INFORMATION TECHNOLOGY & INNOVATION FOUNDATION

5G and Next Generation Wireless: Implications for Policy and Competition

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5G represents a unique opportunity to step back and rethink a new network to radically extend wireless capacity and adaptability.

Industry, academia, and governments around the world are pouring a tremendous amount of effort into developing next generation wireless networks. And rightly so: 5G represents a unique opportunity to step back and rethink a new network, one that incorporates recent technological advancements to radically extend wireless capacity and adaptability. With 5G we will move beyond networks that are purpose-built for mobile broadband alone, toward systems that connect far more different types of devices at much higher speeds.

This report discusses 5G and what it will add to telecommunication markets including potential deployment and implications for competitiveness. It then makes a number of policy recommendations. 5G is still in its formative years, and there is not yet an agreed-upon definition of exactly what it will consist of. Some choose to focus narrowly on the standardization process—which is complicated in its own right. Although standardization processes have historically defined the "generations" of mobile technology, this report takes a broader view, considering how a number of breakthrough technologies outside of radio interface standards will drive wireless in the years to come as we transition to 5G.

Even if there is no one precise vision of what 5G systems will comprise, at their most capacious, next generation wireless networks are envisioned as offering virtually everything for everybody. ITIF expects that with the right policies in place, 5G will provide wildly increased capacity, allowing for super-high definition streaming of augmented reality; far more numerous, less costly connections, supporting a boom to the Internet of Things (IoT); and highly reliable connections, enabling critical communications and large-scale industrial automation.

HISTORY AND CONTEXT

A shared understanding of where the wireless industry is and where it has come from will help ground a discussion of where it is going next.

The “Gs”

Discussions of the evolution of mobile classify the various technologies into different “generations.” The first generation of mobile was, compared to networks in use today, quite rudimentary. It was focused purely on basic voice service, and was an analog (as opposed to digital) service.

The second generation of wireless was still designed for voice, but made the switch to digital standards. 2G saw the development of both GSM and CDMA standards—both of which are still widely in use for voice communications today. These protocols made significant improvements in terms of coverage and capacity over the analog networks of the first wireless generation, but were not adequate for large-scale data use.

The third generation introduced data services, expanding the functionality beyond voice and including multimedia, texting and some limited internet access. It was not until 4G that we got a full Internet Protocol (IP)-based specification. The primary 4G protocol—LTE—was designed to support mobile broadband, and is the dominant industry standard today. The waves of new generations of technology 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.

5G is not yet defined, and it is not clear that a single standard will drive the shift to the next generation of wireless technology. In fact, “5G” is used to refer to a number of different technologies, and not necessarily a particular standard or specification.

Current Challenges

While 4G was designed largely with mobile broadband in mind, 5G allows engineers to look at the horizon of new uses. Different use cases put different demands on the network, and impact different sectors of the economy. 5G must consider, for example, the various networking requirements of industrial automation, precision agriculture, and augmented reality. Where demands push up against the boundaries of what is currently possible with 4G networks, researchers start to consider leaps to whole new technologies instead of incremental additions to the LTE specification.

Development of 5G is driven by the fundamental challenges that existing networks face. The challenges can be roughly divided into whether they are primarily for human users or for machine users. Perhaps more helpfully, the uses cases that necessitate the development of 5G can be grouped under three general headings: enhanced mobile broadband; Internet of Things (IoT); and critical infrastructure or public safety.

Human Users—Enhanced Mobile Broadband

When it comes to human users, the name of the game is enhanced mobile broadband. Additional capacity and lower latency are key to improving the user experience of broadband on-the-go.

Mobile data traffic is only expected to grow, with Cisco's Visual Networking Index expecting an eightfold growth in global traffic between 2015 and 2020.[1] Ericsson measured a 60 percent growth in data traffic in 2015.[2] Mobile video is an important component of this growing demand. A number of technology trends—such as faster mobile processors, larger screens, better batteries, advanced mobile application ecosystems, and the rising popularity of video on social networks—have converged to allow mobile video traffic to explode.[3] Video places an order of magnitude larger demand than most other uses on the capacity of networks, so to enhance mobile broadband, end-user download speed remains the main driver. For mobile to become a more robust competitor for wireline broadband networks, speeds will need to increase, and in a way that is economical as to see larger monthly data plans.

Some criticize usage-based pricing for artificially introducing scarcity that forces users to curtail Internet use. These criticisms are not grounded in reality.

Unfortunately, much of the low-hanging fruit in increasing wireless capacity has been picked, and operators are facing a significant challenge in meeting the projected data demand. When it comes to achieving additional throughput and increasing mobile broadband speeds, wireless operators have only a handful of levers they can pull.

First, consider spectrum. Discussions of spectrum policy can quickly become rather esoteric. Appendix A provides a brief introduction to the topic.

Mobile operators are always looking for more spectrum, as this resource is the key pinch-point limiting mobile networks' capacity. Unfortunately, allocating more spectrum for broadband is a long and difficult process, often requiring an act of Congress, and efforts by the FCC. Finding more spectrum is important, but can't scale up fast enough to meet growing demand. Moreover, deploying new bands of spectrum can be expensive. Mutually exclusive spectrum licenses are now allocated by the government through auction, often for billions of dollars, so any additional spectrum requires additional revenues, either from customers directly or from edge providers paying carriers to offer their content without charging against the customer's data cap.

There is also opportunity to increase the overall capacity of a wireless network by improving spectral efficiency. Early improvements in encoding more bits of information into a given slice of spectrum increased efficiency. Unfortunately, there are hard limits to how far engineers can push spectral efficiency, and engineers are already close to those limits. As hard as getting Congress to pass a new law can be, bending the laws of physics is even harder. There are also trade-offs in any system designed—a protocol designed purely for maximizing throughput may not handle other usage scenarios as well.

Historically, spectrum reuse has been far and away the source of most gains in increasing the overall use of wireless systems. Techniques like making smaller cell sizes or splitting cells into different sectors allow for greatly increased capacity, but this solution is limited as well. As cells get smaller, costs 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 by additions to consumers' monthly bills alone. This will continue to be an important consideration as we move closer to 5G—what the technology can achieve and what is economically feasible to actually deploy may not necessarily coincide, especially now that carriers are restrained from selling prioritized wireless service by the FCC's Open Internet rules.

Machine Users—Massive Internet of Things

Machines rely on connectivity of a very different type than humans. While binge video watching means gulping down large streams of information, most IoT devices take small sips, powering up infrequently to send very small amounts of information, and otherwise conserving battery life as much as possible. This leads to very different requirements of the technology.

