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Mobile Technology and Spectrum Policy: Innovation and Competition

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July 18, 2014

Congressional Research Service
7-5700
www.crs.gov
R43595

CRS REPORT
Prepared for Members and
Committees of Congress

Summary

The convergence of Internet and mobile technologies has, within the last decade, transformed wireless communications and created a dynamo of innovation and economic growth. The list of applications that enable products and provide services through smart wireless devices is long and growing rapidly as new industries incorporate wireless technologies into their products. Wireless and mobile telecommunications products include not only smart phones and tablets but also utility meters, road traffic sensors, robots, autonomous vehicles, unmanned aerial systems, tractors, and household appliances, to cite but a few examples of existing and new technologies that are widely predicted to bring about profound changes in how Americans work and play. The composition of the wireless telecommunications industry is changing as companies with important stakes in spectrum-dependent technologies move from innovation to implementation.

The arrival of these technologies is accompanied by a crowd of policy questions covering issues such as employment, training, education, privacy, cybersecurity, and research and development. This report focuses on the interaction between technological change and spectrum policy, and how the accelerating pace of change may require a timely transition to new spectrum policies. Emerging technologies may require, or work better with, new network concepts to carry wireless transmissions over distances long or short. The arrival of new products, new services, and new concepts in network design may lead to the introduction of new models of competition and investment that might benefit from new spectrum policies. Spectrum policy today focuses on the expansion of commercial broadband with the goal of continuing recent growth trends attributed to the mobile Internet. Expanding policy to more fully include other technologies—including those being developed for the Fifth Generation (5G) of wireless communications—might advance a new telecommunications environment with greater potential for spurring innovation, competition, and economic growth than what has been observed in recent years.

This report traces the current and possible future evolution of mobile communications networks and some of the changes in spectrum policy that might better accommodate innovation. Congress at present is engaged in debates over how to maximize the value—economic, monetary, or other—of upcoming auctions for spectrum licenses, notably the Broadcast Incentive Auction. The evolution of wireless technologies, as outlined in this report, indicates that auctions, as presently structured, are a limited policy tool. Congress, therefore, may move to reconsider the current goals of spectrum policy to more fully accommodate the development of the next generation of wireless technologies. In future reviews of communications law and spectrum policy, Congress may choose to broaden its scope to include spectrum-dependent industries and technologies beyond the telecommunications sector.

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Economic Growth, Innovation, and Demand for Radio Frequency Spectrum

By most measures the United States leads the world in the deployment of mobile broadband technology[1]—networks, devices, applications, products and services—creating a mini-boom of innovation and entrepreneurship, and associated wealth and jobs.[2] Innovations in mobile broadband use the Internet Protocol (IP) to bring new devices, applications and technologies to the airwaves. Cellular Long Term Evolution (LTE) and WiFi are key standards that provide mobile broadband access to the Internet and IP-enabled networks.

Projections of significant growth in demand for mobile broadband—and, hence, for spectrum capacity—have prompted numerous policy initiatives to identify radio frequencies that can be made available for commercial mobile broadband services. Finding additional spectrum for commercial mobile broadband has been a goal for both the Administration and Congress. The Federal Communications Commission (FCC)—which manages radio frequency spectrum for commercial and other non-federal uses—and the National Telecommunications and Information Administration (NTIA)—which represents federal government users—are addressing some regulatory and policy issues, such as those identified in the National Broadband Plan (NBP).[3] For example, the NBP cited spectrum capacity as a critical input for expansion of mobile broadband and set a goal of providing 500 MHz of additional spectrum by 2020, to support expected growth. President Barack Obama issued a Presidential Memorandum[4] in support of the NBP's spectrum goals and, among other actions, instructed the NTIA to work with the FCC in identifying spectrum used by federal agencies to transfer to the commercial sector.[5]

The 112th Congress addressed some of the issues of spectrum allocation and assignment in the Middle Class Tax Relief and Job Creation Act of 2012 (P.L. 112-96, Title VI, "Spectrum Act").[6] The primary intent of the spectrum-clearing provisions of the act appears to be to increase the number of exclusive-use spectrum licenses for mobile broadband coverage. Among its provisions, the Spectrum Act included mechanisms to reassign television broadcast spectrum (Broadcast Incentive Auction) for licenses to be auctioned, and to transfer spectrum assets from federal to commercial use.

[1] Broadband delivers large amounts of data at high speeds. The IP-technology currently being deployed for broadband is Long Term Evolution (LTE), which is categorized as a fourth-generation (4G) wireless technology. Substantial new investments for deployment of the next version of LTE, known as LTE Advanced, are expected to occur in the United States in 2014. Information about LTE, at http://www.4gamericas.org/index.cfm?fuseaction=page&sectionid=249; about LTE Advanced, at http://www.4gamericas.org/index.cfm?fuseaction=page&sectionid=352.

[2] The White House, Office of Science and Technology Policy & The National Economic Council, *Four Years of Broadband Growth*, June 2013.

[3] Federal Communications Commission, *Connecting America: The National Broadband Plan*, March 17, 2010, http://download.broadband.gov/plan/national-broadband-plan.pdf.

[4] Presidential Memorandum: Unleashing the Wireless Broadband Revolution, June 28, 2010.

[5] Key NTIA actions are discussed in CRS Report R42886, *The National Telecommunications and Information Administration (NTIA): Issues for the 113th Congress*, by Linda K. Moore.

[6] Key provisions in the act are discussed in CRS Report R43256, *Spectrum Policy: Provisions in the 2012 Spectrum Act*, by Linda K. Moore.

The act also addressed the need for unlicensed spectrum, heavily used for WiFi communications, among other applications. It included allowances for unlicensed spectrum in planning for repurposed broadcast spectrum, and called for the release of spectrum in the 5 GHz band for unlicensed use. Many of the frequencies at 5 GHz are currently allocated for federal use.

As new wireless technologies are introduced and perfected, access to spectrum capacity is becoming essential to doing business and to life-style choices. Debates within Congress regarding spectrum policy cover a wide range of concerns, such as competition, economic growth, access to wireless services, affordability, and opportunities for new entrants. Much of the debate appears based on assumptions about wireless technology and spectrum demand and capacity that may not fully recognize the ever-accelerating pace of technological innovation. Current spectrum policy, for example, supports high-speed downloads of movies to smart phones but not a future driverless vehicle as it moves across the country.

Policy goals that focus on supporting commercial mobile broadband may favor commercial wireless carriers at the expense of other industry sectors that will require spectrum for future growth. Policy makers largely recognize the need to strike a balance between meeting immediate needs to sustain growth for mobile broadband and finding solutions to support future growth in other wireless technologies, such as those discussed below and in the **Appendix**. Nonetheless, there appears to be a significant and widening gap between what emerging wireless technologies require and current spectrum policy delivers. Faced with this apparent policy vacuum, the 113th Congress has posed the question of what changes may be required in order to provide sufficient spectrum capacity for the future.[7]

Future questions from Congress may introduce a wide-based discussion about established goals for competition and access,[8] and about the demands on spectrum capacity made by new technologies.[9] In addition to mobile broadband, many other technologies that promise substantial growth through innovation also require access to spectrum. Policy makers may choose to explore how spectrum policy can support sustainable innovation and growth in emerging wireless technologies through better management of spectrum resources. Policy makers involved in the debate on spectrum policy may wish to see Congress take a leadership role in identifying the changes in law, regulation, and policy that are needed to fuel broad-based growth of wireless

[7] U.S. House of Representatives, Committee on Energy and Commerce, Subcommittee on Communications and Technology, Background Memos and Hearings:, "Equipping Carriers and Agencies in the Wireless Era," June 27, 2013; "Challenges and Opportunities in the 5GHz Spectrum Band," November 13, 2013; and "Oversight of the Federal Communications Commission, May 20, 2014. Also, U.S. Senate, Committee on Commerce, Science, and Transportation, Subcommittee on Communications, Technology, and the Internet, Hearing, "The State of Wireless Communications," June 4, 2013. The Committee of Energy and Commerce has issued a white paper entitled "Modernizing U.S. Spectrum Policy," which lays out a series of questions about spectrum policy that Congress may act to address, April 1, 2014; link at http://energycommerce.house.gov/press-release/committee-releases-commactupdate-white-paper-focused-spectrum-policy.

[8] The Omnibus Budget Reconciliation Act of 1993 (P.L. 103-66) amended the Communications Act of 1934 with a number of important provisions affecting the availability of spectrum. The act laid out the general requirements for the FCC to establish a competitive bidding methodology and consider, in the process, objectives such as the development and rapid deployment of new technologies. (47 U.S.C. §309 (j), especially (1), (3), and (4).) The law prohibited the FCC from making spectrum allocation decisions based "solely or predominately on the expectation of Federal revenues. " (47 U.S.C. §309 (j) (7) (A).)

[9] U.S. House of Representatives, Committee on Small Business, hearing, "Building on the Wireless Revolution: Opportunities and Barriers for Small Firms," February 11, 2014.

technologies. Others may prefer a minimal role for Congress and greater latitude for market forces to resolve the challenges presented by new technology.

Spectrum-Dependent Industries

A May 2013 study by McKinsey & Company[10] identified a dozen "disruptive technologies" and the industries that are likely to significantly change the ways that people and businesses organize their work and personal life styles. At least five of the technologies identified in the report (McKinsey report) are dependent on licensed and unlicensed spectrum to be fully functional. These technologies and others offer opportunities for economic expansion but often bring with them shifts in demand for human capital, unmet needs for new skills, challenges to security and privacy, and other changes that may need to be addressed with new public policies. Similarly, new policies and regulations may be needed to make room for innovation, while equitably preserving the value of existing infrastructure, where possible.

