ITIF | INFORMATION TECHNOLOGY & INNOVATION FOUNDATION

June 18, 2020

National Telecommunications and Information Administration
U.S. Department of Commerce
1401 Constitution Avenue NW
Washington, DC 20230

RE: Comments on the National Strategy to Secure 5G Implementation Plan
Docket No. 200521-0144

The Information Technology and Innovation Foundation appreciates this opportunity to comment on the development of a national strategy to facilitate a secure 5G deployment in the United States and around the world.[1] ITIF strongly believes that continued wireless innovation plays a critical role in integrating a wide range of emerging technologies into productive capacities throughout the economy. A successful deployment of 5G, as well as sustained wireless innovation beyond 5G, are opportunities of national importance. This fact is not lost on our geopolitical rivals: For years China has enacted policies—some fair and legitimate, many not—to boost its domestic development, manufacture, and use of wireless technology. It is past time for a coordinated U.S. response.

The administration is tasked with developing a comprehensive national strategy for 5G.[2] NTIA's request for comments outlines four potential areas of effort: (1) facilitating domestic 5G rollout; (2) assessing the cybersecurity risks to and identifying core security principles of 5G capabilities and infrastructure; (3) addressing risks to United States economic and national security during development and deployment of 5G infrastructure worldwide; and (4) promoting responsible global development and deployment of secure and reliable 5G infrastructure.[3] ITIF's recent report, "A U.S. National Strategy for 5G and Future Wireless Innovation," enclosed herein, addresses these points.[4] For further information on how China's policies have

[1] ITIF is an independent 501(c)(3) nonprofit, nonpartisan research and educational institute—a think tank. Its mission is to formulate, evaluate, and promote policy solutions that accelerate innovation and boost productivity to spur growth, opportunity, and progress. ITIF's goal is to provide policymakers around the world with high-quality information, analysis, and recommendations they can trust. *See* About ITIF: A Champion for Innovation, *ITIF* (accessed June 2020), https://itif.org/about; National Telecommunications and Information Administration, "The National Strategy to Secure 5G Implementation Plan," RFC Docket No. 200521–0144, 85 Fed. Reg. 32016 (May 28, 2020), *available at* https://www.ntia.doc.gov/files/ntia/publications/fr-secure-5g-implementation-plan-05282020.pdf.
[2] Secure 5G and Beyond Act of 2020, Public Law No. 116–129, 134 Stat. 223–227 (2020).
[3] The National Strategy to Secure 5G Implementation Plan, *supra*.
[4] Doug Brake, "A U.S. National Strategy for 5G and Future Wireless Innovation," *ITIF* (April 2020), https://itif.org/publications/2020/04/27/us-national-strategy-5g-and-future-wireless-innovation.

undermined the global telecommunications equipment industry, please also see the forthcoming ITIF report "How China's Mercantilist Policies Have Undermined Global Innovation in the Telecom Equipment Industry."[5]

Accelerating a secure 5G deployment will be a force multiplier for growth, justifying government assistance the private sector-led rollout and subsidies for uneconomic areas. Government agencies should leverage 5G for their own processes and encourage its use in their related industries, and state and local governments should eliminate barriers to deployment. Congress should appropriate funds for pilot programs to identify and overcome challenges with the ongoing transition to virtualize network functions, introducing more software running on generic hardware infrastructure in wireless networks. Policymakers should increase funding for early stage wireless R&D, setting the stage for 6G; support fair processes in standards-setting organizations; assist allies to see a larger market for trusted vendors; and protect IP rights for innovators. It is critical networks are built with secure components. A ban on Chinese 5G equipment entering the U.S. makes sense, but a direct ban on exports to Huawei only hurts U.S. technology firms.

A better strategy should drive wireless innovation beyond 5G, with equipment from a diversity of suppliers. Efforts to define standard, open interfaces between critical components of wireless networks are a promising opportunity to shift the radio access equipment market toward one that is more innovative, less costly, and more difficult for any single company to corner. The government should look to develop appropriate mechanisms to help openly define radio access equipment interfaces and assist in identifying and overcoming challenges with the deployment of such equipment at scale. For example, the Manufacturing USA program should begin a wireless institute focused on scaling up the manufacture of secure, open radio equipment in the United States. For more details, please see the report below.

Thank you for your consideration.

Sincerely,

Doug Brake
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The Information Technology and Innovation Foundation

[5] Robert D. Atkinson, "How China's Mercantilist Policies Have Undermined Global Innovation in the Telecom Equipment Industry," *ITIF* (forthcoming, June 2020).

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A U.S. National Strategy for 5G and Future Wireless Innovation

DOUG BRAKE I APRIL 2020

5G wireless will drive economic growth for decades to come, but we need a comprehensive strategy to ensure a robust deployment and adoption of secure networks. A U.S. strategy for 5G should play to our strengths to overcome unfair practices that have made Huawei a leader.

KEY TAKEAWAYS

- 5G will make wireless connectivity more flexible and better able to be tightly integrated into different functions throughout the economy. Accelerating a secure deployment will be a force multiplier for growth.
- The private sector will lead the 5G rollout, but governments need to help. Agencies should leverage 5G for their own processes and encourage its use in their related industries. State and local governments should eliminate barriers to deployment.
- Congress should appropriate funds for pilot programs to identify and overcome challenges with the ongoing transition to virtualize network functions, introducing more software running on generic hardware infrastructure in wireless networks.
- Policymakers should increase funding for early stage wireless R&D, setting the stage for 6G; support fair processes in standards-setting organizations; assist allies to see a larger market for trusted vendors; and protect IP rights for innovators.
- It is critical networks are built with secure components. A ban on Chinese 5G equipment makes sense; a ban on exports to Huawei does not. A better strategy should drive wireless innovation beyond 5G, with equipment from a diversity of suppliers.

INTRODUCTION

These are frenzied days for 5G. The transition to this next generation of wireless technology presents unique opportunities and challenges that must be carefully thought through and addressed if the United States is to maximize the successful flourishing of next-generation wireless networks and the applications that rely on them. Policymakers are faced with complex technologies and economic dynamics around 5G, wherein decisions have an outsized impact on long-term national competitiveness and security.

Headlines feature consternation over the pace of 5G deployment, as well as the limited number of 5G equipment manufacturers and the risk posed by the continued rise of Chinese vendors, especially Huawei. Some warn that unless the United States engages in a fast and extensive 5G deployment, it will fail to gain a competitive edge in the applications that will leverage 5G networks. A national 5G strategy needs to address both production and adoption issues.

However, any such strategy should also aim to support continued wireless innovation beyond the next few years, while helping to ensure the development of future wireless technology (e.g., 6G) is not ceded to geopolitical rivals, and ideally enables at least one U.S. producer to emerge and thrive. The complex and interrelated nature of these policy considerations, and the considerable excitement—perhaps overexcitement—around the technology itself, has contributed to a lack of clear strategic vision from the United States. It is time for a reset.

A constant stream of op-eds, essays, and reports extol the virtues of next-generation networks and emphasize the importance of "winning the race" to 5G. There are several different dimensions through which 5G leadership or "winning" matters—some much more than others. The competitive and security dynamics of 5G, especially as they relate to China and Huawei, have seen near panic in some circles. Yet the ban on Chinese equipment in U.S. networks largely addresses short-term security concerns. The longer-term challenge is whether the other major equipment providers—Ericsson, Nokia, and new entrant Samsung—will be strong enough to avoid an eventual global dominance by a Huawei that's supported in part by unfair Chinese policies, especially if the European Union forecloses any future merger between Ericsson and Nokia that might be required.

The challenge posed by an ascendant, increasingly global juggernaut championed and backed by our primary geopolitical rival—Huawei—is real, if at times overstated. Next-generation wireless equipment is connective tissue for emerging applications such as artificial intelligence (AI) and automated smart-city controls. It makes little sense to allow control of such important infrastructure to be influenced by a government that does not have U.S. interests at heart.

However, it is critical policymakers do not overreact to a perceived threat with steps that risk undermining the advantages of the U.S. system, including a complex environment of dynamic competition, voluntary industry-led standards development, decentralized and rapid innovation, and a leading semiconductor sector. By and large, the system for generating and deploying new wireless technology is working well. There is no need to panic. Instead, policies should double down on what has been shown to work: strong support for our research universities and institutions; a strong intellectual property (IP) protection system and support of the business models needed for the entities bringing research breakthroughs to market; and encouragement of fair voting and healthy institutional practices at standards-setting bodies such as the Third-

Generation Partnership Project (3GPP). At the same time, policy needs to strengthen support for both the current, successful commercial U.S. wireless system and company efforts to deploy 5G systems throughout the nation.

The White House released a brief framework outlining a "National Strategy to Secure 5G."[1] This is an encouraging step, but this issue deserves more substance. That document is a beneficial initial framing, but a more fulsome report should be more forward-looking and creative, especially in how U.S. policy can encourage a diversity of secure vendors that are viable innovators. What we need is a coherent and comprehensive national strategy for 5G, which should have the following components:

- **Deployment**: The United States leads the world in successful Internet firms partly due to our early deployment of broadband and wireless networks. While the "race" to 5G is clearly more like a 10K run than a sprint, an early and broad deployment of 5G is critical. Two main levers to accelerate deployment are spectrum and infrastructure policy:
  - **Spectrum**: Demand for commercial access to the wireless airwaves that connect our devices only continues to grow. The United States has led in allocating high-band 5G spectrum, but more mid-band spectrum is needed.
  - **Infrastructure**: Compared with previous wireless networks, 5G will require smaller and less obtrusive—but much more numerous—cell sites. This "densification" will justify new rules around local access to poles and rights of way, as well as support for buildouts in high-cost areas.
- **Adoption**: Just having the network out there is not enough—we must also make productive use of it. Developing applications that take advantage of 5G breakthroughs is more difficult than in previous generations, justifying support for digital transformation research and development (R&D), smart-city test beds, smart manufacturing and agriculture, and government-agency adoption of 5G and 5G applications.
- **Security and China**: Given its potential pervasiveness, 5G must be secure and built with trusted components. However, overreaction and poorly targeted policy risk accelerating Chinese technological independence, hurting U.S. component suppliers, and undermining U.S. strengths. There are several aspects to enabling a more secure 5G ecosystem:
  - A ban on equipment deemed a security risk is likely justified, but should be based on clearly stated policy and transparent risk analysis. Removing and replacing existing equipment in rural areas is likely not worth the cost; it may well be better to wait for the natural upgrade cycle.
  - The United States should work with like-minded allies to ensure a large-enough market of trusted wireless equipment suppliers. The State Department should create an elevated position designed for 5G-related and other international concerns around security and emerging technologies.
  - Policymakers should support continued wireless R&D, fair processes in standards-setting organizations, and equipment interoperability. Also, U.S. technology leaders that support innovation in wireless offerings need to be

protected through strong IP rights, with a competitiveness screen applied to all antitrust actions.

- Policymakers should help encourage the transition to virtualized radio access network (vRAN) infrastructure, without unduly controlling the architecture of 5G networks as demand shapes the deployment. Now is the time to start pilot programs designed to identify and addressing practical challenges to scaling vRAN deployment, as well as signaling to the market that this is a policy priority of the United States.

WHAT IS 5G?

At one level, 5G is simply the next generation of wireless infrastructure. New generations of mobile come in waves, requiring changes throughout the network. The first generation of mobile telecommunications was focused purely on basic voice service. The next generation, 2G, was still focused on voice, but made the switch to digital standards and enabled text messaging. 3G then introduced data services, expanding the functionality beyond voice to include multimedia and limited Internet access. It was not until 4G that a full specification based on Internet Protocol allowed for functional mobile broadband, in turn serving as a platform for dizzying innovation in mobile applications. These waves of technological changes have come in roughly decade-long cycles: 1G mobile voice in the 1980s, 2G in the 1990s, 3G basic data in the 2000s, and 4G LTE data in the 2010s.

In one sense, 5G is simply the next step in this cycle. Yes, 5G will offer new-and-improved capabilities (e.g., lower latency, higher capacity, and support for a larger number of connections). 5G will see a much greater capacity of mobile networks, thereby driving down unit costs and increasing consumer surplus, and likely expanding the dynamic competition between fixed and mobile network providers. 5G will likely serve an important role in future digitization and automation of systems, connecting smart sensors with AI.

The real hallmark of 5G (as well as other next-generation wireless standards such as Wi-Fi 6) is in flexibility and adaptability. 5G can change various technical parameters to tailor connectivity to different use cases. Whereas the LTE air interface for 4G was designed primarily for smartphone- and tablet-oriented mobile broadband, the New Radio (NR) standard for 5G can adapt to a much wider variety of uses, and may support an explosion in cheap sensors for machine-to-machine or Internet of Things (IoT) devices.

5G is not a monolith. There are different component technologies to 5G—and different versions of it will be deployed in different areas over time. Crucial policy decisions involved in a national strategy for 5G turn on important, if somewhat obscure, distinctions of different parts or flavors of 5G networks, such as the difference between the core and the edge of the network, and between stand-alone and non-stand-alone networks.

Technology Components and Architecture

This section offers an overview of some of the wide variety of technologies and improvements that will be incorporated into next-generation 5G networks. A basic understanding of the technological components of 5G gives a better sense of the important policy decisions that must be made in order to drive a more nuanced and strategic vision for U.S. networks.

New Radio Standard

At the center of any generation of mobile technology is what is known as the "radio interface," which allows the end-user device (e.g., a smartphone) to connect with the rest of the network over the air. Throughout the country, mobile operators have deployed hundreds of thousands of base stations—usually rectangular boxes a couple feet tall located on cell towers or on top of buildings. These base stations use electromagnetic spectrum (i.e., radio waves) to send signals of encoded information to smartphones or other wireless devices. Wireless networks are in actuality mostly wired, only going "wireless" for the last few hundred or thousand feet. "Radio interface" (or "air interface") refers to the language phones, tablets, and other devices use to communicate with the base station in order to access the Internet. For 4G, this radio interface technology is called Long Term Evolution, or LTE. For 5G, the standard is NR—an apt, albeit not-so-creative, name.

The NR standard is developed within the standards-setting organization known as 3GPP. While 3GPP has agreed on the initial specifications for 5G, the body is constantly improving and adding new features through new releases. The standard does not stand still. Equipment manufacturers also offer their own non-standardized features, so the 5G air interface continues to evolve and is not a single monolithic offering. The 3GPP standardization process is an important, if obscure, locus of geopolitical strife over what innovations make it into the marketplace.

Massive MIMO and High-Frequency Spectrum

An important development in wireless communications is the use of multiple antennas on either end of a wireless link. Transmitting and receiving data over multiple antennas—known as Multiple-Input Multiple-Output (MIMO)—increases the capacity of the link, adds redundancy, and improves performance wherever radio signals are bounced and reflected off buildings.[2]

While MIMO of a smaller scale, say two or four antennas, is common today, one of the breakthroughs driving 5G investment is Massive MIMO, which uses significantly more antennas. Antenna size is generally proportional to the wavelength of spectrum used, so higher-frequency spectrum allows for smaller antennas. Using higher-frequency spectrum allows devices to accommodate hundreds of tiny antennas, dramatically increasing performance.