The number of IoT devices is expected to grow dramatically, with sensors deployed for a wide variety of applications such as building security and automation, smart metering and utilities, infrastructure maintenance, and automotive, health-care, and consumer electronics applications. Projected numbers vary considerably based on what is considered an IoT device. Gartner estimates that roughly 5.5 million new things will be connected to the Internet every day of 2016, with a total of 20.8 billion IoT devices connected by 2020, which gives some sense of the scope of this market.[4]

Today, around 70 percent of cellular IoT modules are based on 2G GSM technology, whereas LTE only has about 5 percent share.[5] LTE, being designed primarily to facilitate mobile broadband, has some limitations as a potential tool for large-scale IoT deployments, and as carriers phase out legacy GSM technology existing machine-to-machine connections will be up for grabs.[6] Cellular companies using licensed radio spectrum face stiff competition here, with numerous open and proprietary IoT protocols being developed for use on unlicensed spectrum.

Efforts are underway to develop variants of 4G technology designed for the IoT market, such as Narrow-Band IoT.[7] These technologies are a good illustration of the evolution of LTE toward a new type of network, with some calling Narrow-Band IoT "4.5G." The opportunity exists for mobile operators and equipment vendors to design 5G to position their technology as a preferred solution for the wave of expected IoT connections.

Massive IoT deployments require a new level of scalability—the network must be engineered to handle far more simultaneous connections than before. For networks to handle the billions of devices envisioned as part of the Internet of Things, the signaling information has to be simplified so as not to overwhelm the network.

Another key goal in enabling large numbers of low-cost sensors is energy efficiency. Long-term sensor installations separated from wired power supplies need as long a battery life as possible—some say a decade of life can be achieved. To reach this goal, the signal processing overhead for the device will need to be reduced, with some of the work moved into the powered base-station.

But not all devices have the same requirements—5G networks will have to be adaptable even to different types of IoT devices. For example, some connected devices require mobility, like drones or connected vehicles. The ability to maintain a relatively low-latency connection while handing off from cell site to cell site takes resources that are simply not needed for a water sensor sitting in a farmer's field. 5G networks will need to be able to provide mobile functionality when needed, and otherwise conserve resources to maximize power efficiency.

It is also important to note that not all machine connections have low bandwidth requirements. Generally, any application that involves video—such as inspection drones or connected security cameras—will be bandwidth-intensive. Constantly running sensors for industrial big data analytics can also produce surprisingly large amounts of data.[8]

Medical applications provide another example of how some of the 5G developments might come together to make what was previously difficult and expensive easy and cheap. With the higher frequencies envisioned for use by 5G networks, antennas can be significantly smaller, allowing for tiny, low-power implantable devices. For example, researchers at University of Madison in Wisconsin have developed stretchable circuitry—a "skin"—of integrated circuits, using millimeter wave bands that would allow for remote patient monitoring with ease and comfort.[9]

Critical Communications and Public Safety

Another envisioned component to next generation mobile is support for critical communications—incredibly resilient, dependable networks that can support public safety uses, or high-value industrial automation. Automation of heavy equipment or fleets of connected cars flying down the highway have little margin for error.

Public safety will be an important user of next-generation wireless technology. FirstNet is in the process of standing up a wireless broadband network for first responders in the 700 MHz band. As we continue the transition away from the legacy public-switched telephone network, the role of mobile communications will likely grow for public safety. 5G should be designed to have high levels of reliability and robustness when required.

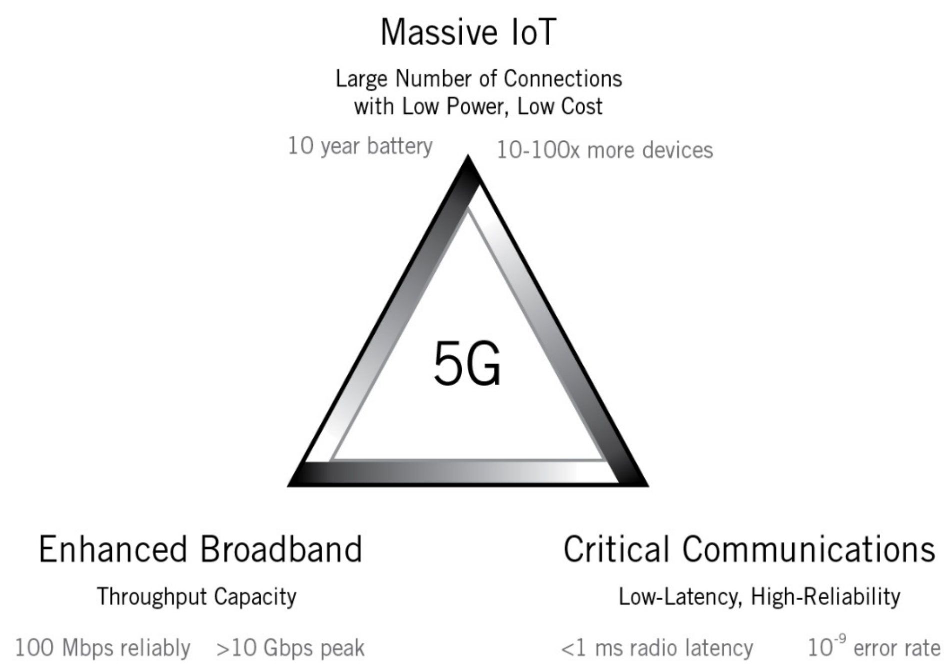
5G will also likely be a key tool in supporting autonomous vehicles, with one forecast estimating driverless cars will account for 3 million 5G connections by 2025.[10] To the extent 5G is relied upon for actual safety-related features (and not just in-car entertainment), a reliable, low-delay network will obviously be crucial.[11]

The Goals of 5G: Benchmarks

For 5G to adequately serve the various use cases that are envisioned down the road, networks will have to hit several benchmarks. There are slightly different numbers bandied about by different suppliers and vendors, but there is a general consensus around a few target benchmarks. Also, the exact benchmarks are still being worked out—what is actually feasible given potential engineering tradeoffs and what use cases are driving the economics of development will continue to shape the exact targets for 5G.

When it comes to capacity, the telecommunications wing of the United Nations, the International Telecommunications Union (ITU) has put out an initial benchmark goal of peak download rates of 20 Gbps, and 100 Mbps per user reliably. Actual download speeds will fluctuate depending on the needs of specific applications, allowing for much more economical provisioning of network resources. This will be an important transition away from advertised speed and toward bandwidth on demand—providing throughput where it is needed.

