfairly advantage one state's industrial policy objectives, while generating costs for innovators who rely on licensing to recoup R&D investments.[61]

China has implemented a top-down logic to standardization, in contrast to the bottom-up approach practiced in the United States and the EU.[62] China's companies can and should participate in standard-setting processes, but government imperatives drive bloc voting tactics, according to interviews conducted by the Center for American Progress.[63] Additionally, peer pressure and public shaming among companies likely motivates support for one another's proposals. In one instance during the 5G New Radio standards process, after Lenovo voted against Huawei's proposal to use polar codes, Lenovo changed its opinion in favor of the Huawei proposal and issued a public recantation, stating: "We all agree that Chinese enterprises should be united and not be provoked by outsiders," and calling in strong words for cadre unity.[64] Even outside of network technologies, China's Standards 2035 plan lays out a strategy to increase the state's centrality to next-generation technologies.[65] Standard-setting bodies, accustomed

to a more technocratic approach, are not equipped to defend against these dynamics.

U.S. policy has also interfered in standard-setting processes, albeit avoidably and inadvertently. In May 2019, the Department of Commerce added Huawei to its Entity List.[66] Each entity on the list has specific licensing requirements.[67] In this case, the requirements banned technology transfers without a license in a way that blocked U.S. companies from engaging in standard-setting discussions that included Huawei.[68] The U.S. government, if it enacts future restrictions on companies involved in standard setting, should bound requirements to avoid collateral damage to its own innovation base. In lieu of restrictions, it should promote participation, for example by offsetting the approximately $300,000 per year it costs even small companies for one engineer to build proposals and attend meetings.[69] As 6G's standards build from 5G, these challenges will only continue.

HIGH-TECH ILLIBERALISM

Telecommunications networks have a rich history of illiberal governments abusing them for surveillance and population control. More advanced networks can increase both the mass and granularity of surveillance initiatives if privacy measures are not baked into the technology and the management of it. In legacy telecoms, surveillance can be as simple as unfettered government access to call records, as ZTE facilitated for Ethiopia's government, or targeted spying of political opponents, as Huawei engineers performed for officials in Uganda and Zambia.[70] More notoriously, Xinjiang has been described as a "surveillance laboratory" and is home to a modern-day, high-tech-powered genocide.[71]

5G and future 6G networks will pave the way for mass sensor deployment—with dual-use applications bridging smart cities and surveillance initiatives—through increased capacity to transmit data. The ability to use terahertz spectrum for sensing as well as data transmission adds an extra challenge in 6G. In the CNAS report "The Razor's Edge," Kara Frederick describes surveillance ecosystems as "loosely composed of sensors, networks, and processing capabilities" that are "mutually reinforcing technologies."[72] Without privacy and security built into these technologies, 5G and 6G ecosystems may supercharge the power of authoritarian governments.

Beyond risks to security and economic power, network modernization carries ramifications for human rights. China's digital exports had the effect of jumpstarting a U.S. government reaction. 5G network rollouts spurred a flurry of analysis and policy activity about security, digital authoritarianism, market imbalances, and digital development financing. Now, as technology evolves and lends more advanced tools to friends and foes alike, this cross-cutting challenge necessitates that leading techno-democracies assemble a more coordinated approach. Coordination will ensure that the development and deployment of next-generation networks promote digital freedom, and that the networks are available to countries that seek them.

These technical and broader policy lessons constitute one part of informing a comprehensive approach to 6G. To make sound decisions at home, U.S. policymakers must also understand the global 6G research landscape. The following overview of 6G-related activity around the world focuses on the main players in the Indo-Pacific, Europe, and the Americas.

Global 6G Activity

Across the globe, 6G activity is taking off with national and multinational initiatives led by governments and industry. China, Finland, Japan, India, South Korea, Sweden, and the United States are most prominent. Despite considerable research activity, however, only the governments of China and Japan have put forward detailed visions for a 6G future. Both see 6G as an important enabler for meeting national priorities such as social challenges and economic power. Activities across the board include implementing R&D investments and infrastructure, establishing objectives for intellectual property (IP) and standards, and facilitating international research projects. But, in a mutually reinforcing trend, just as development of network technologies impacts dynamics between nations, the dynamics in turn affect the development of 6G. Many nations seek to strike a delicate balance between security imperatives and priority relationships. A survey of 6G activity around the world carries inspiration and opportunities for the United States, while also highlighting challenges and potential pitfalls.