These advanced Massive MIMO antennas unlock the potential of spectrum previously thought unusable for mobile communications.[3] This extremely high-frequency spectrum, often referred to as "millimeter wave" (mmWave) because its wavelength is measured in millimeters, offers the potential for a tremendous throughput capacity, as there is a large amount of spectrum available that is well-suited for small cells that reuse the same spectrum across different areas.

The massive amounts of bandwidth available at higher-frequency spectrum unfortunately come with a trade-off: Higher-frequency spectrum generally does not propagate as far as lower-frequency spectrum at the same power level. It is likely mmWave spectrum use in 5G systems will initially be focused in areas of concentrated high demand, such as high-density urban areas.

MIMO, however, can also be used with spectrum that has better propagation characteristics. In particular, so-called mid-band spectrum represents the sweet spot in terms of geographic coverage and capacity for higher throughput—and mid-band spectrum of a certain frequency and higher can successfully leverage the multiple antennas of MIMO, though mid-band spectrum

generally does not use as many antennas as the smaller-wavelength mmWave bands. This means, while there is no single "5G band," there is a particular range of frequencies—roughly 2.5 to 6 GHz—that are in extremely high demand for 5G systems because they make best use of recent technological advances.

Small-Cell Architecture

Historically, spectrum reuse has been far and away the source of most gains in increasing the overall use of wireless systems. Techniques such as making smaller cell sizes or splitting cells into different sectors allow for greatly increased capacity. Smaller cell sizes allow operators to essentially "reuse" the same frequencies at each geographic site. This trend toward smaller cell sizes, especially in areas of high demand, is not unique to 5G. But the next-generation deployment is anticipated to greatly accelerate the trend toward small cells, especially wherever mmWave spectrum is leveraged.

But this smaller-cell-size solution is limited as well. As cells get smaller and smaller, costs begin to skyrocket. The expenses of additional equipment, backhaul connections, rights-of-way negotiations, and the engineering to avoid self-interference quickly swamp the benefits and cannot easily be borne alone by additions to consumers' monthly bills. Policymakers can help alleviate some of these costs by right-sizing regulations that historically may have been designed for large macro-towers.

Understanding Virtualization: SDN, NFV, vRAN, cRAN, and O-RAN

Access network operators are quickly adopting technologies to shift aspects of networking traditionally performed by hardware into more agile software environments. The last few years have seen a dramatic rise in the use of software-defined networking (SDN) techniques. SDN is a technology that essentially separates out the control over the routing of network traffic, and allows centralized software—rather than individually configured pieces of specialized hardware—to dynamically adjust the network.

In the traditional mobile networking approach, the core network includes a variety of hardware appliances designed for specific functions. These appliances include, for example, routers, firewall devices, network address translators, session border controllers, gateways, and load balancers. These pieces of hardware are necessarily fragmented and purpose built, with each individual appliance requiring physical installation, configuration, and power. It is a costly and cumbersome process to build or change a network with all these individual components, which slows the innovation cycle.

Virtualization of these functionalities—known as Network Functions Virtualization (NFV)—represents an important disruption of this system, wherein operators are transitioning to general-purpose servers and switches throughout the network instead of purpose-built hardware that must be individually installed and configured. The functionalities can then be provided in software at a lower cost and with a faster pace of innovation. Generic, commercial, off-the-shelf hardware can be used, resulting in a greater diversity of suppliers at a lower cost.

The new software-based control over networks also enables network slicing, which gives control over logically separate data flows, and allows the network to tailor specific technical requirements for different use cases. Network slicing also provides better performance,

supplying resources on demand and potentially enabling new business models beyond the classic mobile subscription.

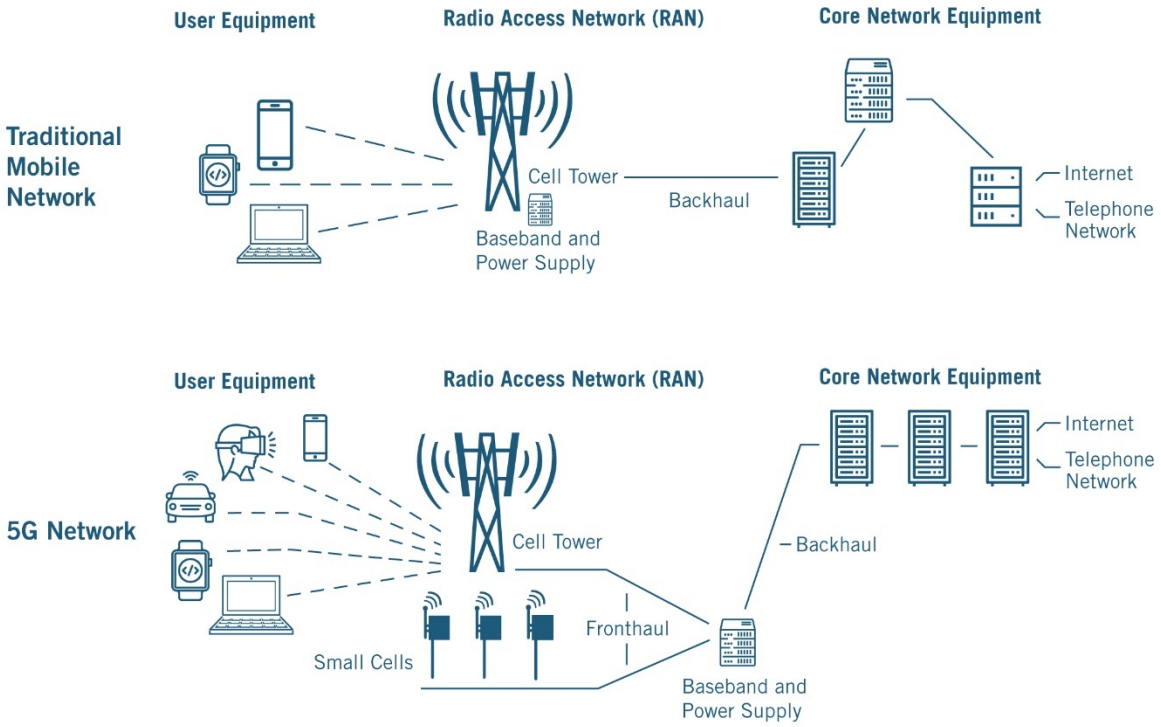
These technologies allow for a far more dynamic network that can adapt to the needs of specific applications on a granular basis. And while the corresponding changes to how networking is done may seem obscure and technical, they comprise crucial changes to how networks—both wired and wireless—will transition to 5G, and evolve beyond.

Key policy questions surround the virtualization of the radio portion of the network—known as vRAN—such as it potentially helping to challenge the rapid growth of Chinese national champion Huawei. There are some risks and challenges in transitioning to a more virtualized network, but there are also opportunities for policy to carefully encourage market forces already driving the industry toward a more open, less costly, and more innovative equipment ecosystem.

There are a slew of technologies—and abbreviations—related to vRAN. At its most basic, a vRAN involves a separation of the antenna element of a base station from the processing for the baseband unit and other components that prepare information to be sent out over the air. Like the virtualization of other functions in the core of the network, the signal processing necessary to encode and decode information can then be run in software on relatively generic hardware. Instead of a specialized, integrated piece of equipment sourced and maintained from a single vendor, a vRAN might include a wider diversity of companies specializing in the software that runs the cells' functions, and generic hardware similar to high performance servers.

A vRAN also allows for a related cloud RAN (cRAN), wherein the resources needed to do the baseband processing are pooled together instead of provisioned individually for each base station. While at not nearly the same scale as cloud computing, the basic idea is the same: It is dramatically more efficient for several cell-tower base stations or small cells to share processing, memory, power, etc., rather than have redundant systems for each individual cell. Today, the signal-processing resources of base stations are generally inefficiently used, as they must be provisioned for peak utilization of each cell. There are, however, some limitations to cRANs. The communication between the signal processing and the radio antenna units must be in tight synchrony, so high-quality, low-latency connections are required. Engineers will continue to improve the opportunities around cRANs, although cRANs will likely only be used for clusters of cells in each area, rather than for an entire network.

Figure 1: Mobile network architecture comparison



Open RAN (O-RAN) generally refers to the interfaces between different components of a vRAN system, which can use open, interoperable interfaces and application programming interfaces, or closed, proprietary interfaces. The term "O-RAN" was pioneered by the O-RAN Alliance, which is an operator-led organization that pushes for more open interfaces in RAN equipment. However, other organizations, such as the Facebook-led Telecom Infra Project (TIP) have been working along similar lines. Whatever the exact term or specification, more open RAN interfaces will allow for a wider number of potential vendors for both the software and hardware.

The term "virtualization" may be somewhat confusing, as it makes it seem as though the network itself is immaterial, existing only in the cloud. This is not the case. Only the specific functions are virtualized, and still must run on hardware, even if that hardware can be commoditized, commercial-off-the-shelf components. Antennas and small cells still have to be deployed throughout neighborhoods and communities; fiber fronthaul (connecting the radio antenna units to the baseband signal processing equipment) and backhaul (connecting that signal processing back to both the core network and the wider Internet or telephone network) must be installed. Advanced vRANs are no less—and often more—dependent on the physical infrastructure. However, open vRAN equipment features several advantages, with lower cost, faster innovation, more supplier diversity, and more-efficient use of resources among them.

Edge Computing

Edge computing refers to the practice of moving computing resources closer to the edge of a network. Mobile or multi-access edge computing can be thought of as the hosting of a miniature data center much closer to the user, perhaps in the central office of a telco provider or even on the premises in the case of sophisticated manufacturing or enterprise use cases.

As it is still in its early days, it is not clear exactly how edge computing will change the dynamics of the broader tech and telecom sector.[4] Edge computing is widely expected to bring large benefits to data and processing-intensive applications that benefit from very low latency, such as virtual and augmented reality, robotics control, and other industrial uses. Applications enabled by edge computing are expected to benefit producers in the manufacturing sector through digital twin technologies.[5]

A good example of how edge computing is likely to develop is Verizon's announced partnership with Amazon's AWS to provide edge services.[6] This partnership will enable developers to work with the already highly scalable AWS environment to optimize performance for extremely low-latency services. One potential use case is gaming, wherein Verizon and AWS are currently working with video game publisher Bethesda Softworks.[7] Similarly, AT&T has announced a partnership with Google Cloud.[8] Low latency is crucial to a seamless virtual or augmented reality experience. For example, 5G combined-edge computing and high-performance augmented-reality glasses could bring tremendous benefits to productivity throughout the economy, in addition to enhancing entertainment.

Overview of Actors in the Dynamic Wireless Ecosystem

Wireless networks and their equipment components are complex systems with dizzying supply chains. Nearly all of them are undergoing rapid transformation under the transition to 5G. Consider, for example, Apple—which represents just one company within a much broader system—and its list of more than over 200 suppliers that provide components for its products.[9] It is important policymakers have a rough understanding of all the different players participating in the complex system that brings 5G to the market. This section offers a general explanation of those various actors, many of which are small players making interesting contributions (which is necessarily an oversimplification).

Foundational Technology

At the base of 5G, to enable efficient communication over the airwaves, there is technology that requires tremendous R&D across a range of different fields. The coding algorithms to efficiently detect and correct errors, for example, is an area of continued research and innovation.[10] The channel modelling to study the use of different frequencies of spectrum sees ongoing work. Materials sciences also continue to make contributions that, for example, improve antenna, chipset, and battery performance.

There are many companies and research institutions that contribute to the foundational technology of wireless communications. The U.S. company Qualcomm is a clear leader in developing the underlying technology of 5G, especially technology related to efficient use of spectrum resources. Numerous other companies involved in RAN-equipment development, such as Ericsson, Huawei, Nokia, Samsung, ZTE, and NEC, are also major contributors. These firms offer proposals to standards-setting organizations, such as 3GPP, to be incorporated into the 5G

specifications. Often, these proposals aim to get a firm's patented technology incorporated as essential to the standard, which would result in royalties to that firm for each device using the technology.

These foundational technologies and techniques may be obscure to the everyday consumer, but are critical to the basic and efficient functioning of mobile wireless communications. For example, there is an important group of foundational technologies that deals with both the way in which information is encoded before it is sent over the airwaves, and how errors are checked and corrected. 5G wireless connections are designed to automatically optimize for a wide variety of use cases, from battery-sipping moisture meters on farms to the streaming of ultra-high-definition videos to high-speed trains. Some of these require very high reliability and throughput, while other connections prefer communications to be as simple as possible in order to save on other resources, such as battery life and processing power. To make these trade-offs efficiently, the foundational technology must be flexible and scalable across a number of characteristics. Coding algorithms and error-correction technologies, for example, continue to see innovations and developments—and the selection of these foundational technologies for inclusion in the 5G standard is a major decision.

Discussions around supplier diversity and security concerns in the RAN-equipment market have reached a fever pitch, though often the foundational technology and the research that goes into developing a new wireless standard is not as widely considered.

A firm understanding of the role of the various foundational technologies underlying continual wireless innovation is notably lacking from U.S. 5G policy conversations. Discussions around supplier diversity and security concerns in the RAN-equipment market have reached a fever pitch, though often the foundational technology and the research that goes into developing a new wireless standard is not as widely considered. Increased support for R&D that filters through U.S. research universities, our National Labs, and the National Science Foundation (NSF) is critical to continued breakthroughs in the underlying mobile technologies. It is also crucial that a long-term national strategy consider both the business models needed to bring such inventions to market and the IP framework needed to protect those innovations, and appropriately support well-functioning, democratic standards-setting institutions that incorporate foundational technology.

Network Equipment

Network equipment obviously plays a critical roll in the overall telecommunications system. A healthy and secure telecommunications sector depends on the suppliers of a variety of equipment inputs. In many ways, several national policy goals are tied to network equipment suppliers. The pace of innovation throughout the mobile communications industry, the integrity of the supply chain, and the capability to enhance connectivity to boost productivity throughout a number of traded sectors are, to one degree or another, tied to the equipment suppliers.

Over recent decades, the telecommunications-equipment industry has seen rapid consolidation on a global scale. In part, this is due to economic forces driving companies toward achieving ever-greater economies of scale—on both the equipment side as well as the purchasing side of the operators. The two sides of this market—vendors and operators—typically work together through repeat business, with a tendency for operators to stick with suppliers they know and

trust. While the equipment sector continues to make large investments in innovation, the considerable economies of scale, relative concentration, and difficulty for small players to enter the market mean dynamic shifts in the market move relatively slowly.