Figure 1: The 5G Triangle



Latency, the time delay as information travels across a network, will be another important consideration for 5G. Today, latency is a factor for some Internet applications. For example, cloud applications require latency under 100 millisecond (ms) to be comfortably usable; real-time games respond more smoothly at lower latencies; and voice calls over the Internet require less than 150 ms to avoid awkward delays between the speakers.[12] Other applications, like email or buffered video, have little concern for latency. But as we continue to see greater real-time interaction between humans and machines, the latency of 5G networks becomes more important for comfortable usability. Reliable low-latency connections also enable previously impossible applications.

Virtual and augmented reality provides a striking example. The ITU has dubbed these sorts of applications, featuring a tighter coupling between humans and machines enabled by lower latency, the Tactile Internet.[13] The term "tactile" is apt—with low enough latency, humans will be able to interact with machines at a distance as if manipulating objects directly in front of them. In addition to virtual reality and augmented reality, robotics, telepresence, telemedicine, connected cars, smart grid, and a wide variety of interactive sensors and actuators are technologies that will place extreme demands for low latency on networks.

IoT applications bring their own benchmark goals, with networks taking on extra functions to help achieve extra-long battery life and scalability to connect and route signals among billions of devices.

Cost efficiency is also an important component of designing 5G systems. With the expected massive influx of IoT devices, there will be strong downward pressure on the revenue per connection, meaning efficiency will be key for mobile operators. It is also unlikely that customers will be willing to pay much more for smartphone connectivity, especially if improvements are incremental instead of true game-changers. Small-cell densification—a key component of next generation networks—is costly, so deployments will likely be incremental as the economics permit.

The two major trends as we move toward a formal 5G standard are cell site densification and additional flexibility enabled by a more software-centric network.

It is important to note that the desired benchmarks may vary by market and are still in flux.

THE TECHNOLOGY

Historically, it has been the process of setting standards that defined shifts in mobile generations. When a new standard, such as 4G LTE, came along it required new equipment within the network as well as new phones on the user side. This makes for a clean cut to the next generation, a step that is made clear by extensive marketing around the technology change.

There is certainly a conversation about standard setting when it comes to 5G. The ITU has launched a high-level process called the International Mobile Telecommunications for 2020 and beyond, with the goal of eventually landing on a global 5G standard to drive economies of scale in equipment. But 5G technology is being developed and incorporated into networks well before the formal ITU process.

The two major trends as we move toward 5G networks are cell-site densification and additional flexibility enabled by a more software-centric network. There are a number of technological developments unfolding that will be incorporated into mobile networks as 5G becomes more concrete. Three key components bear special discussion: high-band spectrum, advanced antennas, and software-based networking.

High-Band Spectrum

The use of extremely high-frequency spectrum is one of the most prominently discussed components of a future 5G system.

For discussion purposes, mobile spectrum can be broken down into three different ranges: low-, mid-, and high-band spectrum. Low-band spectrum is below 1 GHz—generally the 700 MHz spectrum freed up from the digital television transition, and 600 MHz spectrum currently being repurposed as part of the FCC's incentive auction. Mid-band spans from 1 GHz to 6 GHz, including the PCS bands and unlicensed spectrum at 2.4 GHz and 5 GHz.

The high-band spectrum envisioned for use as part of 5G systems is way up above 24 GHz. These are often called the millimeter wave bands (or mmWave), as their wavelengths can be measured in millimeters.

These bands were long thought useless for mobile applications, as their propagation is severely limited. Signals in this frequency range are easily blocked by clutter on the ground—like buildings or trees. Rain can significantly impede these transmissions, and electromagnetic energy is even absorbed by oxygen at some portions of high-band spectrum.[14]

The hope is that recent advancements in advanced antenna technologies can overcome these challenges and make these bands more practical for mobile operations than previously thought. NYU Wireless at New York University has been a research leader in exploring the feasibility of using this spectrum for mobile broadband.[15]

Sharing high-band spectrum with existing users, such as satellites, has to be worked out, but bands of this high frequency are relatively greenfield, with large swaths of spectrum available.[16] To illustrate this, consider that mobile spectrum today uses blocks 5 to 20 megahertz wide. For high-band spectrum the FCC is contemplating licensing 200 megahertz-wide blocks. This makes for channels with enormous bandwidth compared to mobile systems today, meaning where a 5G mmWave signal is clear, the radio portion of the network will likely no longer be the limit on download speeds it is today.

Antenna Technology

High-band spectrum really shines when combined with advanced antenna technologies. Antenna size is inversely proportional to the spectrum frequency the antenna is built for. By turning to the millimeter wave bands, engineers can shrink antennas tremendously compared to what are used for wide-area networks today. In turn, far more of these small antennas can be fit into devices and equipment.

Using multiple antennas to transmit a single stream of information is a technique known as Multiple Input Multiple Output (MIMO). A particular flow of traffic can be broken down into pieces and intelligently transmitted through multiple antennas, with the effect of dramatically increasing throughput and reliability. MIMO can be used with other spectrum bands, but the small antenna size enabled by high-frequencies allows for large arrays of antennas to be used—known as massive MIMO.

MIMO becomes especially potent when signals are carefully controlled and directed at a particular device. Beam-forming and steering allow base stations to direct narrow beams of electromagnetic energy, effectively extending the signal's distance and allowing for more re-use of the same spectrum, increasing overall throughput.

Advanced antenna technologies can help compensate for the limited propagation of high-band spectrum.

Software Networking

Access network operators are quickly adopting technologies to shift aspects of networking traditionally done by hardware to software environments. Specifically, the last few years have seen a dramatic rise in the use of software-defined networking (SDN) techniques. This is a technology well-proven in data centers; it essentially creates another layer of abstraction that separates the control over where network traffic is sent from underlying systems.

SDN allows for far more flexible and efficient provisioning of network resources. An important technology enabled by SDN is network functions virtualization (NFV). NFV allows operators to take what used to be large, purpose-built network appliances—hardware devices such as load-balancers, address translators, firewalls, and other security features—and run them in virtualized systems on general-purpose computers.

These changes to how networking is done may seem a bit obscure and technical, but they are incredibly important to how networks will be run as we transition to 5G. These technologies allow for a far more dynamic network that can adapt to the needs of specific applications on a granular basis. However, these capabilities will not see their full potential if regulators limit network flexibility in the pursuit of so-called net neutrality.