China

Zhang Ping, a member of the Chinese Academy of Engineering, described 6G as follows: "4G changes our lives, 5G changes society, and 6G will change the world" (4G改变生活、5G改变社会、6G改变世界).[73] China sees itself as leading the 5G technology race, and network technology has been identified as critical to China's geopolitical and strategic aims. As early as 2015, 5G was featured in official government strategy documents including the 13th Five-Year Plan and Made in China 2025.[74] Leadership in telecommunications technologies,

as part of a larger digital governance strategy, supports China's efforts to establish itself as a "network power" (网络强国).[75] The nation's leading policy voices have reiterated the importance of 5G and 6G to long-term economic competitiveness and the historic opportunity for international leadership.[76] Looking forward, China will continue to develop a strategy to dominate the next generation of telecommunications technology. National strategy documents such as the 14th Five-Year Plan (covering 2021–25) mention 6G technology alongside China's vision for an interconnected, ubiquitous network that integrates space and earth (天地一体).[77]

The 6G competition has already begun. The Chinese technology company Huawei started quietly researching 6G as early as 2017.[78] In November 2019, China officially started research on 6G technologies, with an initial meeting between government ministries and research institutes.[79] In June 2021, a government-backed industry body, known as the IMT-2030 (6G) promotion group, released a white paper on 6G, observing that "China's generational leadership in 5G will be extended to 6G."[80] Members of the IMT-2030 group include major Chinese operators, vendors, universities, and research institutions. The group was established by the Ministry of Industry and Information Technology (MIIT) in 2019. But China's 6G efforts are not limited to academic institutions. Huawei is currently conducting 6G R&D in Canada,[81] and ZTE has joined a partnership with China Unicom to develop 6G technology.[82] In September 2021, Huawei's founder and CEO told employees that his company will attempt to establish global leadership in 6G.[83]

6G is a dual-use technology of military significance and will be linked to the nation's military-civil fusion strategy, as 5G has been.

While China's recent white paper on 6G did not explicitly include military applications, 6G is a dual-use technology of military significance and will be linked to the nation's military-civil fusion strategy, as 5G has been.[84] In a 2018 speech, Chinese President Xi Jinping highlighted the strategic and military aims of dual-use technology, referring to cyberspace and network technology as the most dynamic field for military-civil fusion.[85] In this way, 5G is connected to China's plans for a "world-class" military (世界一流军队), and might include applications for information support, machine-to-machine communication among drones, or other improvements in situational awareness and reconnaissance alongside navigational technology.[86] China's domestic telecommunications companies, through alliances with the country's defense industry, have already supported 5G pilot projects with intended dual-use or military deployment.[87] For 6G, leaders have focused on use cases involving space and satellite communications technology, and China claims to have tested a "6G satellite."[88] Chinese officials have also mentioned the 6G integration of terrestrial, aerial, and maritime communications into a robust network (对空天地一体化网络), which could eventually have military applications for navigation, signaling, or missile warning functions.[89] Based on China's investments in dual-use technologies, its telecommunications companies will almost certainly work with China's defense industry on pilot 6G projects.

U.S. policymakers should anticipate that China will be as ambitious with 6G as it has been with 5G. While it was not the first to officially launch a 5G network, China began the testing and verification process for 5G early, and network rollouts in China have proceeded at a staggering pace.[90] According to Liu Liehong, vice minister of the MIIT, China has 70 percent of the world's 5G base stations and 80 percent of the world's 5G connected devices.[91] Of course, China's approach to 5G has been vastly different than that of the United States. In China, state subsidies, credit facilities, and tax breaks totaling more than $75 billion for Huawei have allowed the company to scale its legacy hardware approach—using existing technology to deploy quickly and cheaply.[92] But this initial advantage also comes at a cost.[93] As networks become increasingly virtualized, which removes the need for expensive radio equipment, U.S. and other international firms could leapfrog over Huawei's pricing advantages with large-scale virtual networks.[94] Understanding China's and Huawei's current approach to 5G may reveal a blueprint for how to address competition and security challenges around 6G technologies.

Finland

Finland, home of the telecommunications firm Nokia, is at the forefront of 6G-related R&D and is shaping a vision of what next-generation wireless telecommunications could be. The 6G Flagship at the University of Oulu, billed as the world's first 6G research, development, and innovation program, is the country's main hub for this activity. Founded in 2018, the center's goal is to achieve scientific breakthroughs in four strategic research areas: wireless connectivity, devices and circuit technology, distributed computing, and services and applications.[95] Much of the center's work is funded by the EU through partnerships with Horizon Europe, a major research and innovation funding program.[96]

Although Finland currently lacks a 6G vision articulated by its government, the 6G Flagship produces numerous publications and videos that describe a future enabled by 6G networks. This future is positive and techno-optimistic, including concepts for high-speed transportation, a fusing of physical and cyber worlds to improve health care, smart clothing that monitors vitals, an array of super-functional products, and smart materials such as printed electronics.[97]

Finland's preeminence in telecommunications technologies is reflected by the fact that Nokia is the overall lead of the EU's Hexa-X initiative. This public-private consortium focuses on developing new radio access technologies, incorporating AI, and creating novel network architecture techniques to improve network performance.[98] The University of Oulu is also a consortium member.

