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5G

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The Technology Factsheet Series was designed to provide a brief overview of each technology and related policy considerations. These papers are not meant to be exhaustive.

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Executive Summary

5G refers to fifth-generation cellular network technology, and includes both the mobile broadband infrastructure as well as 5G devices that rely on the network. Compared to 4G (fourth-generation cellular network technology), 5G offers not only faster network speeds but also many new functions such as increased machine-to-machine communications and low-latency data transfer.[1] Through these upgraded capabilities, 5G will enhance and enable technologies such as the Internet of Things (IoT) and augmented and virtual reality (AR/VR). Use cases for 5G include autonomous vehicles, smart cities and smart grid automation, industrial IoT, remote surgery robots, public video surveillance, and immersive media.[2] The first 5G networks in the US and world were launched in mid-2019, though current 5G networks are early versions with limited capabilities. 5G network standards are projected to be completed by the early 2020s, while technical features will continue to be developed throughout the decade.

The introduction and integration of 5G poses opportunities and risks, both of which are important to consider from a public sector and private sector standpoint. The promise of 5G's faster connectivity and scaled data processing capacity is counterbalanced by foreseeable risks around national security and safety, individual privacy, and a lack of inclusive accessibility.

Regulation of 5G in the United States exists primarily at the federal level, focusing on supply chain integrity, infrastructure development, spectrum allocation, and network deployment. At an international level, 5G is mostly regulated through technical standards set by global industry groups through standards organizations, such as the 3rd Generation Partnership Project (3GPP) and the United Nation's International Telecommunication Union (ITU).[3] 5G is expected to be a core component of digital infrastructure in the 2020s and 2030s, demonstrating an importance for U.S. policymakers to continue to engage in the public purpose considerations associated with the technology and examine pathways for effective governance and regulation.

1 "3GPP Release 15 Overview," n.d. https://spectrum.ieee.org/telecom/wireless/3gpp-release-15-overview

2 "The Top 5G Use Cases," November 17, 2017. https://www.sdxcentral.com/5g/definitions/top-5g-use-cases/

3 "5G Standards: What You Need to Know," October 30, 2017. https://www.sdxcentral.com/5g/definitions/5g-standards/

What is 5G?

5G refers to fifth-generation cellular network technology. 5G is commonly used to refer to the mobile broadband itself, but it also includes the underlying network infrastructure and network-reliant 5G devices. As an upgrade over 4G-LTE, 5G offers not only faster network speeds but also further advances such as lower latency (communication lag time between devices and servers), increased device connections, and edge computing.

Technical Overview

As the fifth-generation of cellular network technology, 5G builds upon the foundations of 2G, 3G, and 4G. Industry groups have established a set of specifications that define 5G technology; the three most significant are Enhanced Mobile Broadband (eMBB - peak rates greater than 10 Gigabytes/second), Ultra-Reliable and Low Latency Communications (URLLC – less than 1 millisecond latency), Massive Machine-Type Communications (MMTC - 1 million device connections/km^2). As a comparison, 4G can only reach peak data rates of 1 Gigabyte/second, 50 millisecond latency, and 100,000 device connections/km^2.[4] This means that with 5G infrastructures, an increased number of clients and consumers would have the ability to interact with larger amounts of data, and at a faster speed.

The primary components of 5G include the core network, the radio access network (RAN), the end-user device, and wireless spectrum. While the components are largely the same as 4G hardware, there are key differences in 5G components to enable additional functionalities, such as network function virtualization (which replaces some hardware functions with software) and multi-access edge computing (which migrates some applications from the core to the RAN).[5] This practice of "edge computing" means that computing is done in closer to the source of data, instead of relying on the cloud (or the "core") as the main location for data processing. 5G networks therefore also shift more *control* from the core network to the RAN (i.e. the edge), changing the cybersecurity landscape for networks to a more decentralized model.