One of the impacts of disruptive technologies is on business models: new ways of business flourish and old business practices wither. The Internet is an example of a disruptive technology. Its impact is far-reaching and still growing. One of the early impacts of the Internet was to change and eventually diminish the role of proprietary network technologies. Business plans that were built on attaining market share through control of a superior proprietary network were eroded or made obsolete. Today, some maturing companies that built business plans on expectations of how the Internet would be deployed are faced with accommodating shifts in market demand from the wired Internet to the mobile Internet.[11] Today, the IP standard developed for the wired Internet is being incorporated into mobile network standards; tomorrow, a new standard for the mobile Internet may emerge, setting off a new cycle of technological innovation and infrastructure investment.[12]

In the McKinsey report, technologies were evaluated according to projected increases in growth, globally. Based on the report, categories of disruptive technologies that offer significant opportunities for growth, and are dependent on access for spectrum to achieve much of that growth, are

- Mobile Internet: mobile broadband devices that access the Internet;
- Cloud technology: access to off-site computing and other information-based capabilities;
- Internet of Things: the interconnection of electronic and mechanical devices through the Internet, also known as the Internet of Everything;

[10] McKinsey Global Institute, *Disruptive Technologies: Advances that will transform life, business and the global economy*, May 2013, available at http://www.mckinsey.com/insights/business_technology/disruptive_technologies. Note that projections are for global growth and may not accurately represent a technology's role in the U.S. economy.

[11] See, for example, "A Bruising Fight for Survival; mobbed by mobile devices, big players in PCs struggle to adapt," by Nick Wingfield, *The New York Times*, July 29, 2013.

[12] See, for example, "DARPA Seeks Clean-Slate Ideas for Mobile Ad Hoc Networks (MANETS)," DARPA, April 30, 2013 at http://www.darpa.mil/NewsEvents/Releases/2013/04/30.aspx; National Science Foundation Future Internet Project http://www.nets-fia.net/ and Named Data Networking http://named-data.net/.

- Advanced robotics: high-level robots that equal or exceed human abilities to perform tasks; and
- Autonomous and near-autonomous vehicles: any vehicle, land-based, airborne, or maritime, that moves with little or no human intervention.

In addition, other industry sectors cited by the McKinsey report as affected by disruptive technologies may also rely in part on wireless technology; for example, the electric power grid requires wireless communications to manage information about demand and usage; and gas and oil exploration and production use wireless sensors.

A summary of the McKinsey report discussion of selected disruptive technologies appears in the **Appendix**.

Although not all-inclusive, the list indicates the wide range of spectrum-dependent technologies and the critical role they may play in economic growth. A number of these technologies were originally developed by the Defense Advanced Research Project (DARPA).

Other than the mobile Internet, the McKinsey report did not explore the dependence of these technologies on wireless communications, or discuss their need for spectrum capacity. Broadband for the mobile Internet may be an essential part of mobile technology but, in the long run, its future development may have less impact on U.S. economic growth and productivity than mobile technologies used to support emerging technologies, such as those described, by McKinsey, as disruptive.

The benefits of innovation are rarely evenly distributed. There are often unintended consequences and some sectors of society and the economy may suffer harm. Therefore not everyone will agree that some of the disruptive technologies discussed by McKinsey and in this report should be nurtured. The focus of this report is the value of spectrum access to a broad range of industries beyond the traditional telecommunications field. Spectrum policy may inadvertently restrict that access, thereby creating a de facto industrial policy without full consideration of the value of the affected industries and their ability to innovate.

Innovation and Transition

Disruptive technologies, by their nature, lead to additional innovation, new markets, new business models, new forms of competition, new investment opportunities, and other changes. Innovation and entrepreneurship may be curtailed if regulatory policies favor one technology, one market, or one business model, over others. Consistent regulatory policies, however, tend to be beneficial for existing businesses and investors to the extent that they provide certainty and establish parameters for doing business. There are challenges in making the transition to new policies just as there are challenges in making the transition from one technology to another. In the case of wireless technology, successive introductions of new technology in general build on past investments in infrastructure.

Current Environment

Key factors that—separately or together—may shape current policy decisions and regulations regarding spectrum access include (1) high demand for spectrum access; (2) competitive benefits

from economies of scale for wireless carriers; (3) standardization; and (4) global harmonization of spectrum allocation.

Access to Radio Frequency Spectrum

Spectrum bands have typically been allocated for a type of use, such as television broadcasting or Advanced Wireless Services (AWS), and assigned through licensing. Most commercial license assignments in the United States are now done through the auction of licenses for exclusive ownership, which conveys the right to exclusive use, although license-holders may sublet access to their holdings. Some spectrum is allocated for unlicensed use, which permits access through certification of specific devices and the enforcement of regulations limiting interference among users. Unlicensed spectrum is shared by approved devices, with access determined largely by the type of device in use. Access to licensed spectrum may also be shared. One common model for sharing today is for two or more commercial license-holders to reach a contractual agreement to share. Another common model is for federal users to permit commercial access to its assigned frequencies, often on a geographic basis (access to some areas) and/or a time basis (certain times of a day or specific days). In these shared environments, access is dependent, in part, on permission by the primary user or license-holder.

Economies of Scale

The current environment for commercial mobile network expansion appears to favor continued investment by large, often global, carriers, in LTE and LTE Advanced network infrastructure. Regulatory policy assumes that wireless communications deployments benefit from economies of scale, because of required investments in technology-driven infrastructure, among other causes. For example, U.S. wireless carriers reportedly spent over $34 billion on their networks in 2013.[13] Much of this was spent on what is sometimes referred to as the macro network, that is, the typical configuration of cell towers and base stations, linked above ground by wireless microwave transmissions and below ground by fiber-optic networks. The macro network facilitates nationwide wireless coverage. The high costs and difficulties in raising capital to cover these investments may place smaller carriers at a competitive disadvantage.[14] Furthermore, the high cost of entry may discourage new competitors. Not including the price of purchasing spectrum licenses, billions of dollars are required to build new infrastructure. The sunk costs of incumbent wireless service providers therefore set a high bar for new entrants if they are to compete effectively in major markets. Furthermore, existing wireless carriers with substantial investments in infrastructure and large customer bases are generally prepared to pay more at auction than high-risk new ventures, reinforcing barriers to new entrants.

Standards

Industry standards provide numerous benefits such as improved interoperability of systems and equipment, lower manufacturing costs, and greater ease-of-use for consumers. Standards may also be established by one industry group at the expense of other groups that may not have been

[13] Testimony of Randal S. Milch, Executive Vice President and General Counsel, Verizon Communications Inc., U.S. Senate, Committee on the Judiciary, Subcommittee on Antitrust, Competition Policy, and Consumer Rights, "An Examination of Competition in the Wireless Market," February 26, 2014.

[14] Thomas Gryta, "U.S. Cellular, NTELOS in Focus After Leap Wireless Buy," *Wall Street Journal*, July 15, 2013.

active participants in the standards development process. Wireless standards adopted by market leaders for mobile broadband may place smaller rivals at a competitive disadvantage, or preclude innovation and growth in other industries.[15]

Regulators and policy makers may rely on standards-setting groups to provide technical frameworks for regulations and policy goals. Standards may be reproduced in rules and regulations—such as rules established by the FCC for spectrum license auctions—that some stake-holders view as perpetuating existing business models to the possible disadvantage of new entrants with different business models.[16]

In the United States, the two sets of standards most used for new wireless broadband technologies are cellular LTE, for licensed spectrum, and IEEE (Institute of Electrical and Electronics Engineers) 802.11, for unlicensed spectrum. There are additional IEEE standards for Wide Area Networks. An LTE standard has been developed to operate on unlicensed spectrum (LTE-U).

The main standards-setting body for LTE/LTE Advanced is the Third Generation Partnership Project (3GPP).[17] Standards organizations represented through members of 3GPP are the European Telecommunications Standards Institute (ETSI),[18] the Alliance for Telecommunications Industry Standards (ATIS),[19] and several Asian standards groups.[20]

Policy decisions about unlicensed spectrum are generally centered on providing additional capacity for channels used for WiFi. Standards for WiFi are developed by the IEEE 802.11 Working Group and supported by the Wi-Fi Alliance.[21] Activities of the Alliance, an industry association, include support of industry standards, certification of devices, and development of new product specifications. The 802.11suite of standards includes 802.11.a, the original WiFi standard for operations at 5 GHz and 802.11b, designated for WiFi at 2.4 Ghz. New spectrum

[15] For example, 3GPP created separate standards for two band classes in the 700 MHz band. After Auction 73, for commercial licenses in the 700 MHz band, small carriers were concentrated in a less-favored band class in the lower half of the 700 MHz band. These carriers complained to the FCC that manufacturers were not providing devices for their band class because of the limited size of the market. They requested the FCC to mandate interoperability across all band plans in the lower 700 MHz band. Among the countervailing arguments against interoperability was that it would undermine future investments in 3GPP standards. An agreement was reached for a voluntary industry solution. In October 2013, the FCC adopted a Report and Order and Order of Proposed Modification to implement the agreement, http://www.fcc.gov/document/700-mhz-interoperability.

[16] For example, public comments regarding service rules for spectrum licenses in the 700 MHz band that were auctioned in 2008 (Auction 73) revealed significant differences between wireless carriers and the wireless technology industry. The latter argued—with little success—for rules that would increase spectrum access for new entrants and new businesses.

[17] Information about 3GPP is at http://www.3gpp.org/about-3gpp. 3GPP is represented in the United States by 4G Americas, http://www.4gamericas.org/index.cfm?fuseaction=home. The mission of 4G Americas is "to promote, facilitate and advocate for the deployment and adoption of the 3GPP family of technologies" and "to develop the expansive wireless ecosystem of networks, devices, and applications enabled by GSM and its evolution to LTE."