India

While 5G has yet to launch in India, researchers and government officials are already preparing for the future rollout of 6G networks.[99] India has the potential to be a leader in telecommunications technology. However, several factors, including low fiber connectivity in rural areas and supply chain challenges related to the ban on foreign hardware, have contributed to the slow rollout of 5G networks. Yet India's telecommunications companies have demonstrated remarkable technical capabilities, which has led to significant advancements in broadband coverage. For example, Reliance Jio, one of the largest telecommunications firms in India, expanded 4G coverage to 99 percent of India's population in 2019.[100] While the country's challenges with 5G should not be overlooked, its government has approached the 5G rollout with a focus on security and supply chain integrity.[101] India has incorporated Open RAN–compliant architecture, often through collaborations with Indian, American, and Japanese firms. A recent relief package for the cash-strapped telecommunications industry, which could promote greater investment in digital technologies, is a step in the right direction.[102]

India's role in the Quadrilateral Security Dialogue (Quad) will be important for the future rollout of secure 6G networks.[103] With a world-leading software industry, India can provide momentum for Open RAN solutions. Technology partnerships with other Quad members will yield strategic benefits and strengthen the role of the Quad as a regional technology counterweight to China. More generally, if India and other techno-democratic states work in partnership on emerging technologies such as 6G and quantum computing, such ambitious moves will catalyze innovation and disrupt China's dominance in communications technologies.[104]

U.S. President Joe Biden hosts leaders of the Quadrilateral Security Dialogue (Quad) at the White House in September 2021. Technology partnerships among the Quad, including for 6G development, can strengthen their regional position in the Indo-Pacific. (Pool/Getty Images)

Japan

Japan expects that Beyond 5G will be the main infrastructure for society and industry by the 2030s, and its ambition is to create what it terms Society 5.0, which blurs the physical and cyber worlds to solve social challenges. To this end, the National Institute of Information and Communications Technology (NICT) delineates social challenges and scenarios of various scales to construct a moonshot-like approach to 6G innovation. On a small scale, NICT recognizes increasing demand for nursing care and an insufficient labor force, naming telepresence as a solution. Human users could engage through machines and receive three-dimensional haptic feedback by way of high data throughput, low latency, and high precision position capabilities to bridge the physical space between available labor and the place where it is needed. Another example is the expansion of telecommunications into the maritime domain, where using flexible network nodes and proliferation of IoT can assist with early tsunami detection. On a grand scale, the NICT has explored a City on the Moon scenario and key technologies required for its implementation.[105] While a 6G-equipped lunar base is not the objective of the scenario, the quest to design enabling technologies may lead to breakthroughs in non-terrestrial optical networks or reap other future surprises. Horizon-scanning efforts will be important for U.S. policymakers to anticipate how 6G ecosystems may evolve outside of traditional telecommunications modalities.

Security considerations, economic prosperity, and values go hand in hand for technology development, including 6G. Senior Japanese politician Akira Amari identifies the need to "secure the superiority of the new infrastructure of our digital society" by defining the values underpinning future technologies before authoritarians can set those standards.[106] Japan's overarching proposition for technology—a proactive counter to authoritarian models—seems centered on decentralization and interoperability across borders. The nation's overarching Data Free Flow with Trust concept seeks to promote cross-border data flows while addressing security and privacy, and similar themes emerge in 6G plans.[107] NICT's "Beyond 5G/6G White Paper" anticipates that future networks will "eliminat[e] various barriers and differences such as urban and rural areas, borders," and social conditions, and that infrastructural resources will pivot "from monopolistic to sharing."[108] Countering monopolies and promoting sharing will likely remain prominent in Japan's approach to network technology development.