Moreover, 5G relies on different parts of the wireless spectrum from those used by previous network generations; the three sections are low-band (less than 1 GHz frequencies), mid-band (1 to 6 GHz frequencies), and high-band/mmWave (24 to 100 GHz frequencies).[6] Spectrum usage affects 5G capabilities, with higher frequencies being faster but more limited in broadcast distance. Furthermore, some frequencies are already occupied; for example, much of the mid-band spectrum in the US is reserved for military use.

4 "5G vs. 4G – A Side-by-Side Comparison," September 6, 2019. https://datamakespossible.westerndigital.com/5g-vs-4g-side-by-side-comparison/

5 "5G Architecture," n.d. https://www.viavisolutions.com/en-us/5g-architecture

6 Marek, Sue. "Low-band, Mid-band or High-band — Why Spectrum Bands Matter in a 5G World," February 11, 2020. https://www.futurithmic.com/2020/02/11/why-spectrum-bands-matter-in-a-5g-world/

In order to enable a smoother transition between previous network generations and 5G technology though, network corporations including Vodafone, Ericsson, Huawei, and Qualcomm, collaborated to roll out dynamic spectrum sharing (DSS).[7] DDS allows network operator to deliver both 4g and 5G within the same spectrum. This is unique from previous rollouts: 2G, 3G and 4G standards were initially rolled out on dedicated blocks of spectrum, which meant that re-allocating for the next generation was an extremely slow—not to mention expensive—process. With DDS, this can be done overnight with a simple software upgrade to a 5G non-standalone device.[8]

Spectrum sharing more broadly, or the ability to support various use cases and users on a given spectrum, is an approach that is posed to be advantageous for 5G given the sophistication of the technology infrastructure and its ability to "slice" networks. Network slicing is the ability to partition off segments of the 5G network with specific latency, bandwidth, and quality-of-service guarantees.[9] **Network slicing** could give way for companies to provide better connectivity and help offset the financial costs associated with deploying new networks.

Another important component of 5G development and deployment is the support of **long-term evolution (LTE)**, which was initially introduced during the rollout of 4G. LTE is not as much a technology as it is an avenue followed to achieve 5G speeds. As governing bodies have defined minimum speeds and standards for 5G, LTE gives network providers the options for an incremental and evolutionary rollout of the new network while continuing to capitalize on existing 4G infrastructure in the interim

NSA & SA 5G

Within 5G, two main sub-categories of networks are non-standalone 5G (NSA) and standalone 5G (SA).[10] NSA relies on a 4G core and RAN infrastructure with a 5G carrier to enable eMBB and limited functions; it is an intermediate phase that utilizes existing infrastructure for market testing and developing limited new use cases. SA is built on a 5G core with 5G infrastructure, and will allow for more advanced functions of 5G. Early deployments of 5G have been NSA, while SA may begin to be deployed in the early 2020s.

7 "Dynamic Spectrum Sharing: the Key to a Quicker 5G Rollout?" Vodefone, January 31, 2020. https://www.vodafone.com/perspectives/blog/dynamic-spectrum-sharing.

8 Ibid.

9 Higginbotham, Stacey. "Network Slicing Is 5G's Hottest Feature." IEEE Spectrum: Technology, Engineering, and Science News, February 19, 2020. https://spectrum.ieee.org/telecom/wireless/network-slicing-5gs-hottest-feature

10 Ekstrom, Hannes. "Non-standalone and Standalone: Two Standards-based Paths to 5G," July 11, 2019. https://www.ericsson.com/en/blog/2019/7/standalone-and-non-standalone-5g-nr-two-5g-tracks

5G RAN Types

Another important subdivision in 5G is at the RAN-level. The RAN has been in use since the establishment of cellular technology and has evolved through the generations of mobile communication (1G through 5G).[11] Variations in the RAN are noteworthy because they have different implications for service providers as they roll out the next generation of network architecture.