[18] Information about ETSI at http://www.etsi.org/about/introduction.

[19] ATIS and the Telecommunications Industry Association (TIA) are global standards development groups based in the United States. Information about ATIS at http://www.atis.org/. Information about TIA at http://www.tiaonline.org/about/.

[20] About 70% of the approximately 400 members of 3GPP are represented as members of ETSI. ATIS represents about 8% of members, including the top four U.S. wireless carriers. The balance of members are represented through Asian standards groups. See http://www.3gpp.org/about-3gpp/membership.

[21] Information about the Wi-Fi Alliance at http://www.wi-fi.org/.

assignments are being sought within the 5 GHz range[22] for the expansion of 802.11.ac VHT (Very High Transmission), sometimes known as Gigabit WiFi.[23] Spectrum that has been made available for WiFi on TV White Spaces is accessed by 802.11.af, sometimes referred to as White-Fi. Gigabit WiFi , White-Fi, and other new standards use technologies that can identify locations of users to manage transmissions without causing interference. These standards, which are sometimes referred to as Fifth-Generation Wi-Fi, are important building blocks in developing new forms of sharing, such as between federal and commercial network operators.

Harmonization

Harmonization refers to the allocation of spectrum across national borders. Compatible designations for using spectrum facilitate economies of scale in designing and producing wireless devices. Harmonization also facilitates cross-border travel and trade, among other benefits. The global champion for harmonization is the International Telecommunications Union (ITU), the lead United Nations agency for information and communications technologies.[24] ETSI, 3GPP, and the GSM Association[25] are among the groups that work closely with the ITU in developing standards to harmonize spectrum for mobile broadband. Agreements on international harmonization are typically negotiated as treaties under the auspices of periodic World Radio Conferences (WRC),[26] supported by the ITU. There are over 30 spectrum harmonization proposals currently under consideration by the WRC. Many of these proposals would require repurposing spectrum band allocations to accommodate mobile broadband.

Proposals for harmonization and coordination of spectrum access are also being developed by national and international groups for wireless technologies for machine-to-machine communications; robotics; maritime, terrestrial and aerial unmanned vehicles; cloud computing; and other emerging technologies.[27]

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[22] As required by the Spectrum Act, the FCC commenced a proceeding to identify new unlicensed spectrum capacity at 5 GHz, http://www.fcc.gov/document/5-ghz-unlicensed-spectrum-unii. See also CRS Report R43256, *Spectrum Policy: Provisions in the 2012 Spectrum Act*, by Linda K. Moore.

[23] Using the International Electrical and Electronic Engineers standard, IEEE 802.11ac, see http://www.ieee.org/index.html. Also, link to tutorial at http://www.radio-electronics.com/info/wireless/wi-fi/ieee-802-11ac-gigabit.php.

[24] See http://www.itu.int/en/about/Pages/default.aspx. The Government Accountability Office notes that "The federal government considers ITU the principal, competent, and appropriate international organization for the purpose of formulating international treaties and understandings regarding certain telecommunications matters*." Better Coordination and Enhanced Accountability Needed to Improve Spectrum Management*, GAO-02-906, September 2003, p. 19, fn. 26.

[25] The standards developed by the Groupe Special Mobile (GSM) were first adopted by European Union member countries; deployment began in 1998. The GSMA global membership is comprised of GSM and LTE network operators; http://www.gsma.com/aboutus/history.

[26] The next WRC, WRC-2015, is scheduled to occur in November 2015; http://www.itu.int/en/ITU-R/conferences/wrc/2015/Pages/default.aspx. Separate tracks of preparations to develop the U.S. positions on WRC agenda items are handled by the FCC and the NTIA. The Office of Spectrum Management of NTIA, in consultation with federal agencies, reviews the WRC agenda and prepares its comments for the U.S. position. NTIA and the FCC solicit input from the private sector and create working groups to address specific agenda items. NTIA and the FCC submit recommendations to the Department of State. The Department of State coordinates and mediates the development of the U. S. position for each WRC and leads the U.S. delegation at each conference. sector.

[27] For some examples, see http://ec.europa.eu/digital-agenda/en/rspp-roadmap-wireless-europeand http://ec.europa.eu/digital-agenda/.

One aspect of harmonization that may be an issue is that requirements for standards may be part of the agreement. For mobile technologies, there appears to be an inclination to make LTE the default standard for harmonized frequencies. Also, harmonization of unlicensed spectrum has proved difficult to negotiate in international discussions. The global trend, therefore, might be described as harmonization for licensed spectrum assigned exclusively to network operators using LTE/LTE Advanced standards.

Transition

As wireless carriers increase their deployment of the mobile Internet, delivered by broadband LTE technologies, new trends are developing in network design and investment strategies. The development of and constant improvements in small cell technologies[28] have enabled the deployment of Heterogeneous Networks, or HetNets. In an LTE environment, a HetNet is viewed as an extension of LTE network concepts and standards. HetNets combine macro and micro infrastructure to increase the reach of wireless transmissions. The macro network is a high-site cellular network, operating on dedicated spectrum, and relying on fixed infrastructure such as towers and masts. The micro network is composed of multiple placements of low-site small cells.[29] These micro networks operate on licensed or unlicensed spectrum. Wireless carriers are investing in sites for small cell installations in order to increase network capacity, and building out micro networks to supplement or possibly replace investment in more capital-intensive macro networks. Within the LTE/LTE Advanced technology development envelope, many industry experts predict a shift in investment from building macro networks to building micro networks.[30]

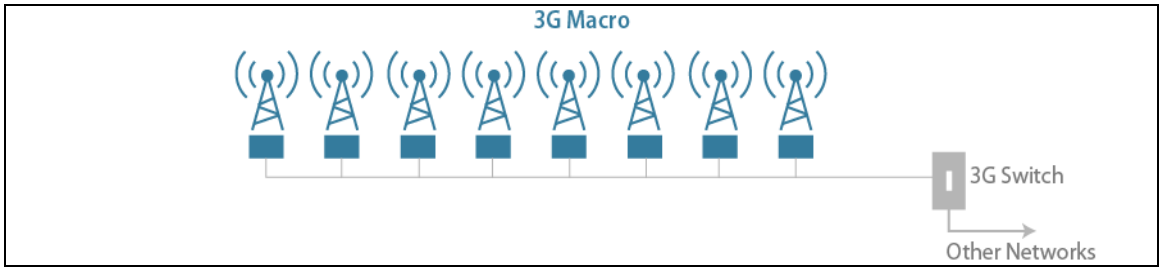
Figure 1 depicts a built-out Third-Generation (3G) macro network. Its primary physical components are antennas for transmitting and receiving wireless signals—placed on towers, tall buildings or other structures—and base stations for connecting to other communications networks, such as the Public Switched Telephone Network and the Internet. Investment in towers and base stations is critical to providing coverage and ubiquitous service to geographic areas that, typically, correspond to spectrum licenses for exclusive use.

[28] Small cells are low-powered radio access nodes that are used to boost capacity and manage network interference and connectivity. The types of small cells are Femtocells, typically used in a home; Picocells, that may serve a business; Metrocells, for urban areas; and Microcells, the largest in terms of geographic coverage, used primarily in rural areas.

[29] High site refers to antenna placed on cell towers or other tall structures, to maximize coverage in a large geographic area. Low site indicates that the placement of antennas for small cells is not dependent on height to provide coverage.

[30] A projection of capital expenditures prepared by Mobile Experts shows investment in macro networks plateauing in 2014 and then trending downward while investment in small cell infrastructure continues to rise. The data might be interpreted to indicate that the trend lines will cross as early as 2020. “Mobile Infrastructure Trends,” May 2014.

Figure 1. 3G-Macro Network



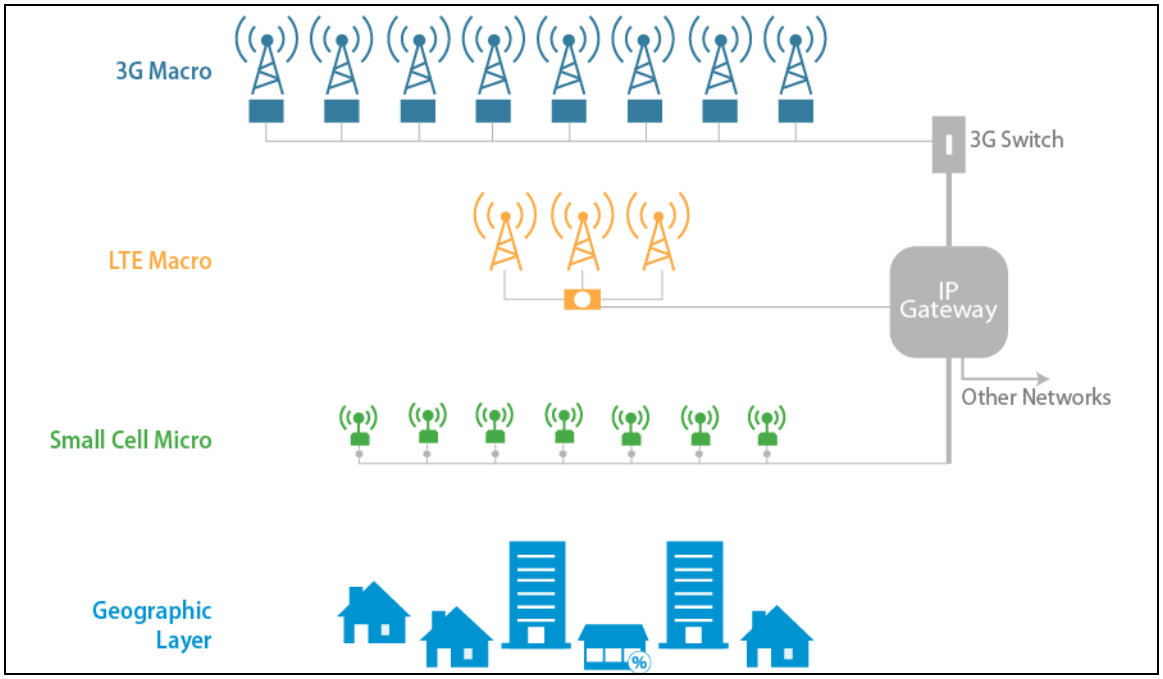
Source: Peter Rysavy research for 4G Americas, *Mobile Broadband Explosion; the 3GPP Wireless Evolution*, August 2013, Figure 57, p. 117, http://www.rysavy.com/Articles/2013-08-4G-Americas-Mobile-Broadband-Explosion.pdf.