There are a variety of types of equipment within the network. Optical equipment used to transport very large amounts of data between networks in different cities, routers and switches used to direct traffic throughout the network, and equipment that translates between wired and wireless portions of mobile networks all have their own subsectors of network equipment, with different companies specializing in separate parts of the network.

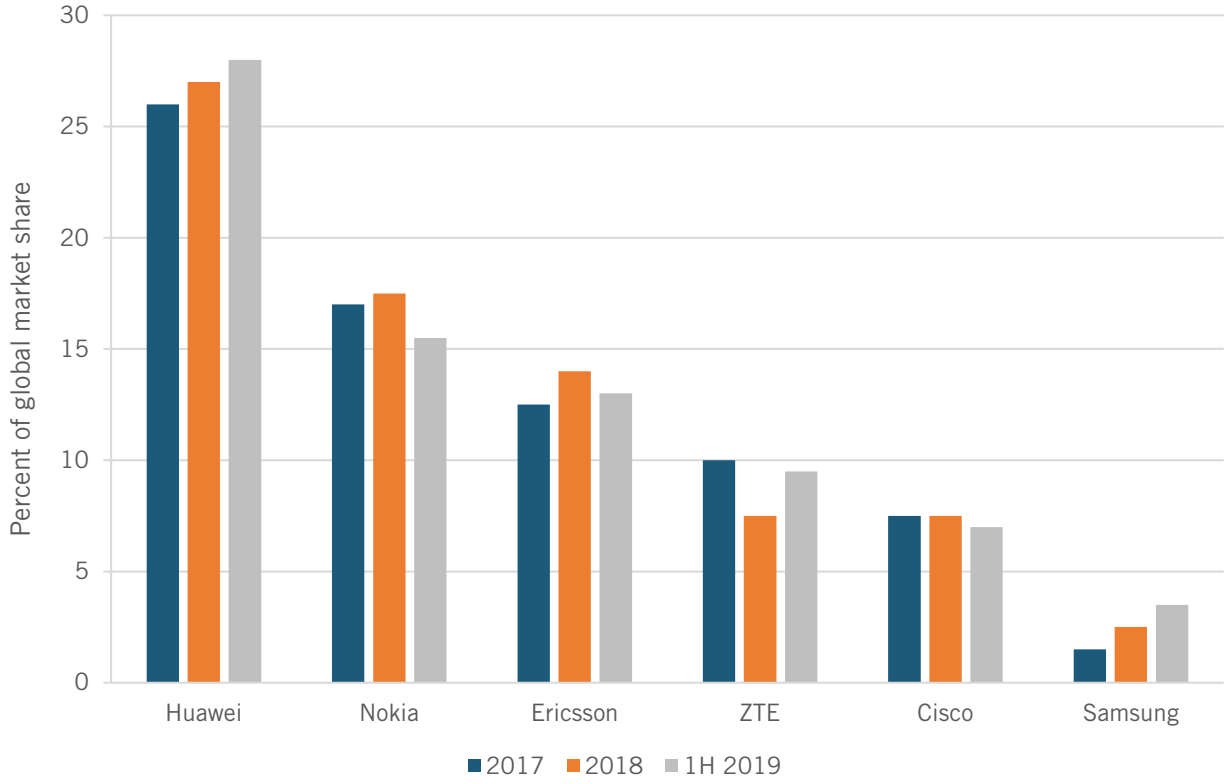
While perhaps oversimplified, a key distinction is between equipment for the core and the edge of the network. The core of the network is generally wired using fiber or coaxial cable, and contains equipment that provides the functionalities of an individual company's network, and then connects users to the broader Internet or telephone network.

The edge of a mobile network refers to where the network signals transition from wired to wireless. This component of the network is the RAN. An important focus for policymakers for a number of reasons, RAN equipment is expected to represent the largest percentage of overall 5G deployment cost.[11] The RAN comprises 65 to 70 percent of the total cost of the network.[12] This market is also where Huawei has achieved considerable success and market share.

After a series of mergers and acquisitions, the United States no longer has any sizeable companies that provide RAN equipment. It used to lead the world in the production of telecom equipment through AT&T's Western Electric (and related Bell Labs), but overly aggressive antirust actions coupled with a complete lack of industrial policy focus on the U.S. domestic telecom equipment industry has meant the almost complete loss of industry capabilities. After AT&T spun off Western Electric (later renamed Lucent), in response to the Department of Justice's (DOJ) requirement separating the company into regional Bell operating entities, a series of management failures and strategic mistakes led to the Lucent losing significant market share. Lucent lost its way in part because it mistakenly chased opportunities created in the wake of the 1996 Telecommunications Act related to the artificial, and ultimately doomed, government-induced creation of market competitive local exchange carriers (CLECs). Unlike foreign telco equipment companies, Lucent bet heavily on the CLEC market—including providing generous financing for their equipment—and as a result had to write off tens of billions of dollars of bad financing. It also didn't help that Lucent was much more aggressive in pursuing short-term stock-price inflation. Continued weaknesses led it to merge with Alcatel to become Alcatel-Lucent, which in turn was purchased by Nokia. During that same time period, in 2009, Nortel, a Canadian firm with significant employment presence in the United States went bankrupt, suffering in part from Chinese IP theft and overaggressive prosecution by the U.S. Securities and Exchange Commission.

The United States does have companies that make networking equipment, most notably Cisco and Ciena, though they largely focus on optical and switching equipment for the network core rather than the RAN equipment market. What's surprising is, while Lucent and Nortel were falling off a cliff, virtually no one raised the concern that North America would no longer have a viable telecom equipment producer.

Figure 2: Global telecom equipment market share[13]



After the decline and fall of North American RAN equipment makers, leadership shifted to Europe—particularly to Ericsson and Nokia. However, in the last two decades, Chinese champion Huawei has grown extremely rapidly to become the world's largest provider, in part due to a protected Chinese market and Chinese government subsidies.[14] Since the 2000s, Huawei has been able to gain significant market share, in both China and elsewhere, by selling equipment at between 20 to 30 percent below the price of the other major providers—or approximately the same amount the Chinese yuan has been devalued.[15] It also may have benefited from IP theft, especially from Nortel.[16] Chinese state-owned ZTE also provides RAN equipment, and Samsung of South Korea has a small-but-growing presence in the RAN market. There are some small United States-based RAN vendors, but they are generally focused on innovative new virtualization techniques, and do not have large-scale manufacturing capabilities.

Huawei's impressive economies of scope and scale have troubled Western security analysts who fear continued economic pressure on trusted providers of RAN equipment could make a significant share of the world's telecommunications equipment subject to a geopolitical rival.[17] Huawei's rise has put financial pressure on the incumbents Ericsson and Nokia, which in turn has led to reductions in each of their R&D budgets.[18] Nokia has reportedly been exploring a merger or asset sales to help shore up its financial position.[19]

Huawei, on the other hand, continues to pour large amounts of money into R&D. On a purchasing-power-parity basis, it is now the largest investor in R&D in the world—although approximately 10 percent of that is provided by Chinese government grants.[20] In 2018, Huawei spent about as much on R&D as Nokia, Ericsson, and Qualcomm combined.[21]

Operators

Mobile network operators are the consumer-facing businesses in the wireless system. In the United States, the major nationwide operators are AT&T, Sprint, T-Mobile, and Verizon. There are also several smaller regional and rural carriers. These companies integrate a number of components and services into their offerings. For example, they purchase network equipment, as well as services to keep that equipment running and up-to-date with latest advances, from the providers. Operators procure spectrum, typically through auctions held by the Federal Communications Commission (FCC) or secondary-market transactions. They work with tower companies, such as American Tower, Crown Castle, SBA Communications, and others, to rent space and get power for their equipment.

Operators and their various contractors make a dizzying array of decisions regarding how networks are deployed, the particular architecture that suits a neighborhood or area, and what spectrum to use where and how. Operators must carefully design networks to avoid self-interference between cell sites to efficiently serve the various levels of demand between neighborhoods. Deploying and operating a mobile network is an incredibly complex undertaking, wherein basic decisions around the design and architecture of the network are made under intense competitive pressure.

Devices and Components

Connecting to the operators' networks on the device side are all the various smartphone handsets, IoT sensors, and mobile connected devices. Global market leaders in the smartphone arena are well-known brands internationally, while the Chinese brands are not popular in the United States. They include Samsung (South Korea), Huawei (China), Apple (United States), Xioami (China), and OPPO (China).[22] Devices other than smartphones, of course, also connect to 5G networks. Laptops and tablets feature 5G connectivity, but so do a wide variety of IoT devices, smart-city sensors, and industrial and manufacturing equipment. Major providers of industrial IoT hardware include Cisco (United States), Huawei (China), Ericsson (EU), TE Connectivity (EU), and Qualcomm (United States).[23]

Each of these devices is made up of component parts sourced from a variety of suppliers. One of the key components for mobile devices is the various semiconductor chips necessary for communications, processing, and other functionalities, which, for smartphones, are sold to device manufacturers as an integrated "system on a chip" that contains a processor, memory, and a modem to enable connection to the network. Here again Qualcomm is a leader, both in chipsets and particularly in designing the modems that provide connectivity. Huawei's HiSilicon brand has a strong production in an array of semiconductors, and has begun development of many chips that were cut off from the U.S. market.

Operating Systems and Applications

Android and iOS, developed by Google and Apple respectively, are far and away the most popular operating systems for smartphones. Estimates for the share of devices running some flavor of Android worldwide are around 75 to 85 percent, with most of the remaining running iOS.[24] Android OS is open source, so its large market share represents a variety of versions and flavors controlled by different companies. Huawei has developed its own operating system, called Harmony OS, and has begun to deploy it in a number of products, though notably not yet in

phones or tablets.[25] Recent U.S. export controls intended to thwart the ability of Huawei to use U.S. software only accelerated this development.

New and Evolving Stakeholders

The new technologies and dynamics around 5G are bringing new entities into the mobile system. Cable providers, for example, are a perhaps underappreciated stakeholder in the 5G ecosystem. The exact role cable will play in 5G—collaborator, competitor—is not yet clear. In many parts of the United States, cable companies such as Comcast and Charter have extensive high-speed networks that provide quality backhaul services.[26] In many jurisdictions, these companies are able to install and power small cells on the strands of cable hung between pre-existing poles, and thereby potentially avoid the lengthy processes and expensive fees associated with small-cell siting.[27] Although cable providers do have mobile offerings, much of that traffic today is routed via the large Wi-Fi deployments the cable companies offer access to or otherwise relies on bandwidth from mobile operators such as Verizon (via wholesale agreements).

There are indications the cable industry may in the future be an important user of the 3.5 GHz Citizens Broadband Radio Service (CBRS) spectrum that is coming online, potentially building systems on that lightly licensed spectrum. This more-flexible spectrum-access system might enable a shift toward more private networks, especially for large enterprise campuses. The ability to access clean spectrum at a low transaction cost through the CBRS spectrum could bring in new participants to the wireless space operating at a smaller scale for specialized use cases and locations.[28]

Virtualization is quickly disrupting established practices. The operational savings and new flexibility are driving operators to transition to SDN and NFV soon. For example, AT&T aims to control 75 percent of its core network functions with software by the end of 2020.[29] Many companies relatively new to the telecommunications sphere are helping in this revolution. VMWare is a major player in virtualization across the board, and telecommunications is no exception. IBM is offering new open-source telecommunications services through RedHat. A slew of small and medium-sized companies are developing this technology and offering services. U.S. companies such as Mavenir, Parallel Wireless, and Altiostar are gaining attention for focusing on equipment with open interfaces that can leverage these new changes in networking.

The O-RAN Alliance, an association of companies exploring open specifications and interfaces between components of RAN equipment, has received much of the attention on the potential solutions for vRAN specifications based on open interfaces. The O-RAN Alliance boasts a large and growing membership, initially championed by mobile operators. As of this writing, 22 mobile operators are members, including the major network operators of the United States, South Korea, Japan, India, China, and Europe. The Alliance is driving toward SDN solutions that would leverage "white box" network architectures with generic off-the-shelf hardware. Other organizations, such as the Facebook-led Telecom Infra Project, also have considerable momentum.

WHY 5G IS IMPORTANT: SEPARATING HYPE FROM REALITY

To listen to some breathless accounts, 5G will do everything—potentially even having a hand in curing cancer.[30] Some have argued 5G will be central to U.S. military capabilities; others tout remote-controlled robotic surgery.[31] Some of 5G's potential is at risk of being oversold. Gartner,

in its famous "Hype Cycle" of technological development analysis, put 5G at the very peak of hype in its 2019 report.[32]

With any new technology there is always hype, and at one level this is positive because it creates excitement, motivating companies, consumers, and policymakers to support innovation. But too much hype is harmful, as it risks leading to a backlash and cynicism from dashed expectations. Overinflating the importance of 5G—making it a stand-in for a country's overall technological prowess—also invites bad policymaking made out of misguided national security or geopolitical fears.[33] In reality, what 5G can actually do is more than enough to warrant significant excitement without going overboard with unrealistic hype.[34]

5G is being designed to meet three general types of use cases: enhanced mobile broadband, massive IoT connections, and critical high-reliability and low-latency services. The goal is to have a flexible network that can adapt to a wide variety of use cases throughout a number of different vertical industries. Enhanced mobile broadband should see faster throughput (with gigabit-per-second speeds possible), latencies as low as 1 millisecond, and a consistent user experience. Massive IoT services within 5G are being designed for power efficiency and simplification to keep device costs low, for longer ranges, and to support far-denser IoT connections. Connections can also be tailored to maximize reliability, thereby facilitating investments in high-value use cases with tight timing and low error requirements, such as precision manufacturing and large-scale industrial robotics.

Although perhaps not as exciting as the exotic applications unlocked by super-low latency, the most immediate benefit of 5G for the consumer market may simply be the massive additional capacity it offers. New technology that takes advantage of previously unused spectrum means much more bandwidth, putting strong downward pressure on the volume price of data plans once the capacity is available.

Fixed Wireless to the Home

Some initial deployments of mmWave spectrum have focused on home broadband connections. By using the massive amounts of bandwidth available in high-frequency spectrum, wireless providers are able to offer home broadband—wherein, for example, devices can be hung outside a window to pick up mmWave signals from a nearby cell tower that might otherwise be impeded by walls or reflective widows, and then beam Wi-Fi to the inside of the house—with performance characteristics similar to existing wired options. These initial fixed wireless products are offered outside the original wired footprint of wireless, such as AT&T's and Verizon's fixed-telco networks, and add an often overlooked dynamic in broadband competition.[35] The cable industry will likely play in important role as a backhaul provider for 5G wireless networks.[36] Cable companies also have wireless offerings of their own, leveraging their deep Wi-Fi hotspot networks and partnerships with existing wireless networks. 5G will drive interesting competitive dynamics, potentially deepening existing partnerships through backhaul and reseller agreements, and accelerating cable networks' transition to independent wireless providers. Higher-performance wireless networks with greater capacity may be offered to those willing to cut the cord entirely. This dynamic is expected to accelerate when the New T-Mobile is able to deploy its combined Sprint and T-Mobile spectrum assets.[37]

More broadly, continued wireless innovation is also a relatively important industrial sector in and of itself. While the United States does not have an equivalent wireless equipment manufacturer to Ericsson or Nokia, U.S. companies do still supply devices and important components—such as the variety of chips that go into handsets—as well as develop some of the foundational technology of a wide variety of communications, while also providing much of the valuable software that relies on these networks.