High-band spectrum, advanced antenna technology, and more flexible, software-based networking are the key building blocks of 5G, though other technologies are being developed.[17]

THE LONG RUNWAY

Existing LTE standards have a long shelf life: a number of features are not yet in use and will continue to be developed as operators incorporate different 5G technologies. The 3rd Generation Partnership Project (3GPP), an industry-led membership organization that has long led mobile standard setting, continues to develop new versions, or "releases," of LTE which incorporate additional features. LTE will continue to be in use for a long time before a wholesale transition to a new radio access standard.

One example of the long life left in advanced versions of LTE specification is carrier aggregation. Carrier aggregation allows operators to combine multiple signals in different bands of spectrum into a single source of bandwidth for the end-user, dramatically increasing data rates. The LTE specification has supported this functionality for years, but it is not yet widely in use, and where it is used, the technology is not being deployed to the fullest extent possible.[18]

As particular aspects of 5G are developed, they will likely be put to use for specialized purposes well in advance of a wholesale shift of the mobile ecosystem. For example, high-band MIMO technology is likely first to be deployed as fixed wireless services to the home. A number of companies, including Verizon, AT&T, Google, and Starry, have been exploring this service.[19] High-band MIMO will deliver to homes a high-performance broadband alternative to fiber (FTTH). A wireless link over approximately the last 500 feet to a unit mounted on the side of a home will reduce costs considerably compared to trenching and installation of fiber through every yard.

Some vendors are already marketing technology as "pre-5G" or "4.5G." For example, ZTE took home multiple awards at the 2016 Mobile World Congress for its "pre-5G" massive MIMO base station, which uses beam-forming and over a hundred antennas to offer 400 Mbps to existing 4G handsets.[20]

There have been some policy concerns in unrelated contexts about deployment of so-called "pre-standard" network equipment.[21] But the transition to 5G will definitely involve use of "pre-standard" equipment, especially by large operators with the customer base and scale needed to drive devices compatible with their network. This is a good thing, allowing competition to drive discovery of new technology.[22]

High-band MIMO technology will likely first be deployed as a fixed wireless service to the home.

5G STANDARDIZATION PROCESS

Much work is already underway on the technological components of 5G and these will likely be incorporated into wireless systems gradually. However, there is also a more formal, international process to define 5G. Here, the ITU has set the stage for a standardization process for a global 5G radio interface. The ITU's Working Party 5D is responsible for shaping the standard for "futuristic mobile technologies" to support International Mobile Telecommunications (IMT) for 2020 and beyond.[23] This process is known as "IMT-2020."

The next two years of the ITU's process are still focused on defining the details of the performance requirements and a methodology to evaluate proposed radio interface specifications. The ITU working group will then solicit proposals from outside bodies, which the ITU expects to evaluate in the 2018-2020 timeframe.[24]

A key body to watch for a submission for evaluation is the 3GPP. This organization has developed a tentative timeline to achieve a great deal of work before the IMT-2020 target.[25] Within such a consensus-based, industry-led body there is room for refinement of the most technical details, for example the appropriate channel models for high-band spectrum.[26]

Other bodies are working with much more explicit government collaboration to shape future specifications in large part to help give domestic telecom and equipment companies an unfair advantage. For example, the EU Commission formed the 5G Infrastructure Public Private Partnership, or 5G PPP, with the European information and communications technology industry. With €1.4 billion in funding and a goal to "have

European industry driving the development of 5G," 5G PPP represents the European style of a much more active government hand explicitly developing industrial 5G policy and attempting to guide the standards setting process.[27]

In the United States, policymakers generally take a far more hands-off approach to the standards setting process. This stance was well summarized by FCC Chairman Tom Wheeler in a recent speech at the National Press Club:

> Turning innovators loose is far preferable to expecting committees and regulators to define the future. We won't wait for the standards to be first developed in the sometimes arduous standards-setting process or in a government-led activity. Instead, we will make ample spectrum available and then rely on a private sector-led process for producing technical standards best suited for those frequencies and use cases.[28]

Overly-enthusiastic government involvement in standards setting is likely to reduce, not maximize, global wireless innovation, with some nations "winning" but the global wireless ecosystem losing.

There is certainly a role for government in encouraging 5G to flourish, but industry-led standard setting better allows discovery of new technologies and a more nuanced understanding of what areas are most economical to explore. The goal should not be a race to create the standard that, say, best plays to the intellectual property of a region's favorite firm. Instead, the next several years should be an exploration of different solutions for different markets as the various 5G technologies develop before agreeing on a new standard or standards.

Overly-enthusiastic government involvement in standards setting is likely to reduce, not maximize, global wireless innovation, with some nations "winning" but the global wireless ecosystem losing. Moreover, as ITIF has written, depending on whether the government-backed standard becomes the global standard, a nation risks developing the Galapagos Island Syndrome, where its standard might be innovative, but not global.[29]

COOPERATION AND COMPETITION UNDER 5G

Many of the new wireless technologies introduced in the coming years will impact the costs of deploying or operating networks. Some will lower costs. For example, the general transition of virtualizing more network functions, running them in software instead of purpose-built hardware, is expected to significantly lower the cost of operating a large-scale access network—some estimate by about 30 percent.[30] On the other hand, some new technologies will require significant investment to deploy. In particular, the limited propagation characteristics of high-frequency spectrum, deploying millimeter wave radios in a meaningful way will require large amounts of capital investment.

Beyond the equipment itself, negotiating siting locations, and acquiring backhaul connections and rights-of-way, all compound the transaction costs of deploying 5G networks. As we look to a new level of density of cell sites, the rise of these types of costs may lead to new models of infrastructure sharing. It also opens an opportunity to those with existing wired infrastructure—as wireless increasingly competes with wired, traditional fixed broadband companies will look to augment their bundle with a more robust wireless component.

5G is likely to see a considerable uptick in converged competition between wired and wireless actors as performance of wireless networks continues to improve and mobile bandwidth caps continue to increase. Infrastructure and backhaul connections will play a key role in enabling the dense networks of 5G, so those with existing wired networks will be able to leverage that asset in further exploring wireless offerings. With the FCC looking to make available large amounts of unlicensed, high-band spectrum, wired operators or other new entrants will have the opportunity to expand wireless networks using unlicensed spectrum.

Infrastructure Sharing

Unless there is a sizeable change in local policies toward streamlining deployment of wireless infrastructure and fiber backhaul, it is likely that 5G deployment will face significant transaction costs. This may lead to new opportunities for actors specializing in securing small-cell or mmWave deployments, or new levels of infrastructure sharing to reduce the overall cost of competitive deployments.