Subcategories of the RAN include cRAN (centralized RAN), vRAN (virtualized RAN), and oRAN (open RAN).[12] cRAN shifts the baseband units (BBUs) of the base stations to a centralized server; vRAN then virtualizes the hardware-based BBUs; and oRAN builds on vRAN to allow for hardware interoperability by separating hardware from software functions. The evolution to oRAN is critical for reducing specialized hardware suppliers' dominance in the telecom market by allowing new market entrants and for improving US and global supply chain integrity. Though oRAN is the preferred RAN type in the U.S., the type of RAN that ultimately dominates 5G rollout will depend on international consensus (since the network itself is so globalized).

Related Tech

WiFi

Besides 5G, another important wireless technology being developed is WiFi 6.[13] The next generation of WiFi, WiFi 6 will offer faster speeds and manage multi-device networks. WiFi 6 and 5G technologies have complementary advantages (such as 5G being more suited for use outdoors and WiFi 6 for indoor networks) and will likely be used in parallel across different use cases. 5G will also rely on technologies such as cloud computing (for the core network and the RAN), semiconductor chips, artificial intelligence. The relationship between 5G wireless cellular networks and WiFi 6 is unique in that it embodies and represents converged standards between cellular networks and WiFi networks.[14] Thanks to better network use-case definition and expanded digitization opportunities, this convergence is posed to allow for an improved consumer experience with connected digital devices.

11 "Network Architecture Domains." Rep. *Network Architecture Domains*. Telefonaktiebolaget LM Ericsson, n.d.

12 "vRAN: The Next Step in Network Transformation," n.d. https://builders.intel.com/docs/networkbuilders/vran-the-next-step-in-network-transformation.pdf

13 Hill, Simon. "5G vs. Wi-Fi: How They're Different, and Why You'll Need Both," November 21, 2019. https://www.Hdigitaltrends.com/mobile/5g-vs-wi-fi/

14 "5 Things to Know About Wi-Fi 6 and 5G." Cisco. Cisco, May 21, 2020. https://www.cisco.com/c/m/en_us/solutions/enterprise-networks/802-11ax-solution/nb-06-5-things-WiFi6-5G-infograph-cte-en.html.

Artificial Intelligence

The relationship between 5G and artificial intelligence (AI) is two sided: AI has the capability to enhance 5G network management, while 5G simultaneously has the ability to heighten AI applications for IoT.[15]

In order to operate efficiently and effectively, 5G networks will need to become continuously self-healing, self-managing, self-securing, self-repairing and self-optimizing. Development of this oversight has turned to embedding of machine learning and other AI models to automate application-level traffic routing, quality-of-service assurance, performance management, root-cause analysis, and other operational tasks at scale more predictably, rapidly, and efficiently than manual methods alone.[16] Often called "AIOps," short for AI operations, this has become core to providers' models for delivering on their promise of substantially faster, more reliable, and more RF-efficient connections relative to previous wireless technology.

AI, in turn, will benefit from increased speed and high-volume data streams. Businesses will be able to collect larger amounts of data continuously from mobile devices, thermostats, sensors, and other 5G-equipped devices concurrently supported in any given geographic location.[17] With this, increased ability for cost-effective machine-to-machine communication and edge-point data processing, AI application developers and data scientists will be able to build more robust and sophisticated analytics and AI models for real-time applications in IoT, mobility, industrial automation, smart cities, and more.

Limitations of 5G

Though technical specifications have set promising goals for 5G, the realized advantages over 4G in most current deployments are limited, largely due to sparse 5G coverage[18] and 5G-compatible devices that are only recently on the market, as well as the absence of key features from NSA 5G. A full transition to SA 5G is several years away, with operators planning SA deployments. Additionally, properly capitalizing on 5G's features and economic value will require building an ecosystem of new 5G-reliant devices. There has been such a heavy focus on 5G infrastructure development and deployment, that there are observable gaps emerging for the larger 5G ecosystem.

15 Kobielus, James. "How 5G Will Serve AI and Vice Versa." Datanami, December 10, 2019. https://www.datanami.com/2019/12/10/how-5g-will-serve-ai-and-vice-versa/.