Ultimately, the most important aspect of 5G is its potential to drive productivity gains through the variety of industries and sectors that can leverage wireless connectivity. While companies and other organizations currently use 4G connections designed for mobile broadband, 5G will bring a number of benefits and open up a broader number of use cases. One important advantage of 5G is low latency. Another is the ability to combine a significantly larger number of inputs into the network with finer grain control, allowing for tighter integration with a wide array of verticals throughout the economy compared with 4G.

Several studies of 5G attempt to estimate its economic impact. The GSMA, an international mobile trade association, has estimated 5G will contribute $2.2 trillion to the global economy over the next 15 years—or roughly 5.3 percent of gross world product (GWP) growth.[38] The GSMA estimate says 35 percent of those productivity gains from 5G technology will be in the manufacturing and utilities sector, and 29 percent in the professional and financial services sector. IHS Markit estimated that, by 2035, the 5G value chain alone will drive $3.6 trillion of economic output, and support 22.3 million jobs.[39]

It is difficult to know for sure the ultimate impact of 5G as compared with such connectivity solutions as 4G or previous IoT-focused protocols. A report by Accenture commissioned by the wireless trade association CTIA estimates 5G will require infrastructure investments by U.S. telecom operators of about $275 billion, and ultimately contribute 3 million jobs and $500 billion in gross domestic product (GDP) growth to the U.S. economy.[40] One reason for the considerable excitement about 5G is it has potentially significant applications in a wide array of

producer areas, including logistics, utilities, manufacturing, city management, health care, and others. Some of the benefits are expected to flow from smart-city applications. For example, 5G connectivity, combined with data analytics, could be applied to the management of vehicle traffic and electrical grids, which could produce $160 billion in benefits and savings through reductions in energy usage, traffic congestion, and fuel costs.[41]

Arguably, the United States led in the last wave of Information Technology (IT) innovation in part because it led in 3G and LTE, and because of good national policy, including regarding spectrum. The 3G and 4G platforms enabled U.S. innovators to get into the market, first with innovative offerings, and ultimately to scale those offerings and gain first-mover advantages around the world.

The long-term goal is a combination of 5G connectivity and AI, not just within the orchestration and operation of networks, but to enable the coordination of decision-making at the application layer. As researchers with Huawei have put it, "One of the most fundamental features among the revolutionary techniques is in the 5G era, i.e., there emerges initial intelligence in nearly every important aspect of cellular networks, including radio resource management, mobility management, service provisioning management, and so on."[42]

CHALLENGES AND THREATS TO AN INNOVATIVE, SECURE WIRELESS ECOSYSTEM

There are a number of challenges facing U.S. policymakers and private-sector actors in the transition to 5G. Understanding each distinct challenge is the first step in crafting policies to effectively address each task ahead. A relatively early and broad deployment is an obvious area of focus, but a national strategy should also address acute security concerns related to the supply chain, long-term wireless innovation, and demand-side adoption efforts to see 5G effectively integrated with the economy.

Deployment

A swift deployment of 5G is important, but much of the media concern over the race to be the first country to deploy 5G is misplaced. When it comes to the biggest impact of 5G—the overall economic value creation—what matters is having a network of large-enough scale such that U.S. companies are able to develop new applications and uses that require the capabilities of 5G. There is something of a first-mover advantage, but it is not a significant setback if the United States is not the first to achieve similar coverage deployment as other countries (as will likely be the case considering the cost structure of America's dispersed populations).

The aim should not be to deploy 5G as quickly as possible, but to set the conditions for successful long-term innovation and growth of this important platform. All nations, including the United States, are striving to be early in deploying large-scale networks. In the United States, there is no reason to believe the three intensely competitive and financially healthy wireless providers—plus the hungry new entrant, Dish—will not have the capability or incentive to deploy 5G networks to meet demand. However, there are obvious policy levers to help accelerate deployment: infrastructure, spectrum, and tax policy. As the first two levers have been widely discussed elsewhere and are not the core focus of this report, we will only briefly address the policies to accelerate the deployment of 5G—the table stakes of a national 5G strategy.

Chinese operators do not face the same impediments to deployment as those in the United States, in part because of much higher population densities in China, and Chinese carriers being state-owned enterprises that are "encouraged" by government to deploy quickly. It is estimated that Chinese mobile providers have deployed about 15 times as many 5G base stations as the providers in the United States.[43]

Equipment Supplier Challenges

Chinese companies are seeking to lead across the 5G ecosystem—in its foundational technology, equipment, devices, and applications. China Mobile has set aggressive timelines for deployment of next-generation wireless. This aim at 5G leadership has seen Chinese companies, such as Huawei, take on a much larger role in standards-setting organizations, and in equipment design and manufacture in a way that sees a much more outward, global focus compared with prior generations of wireless technology.

The Threat of Foreign Domination of Radio and the Formation of the Radio Corporation of America[44]

During WWI, the U.S. government took over most civilian radio stations. After the war, Congress forced a reluctant Navy to give the stations back to their original owners. The Navy was particularly concerned about returning the high-powered international stations to American Marconi, which was majority owned by the British, who also controlled most international undersea cables.

The Navy then looked to prevent British oversea radio dominance through another route. In 1919, General Electric (GE) developed a new breakthrough component for high-power transoceanic radio—the Alexanderson alternator transmitter. GE was negotiating to sell its entire production to the British-controlled Marconi companies, but the Woodrow Wilson administration applied pressure to block the sale. GE resisted—as the British companies accounted for the entire sales of the machine, which was expensive to develop—but worked with the U.S. government to develop a consortium including AT&T, Western Electric, and others to buy out American Marconi in order to create an all-American radio company: the Radio Corporation of America (RCA). RCA later fell into trouble after DOJ forced it to license its television patents, even though the evidence showed their market power had almost no negative impact on consumer prices, and actually spurred innovation. This misguided DOJ action provided the crucial leg up for Japanese television producers, which in turn led to the complete collapse of the U.S. television manufacturing industry.[45]

The support of "national champions" to lead in 5G is explicit policy in China. The U.S. China Economic and Security Review Commission outlined six major ways in which Chinese policy has successfully created globally competitive telecommunications firms and reduced dependence on foreign technology: (1) providing significant financial support; (2) utilizing localization targets and government procurement to favor domestic firms; (3) promoting Chinese technology standards domestically and internationally; (4) constraining foreign market access; (5) cultivating national champions (e.g., Huawei and ZTE); and (6) allegedly engaging in cyber espionage and IP theft.[46] They could have added the policy from the 1990s and first decade of the 2000s that

required foreign equipment makers to "trade technology for market access," which was responsible for training thousands of Chinese engineers and managers.[47]

In some ways, increased Chinese integration within the global telecommunications supply chain could in theory be a good thing if it succeeds in providing increasing economies of scale, globally interoperable equipment, low-cost roaming, and cheaper devices. But it must be remembered that even a private company such as Huawei would not exist today absent protectionist and mercantilist policies by the Chinese government. Moreover, the focus on Chinese participation in the telecommunications supply chain must be considered in context, and may ultimately undermine U.S. interests, as well as the broader wireless innovation ecosystem, unless tailored policy responses are put in place. This will particularly be the case if Chinese equipment firms succeed in significantly weakening or even putting out of business either Nokia or Ericsson. To date, the evidence is clear that Chinese mercantilist policies generally have harmed innovation in developed nations.[48]

Policymakers have to carefully understand not only the risks involved with using Chinese equipment or allowing it to be used by our allies, but also potential Chinese dominance of the global industry, and tailor our responses appropriately.

Short-Term Security Threat

Security of 5G networks has been an intense focus for Washington, but unfortunately, much of the discussion has taken on the character of fearmongering over staid risk analyses or thoughtful policy approaches to mitigate what risk exists. Part of the challenge is much of the policy direction is from government officials who are able to view to classified briefings the rest of the policy community does not have access to. Operating without similar knowledge as to the scope and scale of the problem makes it difficult to offer good advice.

In some circles, there is an unduly narrow focus on where each piece of technology is sourced—and whether components are manufactured, if not designed and developed, in China. While many electronic components do pass through China, this concern may be driving a broader decoupling of the U.S. and Chinese markets.[49] Moreover, software-based firmware updates mean no risk analysis can be 100 percent certain, and the risk profile can change over time.

At the furthest end of consideration, with very low probability but very high potential damage, there is at least a conceivable possibility of sabotage, whereby service providers of the RAN equipment, such as Huawei, could shut down communications. While highly unlikely outside of a wartime scenario, such a scenario is unfortunately one that should be considered.

It is also be possible wireless equipment could be used for state-level espionage. This concern can be somewhat mitigated for sophisticated users through encryption and zero-trust techniques, although access to high-level metadata would remain a security concern.[50] There is a valid, albeit vague, concern that any company under China's authority could be compelled to assist the Chinese government. For instance, China's National Intelligence Law of 2017 demands cooperation in intelligence gathering when requested.[51] Article Seven of the law requires "'any organization or citizen shall support, assist, and cooperate with state intelligence work according to law.' Article 14, in turn, grants intelligence agencies authority to insist on this support: 'state intelligence work organs, when legally carrying forth intelligence work, may demand that

concerned organs, organizations, or citizens provide needed support, assistance, and cooperation.'"[52]

In addition to espionage for Chinese national intelligence purposes, it is conceivable similar tools may be used for industrial espionage and IP theft. Huawei has been accused of this with regard to Nortel in the early 2000s.[53] It also happened more recently.[54] 5G is designed to offer tools and an environment for companies to develop and run systems that are core to their production processes. 5G could conceivably offer an attractive attack vector to steal a wide range of trade secrets from companies relying on compromised equipment.

Researchers have uncovered ties between leadership positions in Huawei and the People's Liberation Army, the Communist Party, and the Ministry of State Security.[55] There is also evidence of cooperation between Huawei and Chinese state-backed hackers, such as Boyusec and APT3.[56] Other risks in working with Huawei have been identified, such as existing exploits in handsets and equipment identified by the National Security Agency (NSA); allegations of bribery or corruption; and sanctions violations, including allegations of re-exporting U.S. technology to Iran, Sudan, and Syria.[57]

The potential for cooperation with the Chinese government is generating considerable animus toward Huawei from the Trump administration. Secretary of State Mike Pompeo made this equivalence between the company and the party clear, "Huawei is an instrument of the Chinese government."[58] Reports indicate the U.S. State Department has been sharing strong evidence that Huawei works directly with Chinese security agencies.[59] It appears the conversation has largely moved past whether or not there are backdoors or vulnerabilities to what should be done about them.

Some countries believe the risk of using Chinese equipment in the so called "edge" (i.e., the RAN radio equipment) is considerably lower than using such equipment in the core of the network that provides the functionality of telecommunications services and connects users to the rest of the Internet. Most notably, U.K. rules cordoned off Huawei equipment to only the RAN in particular less-sensitive areas of their 5G networks.[60] The United States, however, is of the position that, in the words of Deputy Assistant Secretary for Cyber and International Communications and Information Policy Robert Strayer, "[T]here is no way that we can effectively mitigate the risk to having an untrustworthy vendor in the edge of the network."[61]

There is also long-term concern that with the help of Chinese policy, Huawei may well continue its meteoric rise and eventually threaten the viability of other equipment manufacturing companies and become the predominant network provider globally. This monopolistic position would not only result in economic harm—not the least of which would be higher prices and potentially less innovation—but significant vulnerabilities and dependencies. This could very well force Europe and its allies to consider plans now for what to do if Nokia or Ericsson fail.

Long-Term Innovation Mercantilism in Wireless

The short-term theoretical threat of trade-secret theft, espionage, and even sabotage from untrusted equipment in the 5G supply chain has captured a lot of attention in the media and political circles. However, a targeted ban on the use of high-risk vendors in the United States, combined with cost-effective risk-mitigation strategies undertaken by U.S. allies goes a long way toward mitigating that risk. In addition to those relatively straightforward concerns, policymakers

should also be looking toward supporting long-term development of new wireless technologies—to "skate to where the puck is going." The goal should be to carefully encourage ongoing market forces toward an innovation ecosystem that plays to U.S. strengths. There are several components to this strategy, but first it is worth understanding the nature of wireless innovation development and commercialization, and the challenges posed by some of China's policies.

Standards

Standards are an incredibly important component of global trade and the broader development and commercialization of a wide variety of innovations. Standards setting plays a central role in the transition to a new generation of wireless devices. Developed by technical experts, standards foster economies of scale and efficient trade by making it relatively easy for firms to produce a good or service that conforms to mutually accepted technical characteristics across markets. At their most basic, standards establish the size, shape, and capacity of a product, process, or system. They define key terms so there is no misunderstanding among those using the standard, and reduce uncertainty by creating a common technological platform upon which any actor can develop new applications, thereby enabling modularity and specialization through common interfaces. Standards-development processes and systems to ensure conformity to standards—including testing, certification, and laboratory accreditation—are therefore an important part of modern production and trade.[62]

China has a long track record of enacting discriminatory and restrictive domestic standards, which act as a barrier to trade for high-tech goods and services.[63] As the Information Technology and Information Foundation's (ITIF) report "The Middle Kingdom Galapagos Island Syndrome: The Cul-De-Sac of Chinese Technology Standards" argues, China has made the development of indigenous technology standards—particularly for information and communications technology (ICT) products—a core component of its industrial development strategy, and wireless is no different.[64] Most recently, in 2018, China introduced a new standardization law that favors local firms and goods and services, as it references "indigenous innovation" while failing to reference either World Trade Organization (WTO) commitments and best practices, or its acceptance of international standards that already exist.[65]

3GPP is industry-led and the primary standards-setting organization for mobile technologies—and participation is on a voluntary basis. 3GPP publishes its standards in what are called "releases"—Release 15 was the first full 5G standard, but the body continues to iterate and release new versions, with improved features and functionalities, over time.[66]

A look back at 3G technologies provides a good example of the history of somewhat obscure policies and the use of standards that have supported the growth of geopolitically strategic companies such as Huawei. China, through the China Academy of Telecommunications Technology in collaboration with Datang Telecom and Siemens, developed a unique 3G standard based on Time Division Synchronous Code Division Multiple Access (TD-SCDMA), rather than frequency division duplexing, as was used in the rest of the world.[67] "Duplexing" refers to the bidirectional nature of communications—frequency division and time division are simply different ways to divide the signals coming down from the base station and those going up from the handset. In time division duplexing, the signals are divided in time using the same spectrum, whereas in frequency division, they go up and down using different spectrum.