Infrastructure has been shared to one degree or another throughout the history of telecommunications. At times, sharing has been forced in the form of mandatory unbundling of network elements, regulated roaming, or spec as a means to spur static competition on prices or services.[31] Other infrastructure sharing, such as shared towers, is undertaken on a private, contractual basis, allowing for a more adaptable system. There should be a general preference for this more flexible approach, avoiding a more sclerotic regulatory framework with regulatory barriers to new entrants. Until we better understand the transaction costs of these new deployment scenarios, it makes sense to leave sharing decisions to the market.

Increased cooperation from local governments and utilities will also be key to efficient buildout of 5G networks. Backhaul is a significant challenge with dense deployments of small cells—municipalities should seek to assist these builds in a cooperative effort.

International Competitiveness

5G, if implemented as hoped, will prove a significant boon to economic output and consumer welfare. Similar to 4G, it will likely play an important role as a platform enabling other innovations adjacent or on top, meaning there may well be something of a first-mover advantage for countries that facilitate an early deployment of this platform, and successfully integrate it with other parts of the economy.

Many countries are active in the race to 5G, both for economic reasons and to display technological leadership. Target 5G launch dates in South Korea and Japan correspond to the 2018 Winter and 2020 Summer Olympics hosted in those countries respectively.

The international scramble for leadership is certainly not a zero-sum game, and there are significant advantages to global cooperation. Identifying an agreed-upon standard for wireless communications yields tremendous economies of scale, as companies around the world organize production around a single specification.

At the same time, there is value in open innovation around these new technologies, and it is important not to rush through experimentation and fast-track a particular standard. This is especially true at the international level, as markets around the world differ significantly. For example, network operators in parts of East Asia have a customer base that highly values the enhanced mobile broadband aspects of 5G and already have relatively dense fiber networks, meaning the incremental cost of adding mmWave small cells is smaller compared to suburban-sprawl countries like the United States.

Different countries will elevate certain components of the technology mix depending on their market structure, costs, and what sort of use cases make the most sense for investment. Some analysts expressed alarm that industry may unduly rush to judgment in defining a new radio standard, saying, for example, "the proposed timeline for the 5G standardization process seems rushed and without any clear purpose, except one…. [The] major sporting events," a reference to the Olympic games in Japan and Korea.[32]

A priority for policymakers to set the stage for 5G is allocation of high-band millimeter wave spectrum.

As mentioned above in the discussion of standards setting, the United States government tends to take a more hands-off approach compared to other countries, allowing industry to lead the development of new technologies. Generally speaking, this is the preferred approach, allowing industry to find which use cases of a new technology merit the most investment, and on what timescale.

Too strong a government hand in guiding technical standards, especially when tied to arbitrary deadlines, can lead to sub-optimal outcomes. This is not to say there is no role for government in enhancing a country's competitiveness in developing and deploying 5G technology. Once a global standard is agreed on, robust and smart government action to encourage adoption of the technology and use cases can boost growth and competitiveness.

POLICY RECOMMENDATIONS

Given the fact that many of the technological components of 5G are still in flux, that deployment scenarios are still being explored, and that there is still a good deal of gas in the LTE tank, government action around 5G should be more stage setting than full industrial policymaking. The primary goals are getting new spectrum available and local efforts to streamline infrastructure deployment.

Spectrum

A priority for policymakers to set the stage for 5G is allocation of high-band millimeter wave spectrum. Here the FCC is setting a great example. In 2015 the Commission proposed rules as to how best to put high-band spectrum to use.[33] The FCC is following through on this proposal by circulating an order that, if approved, would open up a significant amount of high-band spectrum: 3.85 gigahertz of licensed, flexible use spectrum and 7 gigahertz of unlicensed spectrum. Six hundred megahertz will be reserved for experimental spectrum-sharing models.[34]

To put that amount of bandwidth into perspective, the draft order would open up more than four times the amount of flexible-use spectrum the FCC has licensed to date, and 15 times as much as all unlicensed Wi-Fi spectrum in lower bands.[35] It is worth reiterating that not all spectrum has the same characteristics or economic value. High-band spectrum has particularly limited propagation characteristics, and is easily blocked by buildings, trees, and rain. So this large amount of spectrum is not a silver bullet for our rapacious demand for wireless capacity—good spectrum policy has to be paired with additional investment in technology and infrastructure.

The FCC deserves credit for moving quickly to get high-band spectrum into the hands of innovators, and for not being beholden to international bodies, such as the ITU, who are slow to allocate this spectrum to mobile.[36] There is some concern that by moving quickly, the band plan in the United States may not necessarily match those abroad, undermining economies of scale in equipment and devices. While internationally harmonized spectrum would be ideal, the advantages of getting this spectrum into the hands of innovators and industry as quickly as possible far outweighs the possible benefits of waiting for agreement.

Local governments should view wireless infrastructure build-out as a cooperative goal, assisting citizens in their daily lives, and helping cities provide better government services.

To be clear, the use of high-band spectrum is an important development for next-generation systems, but low- and mid-band spectrum continues to be important. Wireless networks will continue to rely on a variety of spectrum bands, and governments should continue efforts to repurpose additional spectrum of different frequency, including spectrum now used by the government, for flexible uses.

In order to see large investments for robust, reliable wireless systems, operators require long-term licenses, relatively broad geographic rights, and flexible-use allowances. This strongly suggests the need for large-scale spectrum management reform in regions like the European Union.[37]

Regulators should also exercise caution in setting reserve prices or payments when it comes to auctioning high-band spectrum. Unnecessarily high auction prices discourage investment in new, unproven technologies that will have significant deployment costs of their own.[38]

Infrastructure

High-band spectrum, or any small-cell densification for that matter, will require significant investment in infrastructure—both for siting the antenna equipment and for backhaul.

Here, more cooperation from municipalities would greatly assist in streamlining cost-effective deployment of next-gen wireless systems. Local governments should view wireless build-out as a partnership goal that will not only assist citizens in their daily lives, but also help cities provide better government services. These efforts should not be like franchise agreements of the past, which cities viewed as a cash cow, but like cooperative endeavors.

Many of the same recommendations touted for deployment of wired networks apply, as backhaul will be a constraint in build-out of small cells. Streamlining of permitting and access to rights-of-way, dig-once policies for streets and sewers, installation of additional conduit where available, consolidated paperwork, a single point-of-contact, and discouraging "not in my backyard" thinking for wireless equipment would all go a long way to facilitate 5G.

Key infrastructure assets for small cell deployment are utility poles and streetlamps. Utility poles have existing access to power, and often fiber that can be leased; they are positioned in populated areas, and at an appropriate height for small cells.