Figure 2 shows an example of a HetNet composed of a partly-built LTE network bolstered by a micro network of small cells being used as a bridge between 3G infrastructure and LTE towers. The micro network, for the most part, connects to the infrastructure that supports the macro network base stations.

In this simplified schematic, the 3G macro layer switch connects to the Internet and other networks through the IP gateway serving the 4G macro and micro layers. The 4G macro base stations and small cell locations are all IP-enabled.

The geographic layer represents the communities served by the HetNet. A HetNet build-out typically uses spectrum licensed to the carrier to carry traffic over both macro towers and small cell placements. Additional capacity is provided by WiFi. The LTE micro network serves many of the same customers in the geographic layer as Wide Area Networks (WAN) using IEEE 802.11 (WiFi/WAN).

Figure 2. LTE Heterogeneous Network



Source: Peter Rysavy research for 4G Americas, *Mobile Broadband Explosion; the 3GPP Wireless Evolution*, August 2013, Figure 57, p. 117, http://www.rysavy.com/Articles/2013-08-4G-Americas-Mobile-Broadband-Explosion.pdf.

This depiction of a HetNet configuration assumes that LTE will become the predominate technology for micro networks, using both licensed and unlicensed spectrum. The effectiveness of the HetNet in linking macro and micro network infrastructure depends in part on the proximity of IP-enabled network nodes.

The key elements of the network architecture are

- LTE macro network, which would typically be considered the transport network;
- Network interfaces such as the IP gateways;
- Micro network, which increases capacity and coverage; and
- End users and their devices, residing in the geographic layer.

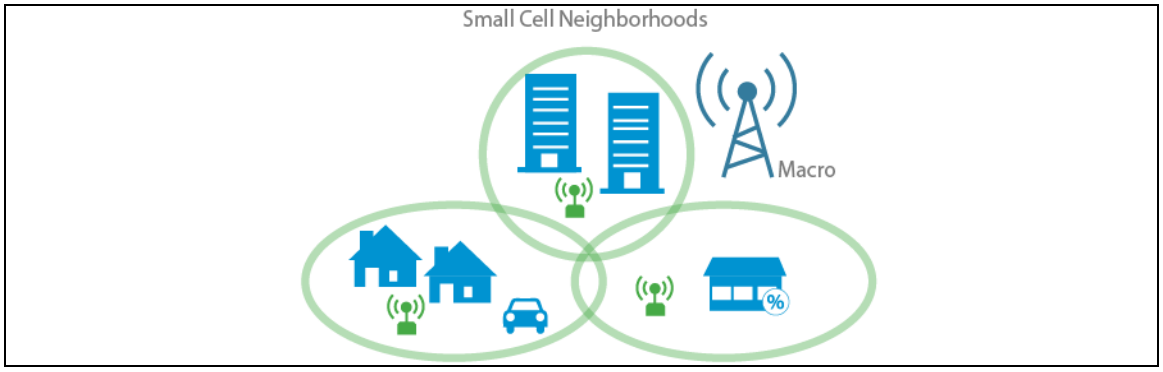
The macro network provides coverage and the micro network provides capacity as well as extra coverage. In urban areas, a HetNet may carry as much as 80% of its traffic over unlicensed WiFi. In the macro network, the geographic layer corresponds roughly to license coverage as designated by the FCC. Micro networks operate within geographic areas that are smaller in coverage than the licenses assigned for 3G and 4G build-outs.

Innovation

In the future, micro networks may use spectrum licensed for their purpose, and the coverage areas for these licenses may correspond to small cell neighborhoods. A possible trend in the evolution of mobile networks is depicted in **Figure 3**. In this configuration, the micro network has become the predominate provider of mobile communications coverage and capacity through contiguous small cell networks. The towers of the macro network enhance connectivity and provide additional coverage. Micro networks for small cell neighborhoods exist within or are independent of HetNets. Small cell networks are by and large autonomous, providing coverage for their area and connecting to other small cell networks or cellular towers when needed. Such a configuration might lead to widespread spectrum sharing.

The transition from macro to small cell networks as the main providers of wireless capacity would change the dynamic of spectrum demand. Low-frequency, wide coverage, high-site cellular networks that require exclusive licenses for efficient operation would no longer be the drivers of growth and change. A backbone of cellular towers would remain to serve the ever-growing, ever-changing micro networks that are more agile and more responsive to the needs of a wide range of wireless customers.

Figure 3. Small Cell Neighborhood Micro Network



Source: 4G Americas, *Meeting the 100X Challenge: The Need for Spectrum, Technology and Policy Innovation,* October 2013, Figure AI-1, p. 130, http://www.4gamericas.org/documents/2013_4G%20Americas%20Meeting%20the%201000x%20Challenge%2010%204%2013_FINAL.pdf.

As the network becomes decentralized, with more traffic carried through localized small cell networks, the towers of the macro network might be used primarily for high-value communications that require, for example, a high level of Quality of Service (QoS).[31] One attribute of QoS is the minimization of interference by using dedicated radio frequencies. Assuring QoS is one of the arguments for requiring dedicated spectrum for mobile broadband.

As the number of small cell networks multiply, increasing coverage, mobile communications will likely become less dependent on macro networks and their traffic might decline. In this case, there would likely be an over-supply of spectrum for macro networks and possibly a spectrum crunch for small cell networks. Therefore, if the majority of mobile traffic uses shared spectrum in small cell networks, the amount of dedicated spectrum required for the macro network might conceivably be reduced.

Since small cell networks are expected by most technologists to perform well in shared conditions, spectrum sharing—including, perhaps, licenses that mandate sharing—may provide more effective tools for promoting competition and growth.

Transition might occur as an evolution first from macro to micro networks and then from centralized network controls to user-controlled mobile devices, connecting through traffic management centers that will migrate to the cloud as technology permits. Today's cellular network is predicted to be one of many transport options, with small cell network physical structure integrated into devices or small cell neighborhood structures.

The combination of cloud technology and small cell networks may provide significant savings in capital expenditures for wireless companies. For example, as reported in the Financial Times,[32] AT&T is planning to move some functions of switches and routers to cloud-based, software-defined networks. Consequently, the company expects, in the future, to reduce capital expenditures on networks. The Financial Times article quoted an industry analyst who stated

[31] A set of techniques to manage network resources; predictability is an example of a service quality attribute.

[32] Paul Taylor, "AT&T Shifts to 'Virtualised' Hardware," *Financial Times*, February 26, 2014.

"AT&T is transforming the wide area network the way Information Technology transformed the data center."

The evolution of the HetNet is supported by advances in LTE and IEEE standards. Expected innovations within the LTE envelope are planned for incremental change within linear cellular network architectures. LTE/LTE Advanced, however, does not encompass the universe of wireless innovation. IEEE standards have in general been more flexible in accommodating non-cellular communications for emerging technologies, such as robotics. True innovation, it might be argued, would occur through wireless network technologies that emulate the Internet by using multiple connections that transfer traffic seamlessly from one node to another.

Disadvantages of LTE Network Architecture

Spectrum policies in general favor cellular network architecture. For example, the FCC's working definition of flexible-use service rules for spectrum are apparently based on technical rules for high-site, high power cellular antennas.[33] Although LTE standards provide the framework for high-speed, IP-based networks, LTE's limitations may be a barrier to the development of more advanced network architectures that are fully aligned with the design principles of the Internet.

A study in late 2012 by two researchers at AT&T Labs[34] suggested "a fresh new look" at design strategies and service assumptions in order to move mobile communications away from its "cellular circuit-oriented" origins. The study noted that LTE traces its heritage to the General Packet Radio Services (GPRS), designed to add packet-switched functionality to GSM, and uses the same basic approach to moving communications traffic to and from a centralized gateway. The evolution from GPRS to LTE is described as "tunnel-centric architecture." The flaws of this architecture, as described in the study, become barriers to future scaling and innovation.

The paper commented on the rise in mobile traffic and the "unexpected side effect due to interactions between cellular network architecture and the constant connectivity" required by always-on mobile devices, such as smartphones. Maintaining this connectivity strains "gateways and other network elements." To support wireless devices such as sensors (a critical element in many disruptive technologies, as discussed in the **Appendix**) using current LTE tunnel-centric architecture would require either permanent connections or the addition of "expensive" network signaling to manage usage, the researchers argued.