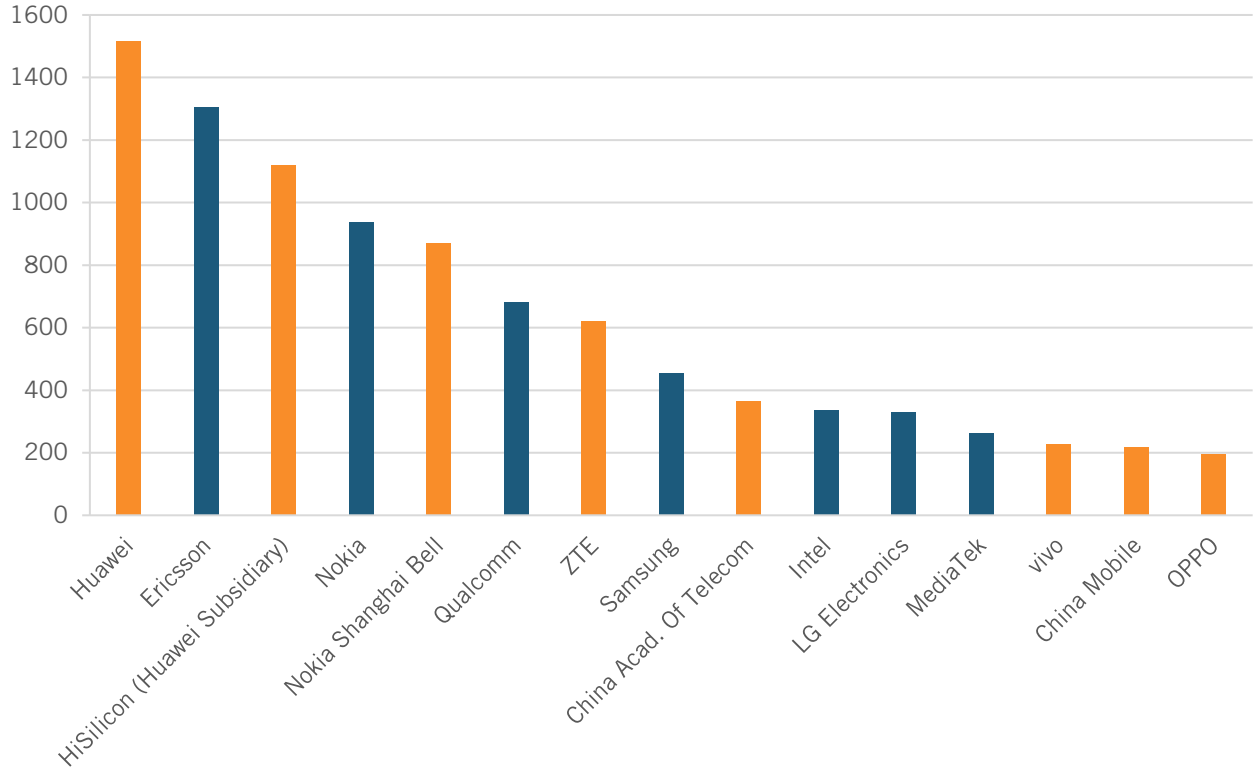
The key point to understand is that for 3G, China developed a standard that required equipment and devices that were different from the rest of the world. China Mobile, which has undergone some privatization but is still majority owned and effectively directed by the state, was then ordered to build a TD-SCDMA network.[68] There are good reasons to prefer time division duplexing, especially in the context of data transmissions, but developing a unique standard without existing equipment or devices available generally makes sense only if for a geopolitical rather than commercial strategy. China's 3G standard did not gain any traction outside of its domestic market, and was ultimately undermined because of a lack of handset chips for the technology.[69]

No country should be able to force coalitions to vote against the best technologies being incorporated into a standard.

The development of TD-SCDMA was undertaken in part as an attempt to avoid paying royalties to Western companies that had innovated first and developed better standards. Huawei benefitted from a joint venture, announced in 2003, with Siemens to develop and manufacture 3G TD-SCDMA equipment for the Chinese market.[70] However, Huawei and other Chinese original equipment manufacturers (OEMs) were confronted with patent claims brought by Qualcomm, which had rights to the underlying CDMA technology.[71] In any event, Huawei benefitted from a large Chinese market that was effectively closed off from international suppliers for much of its initial growth, in part because of Chinese policy affecting standards.

Since 3G and 4G, Huawei has increasingly turned its ambitions outward. Instead of focusing on protecting its own domestic market, or even focusing on relatively low-margin developing markets in Africa and elsewhere, the company has set its sights on the global 5G standard set at 3GPP. This transition, from inward-looking protectionism to outward-facing ambition, represents both an opportunity and a threat to market-oriented entities. There is at least a theoretical opportunity to better integrate the Chinese market with the rest of the world through unified, globally standardized technologies and equipment. But China will not allow foreign equipment providers to attain more than a minimal share of the Chinese market—enough to keep foreign providers such as Ericsson and Nokia from supporting strong trade-enforcement efforts against China, as they know China would retaliate against them. There is also evidence China has and will attempt to unfairly influence voting processes within these bodies in order to advance incorporation of Chinese technology as essential to the standard.[72] The goal should not be to entirely shut Chinese firms out of this process—indeed, it is good they are included—but instead to work to ensure fair voting practices, good institutional design, and strong norms of democratic processes in standards-setting organizations crafting the cutting edge of wireless products. No country should be able to force coalitions to vote against the best technologies being incorporated into a standard. This will require more active global leadership from the U.S. government to first shine the light on unfair Chinese standards processes, and then work with allies to push back against them.

Figure 3: Number of submissions for 3GPP Release 16 standard[73]



Chinese representatives have taken a leading role in the 5G standards working group—3GPP—by one measure submitting 40 percent of the standards and 32 percent of the documents.[74] China's growing engagement with these bodies is to be expected given its increasing technological sophistication in areas such as 5G.[75] Again, in some regards, China's increased participation in global bodies could reduce the incentives for China to enact unique domestic standards that conflict with international equipment. Technology lawyer Eli Greenbaum has convincingly argued Chinese engagement with international standards processes largely aligns with U.S. interests, when done so on fair terms.[76] Although standards organizations can be manipulated by individual firms, cartels, or nations "these risks can be managed within the structures of existing United States trade and economic policy."[77]

However, Chinese actors appear to be coordinating votes to support favored companies, rather than supporting the best technological solution—something that is easier to do when many of the Chinese companies are wholly or partially state-owned (e.g., Nokia Shanghai-Bell, ZTE, Chinese Academy of Telecommunications, China Mobile) and those that are not are subject to Chinese pressure. The best example of this is in Huawei's success in seeing polar coding adopted as the coding algorithm to connect existing 4G equipment to new 5G gear. Huawei gained a significant win with the adoption of polar coding into part of the 5G standard after it built up a significant patent portfolio around the technology.[78]

There is strong evidence that suggests the vote to adopt this technology over a Qualcomm-backed alternative not having been a fair process. The Chinese state media report "Lenovo 5G incident shows need for Chinese companies to cease mindless competition" is indicative of a vote

coordination scheme. Lenovo was forced to make a public apology after supporting the Qualcomm offer over Huawei's polar-coding proposal for the vote on 5G data transmissions (rather than the connection between 4G and 5G equipment).[79] The Chinese government so publicly and effectively shaming a company—for doing exactly what it should have by participating in 3GPP and supporting the technology that best achieves a particular goal regardless of national origin—should alert observers that China is gaming the standards forum. As Elsa Kania, adjunct senior fellow with the Technology and National Security Program at the Center for a New American Security, has pointed out, such coordination practices are the explicit goal of the joint China IMT-2020 project.[80] This group, formed by China's Ministry of Industry and Information Technology, National Development and Reform Commission, and the Ministry of Science and Technology, includes ZTE, Huawei, and Datang as members—and is designed to "organize and coordinate Chinese participants" in the process of standards setting.[81] To be clear, while the current Chinese process is better than the older one, wherein the Chinese government explicitly set standards, this current process is in some ways a wolf in sheep's clothing. It has the veneer of being voluntary and industry led, but because the firms are not truly independent actors, as they are in other nations, China is unfairly manipulating the global standards-setting process for mercantilist advantage.

Despite the investment of Chinese actors in the 3GPP process, it appears China may be looking to submit its own 5G solution with the International Telecommunication Union (ITU) at the United Nations in addition to the globally popular 3GPP-developed specification.[82] This is especially concerning, as developing countries often look to the guidance of ITU. For example, Huawei could conceivably extend its lock on the lower end of the market through equipment that is not interoperable with the rest of the wireless ecosystem. Votes at ITU are generally more pliable than within a body such as 3GPP. Rather than technical experts (ideally) voting for the best solution, at ITU, each country gets a vote, so China is able to use soft power or development support to win votes. It is not yet entirely clear whether Chinese submissions to 3GPP indicate a willingness to fully integrate with the global market (while undermining the institutions that set the terms for that market) or only one prong of a broader strategy.

However, China's attempts to undermine the governance of 3GPP and other similar standards-setting organizations by vote coordination among its companies—many of which are state owned—is a real challenge that could undermine the incentives for companies to invest over long horizons with the hopes of integrating inventions into a wireless standard. If an inferior technology can be strong-armed into a standard-essential patent, the holder of that patent sees significant unfair economic gain, which comes at the direct expense of those who invested the R&D in competing technologies that were not selected. These standards questions take on increasing importance as ITU nears the World Telecommunications Standardization Assembly, to be held in November in Hyderabad, India.

Subsidies and Other State Aid

Enterprises in key strategic sectors—such as telecommunications equipment and operators—benefit from a range of subsidies that support competitive advantage over other firms. Firms such as Huawei represent a relatively new type of Chinese "national champion" company that is not directly state owned, but does unfairly benefit from Chinese policy.[83] The company is privately owned, and headquartered in Shenzhen, not Beijing. This arm's-length separation from

the government allows it to profess its independence. But in reality, a variety of state policies have helped Huawei get to where it is now.

Huawei receives credit from Chinese banks at extremely favorable rates. It also benefits from a sizable line of credit from the China Development Bank to finance the purchases of Huawei equipment, which was raised to $30 billion to fuel its global expansion in 2009.[84] This financing allowed the company to effectively scale up its operations by focusing on relatively low-margin developing markets. The company, like other Chinese firms, also benefited in the 2000s from Chinese currency manipulation, which artificially lowered the prices of their exports. There is also evidence that ZTE received a direct grant of almost 2 billion yuan, the equivalent of about 30 percent of the penalty for violating Iranian and North Korean sanctions.[85]

Chinese policy overtly supports other parts of the ecosystem that reinforce demand for Huawei and ZTE products and services. Subsidies in a variety of forms, favorable term loans, and local government assistance to lower the cost of deployment assist Chinese operators—who in turn buy mostly Chinese equipment—that are pushing to have a major platform for 5G. State-directed China Mobile has called on the government for subsidized power supply for 5G equipment—a not insignificant cost of the overall operation.[86] China Mobile offers attractive subsidies to make end-user devices cheaper in a way that is not economical or supportable by market-based actors.[87] These device subsidies are anticipated to increase in order to cover the relatively high costs of early 5G handsets, further fueling demand for 5G networks.[88] Local governments are also, of course, able to offer a clear path for infrastructure deployment, unlike in the United States, where local politics often see grassroots resistance to the erection of towers for a variety of reasons—some legitimate, some not.

Early Chinese deployments were admittedly not as large or advanced as initially anticipated. Many had expected an aggressive deployment of full 5G networks, with the latest of both RAN and core equipment. In actuality, China Mobile and others have gone the more economical route and deployed a non-standalone network. As China is facing a number of economic and political pressures, it is important the threat from these policies is not overestimated.

It is clear the Chinese government can put its foot on the gas in a variety of areas to help the entire ecosystem accelerate into the future. Some of these tactics are unfair and drag down other competing innovators; others are worth emulating. In any event, it is important to realize that at this point Huawei is a juggernaut of a company. Its tremendous economies of scale and scope, in a sector wherein they are incredibly important, mean the United States must think creatively.

Global Competitiveness and 5G Adoption

We cannot take for granted that there is sufficient initial demand for 5G services to drive the level of deployment that would be optimal for national competitiveness. These networks are expensive to deploy, and face something of a chicken-or-egg problem when cutting-edge applications that can take advantage of the jump in performance are not yet widely available and may well require significant efforts to be developed.

South Korea, the United States, China, and Japan are expected to be leading adopters of 5G devices. In terms of the share of total connections (excluding Internet of Things), projections estimate 59 percent of South Korea's, 50 percent of the United States', and 48 percent of Japan's connections will be 5G by 2025.[89] Consumer surveys indicate demand for 5G devices is

highest in China, where 46 percent of the adult population intends to upgrade to a 5G device as soon as it becomes available (compared with 28 percent in the United States).[90]

5G is a much more flexible specification than the 4G LTE that was largely designed for mobile broadband. The combination of high-speed mobile broadband with high-performance smartphones has enabled a remarkable innovation ecosystem. The app stores of iOS and Android have given developers easy access to powerful tools—and a simple way to monetize their innovations. Bringing together powerful small computing with numerous sensors, connectivity, and GPS has been an incredible platform for disruptive innovation.

5G is also more complicated, however, with the incremental benefits of lower latency, higher bandwidth, etc. requiring much more of the network user to take full advantage of it. It is not nearly as easy to develop an immersive, low-latency augmented reality application—one that takes advantage of 5G's performance—as it is to develop, say, Pokémon GO. The same goes for industrial robotics, self-navigating mining equipment, and digital twins to optimize manufacturing processes.

5G is an enabling platform that can best be leveraged if policymakers support a full digital transformation across an array of emerging technologies and application areas.

The true promise of 5G, and the transformation it enables, depends on far more than the connectivity itself. 5G network facilities enable the integration of AI; sensing and measuring technologies; pervasive computing with drones; virtual and augmented reality; and automated control systems. 5G is an enabling platform that can best be leveraged only if policymakers support a full digital transformation across an array of emerging technologies and application areas.

This is a challenge, wherein applications that take advantage of the performance characteristics of next-generation wireless technologies require networks of adequate scale, but networks require sufficient demand to justify the large investment needed to achieve widespread deployment. This chicken-or-egg problem is highlighted when comparing deployment in market-oriented economies such as that of the United States, and relatively non-market deployments, such as in China, which have been more willing to address this market failure. To achieve the full spillover benefits of advanced, next-generation deployments, policies should seek to spur the adoption and use of these networks, including through development of cutting-edge applications.