Police officers in Namie, Japan, search for remains of victims of a tsunami in March 2011. Japan envisions that 6G technologies, which will connect Internet of Things devices across land and sea, can solve socially meaningful challenges such as tsunami detection. (Yuichi Yamazaki/Getty Images)

Critical lines of effort in Japan's Beyond 5G Promotion Strategy include R&D, IP, standardization, and 5G deployment.[109] Japan's government supports open architecture and maximum virtualization to lean into its innovation advantages and promote interoperability. To support R&D activities, Japan's government invested the equivalent of $500 million in research grants and facilities in fiscal year 2020. NICT is building testbed infrastructure in FY2021 to support academic and private sector innovation in THz transmission, optic networks, and automated network management.[110] For its IP and standardization line of effort, Japan aims to obtain and hold 10 percent of essential patents for Beyond 5G technologies. It is supporting this goal through its new Beyond 5G IP & Standardization Strategy Center, which brings together industry, government, and academia to implement strategies for standardization. Finally, Japan regards 5G networks as the precursor to 6G and is invested in deployment of fiber-optic networks and base stations, both to lay infrastructural groundwork and to create "living testbeds."[111]

South Korea

South Korea, which claimed to be the first country to officially launch a 5G network, has begun research and development into 6G.[112] With the goal of commercializing 6G as early as 2028, South Korea has one of the most ambitious 6G timelines. In June 2021, the nation's Ministry of Science and ICT (information communications technology) established a 6G R&D action plan with more than $194 million (220 billion won) in investments across 10 strategic technologies including Low Earth Orbit (LEO) satellites.[113] In addition to R&D investments, South Korea is facilitating international research projects and has signed a memorandum of understanding with the U.S. National Science Foundation (NSF) on a joint 6G research project. It has also entered similar partnerships with European firms Nokia and Ericsson. Additionally, South Korea initiated a partnership with China's Academy of Information and Communications Technology.[114]

The nation's private industry has been researching and testing advanced 6G capabilities. Samsung has tested 6G capabilities, including an end-to-end 140 GHz wireless link using a fully digital beamforming (targeted wireless signals) solution. LG has set up testing facilities and demonstrated 6G beamforming in collaboration with German research institutes.[115]

South Korea's confrontation of the "security-trade dilemma," where it must balance ties with the United States, its main security provider, and China, its largest trade partner, extends into technology policy.

South Korea's confrontation of the "security-trade dilemma," where it must balance ties with the United States, its main security provider, and China, its largest trade partner, extends into technology policy.[116] Government leadership has largely deferred to private industry on whether to use Huawei hardware in networks. As a result, the smallest of its three major telecommunications companies, LG Uplus, relies on Huawei. In October 2020, South Korean officials pushed back against U.S. appeals to ban Huawei technology as part of the United States' Clean Network campaign.[117] Huawei's presence in South Korea, including the Seoul 5G research lab it established in 2019 and its equipment, is just one example of the potential challenges around technology cooperation with U.S. allies and partners.[118] Careful diplomacy, trusted alternative vendors, and increased trade engagement with South Korea will be essential to ensure its network security.[119]

Sweden

Sweden is a major player in 6G research, and the telecommunications company Ericsson is central in the country's 6G-related efforts.[120] The firm participates with three universities—two Swedish and one Belgian—in an EU-funded research effort focused on multi-antenna technologies to create a new wireless access infrastructure.[121] Ericsson is the technical lead of the EU's Hexa-X consortium, which seeks to shape 6G development.[122] While company leaders are cautious about the prospects of Open RAN as a viable solution for 5G networks, they see open architecture as a certainty for 6G and are actively investing in compatible technologies.[123]

Other Swedish organizations are also taking part in 6G research. The firm Qamcom is a partner in Hexa-X, and the Research Institute of Sweden is undertaking a project focused on innovations in edge computing for land and space.[124] The Chalmers University of Technology specializes in integrating artificial intelligence to optimize mobile network performance, another Hexa-X funded project.[125]

Sweden, like its neighbor Finland, does not have a government-initiated vision for 6G such as China's and Japan's governments have produced. For now, the Swedish government seems content with having the EU and private industry set the tone for what a 6G future could look like.[126]

United States

The United States is a leader in 6G-focused research. American efforts in 6G began in earnest in 2018, when the University of California at Santa Barbara established ComSenTer, a $27.5 million research center focused on converged terahertz communications and sensing.[127] Backers of ComSenTer include the U.S. Defense Advanced Research Projects Agency (DARPA) and leading research universities.[128] ComSenTer is part of a larger DARPA effort, the Joint University Microelectronics Program (JUMP), which aims to develop breakthroughs in microelectronics. The Semiconductor Research Corporation—a consortium of companies including AMD, Intel, Qualcomm, Samsung, and TSMC—manages JUMP.[129] Industry is also partnering with academia in other research efforts, including satellite links and new

network architectures that could provide significant economic opportunities. Such efforts were launched in 2021 with the University of Texas at Austin and Purdue University.[130]

Researchers deem the availability of spectrum crucial to maintain U.S. leadership in the field.[131] In March 2019, the FCC opened the 95-GHz-to-3-THz frequency band for testing and verification experiments. In fact, a few weeks before that, then-President Donald Trump tweeted, "I want 5G, and even 6G, technology in the United States as soon as possible. It is far more powerful, faster, and smarter than the current standard. American companies must step up their efforts, or get left behind." He was probably the first world leader to publicly call for 6G R&D.[132]