The Scalable Network: Innovation, Competition, Investment

Although micro networks were first seen by wireless carriers as a way to increase the capacity of their macro networks, it is becoming evident to many that micro networks can also be the primary means of providing wireless access. A small cell network can be treated as a separate business enterprise and customers within a closely inter-dependent geographic area can be targeted for additional services. [35]

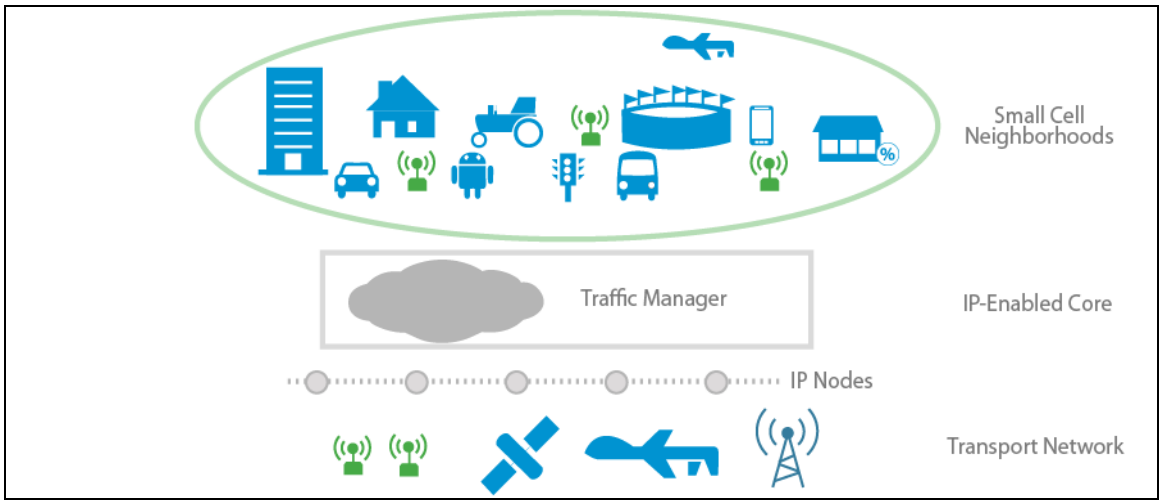
[33] "Interference Limits Policy," White Paper, FCC Technical Advisory Committee, Receivers and Spectrum Working Group, February 6, 2013, http://transition.fcc.gov/bureaus/oet/tac/tacdocs/WhitePaperTACInterferenceLimitsv1.0.pdf.

[34] Byoung-Jo J. Kim and Paul S. Henry, "Directions for future cellular mobile network architecture," First Monday: Peer-Reviewed Journal on the Internet, December 3, 2012, http://firstmonday.org/ojs/index.php/fm/article/view/4204.

[35] James Middleton, "Small Cells Should Be Seen as Businesses, Not Engineering Solution," telecoms.com, February (continued...)

To improve the effectiveness of mobile connectivity, wireless networks are themselves likely to become more mobile, flexible, and deployable (nomadic). Network infrastructure will move closer to the devices it currently supports, as the enabling technologies migrate from the macro to the small cell network. Next-generation traffic management centers will connect to corresponding nodes that connect directly to the Internet instead of through a cellular core network. To provide coverage, cell tower networks may be supplemented by satellites, or by Unmanned Aerial Systems (UAS) using, for example, drones.[36]

Figure 4. Scalable Mobile Access Networks



Source: Congressional Research Service (CRS).

In the design proposal depicted in **Figure 4**, the IP-enabled core uses cloud technology to connect end users to the Internet. The widespread availability of small cell locations and multiple options for transporting traffic allows for scalability ranging, for example, from a small sports stadium to a large urban area.[37]

The key elements of this evolved network architecture are

- End users and their devices, which, using small cells and new technologies, are the main drivers of the network;
- Network interfaces operating largely through the cloud; and
- The transport layer, which now includes macro cell towers, micro small cells, and other systems (satellite, UAS) that are integrated and interchangeable.

(...continued)

12, 2014; and Dan Jones, "SpiderCloud Eyes LTE Enterprise Small Cells in 2014," News Analysis, LightReading, January 17, 2014.

[36] Examples include DARPA's Mobile Hotspots Program that will retrofit drones to provide Wi-Fi to remote areas; Facebook's plans to develop drone technology to assure global Internet connectivity; and Google's acquisition of drone-maker Titan Aerospace.

[37] A presentation on small cell technology by Alcatel Lucent provides a good picture of scalability and the use of micro networks for LTE, FCC Workshop on 3.5 GHz Spectrum Access System, January 14, 2014, http://wireless.fcc.gov/workshop/OVERVIEW%20-%20Milind%20Buddhikot%20-%20Alcatel%20Lucent.pdf.

In the future depicted in **Figure 4**, network architecture is no longer dominated by fixed towers and cellular technology. Access is consumer-driven not network-controlled. Wireless traffic from a plethora of devices is directed through a new generation of traffic management centers to any IP-enabled transport link. The traffic management connections access most physical infrastructure through the Cloud.[38] Coverage is assured through any IP-enabled transport system, whether fixed cell towers, fixed or deployable small cells, satellites, unmanned aerial systems, or other.

In this environment, economies of scale can be achieved through cloud technology, not by network consolidation and spectrum license aggregation. Ownership of exclusive-use licenses may not, therefore, be essential to assure ubiquitous coverage; may no longer be relevant for achieving important economies of scale; and may be counter to policy goals that seek to increase the capacity of spectrum for productive use. Certainty for investors may be provided through policies that balance multiple, competing interests, not through ownership of exclusive-use licenses.

By providing new opportunities for competition, changes in technology also might provide new opportunities for investment. For example, achieving economies of scale has been a driving force in the wireless industry for over a decade, rationalizing consolidation of spectrum license holdings. Micro networks, which operate in small geographic areas, may not require scale economies to be competitive. If scale is no longer critical to success, opportunities for small investors and nascent entrepreneurs may arise, spurring new types of investment models.[39] In such an environment, scale may no longer be the consequence of technological and market forces but might be viewed as an artificial business model favoring monopolistic behavior.

It is possible to envision a wireless business environment where the value for investors derives primarily from ownership of micro networks and intellectual property rights for wireless devices and applications. This shift would likely significantly change investment priorities, redirecting research and development to products that operate on micro networks and to the continuous improvement in products and services.

The Arrival of Fifth Generation Networks

Most announcements about future 5G network designs include some reference to small cell concepts, albeit at a more advanced level of technology than what is in use today. Recent descriptions of 5G emphasize important improvements in network speed and capacity and the introduction of new communications technologies. Industry comments diverge on whether 5G will remain within the suite of cellular technologies—a further advance of LTE—or represent a new direction in network architecture. Some describe 5G as not one standard but a combination of several standards and technology families or of new types of air interfaces.[40] IEEE 802.11.ac standards for 5GHz are seen by many as an important stepping stone in the development of 5G networks that will use both licensed and unlicensed spectrum.

[38] Oceus Networks uses a similar concept to provide communications on the move for the Department of Defense. See http://oceusnetworks.com/.

[39] The Small Cell Forum has published a report on the business case for small cell deployments: http://www.scf.io/en/documents/098_-_Urban_small_cells_in_the_real_world_case_studies.php.

[40] Public discussions of 5G tend to be general in part because of the rapidly evolving state of the technology and its proprietary nature.

Commercial deployments of Fifth-Generation technologies by 2020 have been announced by wireless network officials in South Korea[41] and Japan.[42] In July 2014, Ericsson, a global leader in communications technology, demonstrated the speed of its 5G network design to customers NTT DOCOMO (Japan) and SK Telecom (South Korea).[43]

The year 2020 is the target introduction date for many companies and industry groups that have been established to advance the introduction of 5G. These include IMT-2020;[44] 5G Forum,[45] METIS;[46] the 5G Information Centre;[47] and 5G-PPP.[48]

Changing Spectrum Policy to Accommodate New Technology

A key component of spectrum policy is the allocation of bands for specific uses and the assignment of frequencies within those bands. The allocation and assignment of radio frequencies, particularly as it relates to the five disruptive technologies noted in this report, might today be described as operating in two distinct domains: exclusive-use commercial spectrum licenses and unlicensed spectrum. These two domains are presently dominated by two suites of standards:

- The cellular network track laid out by 3GPP where innovation occurs within the LTE envelope and relies primarily on spectrum licenses assigned for exclusive use; and
- The unlicensed track using IEEE WiFi standards for channels allocated for that purpose, providing access and capacity to all comers.

The first track—a seamless network built using LTE technology—is supported by current spectrum policy, which favors auctioning spectrum licenses for exclusive use. Licenses are a bankable asset that provides some protection to investments in infrastructure, as there is reasonable certainty that investors will hold the asset long enough to realize a return.

The minimum effective bandwidth for assuring quality of service over a wide geographic area with LTE is 20 MHz, many experts say. Carrier aggregation, a feature of LTE Advanced, typically

[41] "SK Telecom Starts Joint Research with Ericsson for 5G," SK News press release, July 7, 2014, http://www.sk.com/Channel/News/view/1219.

[42] "DoCoMo to Conduct 5G Experiment Trials with World-Leading Mobile Technology Vendors," NTT DOCOMO press release, May 8, 2014. The Japanese carrier reportedly is planning to introduce 5G service by 2020, offering 1,000 times the capacity of LTE, https://www.nttdocomo.co.jp/english/info/media_center/pr/2014/0508_00.html.

[43] "Ericsson 5G Delivers 5Gbps Speeds," Ericsson News Center, July 1, 2014, http://www.ericsson.com/news/1810070.

[44] In China 5G research and development is being sponsored by three ministries that jointly established IMT-2020 (5G) Promotion Group, http://www.itu.int/dms_pub/itu-r/oth/0a/06/R0A0600005D0001PDFE.pdf.

[45] Based at the University of Surrey in the United Kingdom, http://www.surrey.ac.uk/5gic/about/.

[46] Mobile and wireless communications Enablers for the Twenty-twenty Information Society, a European Union project, https://www.metis2020.com/.

[47] Based at the University of Surrey, in the United Kingdom, http://www.surrey.ac.uk/5gic/about/.