OVERVIEW OF THE CURRENT APPROACH TO CHALLENGES

U.S. officials have examined the challenges to a successful, flourishing 5G future and decided on a number of tools, many of which appear to be aimed to thwart the rise of Chinese participants, with most of the concern focused on Huawei. It is probably fair to characterize the current approach as "scattershot," with a variety of different actors throughout the government doing what they can to limit Huawei in the United States—or even curtail its rise altogether—and the FCC acting to speed 5G deployment through infrastructure and spectrum policy. There are a lot of moving parts to the administration's 5G efforts. This section offers a summary overview of some of the current key government actions touching 5G and Huawei.

FCC Action

The FCC is a key actor in 5G policy, having both undertaken action to accelerate 5G deployment in the United States through infrastructure and spectrum policy, and initiated policy to prevent high-cost rural subsidies from being spent on untrusted equipment.

FCC Chairman Ajit Pai has termed the agency's 5G strategy "The 5G FAST Plan," emphasizing the importance of a speedy deployment.[91] The FCC characterizes this as a three-pronged strategy, focusing on bringing new flexible-use spectrum to market, streamlining infrastructure policy, and modernizing outdated regulations.

While the FCC has unleashed a large amount of mmWave spectrum, there is a great deal of pressure for additional mid-band spectrum that offers the sweet spot between propagation and capacity while being able to effectively leverage massive MIMO technology. Here, the three-tiered spectrum sharing "innovation band" in 3.5 GHz may provide some relief and added flexibility for new, smaller-scale installations. The FCC is also looking to transition important incumbent users in the C-band—3.7 to 4.2 GHz—to free up hundreds of megahertz of licensed spectrum. While the FCC is thankfully now moving forward with a plan to make this spectrum available for 5G, considerable challenges for a successful transition remain. Reducing fragmentation in the 2.5 GHz band is also an important policy priority, as well as bringing online more unlicensed spectrum in the 5.9 and 6 GHz bands.

When it comes to infrastructure policy, the FCC has worked to streamline the citing process for small cells, modifying "shot clocks" and the fees cities can impose.[92] As ITIF has previously argued, ideally, cities and operators will work cooperatively to see low-cost deployment that benefits residents and city services. But there is legitimate justification for preempting certain cities that are seeking unjustifiably high rents for access to poles and rights of way—as the FCC did.[93] These regulatory changes are facing challenges from local governments in the Ninth Circuit. Other FCC attempts to streamline environmental and historical review processes for small-cell deployments were set back when a U.S. appeals court vacated the agency's order.[94]

The FCC has also adopted a report on supply-chain security that would prohibit the use of subsidies from the Universal Service Fund to obtain equipment or services by a company determined to be a national security threat.[95] The commission is currently evaluating processes and collecting information to replace existing untrusted equipment that has already been deployed in rural parts of the United States.

Trade Policy

The Trump administration has been quick to utilize trade to further policy goals, and the area of 5G equipment concerns is no different. The administration has leveraged both import and export controls in an attempt to undermine Chinese wireless equipment manufacturers such as Huawei and ZTE. The Office of the United States Trade Representative (USTR), led by Robert Lighthizer, has made substantial efforts to get China to abide by the rules and norms of international trade more generally.

On imports, President Trump signed the Executive Order on Securing the Information and Communications Technology and Services Supply Chain on May 15, 2019, which gave extremely broad authority for the administration to block the importation or use of risky 5G equipment.[96] The language of the order is broad enough to prohibit any "acquisition, importation, transfer,

installation, dealing in, or use of [communications technology or services that pose an undue risk and were] designed, developed, manufactured, or supplied, by persons [subject to the jurisdiction of a foreign adversary]."[97]

On the export side, the U.S. Commerce Department's Bureau of Industry and Security added Huawei and its affiliates to its Entity List. As a result of this designation, no company may sell U.S. technology, software, or other items without a special license.[98]

These export controls implemented by the administration have faced considerable criticism, particularly due to the damage to the U.S. semiconductor industry—which is harming U.S. leadership in 5G and related fields without much benefit to speak of.[99] Chinese companies account for about 23 percent of global demand for semiconductors, so cutting off access to that market is a very costly decision.[100] Both of these rules have apparently run into implementation challenges. The full export controls have been delayed; however, the administration is considering expanding their scope through changes to the de minimis and direct product rules.[101] Over 160 major U.S. companies have applied for—and at least some have received—licenses to do business with Huawei despite the Entity List designation.[102]

Diplomacy

The state department has been busy communicating with governments and mobile operators around the world, attempting to convince them to avoid using potentially risky equipment. This effort intersects with a variety of challenges posed by confronting China for unfair practices in trade and policy across a number of industries.

Robert Strayer, the deputy assistant secretary of State for Cyber and International Communications Policy at the State Department has been a lead advocate abroad for the U.S. government's view of the 5G challenges. He and others have held discussions with numerous foreign countries in an attempt to convince them to forego Huawei equipment, with a goal of maintaining a large pool of demand for non-Huawei gear, and lowering the risk of doing business and sharing intelligence over allies' communications networks.

These attempts have seen varying levels of success. The decision of the United Kingdom to allow some Huawei equipment into its 5G networks provides a useful lens to understand the dynamics of international 5G diplomacy. There, the United Kingdom declined to follow the advice of U.S. representatives, and decided to effectively allow Huawei RAN equipment in about a third of its network—mostly the rural parts. While obviously the United Kingdom declined to follow the U.S. recommendation, this is not as big a loss as it might seem. After an analysis that determined only a modest risk in allowing Huawei to touch certain segments of its network, the United Kingdom formally designated Huawei as a high-risk vendor—no small decision—and seems to be inclined to reduce dependence on the supplier over time. The disagreement between the United States and the United Kingdom is more over how to mitigate the risk that is present, with the latter taking a fairly reasonable approach.

Legislation

Lawmakers have proposed numerous measures related to 5G, with two important bills having already become law. As part of the National Defense Authorization Act, effective August 2020, the government can no longer use federal money to purchase equipment or services from "covered" telecommunications companies (such as Huawei). A second bill was signed into law

March 2020: HR 4998, the Secure and Trusted Communications Network Act of 2019, which prohibits the use of federal funds to purchase equipment from companies that pose a national security threat, and creates a reimbursement program to remove and replace equipment in use that was manufactured by entities posing an unacceptable national security risk.

Numerous other pieces of legislation advance a variety of proposals, not all of which are likely to become law.[103] One bipartisan, bicameral effort is the Secure 5G and Beyond Act of 2020, which would require the White House to develop a strategy and implementation plan to "ensure the security of 5G wireless communications systems and infrastructure within the United States; assist mutual defense treaty allies, strategic partners, and other countries in maximizing the security of 5G systems and infrastructure; and protect the competitiveness of U.S. companies, the privacy of U.S. consumers, and the impartiality of standards-setting bodies."[104] Most of this legislation is defensive in nature, and would do little to spur development and adoption in the United States. We need more than defense; we need a national 5G strategy.

A NATIONAL STRATEGY FOR 5G

The United States should establish a coordinated national strategy for 5G that incorporates a range of policy measures; in the short term, streamlining deployment of 5G networks, making additional spectrum available, and helping to lead adoption and demand for advanced wireless systems. In the longer term, we should be making an effort now to support future technological and market competitiveness. Seeding the opportunities for future technology by creating the conditions for robust R&D investment and technology transfer, as well as early-stage research, should be a priority.

Whether or not one is willing to call it "industrial policy," "competitiveness policy," or simply a "strategy," a nation must have a plan of some kind. As Senator Rubio (R-FL) has put it, "[T]he U.S. cannot escape or avoid decisions about industrial policy."[105] Put another way, having no 5G strategy in place is itself a policy decision (albeit an ineffective one). There is increasing bipartisan support for industrial policy generally, and particularly with regard to planning for 5G.[106]

If it is to be successful, any national strategy on 5G should be a component of a broader attempt to curb Chinese innovation mercantilism. The United States needs to continue working, ideally in partnership with allies, to roll back the most egregious features of Chinese innovation mercantilism; it needs to encourage some transfer of U.S. production away from China to other nations; and it should develop and implement a robust domestic industrial strategy.[107] 5G policy is an important component of this effort.

First, What Not to Do: Bad Ideas

In part due to the large, perhaps undue expectations surrounding 5G and its transformative capabilities, many parties are eager to either accelerate or capitalize on its potential. And some ideas that have been proposed are far better than others, to put it lightly.

Bad Idea: A Wholesale 5G Network

Perhaps due to the overemphasis on the importance of 5G networks, some have sought to centralize the single deployment of infrastructure. This approach may have the advantage of eliminating redundant infrastructure, but deeply undermines the competitive dynamics and

specialization at the operator level. Decisions around spectrum portfolio, how much of what spectrum is allocated to what air interface, the architecture of deployment, the partnerships for various services, and, to some extent, the business model itself, continue to evolve. If anything, the dynamic changes at multiple layers of mobile service are changing more rapidly. There is a trade-off between more-efficient use of resources and the elimination of duplicate efforts, but a single wholesale network would go too far and undermine the strength of competition to drive ever-better mobile service.[108] And indeed, for some narrow deployments—such as in stadiums or subways—shared networks might be the right approach private actors should work toward themselves. But government-forced sharing of a single wireless architecture is a bad idea.

One prominent example of this thinking was outlined in the White House memo that leaked in early 2018 calling for "nationalizing" a wholesale 5G network.[109] This idea was widely panned by experts, as it should have been.[110] As long as a ban on Chinese network equipment exists, a government-owned-and-run network would be no more secure than one that is privately operated and run. Thankfully, the U.S. government has repeatedly stated that this was not a policy it would be pursuing.[111] Despite several nails in the coffin of this idea, a small company by the name of Rivada has tried its best to capitalize on the situation by continuing to lobby to play middleman in distributing Department of Defense (DOD) spectrum access.[112] This approach has also rightly been roundly rejected, and where similar schemes have been tried, they have not been successful.[113]

This misguided approach is not limited to the explorations within the Trump administration, as New York City has articulated a "New York City Internet Master Plan."[114] Parts of the plan are quite good, but other parts follow the misguided attempt by the city to build a single open-access network, even though New York City already has robust private-sector wireless and wired networks in place.[115] New York City does not invest in basic wireless R&D, and does not contribute to the ongoing dynamic evolution of next-generation wireless technology. Taking over the network deployment and offering access through resellers would undermine the revenue needed to support investment in developing new technology. Affordability and digital literacy can be real impediments to broadband adoption, but the city would be much better off addressing those issues directly through user-facing subsidies and community-based programs than trying to build its own network.

This gets to the important role cities can play in 5G and wireless connectivity, the most important of which is streamlining access to rights of way, conduit, and poles for small cells. This is no small project, and must be done while navigating constituent concerns—some legitimate, some not. Many cities also have a tremendous unfilled opportunity as users of connectivity and related services. Taken individually, basic smart-city applications may seem banal, but added together are a tremendous opportunity for more efficient, effective cities that are more responsive to the needs of citizens. Sensors that make garbage collection more efficient, or better optimize traffic signals' responsiveness to traffic, or offer early detection of problems in gas or water pipes mean cities can be much more effective and productive. Providing Wi-Fi hotspots in such government buildings as libraries—thereby ensuring communities have the resources they need to navigate the Internet—and streamlining access to city assets for broadband infrastructure deployment are reasonable civic projects. Taking over the actual implementation of networks, however, would be expensive, wasteful, and counterproductive.

Bad Idea: Proposals to Stand Up a U.S. Equipment Manufacturer

There have been a variety of proposals to have the United States either fund the development of a new telecommunications equipment manufacturer or buy out an existing provider. The original draft White House memo that called for nationalizing a wholesale network also called for standing up a U.S. wireless equipment manufacturer within three years.[116]

U.S. Attorney General William Barr, who has a background in both telecommunications and China policy, expressed concern that current explorations of O-RAN architectures would take too long, saying, "The problem is that this is a pie in the sky." He argued, "This approach is completely untested and would take many years to get off the ground and would not be ready for prime time for a decade, if ever."[117] Barr instead called on the government to consider backing a consortium to take a "controlling stake" in either Nokia or Ericsson, or both, to thwart the ambitions of Huawei.[118]

Barr's comments—which put DOJ at odds with the rest of the administration on these issues—highlight the uncoordinated nature of current 5G policy in the United States. Barr is correct that O-RAN alternatives will take time to scale up—and are no silver bullet—but his alternative to take control of European manufacturers is likely worse, in part because it is unlikely the EU would allow it. His proposal was swiftly criticized, from both inside and outside the administration.[119] The scale on which these companies operate would make for a very difficult integration, as it is not clear what U.S. firms would have any interest in such a combination

Instead, policymakers should consider supporting a U.S. company that wishes to combine with either Ericsson or Nokia. A competitiveness antitrust exemption could be justified. This is unlikely to happen for several reasons, but should be allowed—and even encouraged—regardless. Achieving greater scale could help either Nokia or Ericsson better compete against Huawei. But rather than trying to jump into the market for wireless equipment directly, the United States should try to encourage already-ongoing disruption of the status quo in a way that advantages U.S. industries and operators.

Bad Idea: Go Overbroad With Trade Restrictions on Exports to China

The administration's approach, particularly the aggressive export restrictions aimed at undermining Huawei and ZTE, is a risky strategy that likely will not achieve its stated goals. In several ways, the means the administration is grasping for do not seem well suited to achieve its ends. To the extent we want to decouple from China, it should be done carefully and strategically in order to achieve specified goals.

First, if the concern is national security, the most immediate risk is the actual widespread use of untrusted equipment in the core of the communications infrastructure of the United States. This doesn't exist today, and large operators are highly unlikely to incorporate Chinese gear into their systems, even if they were legally allowed to do so. In any event, simple and narrow import restrictions would go a long way toward effectively reducing potential security risks.

Second, to the extent there is a legitimate long-term security concern, it is around maintaining a diversity of RAN equipment suppliers. The export controls likely do little to curtail Huawei's rise in RAN equipment. U.S. components are a relatively small constraint on RAN equipment, and Huawei will soon be able to supply all components of this equipment from other sources (if it is not already able to). Denying Chinese companies access to U.S. technology does little to combat

any security risk. If anything, these export restrictions have served as something of a "sputnik" moment, and accelerated efforts at technological independence and reduced reliance on U.S. technology.[120]

U.S. technology is a much larger factor in the smartphone market, particularly U.S. chipsets and software in the form of Android, and the app store. These areas represent large economic opportunities for U.S. companies with relatively little risk from a national security standpoint. There is little to no upside to the current path the export restrictions are on.

The export controls do not address any immediate security threat, are not effective at slowing down Huawei, are very harmful to U.S. component suppliers, and are likely to accelerate Huawei's technological autonomy.

There is significant economic downside to this approach. Most obviously, these trade restrictions hurt U.S. component and software suppliers. Out of the $70 billion Huawei spent on components in 2018, some $11 billion went to U.S. firms, including Qualcomm, Intel, and Micron Technology.[121] To the extent U.S. suppliers are unable to gain exemptions, this harm is direct, with lost U.S. sales and jobs, and reduced R&D. In many cases, foreign, non-Chinese companies would take that market from U.S. companies. More generally, the extreme uncertainty makes it difficult to do business in this area, thereby undermining the development of 5G equipment and devices that rely on U.S. parts across the board.