16 Ibid.

17 Ibid.

18 Cheng, Roger. "The 5G Wireless Revolution, Explained." CNET, October 27, 2019. https://www.cnet.com/news/the-5g-wireless-revolution-explained/.

Common Applications and Market Development

As a foundational technology, 5G is posed to accelerate the development of emerging technologies and will be relevant to most, if not all, industries. With the technology still being developed, the 5G market is currently in its early stages. Consumer 5G will initially focus on smart devices such as smartphones, but may eventually include autonomous vehicles, AR/VR headsets, remote robots, and other 5G-dependent tech. Industrial 5G use cases include industrial IoT, drones, edge computing, manufacturing automation, and smart cities.

At the network level, the 5G market is divided into network equipment suppliers and wireless carriers. Network equipment providers supply the hardware and software to build 5G networks. Major players in this space can be categorized based on network component:[19]

- **Core Network:** Cisco, Huawei, Juniper, Nokia, Arista, Hewlett Packard
- **Radio Access Network:** Huawei, Ericsson, Nokia, ZTE, Samsung
- **User Equipment – Industrial IoT:** Cisco, Huawei, Ericsson, Qualcomm
- **User Equipment – Smartphones:** Apple, Huawei, Samsung

Notably, there is no major US supplier in the radio access network market. Some argue that the root of the U.S. gap in 5G infrastructure as compared to competing nations, such as China, can be traced back decades.[20] For example, the Telecommunications Act of 1996 removed checks against market consolidation, allowing a series of mergers and corporate consolidation in the years that followed the Act.[21] The result arguably stimulated a decrease in domestic broadband development, rather than an increase.

Without a domestically-generated competitive alternative, it becomes impossible for the U.S. to provide a viable alternative at a similar cost. This has given market priority to vendors with a higher calculated risk with regards to various national values such as privacy, safety, and security, especially in the modern internet era. Concerns over 5G supply chain integration has catalyzed conversations by policymakers and corporations about how the U.S. and its allies can build a competitive advantage in the market.

19 CISA. "Overview of Risks Introduced by 5g Adoption in the United States," July 31, 2019. https://www.cisa.gov/sites/default/files/publications/19_0731_cisa_5th-generation-mobile-networks-overview_0.pdf

20 Kania, Elsa B. "Opinion: Why Doesn't the U.S. Have Its Own Huawei?" POLITICO, February 25, 2020. https://www.politico.com/news/agenda/2020/02/25/five-g-failures-future-american-innovation-strategy-106378.

21 Ibid.

In the US, all four major telecoms (AT&T, Verizon, T-Mobile, Sprint) are active in the 5G wireless carrier space and have deployed 5G networks. Key tasks for deploying 5G networks include acquiring spectrum usage rights from the federal government via FCC auctions; deploying RAN equipment such as base stations (which process 5G signals); and configuring the core network and RAN. Delayed spectrum allocation and decentralized base station deployment regulations have increased the costs and limited the market development of 5G carriers.

Current Regulation and Governance

Regulation and governance of 5G exists primarily at the federal level, focusing on supply chain integrity (i.e. licensing, security reviews, and approval), infrastructure development, and network deployment. The White House and federal agencies (especially the FCC) have played leading roles in national 5G regulation, though there are instances of congressional, as well as state and local legislation.

U.S. Federal Level

Recent regulations include **Executive Order 13873** on securing the communications technology supply chain;[22] and the FCC's **5G FAST Plan** for spectrum allocation, network deployment, and upgrading regulations.[23] Nationalization of 5G networks was explored as an expedited roll-out model but faced pushback from Congress.

U.S. Congressional Level

Despite bipartisan recognition of 5G's importance, congressional legislation on 5G has been limited, though a significant number of bills have been introduced.