[48] The 5G Infrastructure Public-Private Partnership was initiated by the European Union to partner with private sector companies, http://5g-ppp.eu/.

allows for operations on up to five 20-MHz bands, or 100 MHz, by as many as five carriers. Contiguous spectrum of 100 MHz in bands designated for LTE is therefore considered valuable to LTE carriers.[49] To get the full benefit of LTE Advanced coverage, macro network operators also seek licenses with large geographic areas, thereby committing to ever-greater capital investments.

The second track builds on unlicensed spectrum for WiFi and related standards that are expanding to meet the needs of different industries as their technologies evolve. Access to unlicensed spectrum is an important resource for many industries—manufacturing, utilities, agriculture, and others—not generally considered part of the telecommunications industry. Unlicensed spectrum benefits from attributes of small cells, such as their ability to operate on multiple frequencies (spectrum agnostic) or to support shared use.

Under the current regulatory regime, the FCC often chooses to differentiate between macro and micro networks only in terms of licensed and unlicensed spectrum, therefore, arguably, not fully realizing or supporting the growth potential of micro networks on licensed spectrum. It appears, however, that market demand for low-cost, easy access to spectrum will grow as spectrum-dependent industries outside the telecommunications sector continue to expand. Some economists project that some of these industries are on the threshold of exponential growth.[50]

Although unlicensed technologies may be more suitable for their spectrum needs, these new industries often must choose between less suitable and often-costly LTE network solutions or spectrum access under unlicensed regulations that do not provide certainty and may discourage investment.

To meet the needs of these emerging markets and accommodate new entrants, the FCC might modify its spectrum policies, in particular its rulemaking procedures for spectrum license auctions, a key policy tool.

Spectrum Auctions

Auctions, a fairly recent innovation in frequency assignment, are regarded as a market-based mechanism for allocating spectrum. Other market-driven policies include licensing fees based on fair-market valuations of spectrum and flexibility in spectrum usage within assigned bandwidths. Today, spectrum licenses for commercial applications are typically auctioned to the highest bidder.

One ongoing spectrum policy debate centers on how to create a framework for greater competition through widespread ownership of spectrum licenses. One policy tool is the rule-making process for participation in spectrum auctions.

Provisions in existing law require the FCC to provide opportunities for small businesses to compete in auctions, which is accomplished largely by policies for Designated Entities (DE).[51] To

[49] For a more detailed explanation of carrier aggregation, see 3GPP, "Carrier Aggregation Explained" at http://www.3gpp.org/technologies/keywords-acronyms/101-carrier-aggregation-explained.

[50] A discussion of exponential growth as disruptive technologies mature is presented in Erik Byrnjolfsson and Andrew McAfee, *The Second Machine Age: Work, Progress and Prosperity in a Time of Brilliant Technologies*, W.W. Norton and Company Ltd., January 20, 2014.

[51] Qualifying designated entities bidding for licenses in a spectrum auction receive a credit against the purchase price of (continued...)

accommodate economies of scale for macro networks, the FCC has, generally, been increasing the size of geographic coverage of licenses. To assure the licensed spectrum is put to full use, the FCC applies build-out deadlines for network infrastructure, and other requirements.

The FCC's decisions about geographical coverage for licenses are believed by some to influence the number of potential bidders. In designing band plans for spectrum to be auctioned, the FCC chooses the geographic coverage of licenses. Although there are a number of geographic configurations for licenses, the two most frequently used are designated as Economic Areas (EAs) and Cellular Market Areas (CMAs).[52] CMA coverage is based largely on Metropolitan Statistical Areas or Rural Service Areas. The Economic Area license size tends to favor business planning for larger communications networks seeking maximum geographic coverage. Because of economies of scale, their Return on Investment for spectrum license purchases is presumed to be better than the return for a local wireless service provider that may not be able to take full advantage of a geographic coverage that extends beyond its market area. Not surprisingly, larger carriers can, and often do, outbid smaller companies in acquiring licenses.[53] To counterbalance what some consider to be an unfair advantage in bidding competitions, the FCC in the past has employed spectrum caps, limiting the amount of spectrum any one carrier may acquire at auction.

Examples of the role of auctions in allocating and assigning spectrum access and rights can be found in two current FCC rulemaking proceedings. One is for the Broadcast Incentive Auction, which includes decisions on allocation of spectrum between licensed and unlicensed use, and assignment through auctions. Auction rules for the Broadcast Incentive Auction[54] favor license sizes and build-out rules for macro networks. The license coverage will be for Partial Economic Areas (PEAs) that create smaller license coverage areas within EAs, but final rules may allow bidders to aggregate licenses. The other FCC action concerns reallocation of federal spectrum holdings in the 3.5 GHz band. The FCC proposes to designate 3.5 GHz as an "Innovation Band." In part to encourage micro networks and their successor technologies, the FCC proposes reducing the geographic coverage of a license to a single census tract. It is considering criteria for designated entities that might focus less on company size or ownership and more on programs for innovation or research and development.

Reallocation and Assignment: Broadcast Incentive Auction

The Spectrum Act has permitted the FCC to conduct incentive auctions, that is, to establish a mechanism whereby spectrum capacity may be relinquished for auction by some license-holders, who would then share in the proceeds.[55] Many commercial wireless licenses can be resold

(...continued)

a successful bid. Current FCC rules provide for three categories of DE, based on gross revenue: small business, very small business and entrepreneur. Small business and entrepreneur bidders receive a credit of 15%; very small businesses, 25%. (47 CFR 27.1218)

[52] The FCC has been assigning area-based licenses since 1982. A description of the geographic coverage for each type of license is published by the FCC's Office of Engineering and Technology, "FCC Areas," at http://transition.fcc.gov/oet/info/maps/areas/.

[53] In an auction of EA licenses for frequencies in what is known as the H Block (Auction 96, completed February 27, 2014), Dish Network outbid the competition to acquire all 176 licenses on offer.

[54] "FCC Adopts Rules for First Ever Incentive Auction," FCC, *Report and Order*, Docket No. 12-268, released June 2, 2014 http://www.fcc.gov/document/fcc-adopts-rules-first-ever-incentive-auction-0.

[55] P.L. 112-96, §6402,126 STAT. 224.

directly by their license-holders for comparable uses; the purpose of incentive auctions is to reward license-holders, such as television broadcasters, who repurpose their spectrum for a different use. Although incentive auctions might be used for other types of license-holders, the act specifically addresses spectrum assignments for over-the-air television broadcasters.

The act established procedures and guidelines for the FCC to follow in reallocating television broadcasting spectrum licenses for commercial auction. Through a reverse auction process, the broadcasters would establish the amount of compensation they are willing to accept for the spectrum they voluntarily release for auction. Additionally, broadcasters that do not voluntarily relinquish spectrum rights, but are required to relocate or incur certain other costs, may be compensated.

Spectrum voluntarily released by TV broadcasters is to be repurposed for commercial broadband communications, with licenses sold through what the law refers to as a "forward auction." At least one successful reverse auction is required to set minimum prices for a forward auction. The outcome of the forward auction for spectrum licenses depends on the results of the reverse auction. For the results of a forward auction to be valid, auction proceeds must at a minimum cover (1) payments to broadcasters that relinquished spectrum for auction, (2) the costs to the FCC of conducting the auctions, and (3) the estimated costs for relocation of other broadcasters, which are not to exceed $1.750 million, deposited in a TV Broadcaster Relocation Fund for relocation costs. Auction revenue amounts above these three financial obligations are to be deposited in a Public Safety Trust Fund created by the Spectrum Act to receive and disburse proceeds of the spectrum license auctions required by the act.

The Public Safety Trust Fund is scheduled to receive approximately $1.5 billion from Auction 96, which was completed on February 27, 2014.[56] Additional revenue will come from another auction of spectrum licenses (Auction 97) required by the act, scheduled for November 2014.[57] The proposed reserve price (minimum acceptable bid value) is $10.6 billion, of which $5.1 billion is to be applied to the costs of relocation or sharing of frequencies now used by the federal government. Mandated disbursements from the Public Safety Trust Fund include $7.135 billion for the development of a nationwide public safety broadband network, which has priority as a recipient, and $20.4 billion for deficit reduction.[58]

Participation and License Coverage

Increasing the availability of commercial broadband is the stated goal of both the Broadcast Incentive Auction and the FCC. Although the act does not specify that spectrum licenses be sold to allow for the build-out of LTE networks, LTE is the primary standard for broadband on cellular networks. Furthermore, the broadcasting frequencies that are targeted by the FCC for auction are in the 600 MHz band, a band designated for LTE and adjacent to the 700 MHz band, where LTE network build-outs have begun.

[56] "Winning Bidder Announced for Auction 96," FCC Public Notice, DA 14-279, February 28, 2014, http://transition.fcc.gov/Daily_Releases/Daily_Business/2014/db0228/DA-14-279A1.pdf.

[57] FCC, Auction of Advanced Wireless Services Licenses Scheduled for November 13, 2014; Comment Sought on Competitive Bidding Procedures for Auction 98, Docket No. 14-78, May 19, 2014, http://transition.fcc.gov/Daily_Releases/Daily_Business/2014/db0520/DA-14-669A1.pdf.

[58] Disbursements from the Public Safety Trust Funds are detailed in CRS Report R42543, *The First Responder Network (FirstNet) and Next-Generation Communications for Public Safety: Issues for Congress*, by Linda K. Moore.

The FCC has designed rules for the Broadcast Incentive Auction[59] intended to improve competition among current and potential LTE network providers. The licenses will be for 5MHz of paired spectrum, to maximize the amount of licenses available without creating problems of interference with television broadcasts by cellular network transmissions. License coverage will be for Partial Economic Areas, [60] although the auction rules might allow for aggregation, creating even larger licensed coverage. The FCC will require interoperability for devices across all networks built in the 600 MHz band; this will likely benefit smaller carriers as well as improve the efficiency of spectrum access. Qualifications for Designated Entities will be reconsidered in a separate proceeding that may subsequently be applied to the Broadcast Incentive Auction.