Elements of the U.S. government have also acted beyond allocating spectrum. In 2021, the National Science Foundation announced a $40 million program to accelerate research in areas related to next-generation networks.[133] In its FY2022 budget request, the National Telecommunications and Information Administration in the Department of Commerce sought funding to develop AI-enabled spectrum sharing technologies, including for 6G.[134] Lawmakers in the House of Representatives proposed the FUTURE Networks Act that, if passed, would direct the FCC to establish a 6G Task Force, aimed in particular at standard setting.[135]

In response to efforts such as the EU's Hexa-X, the Washington, D.C.-based standards organization Alliance for Telecommunications Industry Solutions started the NextG Alliance. Launched in 2020, this initiative's goal is to promote North American mobile technology leadership. It is private sector–led and centered on technology commercialization.[136] The group's main initiative is to craft industry's vision for a National 6G Roadmap, which it plans to submit to the Biden administration and Congress in 2022.[137] This effort could provide ideas for the broader U.S. 6G policy tool kit, the range of policy options available to administration officials and lawmakers in Congress.

The 6G Policy Tool Kit

U.S. policymakers should include domestic and international components as part of policy for 6G. Actions should include, but are not limited to, NSF-led funding for R&D, domestic spectrum allocations, memorandums of understanding between like-minded allies and partners, and legislative support for the eventual deployment and global dissemination of 6G.

TIMELINE OF U.S. 6G POLICY ACTIONS

- **March 2019**: FCC opens the 95-GHz-to-3-THz frequency band for 6G testing and verification experiments.[138]
- **October 2020**: The Alliance for Telecommunications Industry Solutions, a U.S. telecom standards developer, launches the NextG Alliance.
- **April 2021**: The United States and Japan agree to jointly invest $4.5 billion in 6G.[139]
- **April 2021**: The National Science Foundation, in collaboration with the National Institute of Standards and Technology, the Department of Defense, and private sector partners, forms a public-private partnership with $40 million in funding to catalyze development of resilient NextG Systems.[140]
- **June 2021**: The NTIA submits its 2022 budget request to Congress, featuring an initiative to develop AI/ML tools to optimize spectrum sharing between government radar and next-generation (including 6G) systems.
- **June 2021**: H.R. 4045 (FUTURE Networks Act), a bill to establish a 6G task force, is introduced in Congress and in July passes committee along with other secure network bills.
- **July 2021**: Researchers at the University of Texas at Austin and industry partners (Samsung, AT&T, NVIDIA, Qualcomm and InterDigital) launch a 6G@UT center for R&D. (Other academic-industry partnerships have been developed at Purdue and New York University.)[141]

As policymakers have observed with the 5G experience, the rollout of such technologies comes with challenges, especially due to state and local regulatory frameworks. But at the current stage of 6G development, certain policy options are feasible in the short run. For example, releasing a 6G strategy, creating interagency new working groups, and leveraging existing government testbeds do not face significant legislative or regulatory hurdles. As part of an overall strategy for 6G, the U.S. government should consider practical and feasible next steps, but at the same time engage in planning efforts for the rollout stage.