The FCC has rules around the pole attachment process, and has worked to keep those up-to-date and to address challenges as they arise.[39] However, under statute, states have the right to take on pole attachment regulations themselves. So far, twenty states and the District of Columbia have decided to do so, with varying degrees of success.[40] CTIA recommends that to see efficient buildout of next-generation wireless networks, states should ensure non-discriminatory access, mandatory timelines, just and reasonable rates, and an efficient complaint process as part of their pole attachment process.

CONCLUSION

Noted innovation economist Joseph Schumpeter one wrote that "technological possibilities are an uncharted sea."[41] Nowhere is this more true than wireless, where progress continues to amaze. 5G networks promise radically expanded capabilities. A confluence of technologies is enabling an adaptable network that effectively provides numerous new functions. We will continue to see additional competition in providing broadband access, as the performance of wired and wireless networks converges. 5G networks will also enable a new level of IoT connections, touching key verticals throughout our economy.

But deployment of such a network will be limited by economic realities. Backhaul and siting remain expensive endeavors—policymakers on every level of the government should aim to make those processes as efficient as possible to see the flourishing of 5G networks.

APPENDIX A: RADIO SPECTRUM 101

Talk of electromagnetic spectrum can be esoteric, but, while there is a bit of a learning curve, spectrum is a key factor in the 21st century economy and deserves core policy attention. This appendix serves as a brief introduction to radio spectrum and how it is managed by the government.

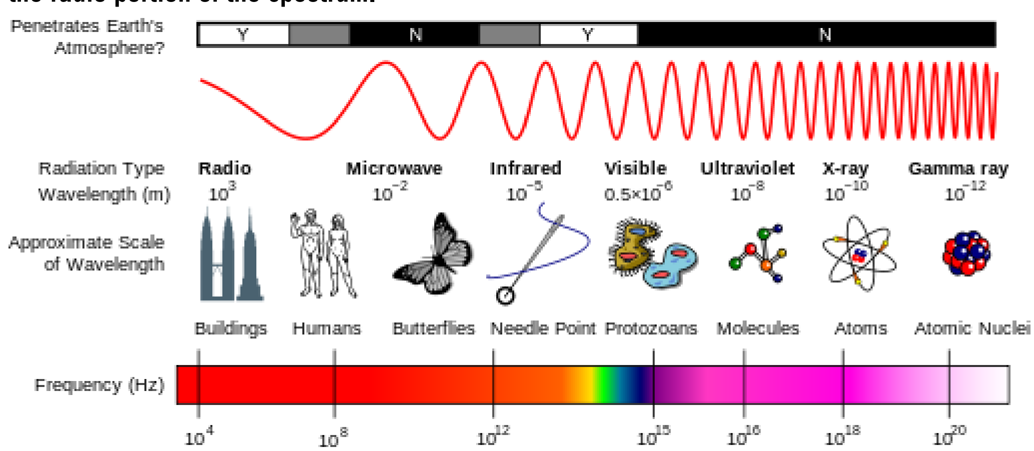
What is Spectrum?

When discussing telecom policy, the term "spectrum" inevitably comes up—it is an essential input to wireless services, a constraining factor in the growth of mobile broadband, and an exceedingly peculiar type of resource.

In the context of wireless policy, "spectrum" is shorthand for a portion of the broader spectrum of electromagnetic radiation with properties useful for wireless applications. In physics terms, electromagnetic radiation is a self-propagating transverse oscillating wave of synchronized electric and magnetic fields.

Electromagnetic spectrum is the physics behind not just radio waves, but also infrared, visible, and ultraviolet light, as well as x-rays and gamma rays. The waves in radio spectrum management are bigger and repeat less quickly, but they are part of the same physical phenomenon of the light we see.

Figure 2: Different portions of the electromagnetic spectrum have different properties, but are part of the same physical phenomenon. Spectrum management is primarily concerned with the radio portion of the spectrum.



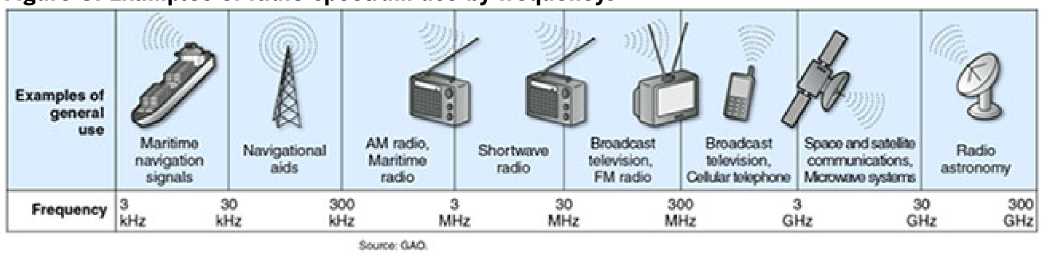
All radio technologies use spectrum in a similar way. For example, a basic radio communication link is composed of a transmitter and a receiver. The transmitter sends out a wave that is "modulated" to be encoded with information. The wave propagates through the air. The distance and direction the wave travels depend on a number of different factors, such as the power at which the signal was transmitted, the frequency of the wave, and whether there is any "clutter," such as trees or buildings in the way. The receiver then "listens" to the signal and decodes the message, assuming it is close enough to hear it.

Scientists first proved the existence of electromagnetic spectrum in the late 19th century, with commercialization of radio in 1897.[42] Since then, the pace of innovation has been astounding.

Why is Spectrum Important?

Spectrum by itself is not so important—it's the uses we put it to that bring value. Indeed, the technologies we have built using radio have fundamentally changed the way we interact.

Figure 3: Examples of radio spectrum use by frequency.[43]



The diagram above shows a handful of the different technologies that rely on spectrum, along with the rough range of frequencies they use. These different radio technologies, such as RADAR, broadcast television and radio, satellite communications, or GPS, have had a profound effect on our lives. These technologies also play a sizeable role in the economy.

Historically, as new wireless technologies were developed, there was plenty of spectrum to go around. Not so anymore. Virtually all the most useful spectrum has been claimed, and in most cases significant investment has been made into various types of equipment with reliance on having access to a particular band.

But technological progress never stops, and now many of the initial assignments of spectrum are obsolete. The task of spectrum regulation has become one of reassigning already utilized spectrum to new technologies that have more social and economic value than old ones. The greatest example of this tension has been the rise of mobile broadband. The challenge to find the spectrum needed to meet the demand for mobile data is one of the key projects for spectrum managers.