A separate Report and Order will establish new guidelines on the amount of spectrum that any one carrier may hold.[61] This evaluation, which imposes limits on ownership to avoid market concentration, often referred to as a spectrum screen, is presently made on a case-by-case basis for merger activity. The FCC plans to apply its new criteria to the incentive auction by placing restrictions on bidding activity intended to handicap the ability of Verizon and AT&T to acquire licenses in certain areas. The majority of the 700 MHz band commercial licenses were purchased at auction in 2008 (Auction 73) by Verizon and AT&T,[62] which together also hold approximately 70% of commercial spectrum licenses below 1000 MHz. [63] The other two national carriers, Sprint (majority-controlled by SoftBank, Corp., a Japanese telecommunications provider, and T-Mobile, Inc. (majority-owned by Deutsche Telekom, AG) own 15% of commercial licenses below 1000 MHz and did not participate in Auction 73. Although Sprint and T-Mobile are generally viewed as the primary beneficiaries of the bidding rules, the rules are also intended to provide opportunities for smaller carriers to bid successfully. Based on the amount of spectrum released by the broadcasters, a block of spectrum will be set aside in each market with bidding priority for Sprint, T-Mobile, and any entrant deemed not to have national network coverage. If, for example, 60 MHz of spectrum is made available by broadcasters, 20 MHz will be reserved; as described by the staff report, all registered bidders would be eligible to compete for licenses not acquired in priority bidding as well as in the remaining 40 MHz. It is uncertain if, or how, the FCC might modify the spectrum screen rules if there is a successful merger of T-Mobile and Sprint, which might occur before the auction takes place.

The announced rules are consistent with past FCC auction practices over time. Testimony by FCC Chairman Tom Wheeler affirmed the FCC's assumption that economies of scale skew competition for spectrum licenses.[64] Given the predicted decline for investment in macro

[59] FCC Docket GN 12-268; the FCC provides information on the auction preparations at http://wireless.fcc.gov/incentiveauctions/learn-program/.

[60] "Wireless Telecommunications Bureau Seeks Comment on a Proposal to License The 600 MHz Band Using "Partial Economic Areas,", DA 13-2351, December 11, 2013; and "WTB Provides Details about Partial Economic Areas," Docket No. 12-268, released June 2, 2014 http://www.fcc.gov/document/wtb-provides-details-about-partial-economic-areas.

[61] "FCC Adopts Revised FCC Mobile Spectrum Holdings Policies," FCC News, May 15, 2014, http://www.fcc.gov/document/fcc-adopts-revised-mobile-spectrum-holdings-policies and *Report and Order,* Docket No. 12-269, released June 2, 20014, http://www.fcc.gov/document/mobile-spectrum-holdings-report-and-order.

[62] The major auction of licenses for the 700 MHz band was Auction 73. Some information about the top ten successful bidders in Auction 73 is available at Wireless Strategy, FCC Auctions, http://www.wirelessstrategy.com/700auction.html.

[63] "Fact Sheet FCC Mobile Spectrum Holdings," May 2014, FCC staff report, http://www.fcc.gov/document/fact-sheet-fcc-mobile-spectrum-holdings-rules.

[64] U.S. House of Representatives, Subcommittee on Communications and Technology, Committee on Energy and Commerce, Hearing, "Oversight of the Federal Communications Commission," May 20, 2014; written Testimony of (continued...)

networks, the success of the auction would appear to depend on attracting new entrants, including entrepreneurs that are looking to serve new markets for wireless services. It is possible, however, that the technical rules developed for LTE networks in the 700 MHz band, to be applied to the 600 MHz band, may limit entrepreneurial innovation, or at least constrain it within the LTE envelope.

The auction rules appear to be giving priority to the policy goal of increasing competition among macro network transport providers, where economies of scale prevail. The FCC has determined that "low-band" spectrum is uniquely desirable for network coverage because it is "better suited for transmitting wireless communications over long distances and through walls."[65] With the new Mobile Spectrum Holdings Policies, the FCC seems to have drawn a line at 1000 MHz, below which it will encourage the build-out of LTE networks and attempt to maximize the number of exclusive-use spectrum license owners to provide network coverage. Allowances are also made to increase unlicensed use as part of the Broadcast Incentive Auction. These decisions reaffirm the two-track spectrum policy that has been in place for decades.

Reallocation and Assignment: 3.5 GHz

In its *Further Notice of Proposed Rulemaking* (FNPRM) that would repurpose spectrum at 3.5 GHz,[66] the FCC has pointed the way toward a third track of spectrum policy. The FNPRM proposes a framework for spectrum management that is considered by many to be a precursor to the development of spectrum policies more aligned with evolving wireless technologies. The proposed rules address important issues for the development of small cells and sharing technologies such as license coverage, license assignment, interoperability, competition from new entrants, and rules for the management of shared access. Many of the proposed rules are in outline form, with requests for comments specifically asking for industry guidance.

Participation and Coverage

The FNPRM proposes establishing three tiers of spectrum access in the 3550-3650 MHz band, taking advantage of advances in small cell and shared-spectrum technologies. Under the proposal, there would be a top tier of Incumbent Access for current users such as the Department of Defense for radar systems, and Fixed Satellite Service. A second tier would use a Spectrum Access System to allot spectrum among pre-qualified users, who will be assigned Priority Access (PA). The third tier would be available nationwide for General Authorized Access (GAA). Although not designated as unlicensed, the GAA layer would serve a comparable purpose. The proposal would allocate at least half of the available spectrum (after allowing for Incumbent Access) for GAA. GAA would be open to all comers, with rules established by the FCC. However, up to 20 MHz of the GAA may be reserved for hospitals, public safety organizations, local governments, or similar—designated as Contained Access Users—for indoor use within their premises. The FCC refers to tiers two and three as Citizens Broadband Radio Service.

(...continued)

Tom Wheeler, Chairman, Federal Communications Commission.

[65] Ibid, p. 2.

[66] FCC, *Further Notice of Proposed Rulemaking,* GN Docket No. 12-354, released April 23, 2014.

The boundaries of the three tiers would shift depending on usage, managed, in general, through Spectrum Access Systems (SASs), that would use dynamic spectrum management technology to manage sharing throughout the band. The FCC assumes that multiple SASs would be in operation on a nationwide basis throughout the band. It proposes that SASs be allowed to collect "reasonable" fees from PA and GAA users.

The proposed rulemaking would create Priority Access Licenses (PALs) with an initial authorization for one year, for a 10 MHz assignment of a single census tract. A PAL license might be assigned directly by the FCC or won through competitive bidding. Longer license periods and license aggregation are being considered. Large players might, either at auctions or over time, be able to assemble licenses covering areas up to 30 MHz. The FCC might also, in auctioning spectrum licenses, provide a mix of license sizes. The expectation is that the availability of small cell area licenses will spur competition and innovation. The FCC is seeking comment as to whether to offer bidding credits to further encourage participation by small businesses. Still the barrier to entry posed by legal costs may remain high for small businesses unless the FCC can further simplify both the requirements for participating in auctions and the certification of devices for license-by-rule allocations.

Economies of scale in device manufacturing are to be met by requiring interoperability of all devices for PA and GAA users across the full 100 MHz being reallocated at 3.5 GHz; requirements may be extended to an additional 50 MHz at 3650-3700 MHz that may be added later. The presumed technologies are LTE-Unlicensed and new and current forms of WiFi.

As the FCC notes in the FNPRM, the effectiveness of its proposals for 3.5 GHz are largely dependent on "the development and implementation of a robust SAS." Their approach, therefore, is to propose several high-level requirements with the expectation that industry participants will develop the technical implementation and any needed standards.

The proposed rulemaking fulfills expectations as an innovation band in that it provides the opportunity to see how effectively small cell and shared technologies can increase spectrum capacity. The proposed coverage areas for PA and GAA users are limited, however, and may not be sufficient to spur competition for PALs, as the economic benefits may be elusive. At present, Incumbent Access users have pre-emptive rights to airwaves on both coasts of the United States, significantly diminishing the amount of spectrum available for licensing.

In establishing the band plan, the FCC adhered to exclusion zones originally established in 2010 by the NTIA. These zones were based on assumptions for the deployment of high-site macro networks using WiMax standards[67] as the main criteria for evaluating interference. Many argue that these criteria are meaningless in a small cell environment. Some expect that, once the three-tier designations are in place and the Spectrum Access Systems operating, the exclusion zones will gradually disappear. In the short term, however, there is concern that the desired competition and influx of new players for PA licenses may not materialize.

Whatever the perceived shortcomings of the yet-to-be-decided final rules, lessons learned from the Innovation Band can be used to develop a road map from present to future policies and practices.

[67] WiMax was an early standard for 4G that has largely been displaced by LTE.

Evolution of Spectrum Policy

Spectrum policy, notably as interpreted by the regulations and action of the FCC and the NTIA, can accelerate or delay the arrival of the network of the future. The key factors identified in this report as influencing policy decisions appear to be changing with the technology and may lead to policy changes.[68]

Access to Radio Frequency Spectrum

The demand for access to spectrum is projected to continue to increase dramatically. The need for spectrum licenses for exclusive use to meet this demand is, however, being challenged by new technology that enables sharing. One policy proposal for sharing would permit the auction of licenses for the right to share federal spectrum. In the United States, this approach is usually referred to as Licensed Shared Access (LSA). Using dynamic spectrum access to monitor and control spectrum availability, access to cellular networks would be available either to the federal incumbent or the licensed network operator. Transitional technologies, such as those being developed for 3.5 GHz, are making possible other forms of sharing and the creation of new categories of licenses.