- **Secure 5G and Beyond Act of 2020:** The Act requires the President to develop and implement a strategy for the adoption of secure wireless communications technology in the United States and abroad.[24] Though this act is framed through a lens of security, the implications of the act focus more on pushing out Chinese market competitors, such as Huawei, rather than addressing identifiable cyber and security vulnerabilities.

22 "Executive Order on Securing the Information and Communications Technology and Services Supply Chain," May 15, 2019. https://www.whitehouse.gov/presidential-actions/executive-order-securing-information-communications-technology-services-supply-chain/

23 "The FCC's 5G FAST Plan," n.d. https://www.fcc.gov/5G

24 "Secure 5G and Beyond Act of 2020," May 21, 2019. https://www.congress.gov/bill/116th-congress/house-bill/2881

Pending Legislation

- **5G Spectrum Act of 2019:** This bill requires the Federal Communications Commission to conduct a public auction of at least 280 megahertz of mid-band spectrum (the band of frequencies between 3700 megahertz and 4200 megahertz) and to deposit at least 50% of the gross proceeds from such auction in the Treasury.[25]

- **STREAMLINE Small Cell Deployment Act:** The bill updates the Communications Act to better reflect developing technology and facilitate the rapid deployment of 5G networks to meet consumer demand by setting standards for public review of infrastructure siting, while recognizing unique challenges for small municipalities.[26]

- **Utilizing Strategic Allied (USA) Telecommunications Act:** Among other things, this bill calls for the establishment of a $750 million O-RAN research and development fund, to be known as the Public Wireless Supply Chain Innovation Fund. The funding would be pulled from the proceeds of spectrum auctions over the next five years and would be dispersed over a 10-year period.[27]

Many bills are still pending because, though 5G has drawn bipartisan recognition, the details of development, deployment, and public considerations remain controversial. For example, one pushback on the STREAMLINE Small Cell Deployment Act is that it moves to remove agency from local communities on 5G small cell rollout tactics.

State & Local Level

At the state and local levels, there has been legislation and debate dealing with public rights-of-way and local zoning authorities, specifically as they relate to telecom providers' ability to deploy and install small cells in public areas. Some states have passed legislation preempting local rights (thus expediting deployment), while others have prevented telecom providers from bypassing local permits and regulation.[28,29] Additionally, many states have focused on passing legislation that explores the health and environmental impacts of 5G technology. Examples include:

- **Connecticut HB 7152:** This bill establishes a Council on 5G Technology and tasks it with (1) reviewing wireless carriers' requests to place personal wireless service facilities and small wireless facilities, as defined in federal law, on state-owned real property and (2) determining which state-owned properties may be made available to the wireless carriers for these facilities.[30]

25 "5G Spectrum Act of 2019," November 18. 2019. https://www.congress.gov/bill/116th-congress/senate-bill/2881

26 "STREAMLINE Small Cell Deployment Act," June 3, 2019. https://www.congress.gov/bill/116th-congress/senate-bill/1699

27 "A Bill to Use Proceeds from Spectrum Auctions to Support Supply Chain Innovation and Multilateral Security," January 14, 2020. https://www.congress.gov/bill/116th-congress/senate-bill/3189

28 "An Act to Establish the Small Wireless Facility Deployment Act; And for Other Purposes," March 26, 2019. https://www.arkleg.state.ar.us/Acts/Document?type=pdf&act=797&ddBienniumSession=2019%2F2019R

29 "Senate Bill No. 68," n.d. http://www.kslegislature.org/li/b2019_20/measures/documents/sb68_enrolled.pdf

30 Morton, Heather, and Lesley Kennedy. Mobile 5G and Small Cell 2019 Legislation, December 21, 2019. https://www.ncsl.org/research/telecommunications-and-information-technology/mobile-5g-and-small-cell-2019-legislation.aspx.