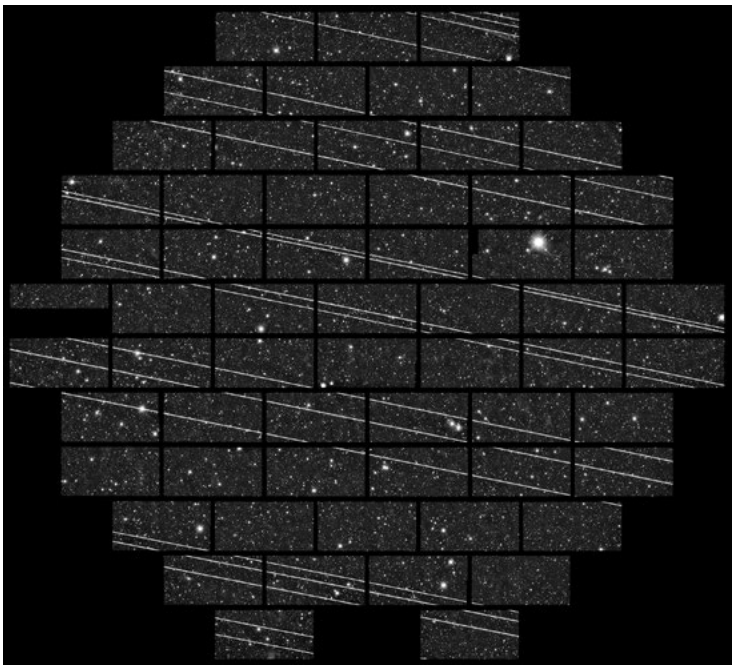
A Framework for U.S. Policy

The U.S. government must coordinate multiple policy and regulatory tool kits that are available across departments and agencies to incentivize and develop 6G technologies. Previous legislation to develop a 5G strategy required consultation with the FCC Chairman, the Secretary of Commerce, the Assistant Secretary of Commerce for Communications and Information, the Secretary of Homeland Security, the Director of National Intelligence, the Attorney General, the Secretary of State, the Secretary of Energy, and the Secretary of Defense.[142] The implementation of this 5G strategy is managed under the leadership of the National Security Council and the

National Economic Council, supported by the National Telecommunications and Information Administration.

A similar approach should be taken for a national 6G strategy to support both the development and eventual rollout of 6G networks. Funding options for R&D and efforts to accelerate 6G testing and verification should be implemented early and should not face significant legal or regulatory roadblocks. Another line of effort should focus on threats and vulnerabilities to next-generation networks. Threat assessments, in addition to addressing supply chain risks, should assist in the development or verification of trusted vendors for rollouts at home and abroad. Finally, while modeling the 5G strategy is a good start, policymakers should attend to the unique needs and use cases of 6G. For example, supporting 6G space-based networks will necessitate coordination with the National Space Council, Department of Defense, and NASA.

Regulation of broadband technology is dispersed among several government organizations that will need to work together on policy for 6G. The FCC, an independent regulatory agency, manages non-federal uses of spectrum and interstate and international communications. It also collaborates with the State Department's Division for International Communication and Information Policy to set international standards.[143] The National Telecommunications and Information Administration, in contrast, has statutory authority over federal uses of spectrum and advises the U.S. president on telecommunications policy.[144] However, the regulatory environment for telecommunications is complex, and certain aspects of the 5G rollout—especially infrastructure buildout—have faced state and local roadblocks.[145] For 6G, these hurdles will not likely be present at the initial R&D testing and verification stage. But the future rollout of 6G in the United States will require local, state, and federal coordination, including appropriate oversight by Congress.



Astronomers at the Cerro Tololo Inter-American Observatory capture streaks from a passing satellite internet constellation. Orbital platforms will likely play a role in future 6G networks to flexibly expand connectivity. (CTIO/NOIRLab/NSF/AURA/DECam DELVE Survey)

Opportunities for International Collaboration

In addition to domestic policy tools, the U.S. government has multiple options for pursuing diplomatic engagement with allies and partners. The Biden administration, while coordinating relevant departments and agencies, should consider opportunities for multilateral and bilateral engagement with like-minded states. For example, international partnerships already feature prominently for 5G, and several nascent 6G efforts are active; 6G-related research is well suited for further cooperation. The United States has pursued cooperative agreements with Japan, South Korea, and the United Kingdom on bilateral bases.[146] The Quad's member countries—Australia, India, Japan, and the United States—announced in a joint statement in September 2021 that they would work together on Beyond 5G technologies. Similarly, Finland's 6G Flagship has numerous international partnerships, including with Singapore and Japan, while the EU provides funding for collaboration among entities in its member states.[147] The U.S. government should seize on this diplomatic momentum to facilitate a shared vision and future interoperability across the 6G ecosystem.

To promote international collaboration on 6G, the United States should establish a regular dialogue with tech-leading democracies at the forefront of 6G, as well as with countries such as Taiwan, which has important capabilities in enabling technologies such as semiconductors. Certain alignments on R&D can tap into complementary innovative capabilities, for example to streamline research efforts. The U.S. government should also pursue public commitments with like-minded nations through joint statements and memorandums of understanding. In a few years, before the deployment of 6G, the United States should coordinate trade policy, including by harmonizing export controls for certain technologies. Collaboration should also include information-sharing on interference in standard setting and coordination of mitigation approaches, such as

anonymous voting or programs to fund attendance by small companies. Close coordination, particularly starting early in the technology development process, will be important to address matters of security, interoperability, and standard setting.

Recommendations

If sensible action is not taken soon, the persistent and often avoidable challenges of 5G will affect 6G rollouts and critical digital infrastructure generally. Swift action is necessary because 6G development is well under way, and because the U.S. position in telecommunications is not as robust as it once was and must be bolstered. Even with stronger U.S. footing, Chinese firms will continue to present competitive and security challenges. The first priority for U.S. policymakers should be to take actions that strengthen American competitiveness in 6G. At the same time, the United States should pursue better cooperation and coordination with like-minded countries on matters such as research, supply chain resilience, and infrastructure development. Finally, security must be a focus from the start, as communications networks, critical infrastructure, and everyday devices are increasingly entangled.