Huawei has been stockpiling U.S. components in fear of a tougher ban, with some estimating they have enough supply to continue making phones unchanged into 2021.[122] What is more, these tactics are causing China to double down on efforts to achieve technological independence. For example, Huawei has succeeded in making a smartphone with no American chips.[123] Estimates put their ability to source all equipment components either internally or through non-U.S. partners at about a year from this writing. The founder of Huawei, Ren Zhengfei, has asserted that he is "more confident we can survive even further attacks," when it comes to trade restrictions.[124]

The restrictions have also apparently not succeeded in driving more business to trusted alternatives. Ericsson CEO Borje Ekholm explained that the Huawei strife has had "very little effects on our order books."[125] He argued that the situation had instead created "uncertainty in the market, reducing investments overall."[126]

The export controls do not address any immediate security threat, are not effective at slowing down Huawei, are very harmful to U.S. component suppliers, and are likely to accelerate Huawei's technological autonomy. This approach should be either abandoned or perhaps recalibrated to address exports in a way that might be more effective in maintaining U.S. national security and competitiveness.[127]

In a series of recent tweets, Trump seemed to indicate a desire to pull back from these trade restrictions, "We don't want to make it impossible to do business with us. That will only mean that orders will go to someplace else."[128] While not explicitly identifying semiconductors or software, Trump's tweets indicated a desire for a more careful, nuanced approach to trade

restrictions, rather than the maximalist proposals being considered. This indication of a desire to abandon broad export restrictions should be made more clearly and forcefully.

Coordinated Government Approach

5G policy consists of interrelated security, competitiveness, and industrial policy that touches numerous different economic verticals. As such, policy should be coordinated to whatever extent possible. A bipartisan group of senators wrote to the White House, concerned by a lack of a "coherent national strategy" on 5G.[129] The group expressed a need for a "5G czar" that can coordinate strategy across a range of government bodies, explaining, correctly, that:

> The current national level approach to 5G is comprised of [sic] a dispersed coalition of common concern, rather than a coordinated, interagency activity. Without a national strategy, facilitated by a common understanding of the geopolitical and technical impact of 5G and future telecommunications advancements, we expect each agency will continue to operate within its own mandate, rather than identifying national authority and policy deficiencies that do not neatly fall into a single department or agency.[130]

Democratic FCC Commissioner Jessica Rosenworcel similarly noted, "We have yet to coordinate our 5G strategy across the government."[131]

Since these comments, the National Economic Council within the White House appears to be taking the lead on coordinating a 5G plan. The administration has appointed Robert Blair as special representative for International Telecommunications Policy.[132] Blair will work with Larry Kudlow, who leads the National Economic Council. Kudlow is also convening a second 5G summit, with a focus on virtualization opportunities (although the COVID-19 crisis has delayed the summit). The White House can take the lead to help identify opportunities to extend and deepen federal support for R&D and cooperative efforts to drive research into production. The National Economic Council should also work with agencies to identify opportunities for the government to be a leading adopter of next-generation wireless technologies, perhaps in a way that would transition inefficient, single-purpose federal spectrum allocations to more general-purpose wireless connectivity.

The FCC's 5G Fast Plan and other efforts to accelerate 5G deployment should be supported and extended by other bodies and levels of, federal, state, and local government. In addition to the FCC's order, almost half of the states have enacted small-cell legislation that streamlines regulations to facilitate the deployment of 5G small cells.[133]

The risk-management strategy of 5G equipment should be better coordinated throughout the government. Congress has passed a law requiring removal of Chinese gear, and allocated $1 billion to do so, but the FCC is still gathering information as to how much it would cost to remove high-risk equipment, or whether there are more cost-effective ways to mitigate the risk. The United States would advance 5G progress much more effectively by allocating this $1 billion not for "rip and replace," but for supporting 5G rollout in higher-cost areas.

International Efforts: Standards, Supplier Diversity, and Subsidies

One of the major challenges of communications policy is ensuring a healthy globalized market of equipment suppliers. As such, a significant component of a broad 5G strategy must have international dimensions: working with like-minded countries to ensure a diversity of secure

vendors, addressing unfair subsidies, and supporting well-functioning practices of standards-setting organizations.

Supporting Standards-Setting Organizations

Standards play an important role in interoperability, enable specialization, and ensure healthy competition without complete vertical integration. Successful standards organizations are critical to the implementation of technological innovations. The track record of innovation coming out of voluntary and consensus-based standards-setting organizations such as 3GPP show this process can work quite well.

Chinese coordination, outsized delegations, vote coercion, and a dramatic increase in proposal submissions, however, risk that process being distorted. It is important U.S. actors not overreact in a way that undermines the effectiveness of these voluntary, industry-led bodies—or encourages an acceleration of these tactics. It would be a mistake for the federal government to try to emulate China; rather, it should lead a global effort to push back against Chinese standards manipulation.

While 3GPP captures much of the 5G attention, a wide range of standards-setting bodies support the broader ecosystem of devices and connectivity that fuels wireless adoption. The Institute of Electrical and Electronics Engineers (IEEE) plays a critical role in developing access technologies such as Wi-Fi, a wide variety of standards for IoT devices, connected vehicles, and efficient convergence and hand-off between Wi-Fi and mobile protocols.[134] IEEE also develops a variety of functionalities that add value to the overall ecosystem, such as Bluetooth. Other bodies, such as ITU, the Telecommunications Industry Association (TIA), the Internet Engineering Task Force (IETF), and the International Organization for Standardization (ISO) also play important roles

Representatives of the National Institute of Standards and Technology (NIST) participate in several standards bodies, both as observers and to contribute to otherwise underinvested public goods, such as public safety-related technology. NIST plays a key role by watching out for unfair practices. Having a broader view than many of the companies themselves, which may only participate in standards bodies related to their industry, NIST and other government participants can help identify problematic participation, and get a better understanding of how widespread a problem is. NIST and other participants also play an important role in ensuring broader societal values are adequately represented at standards-setting organizations.[135]

However, the U.S. government should avoid engaging in similar tactics as the Chinese. Explicit coordination going into standards-setting organizations necessarily involves picking a technology of one company to support, often over the submission of another company. The decisions should be left to the industry's engineering experts. The role for the government should be in identifying and highlighting practices, supporting good governance and fair voting at these institutions, and ensuring support for basic research. U.S. companies should have the support they need to do the R&D and successfully participate in these bodies, but it is not the government's role to coordinate a "U.S. position" on standards outcomes, or flood the zone with large delegations.

Congress and the administration can, however, take helpful actions. To start, Congress should make companies' expenditures on global standards setting eligible for the R&D credit. Business investments to participate in global standard-setting processes, including 5G, are an important component to ensuring U.S. competitiveness. But because of the free-rider problem (wherein

companies benefit from the actions of other companies), U.S. companies appear to underinvest in standards-settings activities, just as they do in R&D. Moreover, China subsidizes company participation in global standards-setting bodies in order to assure the agreed-upon standards favor their companies. To remedy this, Congress should amend the research and experimentation tax credit to allow companies to include their spending on global standards-setting activities when they calculate their total expenditures on research and experimentation.[136]

The United States should also work with its allies who share a similar concern about China's dominance of 5G standards to develop a joint plan about how to counter Chinese efforts to undermine the voluntary, industry-led standards-setting process.[137] This should be part of the Trilateral Framework talks with Japan and the European Union, and also bilaterally with others, such as Australia. This is not to say this should lead to greater government involvement in the setting of actual standards—it is not.[138] That should remain with the technical experts. Rather, the goal is to ensure each respective government is aware of developments and communicates with their respective private-sector representatives, which are engaged in good-faith, independent efforts to develop the best applicable technical standards.

The security of emerging technology on an international scale demands attention and leadership at a higher level. To address 5G security and related issues, the State Department should establish an Assistant Secretary position.[139] This position should focus on shining a light on bad behavior and driving coalitions wherever possible. Exposing Chinese practices that are undermining standards-setting organizations, and communicating these concerns to other countries, is an important example of opportunities for an elevated actor in the State Department to focus on.

Enabling Sufficient Market to Support Supplier Diversity

The United States must work with like-minded countries to ensure there is a sufficient market to support non-Chinese suppliers. In most countries, mobile connectivity is supplied by private actors through a market system—wherein operators have strong incentives to opt for lower-cost but adequately performing equipment. With the transition to 5G, operators are already facing a ramp up in capital investments that will have to be recouped over a long time, with some first-mover advantages.

Europe—especially Eastern Europe, where a significant amount of Chinese LTE equipment already exists—faces acute challenges in forgoing Huawei equipment. While there are forces working toward a much more interoperable multi-vendor network, the unfortunate fact is there are still real difficulties in achieving interoperability with existing equipment. As technology analyst Caroline Gabriel explained, there were "high hopes that the 5G network would turn out to be more open than its predecessors, making it easier for operators to mix equipment from multiple vendors in the same network zones."[140]

In particular, backwards compatibility and networks that combine 4G and 5G equipment have made it difficult to mix different equipment vendors. "Each vendor tends to implement [the interface between 4G and 5G equipment] slightly differently to get superior performance on their own systems," acknowledged Nokia's CTO and head of Bell Labs, Marcus Weldon.[141] Japan faced these challenges as well, and Softbank at least decided to remove existing Huawei gear; smaller operators in Korea are similarly working toward a full-5G network independent of Huawei.[142]

As AT&T CEO Randall Stephenson explained, "If you have deployed Huawei as your 4G network, Huawei is not allowing interoperability to 5G—meaning if you are 4G, you are stuck with Huawei for 5G. When the Europeans say 'we got a problem'—that's their problem. They really don't have an option to go to somebody else."[143] The other equipment suppliers have attempted to develop a solution that makes interoperability with existing Huawei 4G equipment workable, but it comes with significant costs in the form of tower climbs and additional equipment.[144]

The United Sates, to the extent it wants to secure a future with a broad diversity of wireless equipment suppliers, should take a more cooperative approach with foreign countries contemplating their 5G plans. Rather than browbeat poorer nations and their cash-strapped operators, diplomatic efforts should focus on effective risk-mitigation strategies, development of potentially lower-cost alternatives to high-risk vendors, such as open-RAN, and identifying tools to overcome the practical challenges of transitioning away from high-risk vendors. When there are real sunk costs to existing Huawei LTE gear that is difficult to incorporate with 5G equipment of European vendors, rather than turn to second-best risk-mitigation strategies, countries need an economical alternative. However, these nations should also recognize the reason Huawei is able to offer lower prices is at least partially because of unfair government subsidies—and market economies should recognize this in their purchasing decisions.

Addressing Unfair Chinese Export Subsidies

A key source of Huawei's expansion of global share is subsidies, including export subsidies from Chinese state-owned banks such as China Exim Bank. Indicative of this, a 2015 Organization for Economic Cooperation and Development (OECD) report shows China Exim Bank's rapid growth in export credit business. In relation to China's total exports, Sinosure's export credit insurance ($327 billion in 2013) represented around 15 percent, China Eximbank's export credit lending ($40 billion) around 2 percent, and China Development Bank's foreign lending probably around 3 to 5 percent.[145]

China is not a party to the OECD Arrangement on Officially Supported Export Credits or any of its Sector Understandings.[146] Being outside it, China has been undercutting everyone.[147] As former U.S. Exim Bank Chairman Fred Hochberg stated, "They are winning deals in part because they are not playing by the rules."[148] However, China does take part in the International Working Group on Export Credits, which was established in 2011 to negotiate a new export financing agreement that applies to more (non-OECD) countries.[149] A February 14, 2012, meeting between U.S. president Obama and then vice-president Xi Jinping included a statement that the two sides agreed to make "concrete progress towards a set of international guidelines on the provision of official export financing that, taking into account varying national interests and situations, are consistent with international best practices."[150] But as is almost always the case with such declarations, they are not worth the paper they were printed on, as China makes the declarations to "kick the can down the road."

The United States should work with key partners, such as the European Union and Japan, under a stronger trilateral framework to roll back these unfair export subsidies to force China to also abide by the OECD guidelines.[151] If China does not agree within a short period of time to these rules, these nations should commit to not buying Huawei equipment until China does agree. In addition, the United States and others should bring a joint WTO case against Chinese subsidies more broadly, including export subsidies. For example, the European Union should enact specific

remedies if Huawei were to sell equipment to Hungary or Italy using unfair export financing arrangements and thereby taking market share from European firms that are otherwise competing on market-based terms. One positive step is the United States, the European Union, and Japan recently reaching an agreement to expand the types of subsidies outlawed by WTO.[152]

Support Continued Wireless R&D

If U.S.-based companies are to lead in the next wave of wireless innovation, the U.S. government must increase investment in long-term R&D. Many breakthroughs in communications technology were developed with the help of public funding. The original development of the precursor to the Internet, the ARPANET, is an obvious example. The United States has leading research universities, so it is important the federal government continue to support their work. NSF is a leader in supporting the underlying research through a variety of funding opportunities—mostly through academic programs, including its Platform for Wireless Research—and community engagement with researchers, entrepreneurs, and corporations.[153] DOD and the Department of Energy (DOE) also fund some R&D in telecommunications-related areas.

This early stage research must also be commercialized and successfully transferred to the private sector.[154] The federal government should work to launch at least one Manufacturing USA center focused on networking equipment. In addition, Congress should boost the R&D tax credit, wherein the United States continues to lag behind its competitors.[155] Congress should boost the rate of the Alternative Simplified Credit from 14 percent to one that is significantly higher—at least 28 percent.

It is also important the U.S. government support the business models needed to recoup R&D investment. Antitrust investigations should consider U.S. competitiveness as well as the national security implications of disrupting key U.S. innovators in wireless development.

Another component of ensuring adequate incentives for investing in this type of uncertain research that may or may not be recovered over a very long time is the strong protection of IP.[156] Patent and trade-secret protection continue to be critical underpinning policies to support large investments in technological innovations.

Support Demand for 5G Systems

Many of the most advanced applications that leverage the performance advances 5G brings—cutting-edge technologies such as digital twins, augmented reality, and smart factories—require challenging R&D in their own right. Too often, telecommunications policies focus on the supply-side levers—regulation of the networks themselves, spectrum availability, and infrastructure streamlining—without adequately supporting the demand side of the equation. This is especially important now, with much of the low-hanging fruit of wireless connectivity already taken advantage of.

Every government agency should identify how they could incorporate real-time wireless connectivity and analytics into their own processes or the industries they oversee and interact with. The Department of Transportation (DOT) should be working to leverage 5G and related technologies, as well as Wi-Fi-based protocols such as Dedicated Short Range Communication (DSRC), to better support connected roadway infrastructure and more-efficient transportation.