- **Massachusetts HB 2885:** Establishes a special commission to study the environmental and health effects of evolving 5g technology.[31]

- **Wisconsin AB 234:** This bill creates a regulatory framework for the state and political subdivisions (cities, villages, towns, and counties) for the following: 1) the deployment by wireless services and infrastructure providers (wireless providers) of wireless equipment and facilities, including the placement of such items in rights-of-way (ROW); 2) the permitting process for certain activities by wireless providers; 3) the regulation of access to certain governmental structures by wireless providers; and 4) the resolution of disputes.[32]

International Level & Industry Governance

Existing 5G industry governance frameworks primarily deal with the technical standards and are maintained globally through industry partners and products. The 3rd Generation Partnership Project (3GPP), a standards organization, has been the main player in bringing together industry partners and other organizations to lay out technical standards for 5G.[33] These standards are developed in phases (termed "Release"); the final phase of the first 5G release, Release 15, was completed in in spring 2019 and set specifications for NSA 5G. Releases 16 (5G Phase 2) and Release 17 (5G Advanced, including IoT and AI) will be released in the coming months and years, while Release 18 will likely phase into 6G. The Institute for Electrical and Electronic Engineers (IEEE) has also rolled out standards for 5G through international committees including the IEEE 802 Local Area Network/Metropolitan Area Network (LAN/MAN) Standards Committee.[34]

International standards are governed by the ITU and are developed primarily by collections of industry standards associations such as the 3GPP, IEEE, and Internet Engineering Task Force. Standards are developed based on industry contributions, and patents also play a role in formalizing the implementation of these standards. Some industry groups, such as the O-RAN Alliance, have also emerged to focus on developing innovative 5G tech.[35]

During the Trump Administration, the U.S. withdrew official federal-level participation in 3GPP. In an effort to eliminate regulatory schemes, the U.S. pulled itself out of ongoing conversations on international standards and has given way for China's dominance of the prominent standards body.

Since 5G is a foundational technology, standards organizations and primary producers have limited influence over how downstream applications are used. Rather, different stakeholders are contributing to

31 Ibid.

32 Ibid.

33 "3GPP," n.d. https://www.3gpp.org

34 "Standards for 5G and Beyond." IEEE Future Networks, June 2017. https://futurenetworks.ieee.org/tech-focus/june-2017/standards-for-5g-and-beyond

35 "O-RAN Alliance," n.d. https://www.o-ran.org

different aspects of public purpose relevant to their sectors. Among manufacturers, the primary concern is with network security and cybersecurity.[36] Some suppliers have also voiced concern over accessibility and inclusivity (particularly of low-income or rural areas).[37] Meanwhile, telecom providers have raised issues such as privacy, calling on the federal government to standardize privacy requirements.

Public Purpose Considerations

Public purpose issues relating to 5G include:

Supply Chain Integrity: With the US being absent from the RAN provider space, supply chain integrity is a key concern for ensuring the reliability and security of critical 5G equipment, as well as maintaining US involvement in the development of future cellular network technology. The primary concerns are with Huawei and ZTE, which hold a large market share for global RAN equipment and have murky ties to China's authoritarian one-party state.

- **Network Safety & Security:** Given that 5G networks are more decentralized and interlinked locally, cybersecurity for 5G is more complicated than in prior generations due to increased access points of significance in the network. These vulnerabilities may be exploited by hackers, including from nation-states (Russia, Iran, North Korea, China, etc.). It is important to consider how government and organizations of different sizes, ranging from small municipalities and startups to national governments and multi-national corporations, are equipped in varying levels to address enhanced cybersecurity and safety concerns introduced with 5G technology.

- **Enhanced IoT:** With 5G comes the promise to better support and expand IoT. IoT poses many opportunities at a consumer-level and at an organization-level through leveraging sensors and actuators to bring digital services into the physical world, but it also poses many risks, such as the access to sensitive data, network security, physical security, loss of confidentiality, and more.[38] With all of the promises of 5G-supported technology, it is important to consider the individual risks of these technologies to understand the full impact landscape of 5G.