Promote American Competitiveness in 6G

Bolstering the foundation of American competitiveness in 6G requires planning for and investing in its science and technology base—the people and the infrastructure and resources they use to create and innovate. Starting with a top-down vision and a strategic framework in which to execute that vision, U.S. policymakers have a key role in ensuring that America's companies, universities, and research institutes have the opportunity and resources they need to maximize the chances of success.

To that end, the White House should:

- *Craft a 6G strategy.* The United States needs a strategic road map that lays out a vision for American leadership in 6G and the desired international and domestic telecommunications landscape of 2030 and beyond. Necessary elements of the strategy include R&D investments, human capital, security, government incentives, infrastructure, spectrum policy, export controls, norms for technology use, standard setting, and international collaboration.
- *Expand R&D funding for 6G technologies.* The White House should explore opportunities for additional 6G R&D funding through research grants, tax credits, and financial support. Importantly, R&D funding should include support for enhanced governmental and private sector participation in standard-setting processes.
- *Leverage existing capabilities for testing, verification, and experimentation of 6G technologies.* The United States can establish government 6G testbeds (in both the laboratory and field) to support and build upon 5G R&D. Testing and verification can address potential issues with interoperability between commercial and federal entities. To provide institutional structure, the interagency Networking and Information Technology Research and Development Program can lead a 6G testing and verification working group.
- *Open additional experimental spectrum licenses to accelerate R&D efforts.* In addition to higher-frequency bands, the White House should support the commercial adoption of 6G technologies by designating spectrum innovation zones to test 6G in city-scale, outdoor environments.
- *Establish a U.S. 6G Spectrum Working Group.* This group should include representatives from government entities including the Office of Science and Technology Policy, Federal Communications Commission, National Institute of Standards and Technology, and the Department of Defense, among others, along with stakeholders from private industry. The working group should identify spectrum needs for 6G rollouts and offer recommendations for access and management. Ideally, this working group will be under the umbrella of the proposed Technology Security Coordination Group, tasked with coordinating technology and regulatory and policy actions related to the security of supply chains.[148]
- *Promote the development of new 6G use cases by leveraging the purchasing power of the U.S. government.* Federal entities such as the Department of Transportation or Department of Defense can stimulate new applications for next-generation networks by being early adopters of 6G technologies.

Congress also will play a central role in 6G development and rollouts. Congress should:

- *Designate the Department of Commerce as a U.S. intelligence community (IC) member.* The Department of Commerce is a critical player in technology competition for both promoting and protecting innovation. Closer ties to the IC will improve information-sharing on foreign technology policy developments, such as adversaries' future strategies for challenging the

integrity of standard-setting institutions, while integrating the department's analytical expertise and understanding of private industry.

- *Enact R&D funding to solve challenges for rural 6G deployment*. Hardware infrastructure for 5G, such as fiber-optic cables, can be expensive, especially in population-sparse regions. 6G technology development offers an opportunity to develop alternatives such as wireless optic solutions or non-terrestrial platforms to fill network gaps and thereby connect rural areas more readily. These alternatives can also be used to spur network deployment in international emerging markets.
- *Attract and retain much-needed foreign science and technology talent by initiating immigration reform*, such as by raising the cap for H-1B visas, eliminate the cap for those holding advanced degrees in science, technology, engineering, and mathematics, and amend the Department of Labor Schedule A occupations list to include highly skilled technologists. Development of 6G is occurring now, with release expected by 2030. Science and technology talent is key in the short and medium term to meet that timeline. Software developers will be in especially high demand, given the trend of network virtualization.

Another key player will be the National Science Foundation, which should:

- *Create an equivalent of its Resilient & Intelligent NextG Systems (RINGS) program for start-ups.* RINGS, supported by government and major industry partners, offers grants for higher education institutions to find solutions for NextG resilience.[149] While the major industry partners will be key players for implementing network solutions, the NSF should also develop resources to kickstart an emerging ecosystem of 6G start-ups.
- *Expand the Platforms for Advanced Wireless Research Program*, a consortium of city-scale research testbeds, to include software innovation hubs.[150] Because network virtualization will be key to 6G development and deployment, providing testbeds close to software hubs can create mutual benefit through access to one another's resources.