The demand for mobile data is growing rapidly. In the United States, mobile data traffic grew 63 percent in 2014. It is estimated that in 2019 U.S. mobile data traffic will be equivalent to 210 times the volume of mobile traffic 10 years earlier (in 2009).[44] This demand isn't unique to the United States.

U.S. consumers and businesses value mobile services quite a bit, spending to the tune of $172 billion in 2013.[45] A recent report estimated that this $172 billion generated $400 billion in total spending due to the multiplier effect.[46] Essentially, every dollar spent on wireless services generated $2.32 in total spending, and one job in the wireless sector generated 6.5 jobs.[47]

Wireless services also touch a number of different sectors, enabling innovation throughout the economy. Take, for example, agriculture. Beyond the regular communications technologies we all enjoy, farmers rely on GPS to guide large-scale equipment through fields. Also, government-operated earth exploration satellites beam down detailed information on environment, atmosphere, and climate conditions. Private companies are also working to create a private satellite network to collect and provide information to improve crop production. Unmanned aerial vehicles will inspect and monitor crops and livestock. The Internet of Things (IoT) will soon be leveraged to monitor many different aspects of agricultural processes. By some estimates, IoT and big data analytics will soon save 50 billion gallons of fresh water a year globally.[48]

All of these technologies require spectrum, and in order for them to work properly, that spectrum use has to be coordinated to some degree. Spectrum management is a key part of enabling efficient industrial organization as well as allowing innovative new spectrum technologies the bandwidth to grow.

How is Spectrum Managed?

Spectrum is indeed a peculiar sort of resource. In a sense, it is infinitely renewable, always there, ready to be put to use. The problem with unmanaged spectrum is interference.

If a radio receiver tries to interpret two different signals in the same place, at the same time, on the same frequency, it essentially gets confused, and neither message goes through clearly. This is how we get interference.

To protect against interference, different entities have to work together to ensure that multiple senders don’t transmit on the same frequency at the same time in the same place. This is where spectrum management comes in. Spectrum management involves a variety of different rules, such as limitations on the power of signals that can be transmitted, or geographic limitations on where transmitters can be placed, all with the aim of minimizing interference.

One of the most important tools in spectrum management is the license. Licenses are subject to a variety of service rules, but give the license holder exclusive rights to one operator to a defined band of spectrum in a given area. Many different methods have been used to assign licenses, but today regulators auction spectrum licenses. Spectrum licenses then allow operators a clean environment and some flexibility to build their radio architecture as they think best.

Mobile operators rely on licensed spectrum to run their networks. Operators require interference-free spectrum to provide reliable service. Likewise, all the other operations that rely on spectrum, such as RADAR, broadcast television, GPS, or satellite communications, have to be separated through technical rules to ensure smooth operation. This is the role of spectrum managers.

ENDNOTES

1. The United States, where mobile data traffic is expected to grow seven-fold from 2014 to 2019 (a compound annual growth rate of 47 percent), represents a significant portion of this overall demand. Cisco, "Cisco Visual Networking Index (VNI): Global Mobile Data Traffic Forecast Update, 2015–2020" (white paper, San Jose, California, updated February 1, 2016,) www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html. While these predictions are not without controversy (see, e.g., Aalok Mehta and J. Armand Musey, "Overestimating Wireless Demand: Policy and Investment Implications of Upward Bias in Mobile Data Forecasts," 23 *CommLaw Conspectus*, (2015): 300, available at http://scholarship.law.edu/cgi/viewcontent.cgi?article=1557&context=commlaw), ITIF believes mobile broadband to be a key driver of productivity gains and economic growth, and therefore, as a general matter, additional spectrum should be allocated to mobile regardless of the precise trend of data use.
2. "Ericsson Mobility Report: On the Pulse of the Networked Society," *Ericsson*, June 2016 (Ericsson Mobility Report), http://www.ericsson.com/res/docs/2016/ericsson-mobility-report-2016.pdf.
3. Streaming entertainment on mobile networks now accounts for more than 40 percent of downstream traffic during peak hours. Social media, which increasingly includes auto-playing video, accounts for another 22 percent. Sandvine, "Global Internet Phenomena: Africa, Middle East & North America" (Waterloo, Canada: Sandvine, December 2015), https://www.sandvine.com/downloads/general/global-internet-phenomena/2015/global-internet-phenomena-africa-middle-east-and-north-america.pdf.
4. Gartner Newsroom, "Press Release: Gartner Says 6.4 Billion Connected 'Things' Will Be in Use in 2016, Up 30 Percent From 2015" (November 2015) http://www.gartner.com/newsroom/id/3165317.
5. Ericsson Mobility Report.
6. There are versions of the LTE specification that are designed for machine-to-machine communications, like the portion of the LTE specification designed for IoT-like user equipment known as LTE (CAT 1), and IoT focused "narrow band" LTE technologies are being developed. Again, this is another area where LTE has significant life left.
7. Narrow-Band IoT (NB-IoT), being quickly standardized by 3GPP, is a resource-efficient narrow band support for low-cost, low-power devices. It can be deployed "in-band," utilizing resource blocks within a normal LTE carrier, or in the unused resource blocks within a LTE carrier's guard-band, or "standalone" for deployments in dedicated spectrum. *See* NarrowBand IOT, *3GPP* (September 2015) http://www.3gpp.org/news-events/3gpp-news/1733-niot.
8. For example, every pair of GEnx engines, which are installed on Boeing's new 787 Dreamliner, generate a terabyte of information every day. *See* Jon Gertner, "Behind GE's Vision For The Industrial Internet Of Things," *Fast Company* (June 2014), http://www.fastcompany.com/3031272/can-jeff-immelt-really-make-the-world-1-better.
9. *See* Renee Meiller, "Fast, Stretchy Circuits Could Yield New Wave of Wearable Electronics," *University of Wisconsin-Madison News* (May 2016), http://news.wisc.edu/fast-stretchy-circuits-could-yield-new-wave-of-wearable-electronics/.
10. ABI Research estimates by 2025, there will be 67 million automotive 5G subscriptions, three million of which will be for autonomous vehicles. ABI Research, "5G to be Unifying Connectivity Technology for Future Cars; To Enable V2X Communication" (June 2016), https://www.abiresearch.com/press/5g-be-unifying-connectivity-technology-future-cars/.
11. It is not yet clear to what extent critical safety features of V2V communications will be handled by 5G or a more purpose-built technology, such as Dedicated Short Range Communications (DSRC).
12. ITU G.114 specification recommends less than 150 millisecond (ms) one-way end-to-end delay for high-quality real-time traffic such as voice.
13. "The Tactile Internet," (ITU-T Technology Watch Report, August 2014), http://www.itu.int/dms_pub/itu-t/oth/23/01/T23010000230001PDFE.pdf.
14. Most notably in the 60 GHz band. Note this is both a blessing and a curse, severely limiting propagation, while also allowing reducing the risk of harmful interference through geographic re-use.