- **Cognitive Attacks:** Related to network safety, security, and enhanced IoT is the concept of cognitive attacks due to its ability to increase the speed of data exchange with the real-world.[39] The weaponization of information through speedier channels could pose a threat to knowledge and information integrity, an issue that has gathered increased attention with

36 Wheeler, Tom, and David Simpson. "Why 5G Requires New Approaches to Cybersecurity." Brookings. Brookings, October 25, 2019. https://www.brookings.edu/research/why-5g-requires-new-approaches-to-cybersecurity/.

37 Turner-Lee, Nicol. "Enabling Opportunities: 5G, the Internet of Things, and Communities of Color." Brookings. Brookings, January 9, 2019. https://www.brookings.edu/research/enabling-opportunities-5g-the-internet-of-things-and-communities-of-color/.

38 "Cyber Risk in an Internet of Things World: Deloitte US." Deloitte United States, April 24, 2020. https://www2.deloitte.com/us/en/pages/technology-media-and-telecommunications/articles/cyber-risk-in-an-internet-of-things-world-emerging-trends.html.

39 Newsdesk. "IoT Devices More at Risk of Cyber Attack than Ever - Report." SecurityBrief Australia. SecurityBrief Australia, March 17, 2020. https://securitybrief.com.au/story/iot-devices-more-at-risk-of-cyber-attack-than-ever-report.

the dissemination of misinformation and disinformation on media platforms. With an increased attack rate, it could become a greater challenge for governance bodies to effectively reduce the intended impact. Further, it could pose a core threat to individual agency if all accessibly knowledge about a person's environment (through IoT devices, and more) is easily manipulated.

- **Privacy:** Privacy concerns with 5G include proliferation of user data due to 5G devices, increased data harvesting, and telecom providers' responsibilities with user data. For democracies, protecting the rights of individuals worldwide to privacy from increasingly authoritarian states, enabled by surveillance technology, will be crucial.

- **Accessibility & Inclusivity:** As with other communications technologies, deployment to rural areas will be more difficult for telecom providers, and delays in expanding access to 5G outside of urban areas may worsen the digital divide. This is an urgent concern, given that over 10 million American households already lack access to basic broadband.[40]

- **Affordability:** Related to accessibility and inclusivity is the affordability of 5G user equipment, which may be problematic as carriers gradually phase out 3G and the types of 5G devices expand.[41] For example, cellular phones that support the 5G networks of AT&T, Sprint, T-Mobile, and Verizon Wireless range in price, with the higher end devices costing around $1,300[42] Beyond the device itself, the cellular networks offer premium pricing in order to access 5G.

- **Digital Development of the Larger 5G Ecosystem:** Leveraging 5G's capabilities to advance digital development is a key opportunity in 5G, particularly with regards to emerging technologies such as smart cities, autonomous vehicles, immersive video games, and remote robotic control. It is important to consider how policymakers, alongside the private sector, can encourage development and production of the larger 5G ecosystem so that consumers can reap the benefits of the technology.

- **Standards Influence:** Maintaining influence in the standards-setting process is important for embedding US and democratic values in 5G tech development, ensuring the competitiveness of US companies, and preserving global regulation of 5G tech. Although standards organizations are multilateral, China has gained a significant number of seats in recent years and has engaged in top-down coordination and state planning, especially after the recent U.S. withdrawal from 3GPP.[43]

- **International Interoperability:** The US's limited mid-band capacity and the growing tech schism raise concerns about interoperability of 5G equipment and devices across international networks.

- **Accountability & Responsibility:** The development, deployment, and management of 5G and 5G-related technologies, such as IoT, is touched by many actors along the supply chain. With a growing risk landscape, understanding delineations for accountability and responsibility of all stakeholders is important for proactive and effective governance.