Collaborate with Allies and Partners

International collaboration and coordination among the techno-democracies is a must to ensure that 6G deployments are secure and resilient, and that the norms and standards for their use are in line with liberal-democratic principles and values. Cooperative R&D and alignment of standards among the tech-leading democracies will be essential to ensure a robust and competitive telecommunications sector with greater vendor diversity. The Biden administration should double down on current bilateral and multilateral tech development and policy partnerships. Congress should appropriate the funds to expand and provide bureaucratic infrastructure to routinize these efforts. To encourage multinational approaches on 6G, Congress should:

- *Create a Technology Partnership Office at the Department of State.* A new office, headed by an assistant secretary for technology, is needed to initiate, maintain, and expand international technology partnerships, including efforts to engage on 6G standard setting. The Trump and Biden administrations' efforts to establish tech partnerships with key allies are important developments. Ensuring that these partnerships endure will require interagency coordination and support. The current approach of managing these relationships from the National Security Council is a pragmatic initial approach, but not realistic for the long term as the partnerships grow, institutionalize, and become more complex. A proposal to establish such an office is in the United States Innovation and Competition Act of 2021.

The White House should:

- *Organize an international 6G Policy and Security Conference series.* U.S. policymakers should work with foreign counterparts of the techno-democracies to organize regular 6G conferences to discuss key issues including technology development, security, standard setting, and spectrum. Forum participants should include stakeholders from government, industry, and civil society. These convenings could emulate the successful Prague 5G Security conferences. Early and ongoing dialogue on these topics will help to avoid the geopolitical pitfalls experienced with 5G development and rollouts.

The White House, with the support of Congress, should:

- *Lead the creation of a Multilateral Digital Development Bank*. In partnership with export credit and export finance entities in allied countries, the United States should lead in establishing a new organization with the mission of promoting secure and fair digital infrastructure development around the world, with a special emphasis on closing the digital divide in less affluent countries. Such an initiative is needed to provide a credible, sustainable alternative to China's Belt and Road

and Digital Silk Road initiatives. This will provide new opportunities for firms from the techno-democracies to offer customer countries with cutting-edge technologies and requisite training. Through continued engagement between governments, it would also help to counter the spread of illiberal uses of telecommunications technologies.

The State Department should:

- *Spearhead a tech diplomacy campaign.* The United States and allied governments should craft clear and consistent messaging to the Majority World about the risks of using technologies from techno-autocracies, especially China. This effort should also cover helping governments to build systemic mechanisms that account for geopolitical risks in technology policy decision-making.[151] The effort can also strengthen diplomatic engagement on international standard setting by communicating potential risks associated with proposed 6G standards.

Ensure the Security of 6G Networks

Security of 6G networks must be addressed early and throughout the development of new wireless telecommunications technologies. Belated and insufficient attention to 5G security standards posed undue risks. Similar problems with 6G can be avoided by focusing on basic security solutions that involve access control, authentication, public key infrastructure, virtual networking architecture, and mutual authentication requirements. To facilitate network security, the FCC, with the support of relevant agencies, should:

- *Identify, develop, and apply security principles for 6G infrastructure and networks.* An expanding Internet of Things will create a growing number of access points. Greater network virtualization and Open RAN will also mean more vectors for attack. At the same time, however, there is opportunity to develop tools that detect and mitigate cybersecurity breaches, especially with the adoption of zero-trust models. The FCC should adopt a proactive approach, with partners in industry and academia, to identify 6G security risks and ensure that international standards have cyber protections. Participation by a range of federal government departments and agencies will be essential, given the range of 6G applications.

The White House and Congress should:

- *Promote and support the development of open and interoperable technologies.* The United States and allied governments should ensure that 6G networks are open and virtualized. Coordinated outreach, joint testing, industry engagement, and policy collaboration can build global momentum and communicate risks associated with untrusted vendors. More directly, the United States should explore financing support and technical assistance to strategic partners for the deployment of secure and trusted 6G networks. The National Telecommunications and Information Administration could undertake pilot programs, testing virtualized 6G equipment, to accelerate the transition to more open and interoperable networks.
- *Create a 6G security fund, building on existing efforts to ensure 5G security*. This can fund the adoption of Open RAN solutions, thereby encouraging vendor diversity and fostering market competition. Such as security fund can be implemented in concert with the activities of the proposed Multilateral Digital Development Bank.

Conclusion

6G technologies will bring more than just improved data transmission speeds. Communications technology forms the conduit of societies, implicating future economic competitiveness, military strength, and geopolitical influence. While the current policy conversation around telecommunications has largely focused on China's 5G efforts, the United States is engaged in a long-term technology competition that will extend far beyond 5G.

The case for developing policy on 6G, informed by lessons from the 5G rollout, is clear. Delaying steps that other countries have already taken, for example Japan's development of a national strategy for 6G, will hurt American competitiveness and technology primacy. U.S. policymakers in the White House, Congress, and relevant departments and agencies should engage in proactive, affirmative, and collaborative efforts to ensure U.S. leadership in next-generation wireless technologies.

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