15. *See, e.g.,* Theodore S. Rappaport, *et. al*, "Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!" *IEEE Access* (2013), http://faculty.poly.edu/~tsr/Publications/IEEE_ACCESS_May_30_2013_mmWave_Wireless_it_will_work.pdf.
16. Satellite users operate in the 28, 37, and 39 GHz bands.
17. Other technologies in various stages of development include so-called "Cloud RAN," which moves baseband processing of multiple base-station antennas to a central location for a cluster of small cells; device-to-device communications, allowing direct communication between user devices; full duplex, which would allow for simultaneous transmission and reception; and new radio interface technologies, which generally fall into the standards setting process.
18. This is one example of many aspects of the LTE-Advanced spec that remain to be put to use. Others include network MIMO, coordinated scheduling, coordinated multipoint, and enhanced inter-cell interference coordination. Some of these technologies require the rest of ecosystem—base stations and user equipment—to implement the technology as well.
19. *See* Bernie Arnason, "Will 5G Enable Wireless Replacement of Home Broadband and Disrupt FTTH?," *Telecompetitor*, http://www.telecompetitor.com/will-5g-enable-wireless-replacement-home-broadband-disrupt-ftth/.
20. *See* "ZTE Wins Global Mobile Award for Pre5G Massive MIMO at MWC 2016," *Business Wire* (February 2016), http://www.businesswire.com/news/home/20160223006389/en/ZTE-Wins-Global-Mobile-Award-Pre5G-Massive.
21. Namely in the context of the debate over LTE use in unlicensed spectrum.
22. This is one reason that expectations around smartphone portability from network to network does more harm than good.
23. *See* "ITU towards "IMT for 2020 and beyond"
24. *Ibid.*
25. Dino Flore and Balazs Bertenyi, "Tentative 3GPP Timeline for 5G," (March 2015) http://www.3gpp.org/news-events/3gpp-news/1674-timeline_5g.
26. Shu Sun *et al.*, "Investigation of Prediction Accuracy, Sensitivity, and Parameter Stability of Large-Scale Propagation Path Loss Models for 5G Wireless Communications," *IEEE Transactions on Vehicular Technology 65*, no. 5 (May 2016), 2843, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7434656&tag=1.
27. *See* "About Us: Vision and Mission" *5G PPP* , https://5g-ppp.eu/about-us/.
28. Remarks of FCC Chairman Tom Wheeler "The Future of Wireless: A Vision for U.S. Leadership in a 5G World," National Press Club, Washington, DC. (June 2016) http://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db0620/DOC-339920A1.pdf.
29. Stephen J. Ezell & Robert D. Atkinson, "The Middle Kingdom Galapagos Island Syndrome: The Cul-De-Sac of Chinese Technology Standards," *Information Technology and Innovation Foundation* (December 2014), http://www2.itif.org/2014-galapagos-chinese-ict.pdf?_ga=1.259942083.812486504.1449157248.
30. Arthur D. Little & Bell Labs, "Reshaping the Future with NFV and SDN, May 2015, http://www.adlittle.com/downloads/tx_adlreports/ADL_BellLabs_2015_Reshapingthefuture.pdf.
31. In this context, the FCC's special access proceeding is particularly salient, as this regulated service may play a role in backhaul provision.
32. Signals Research Group, "Lessons Learned from the Three Little Pigs," *Signals Flash*, May 9, 2016.
33. FCC "In the Matter of Use of Spectrum Bands Above 24 GHz for Mobile Radio Services: Notice of Proposed Rulemaking," GN Docket No. 14-177 (Oct. 2015) https://apps.fcc.gov/edocs_public/attachmatch/FCC-15-138A1.pdf.
34. FCC Fact Sheet: Spectrum Frontiers Proposal to Identify, Open Up Vast Amounts of New High-Band Spectrum for Next Generation (5G) Wireless Broadband, *FCC* (June 23, 2016), http://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db0623/DOC-339990A1.pdf.

35. *Ibid.*

36. *For discussion, see* Michael O'Rielly, "2015 World Radiocommunication Conference: A Troubling Direction," *FCC Blog* (January 2016), https://www.fcc.gov/news-events/blog/2016/01/15/2015-world-radiocommunication-conference-troubling-direction.

37. Doug Brake, "Spectrum Policy and the EU Digital Single Market: Lessons from the United States," *Information Technology and Innovation Foundation* (December 2015), http://www2.itif.org/2015-eu-spectrum-policy.pdf.

38. *For discussion, see* Ian Corden and Tim Miller, "All Change: How 5G Will Shake Up Spectrum Management," *Plum Consulting* (June 2016).

39. Implementation of Section 224 of the Act, Report and Order and Order on Reconsideration, 26 FCC Rcd 5240 (2011); updated last year with Implementation of Section 224 of the Act, Order on Reconsideration, 30 FCC Rcd 13731 (2015).

40. *See* CTIA, "Enabling the Wireless Networks of Tomorrow: Rules of the Road for Pole Attachments in States Across America," *CTIA* (April 2016), http://www.ctia.org/docs/default-source/default-document-library/enabling-the-wireless-networks-of-tomorrow.pdf.

41. Joseph Schumpeter, *Capitalism, Socialism and Democracy* (New York, 1942), 117-118.

42. James Clerk Maxwell had first theorized the existence of spectrum with the publication of *A Dynamical Theory of the Electromagnetic Field* in 1865. Heinrich Hertz—the namesake of the scientific unit of frequency, the "hertz"—would prove the effects of Maxwell's predictions in a series of experiments from 1886 to 1889. Guglielmo Marconi—credited with the invention of the radio—would build on these achievements. His commercialization of his invention started in 1897 with the founding of The Wireless Telegraph & Signal Company.

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44. "Cisco Visual Networking Index (VNI)," Cisco, accessed December 2015, http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html.

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46. *Ibid*.

47. *Ibid*.

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ACKNOWLEDGMENTS

The author would like to thank The Aspen Institute Communications and Society Program and the participants of the 2015 roundtable on spectrum policy for discussions that greatly assisted in the production of this report. Errors and omissions are the author's alone.

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