DOD has a wide variety of potential 5G applications, and is exploring trials of combat training assisted by virtual reality and augmented reality using 5G networks, and has multiple requests for proposals for 5G for smart warehouses and logistics management.[157] It is likely general-purpose 5G connectivity will be able to replace spectrum set aside for specific, often spectrally inefficient, DOD applications, potentially freeing up additional spectrum for commercial use or sharing.

The federal government should also step up to support local smart-cities projects.[158] While there are numerous wireless options for connecting smart infrastructure, 5G offers a platform city technologies can be confident will have scale and interoperability. The federal government should offer large grants, conceivably as part of a COVID-19-related stimulus package, to build on DOT's 2016 smart-city challenge.[159]

Other potential use cases for federal agencies abound. National Labs and DOE should be considering ways in which 5G could be leveraged to bring real-time analytics and machine learning to laboratory equipment without requiring wired connections. NIST's Manufacturing Extension Partnership should strengthen its efforts to help small manufacturers adopt 5G-based smart manufacturing systems. The Department of Agriculture's Agricultural Extension Service should do the same to help farmers and ranchers adopt 5G systems and applications. The Department of Housing and Urban Development (HUD) should focus on how to ensure public housing projects are 5G ready.

Change the Game on Equipment Security

A U.S. strategy for 5G must address concerns around supply-chain vulnerability in an increasingly concentrated, globalized market for network equipment. Rather than trying to match the tactics and scale of Chinese industrial policy that has seen so much success in recent decades, the United States should play to its strengths—particularly in software—and help accelerate changes to the equipment market itself. Encouraging operators to choose more virtualized systems, with RAN equipment based on open interfaces, offers a promising opportunity for a more secure, more innovative, lower cost infrastructure that benefits from a strong software-development industry and high-performance general-purpose hardware—two areas wherein U.S. industry excels.

RAN Virtualization and Open Interfaces

The opportunity for O-RAN to mitigate potential concerns is now fairly well recognized. At a recent Senate Homeland Security hearing, Christopher Krebs, the director of the Cybersecurity and Infrastructure Security Agency at the U.S. Department of Homeland Security, expressed optimism for vRAN technologies to give the United States a new advantage when it comes to supply-chain security and competitiveness, going so far as to imagine a future wherein our concerns about Huawei are merely a "blip" in the rearview mirror.[160] Despite the challenges to getting there, this should be the goal.

In a 5G future based on virtualized systems, it will be harder for any government to subsidize its way through each individual component. Today, integrated RAN equipment sees relatively high margins considering the constituent hardware, largely to recoup the R&D expense of developing the sophisticated technology, the large amount of software to run this type of equipment, and its ongoing maintenance and service lifecycles. These higher margins make it a ripe target to be undercut on price. Open interfaces mean a wider diversity of companies are able to build

equipment out of generic components, resulting in lower margins, at least on the hardware, which is more difficult to undercut on price.

Virtualization of a variety of network functions holds promise for lower-cost, more-flexible networks. A virtualized future will see a smaller, but more innovative and faster-paced RAN market, with more opportunity for dynamism in spectrum access and business-model innovation through the ability to quickly spin up new services. Moving away from relative monoculture in equipment lowers the risk of any single vulnerability affecting large portions of a nation's networks.

Security challenges in the RAN environment are complex. American operators oversee large-scale networks, with a variety of appliances scattered throughout cities and towns across the country. The radio-access portion of the network is the interface to the rapidly proliferating world of network devices. The RAN is where the so-called "attack surface" of the network opens up dramatically. Virtualization gives much greater operational control and insight into what is happening on the network. This greater visibility and transparency for operators allows them to take control and decide where and when it is appropriate to establish trust, thereby increasing security.

The already ongoing, if gradual, transition is to more virtualized systems throughout telecommunications networks. Thankfully, it appears the administration has been exploring opportunities to help accelerate this transition. The White House has reportedly been communicating with U.S. technology and software companies to help create "advanced software for next-generation 5G telecommunications networks."[161] As Larry Kudlow explained, "The big-picture concept is to have all of the U.S. 5G architecture and infrastructure done by American firms, principally." However, he also explained that the cooperation could "include Nokia and Ericsson because they have big U.S. presences."[162]

There are admittedly some risks with moving too aggressively to promote RAN virtualization. Established firms such as Nokia and Ericsson are somewhat skeptical of a strong push toward the O-RAN environment through, for example, a mandate to replace removed Huawei gear in rural networks with O-RAN-compliant equipment. In Senate testimony, Nokia CTO Mike Murphy noted limited maturity in both O-RAN as specified by the O-RAN Alliance and RAN virtualization.[163] Start-ups focused on RAN virtualization are more bullish. As chief of Strategy for Altiostar, Thierry Maupilé put it, "This is not pie in the sky. This is real innovation which is deployed, working and performing extremely well."[164]

Large operators are indeed moving in this direction. AT&T has been a leader in adopting virtualization generally, and Verizon has succeeded in trials of fully vRAN functionalities.[165] Telefonica has taken a big step for the O-RAN ecosystem by announcing trials of 5G O-RAN technology in Germany, Spain, the United Kingdom, and Brazil.[166] These are still the relatively early days in the testing of this complex transition at scale.

As operators continue to trial deployments of vRAN equipment, both practical challenges and opportunities to reduce risks with the adoption of the technology at scale will be more apparent. Government officials should indicate a willingness to work with operators to overcome impediments to scaling this technology. The venture capital markets have not historically shown a great willingness to invest in wireless equipment, likely due to the tremendous manufacturing

scale globalized incumbents wield. A strong government signal that new virtualized 5G equipment and software are a national priority could go a long way toward activating latent innovation capacity in this area.

Pilot programs, potentially administered through the National Telecommunications and Information Administration (NTIA), could help accelerate the transition to open, virtualized systems, and help identify what challenges need to be overcome. Aggressive pilot programs could also provide training for systems integrators that will likely be needed. Congress should fund pilot programs and other efforts to help speed this transition. One available mechanism is the Utilizing Strategic Allied Telecommunications Act, led by senators Warner (D-VA) and Burr (R-NC).[167] This bill is good policy, although ideally the money would be appropriated through general treasury funds rather than from auction proceeds.

Existing High-Risk Equipment

One of the urgent questions facing the FCC is how to deal with existing Huawei equipment in the U.S. market. The FCC is in the process of collecting information about the extent of existing deployments and the cost to remove that equipment. While it is difficult to make educated policy assessments without more information about the extent of the problem, it is likely concerns about existing equipment have been overstated. There are risk-mitigation strategies that can effectively minimize the potential for harm with far less of a burden on rural operators and taxpayers.

As a part of the United Kingdom's decision to allow limited deployments of Huawei infrastructure, its National Cyber Security Centre offered a thorough assessment of the risks involved with pieces of equipment and potential avenues of attack or exploitation, and identified high-risk areas of concern.[168] It concluded that allowing Huawei equipment to be in 35 percent of the RAN (measured by either the number of cell sites or total data traffic) would be an acceptable risk. U.K. officials apparently having a higher risk tolerance than their U.S. counterparts does indicate there are reasonable steps to minimize the potential harm from high-risk vendors—and also shows the benefits of a transparent risk analysis that grounds these decisions in something more firm and evidentiary than merely the word of intelligence agencies.

Existing high-risk equipment in the United States is already limited to rural areas. But in many cases, this equipment has already been in place for years and could likely be removed by natural market forces as 5G systems become ready and cost effective. It is not immediately clear that a rip-and-replace approach is either necessary or a cost-effective solution. In any event, the Secure and Trusted Telecommunications Networks Act now requires this removal. The FCC, which is in the midst of collecting information on the cost of replacing Huawei gear, should identify the areas of highest risk in order to prioritize removal using its limited funds. The FCC should implement this mandate in such a way that anything ripped out is replaced with 5G equipment. Otherwise, hundreds of millions of dollars will essentially have been wasted.

Accelerate Deployment of 5G Networks

Supply-side policies to accelerate the deployment of 5G networks should be the table stakes of any 5G strategy. While this is the obvious place to start, and has already received a good deal of policy attention, this report does not go into great detail on these topics. There are two main opportunities for the government to help accelerate deployment directly. The first is through streamlining of infrastructure deployment—the policies by which operators and their partners are

able to access city rights of way, conduit, and poles. The second is through providing additional spectrum for commercial wireless users.

Infrastructure

Officials at every level of government should be looking for effective ways to encourage investment in broadband infrastructure generally, particularly considering the need for a broad deployment of small cells. Many of the assumptions, regulations, and processes governing wireless deployment were designed for an era of 200-foot-tall towers. Today, operators and their partners are looking to hide unassuming wireless infrastructure in city bus stops, light poles, and on the sides of buildings.

Given our federalized system of governance, this is necessarily a challenging process for operators facing a new system and different regulations to access rights of way and poles in every city they operate in. There is also a concern that local and national interests do not necessarily align on this issue. From a local government and elected officials' perspective, a community would charge the highest possible price providers are willing to pay in order to deploy the infrastructure. For high-income communities with moderate-to-high geographic population densities, the monopsony power of the government jurisdiction is especially high, as they know providers want to serve those customers. Some level of preemption to simplify deployment is justified, even if the most successful deployments will require a cooperative, collaborative approach between those deploying the infrastructure and the local officials.

The FCC both took steps to streamline infrastructure deployment through changes to the environmental and historic preservation review processes, and established presumptive reasonable fees for pole access.[169] However, they have been challenged in court and face some difficulty being implemented. Although the FCC is doing what it can to streamline deployment, ideally Congress or a broader number of state legislatures would step in and clarify the appropriate processes and fees for small-cell deployment to ensure cities act in the national, rather their own narrow financial, interests.

Spectrum

Electromagnetic spectrum is a key limiting input to wireless networks. Additional spectrum and spectrum reuse through smaller cells are the best tools we have to increase the overall capacity of wireless networks. In addition to streamlining infrastructure, making more spectrum available for commercial wireless use is critical to speeding successful 5G networks in the United States.

The FCC must quickly allocate more mid-band spectrum for flexible mobile use. Mid-band spectrum offers ideal characteristics for 5G.[170] One crucial band identified for 5G is the so-called C-band from 3.7 to 4.2 GHz. At this point, 23 countries have allocated C-band spectrum for 5G use.[171] We can also see the focus on C-band spectrum in the announced 5G devices—band n78, which uses C-band spectrum of 3,300–3,800 MHz, is supported by the most commercial devices to date.[172] The FCC took two years to decide whether to conduct an auction itself or leave it to the parties, eventually deciding on the former. Thankfully, Chairman Pai has announced a plan to move forward with transitioning this spectrum, although it still faces numerous implementation and transition risks.[173] The FCC will require incentive payments to accelerate the transition of the incumbent satellite services out of a large portion of the band.[174] Given the unique challenges with multiple incumbent satellite providers having rights to access the entire band, these payments are good policy to quickly see this spectrum be put to a more socially

valuable use—if anything, these payments may be too small, risking the success and speed of the transition. At this point, Congress should let the FCC move forward. Doing anything else would just delay the opening up of needed bandwidth and give China an even greater lead.

Longer term, policymakers should be working toward better processes and tools to repurpose spectrum, especially federally held spectrum that isn't always efficiently used. There are pragmatic, incremental approaches to opening up federal spectrum that rely on existing mechanisms such as the Spectrum Relocation Fund. For example, NTIA has identified viable options for sharing RADAR with commercial users in the 3450-3550 band, potentially building on the CBRS system.[175] Now that DOD has finally recognized the importance of a robust 5G system in the United States, it will hopefully facilitate, rather than resist, such policies.

Unlicensed spectrum also plays an important, complimentary role in licensed spectrum in the wireless economy. Policymakers should work to make additional spectrum available on an unlicensed or lightly licensed basis that can continue to expand the wireless options, offload demand where wired networks are available, and increase the functionality of 5G devices through local connections, such as Bluetooth. The most obvious next step is the 6 GHz band. Here, the FCC should move to make a significant swath of new unlicensed spectrum available quickly.

Tax Policy

Buying 5G equipment is often expensive. As such, policies that lower the after-tax cost of equipment would spur faster and broader deployment. Indeed, the scholarly evidence is clear that allowing firms to expense machinery and equipment expenditures for tax purposes increases capital expenditures.[176] In 2017, the Tax Reform and Jobs Act included a provision to allow companies to expense for tax purposes all capital investment in the year it was purchased. In other words, 100 percent of the cost of investing in machinery and equipment can be written off for federal tax purposes. However, that provision expires at the end of 2022, just around the time 5G technologies should be ready for wide-scale adoption. Congress should at minimum extend this provision for another five years, or ideally make it permanent.

Rural

Rural wireless deployment is a special case. In many small, rural towns, wireless operators are able to successfully operate even given the challenging economics of serving dispersed populations. But it is important that we see broader coverage in rural areas. Wireless connectivity is crucial for efficient production at agricultural sites. For example, John Deere continues to rely on mobile connectivity for its advanced equipment, and smart-farm processes will always require connectivity of one type or another.[177]

5G technologies have the opportunity to potentially change the cost structure for serving rural areas. Most notably, massive MIMO using mmWave spectrum over point-to-point links could lower the cost of backhaul to remote areas. However, the wide coverage needed in rural America is more a function of the power level and the spectrum used, as low-band spectrum is needed to cover wide areas. The particular breakthroughs in 5G performance are better suited to high-demand urban areas, and are unfortunately no cure-all for rural.

Where dispersed populations cannot support the level of revenue required to justify infrastructure investment, the U.S. government should step in to aid the cause for ubiquitous networks. For years, policy circles have been debating the details of how to do it. At a high level, there is

general agreement that a one-time, large-scale injection of capital expenditures for rural broadband infrastructure—both wired and wireless—is the way to go.[178] Funds should be allocated through a technology-neutral reverse auction, with a focus on unserved areas, and be focused on reasonable speeds (it is both unnecessary and expensive to require every home be served by superfast broadband). There are always up-front judgment calls on what level of funding is necessary to achieve what type of broadband performance in a given area, but we can rely on the auction mechanism to make the difficult decisions of exactly what type of technology or performance quality makes the most sense for a given geography. To ensure the money is spent mostly on areas that are truly unserved, companies should be able to challenge competitors' bids if their proposed coverage areas include more than a de minimis expansion of areas that are already served. This would help avoid wasteful overbuilding in areas that already have broadband.

CONCLUSION

5G poses for the next decade an important opportunity for economic growth and dynamism throughout a number of sectors of the economy. The degree to which 5G is anticipated to be integrated within production processes across the U.S. economy highlights both its importance and the risks inherent to relying on untrusted suppliers—or leaving equipment production up to a globalized market without some further strategy in place. To date, the approach of the United States to 5G has been scattershot, and not always well calibrated to address specific challenges. A national strategy for 5G that invests in research, supports standards bodies, accelerates deployment, and facilitates the transition to virtualized equipment should be a priority.

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