- **Environmental & Health Impacts:** There are many ongoing studies that explore the impact of 5G electromagnetic energy

40 "Eighth Broadband Progress Report," n.d. https://www.fcc.gov/reports-research/reports/broadband-progress-reports/eighth-broadband-progress-report

41 Dolcourt, Jessica. "Why 5G Phones Are so Expensive -- and What Has to Change." CNET. CNET, December 17, 2019. https://www.cnet.com/news/cheaper-5g-phones-on-horizon-but-probably-wont-be-good/.

42 Ibid.

43 Gorman, Lindsay. "The U.S. Needs to Get in the Standards Game-With Like-Minded Democracies." Lawfare, April 5, 2020. https://www.lawfareblog.com/us-needs-get-standards-game-minded-democracies.

on human tissue.[44] These studies have been the basis for international and domestic discussions on how to safely design and regulate 5G technologies. Though the exact impacts of 5G are still uncertain, there is a growing concern of the negative health and environmental impacts of the technology at scale.[45]

The above risks and challenges are of short-term to long-term concern, as they will affect 5G's development and impact in the coming decade. Some issues such as network security and accessibility should be prioritized to ensure a strong foundation for later 5G applications.

44 "What 5G Means for Our Health." Nature News. Nature Publishing Group. Accessed 2020. https://www.nature.com/articles/d42473-019-00009-7.

45 Ibid.

Appendix: Key Questions for Policymakers

Supply Chain Integrity

- Which companies/countries are involved in the production of relevant and market-ready network equipment?
- How have U.S. companies and buyers made an effort to diversify their equipment providers and reduce reliance on single and high-risk providers?
- How can the U.S. and its allies catalyze more domestic innovation for 5G and 5G-adjecent technologies?

Network Safety & Security

- What security approaches should be implemented by providers as a base-line to the core network and RAN?
- What security features should be implemented by providers to prevent tampering with small cells?
- How are data flows audited on provider networks? Can they detect abnormal data exfiltration?
- Have providers undergone cybersecurity testing in the past 6 months, and to what extent? Should there be a required cadence around provider-run security testing?
- Have providers done a comprehensive cybersecurity risk assessment for 5G networks and the IoT?
- Should there be proactive and unified oversight for IoT cyber security? If so, how can that be implemented? What entities should own this oversight?
- How can local municipalities prepare for cyber-attacks, ranging from both low- and high-sophistication?

5G Ecosystem Development

- How can the U.S. catalyze more development beyond 5G infrastructure? How can the U.S. develop a greater emphasis on downstream devices and technology that support consumer-level benefits of 5G technology, such as IoT, video gaming, smart cities, autonomous vehicles, and more?
- How can standards and public purpose be considered for downstream applications?

Allocation of Resources

- How can policymakers determine when and how to purchase and redistribute spectrums for 5G use cases? Should policymakers reassess the current approach to spectrum auctioning?

- How should policymakers consider prioritized use for slices of spectrums, especially considering industrial users, wartime users, public safety users, and more?

Privacy & Consumer Security

- Who will have access to user data and metadata? What authorizations are needed to access that data? Where will it be stored?
- Which data on the network will be encrypted?
- What risks are foreseeable with various IoT devices, and how can governments and private-sector companies be proactive about these risks?

Accessibility & Inclusivity

- What are your broadband deployment plans for non-urban areas?
- How will funding for rural broadband be covered? How much will it cost rural users compared to urban users?

Standards Influence

- Are standards organizations fair and accessible to all contributors?
- Have standards organizations been used by Chinese entities (Huawei, etc.) to favor their technologies?
- What is the relative level of US companies' influence in setting standards, compared to other nations now and five years ago?
- Are governance norms being shaped in standards organizations in a way that undermines civil liberties?

International Interoperability

- What are the greatest risks to unified global standards?
- Will your technology be interoperable with other nations' 5G networks?

Responsibility & Accountability

- How do we hold providers along the supply chain for 5G accountable?
- How is risk and liability distributed? What is the breakdown of a collaborative responsibility scheme?
- How does risk and liability distribution get enforced? What governance bodies—domestically and internationally—hold corporations and organizations accountable through robust oversight?