The question of spectrum to support 5G technologies has barely been addressed in public forums. Spectrum at 15GHz will likely be used for the 5G network scheduled fort deployment in Japan in 2020. 5G introductions based on LTE standards in the United States might use existing spectrum holdings where investments have been made in LTE HetNet infrastructure.

Economies of Scale

The shift to micro networks would appear to reverse the need for large investments in infrastructure and spectrum licenses as a requisite for market participation. New forms of economies of scale might be achieved not by a few investing a great deal but by many investing comparatively small sums. If investment requirements as a barrier to entry are reduced, opportunities for new participants and competitors are likely to increase. Other barriers include lack of certainty about the availability and unit cost of spectrum access and the costs of regulatory compliance.

The importance of economies of scale in the manufacture of devices, already important, is likely to increase as devices become the drivers of the network. Interoperability across multiple bandwidths promotes scale for device manufacturers.

[68] A report from the Organization for Economic Co-operation and Development covers many of the issues discussed in this section. It provides information on shared spectrum regulation, standards, and harmonization from a global perspective; OECD (2014), "New Approaches to Spectrum Management," *OECD Digital Economy Papers*, No. 235, OECD Publishing, http://www.oecd-ilibrary.org/science-and-technology/new-approaches-to-spectrum-management_5jz44fnq066c-en.

Standardization

Substantial resources have been invested in developing a mobile Internet that can link cellular architecture to IP-enabled networks using LTE/LTE Advanced technology and standards. New standards are also emerging for WiFi, Wide Area Network, Cloud technologies, and 5G.

The trend may be shifting away from cellular network technology, although the transition is likely be gradual, given the large investment in LTE network infrastructure. Based on cellular technologies, LTE provides continuity with carriers' legacy systems. Because LTE is IP-enabled, it supports high speed broadband and can connect with most systems that operate with IP protocols.

The evolution of LTE standards is considered by many, notably policy makers within the European Union, as providing the path to future innovation. In this view, innovation occurs within the planned, predictable evolution of LTE; policies for planned growth are predicated on LTE standards for the Internet of Things, autonomous vehicles, robotic sensors, and other emerging or yet-to-be invented technologies that require access to spectrum. Standardization in a planned environment may discourage the introduction of disruptive technologies and may encourage industry cartels.

Domestic and international forums that set standards for mobile broadband may need to give greater consideration to the interdependence of standards. This would include not only the LTE and IEEE standards used in HetNets but other standards that may be crucial to expanding coverage and capacity. This would include standards for Unmanned Aerial Systems terrestrial links, and for the emerging technologies that provide for a mix of spectrum usage within a single network, such as that being tested for 3.5GHz.

Harmonization

Efforts to harmonize spectrum allocations on an international basis have and will likely continue to require reallocation of spectrum to commercial broadband, providing opportunities to further expand LTE networks. However, the diplomacy of harmonization may shift away from allocating or reallocating spectrum for LTE broadband toward placing more emphasis on harmonizing other standards, including 5G. Coordination of unlicensed spectrum and certification of devices for international use may become more important to international forums in the future.

Investment, spectrum access, and standardization interact with each other and may influence both national and global business decisions. As markets become increasingly global, access to spectrum on a worldwide basis may be one of the entry barriers for some American companies. Therefore, international negotiations regarding spectrum use are likely to play an important part in implementing wireless policies.

Internet Infrastructure

Changes in spectrum policies, especially as regards auctions, may improve access to spectrum for a broad variety of players. However, if wireless access is an important input for a growing number of industries, access to fixed communications infrastructure, notably the Internet, is crucial for mobile communications. Micro networks achieve capacity through a proliferation of

small cells, each connecting to the Internet. Less space between antennas means that more connections to Internet infrastructure are required.

Developing the Small Cell Network

Within less than a decade wireless communications has advanced from Third Generation (3G) to Fourth (4G) and is poised to start the transition to the Fifth (5G). Although some industry experts foresee a continued build-out of LTE-enabled towers using small cells to supplement coverage; other experts foresee the evolution of interconnected but separate networks that rely primarily on small cells and emerging new technologies. Some view 5G as a continuation of the evolution of LTE macro networks; others envision 5G as a potentially disruptive micro network technology that may break entirely with its cellular origins. These alternative scenarios likely lead to different outcomes depending in part on spectrum assignment policies. Policies that favor 5G/LTE/cellular networks might imply support for the more efficient use of capital investment in existing infrastructure. Policies that favor 5G/IEEE/non-cellular solutions might be deemed to be more oriented toward innovation and new entrants.

A key goal of spectrum policy is to manage a resource to achieve the maximum benefit to society, for example by creating jobs, opportunities for investment and growth, and new forms of communications available to all. Current policies of spectrum license assignment rely heavily on auctions, where competition to acquire licenses is judged to spur competition within the telecommunications industry and maximize revenue to the U.S. Treasury.[69] These rules largely favor telecommunications companies with major investments in macro networks.

Another policy goal is emerging: to assure spectrum access as a reliable, low cost input for dozens of industries that are not part of the telecommunications sector. This need appears to be critical for broad-based economic growth across many sectors of the economy. As described in this report, efforts to accelerate LTE/LTE Advanced have shown the advantages of using micro networks in addition to macro networks. Many technologists, as discussed throughout this report, have reasoned that the miniaturization and compression of network components potentially places more control of communications access in the hands of users (devices) and is less reliant on macro networks using exclusive-use spectrum. In a policy environment that provides certainty about spectrum availability and access, financial markets may increase investment in micro networks and the many technologies that benefit from their presence. These include the disruptive technologies identified in this report: autonomous vehicles, advanced robotics, cloud computing, and machine-to-machine communications. Other sectors and industries that benefit from reliable access to spectrum, but may not benefit from using LTE networks, include medicine, education, agriculture, retailing, utilities, and manufacturing.

A third, emerging, spectrum policy track provides a bridge between the exclusive use/everybody uses dichotomy that currently predominates. Efforts to commence the transition to a new spectrum regime are evident in the proposed FCC rules for the 3.5 GHz band. They are counter-

[69] 47 USC §308 (j) (8) requires that net proceeds from competitive bidding for spectrum licenses be deposited in the U.S. Treasury. Net proceeds are the auction revenues minus the FCC's expenses. In addition to the Spectrum Act, Congress has twice in the past amended the provision in order to use auction proceeds for other purposes by creating special funds to hold and disburse auction proceeds. The Commercial Spectrum Enhancement Act, Title II of P.L. 108-494, created the Spectrum Relocation Fund; the Deficit Reduction Act of 2005 created the Public Safety and Digital Television Transition Fund.

balanced by the FCC's rulemaking for the Broadcast Incentive Auction. As described above, this rulemaking is focused on rules to accommodate macro networks. Both proceedings address issues of competition for access to spectrum primarily through regulation rather than by leveraging the opportunities provided by technology. Neither of the proceedings fully accounts for the importance of Internet access nor acknowledges the imminent transition to 5G. In the mobile world, Internet access and spectrum access are equally essential.

Whereas some of the engineering solutions that will enable the sharing of 3.5 GHz spectrum have yet to be perfected, the technologies for small cell networks are in current use. The potential exists, therefore, to increase competition and innovation with policies that recognize small cell networks as a separate and distinct sector of the telecommunications industry.

If 3.5 GHz deployments meet expectations and show a clear path forward through an evolution of small cell and spectrum sharing technologies, the United States may in the future have a surplus of exclusive-use licenses that are not being fully utilized on a competitive basis.

The potential for small cell and spectrum-sharing technologies to increase competition, and provide new opportunities for new entrants and innovation might merit fuller consideration than what is offered through the creation of an Innovation Band. Some argue that auction rules that provide small cell area licenses and recognize different build-out and usage requirements for small cell networks would meet goals for maximum benefit and auction revenue. They are asking for a new spectrum management regime that will open access to more types of investments across a broader range of industries.[70] Since evolving 5G architectures are predicted to be heavy users of small area networks, new spectrum policies for small cells may also smooth the path to 5G.

Auctioning licenses for small cell networks might advance the third policy track and move to an environment that no longer focuses on the spectrum needs of the traditional telecommunications industry. The area coverage for these licenses should, most concur, allow for flexibility. Since the technology can support a network that provides service to, for example, a sports arena, then a license with the geographic area of a sports arena should be available, they say.

Some of the same challenges for assuring access and encouraging competition that face policy makers for spectrum also apply to the Internet. Policies to encourage consumer-driven networks may address these issues, at least in part, by creating new markets that will likely attract new infrastructure providers.

Policy Considerations for Congress

Policy challenges created by the rapid evolution of wireless technologies that Congress may decide to consider include the following:

- Developing spectrum policy goals beyond meeting immediate needs for mobile broadband.
- Identifying transitional opportunities for spectrum assignment and allocations.

[70] For example, see remarks made by a panel of experts in a forum organized by New America Foundation, "Implementing the PCAST Spectrum Sharing Report; A Citizens Broadband Service and Beyond," April 4, 2014.

- Improving the application process and reducing the cost of obtaining certification for unlicensed devices.
- Removing regulatory barriers to the development of flexible infrastructure.
- Aligning spectrum access policies with policies governing Internet access.
- Permitting technology to evolve while also balancing regulatory needs to achieve desired policy goals.

Congress may also choose to consider whether the two agencies responsible for spectrum policy—the FCC and the NTIA—are capable of fully meeting their responsibilities. Do they have the right resources to do their jobs? Are they sufficiently accountable for the consequences of their decisions? Are they adequately balancing traditional telecommunications technology with emerging and evolving technology?

Appendix. Spectrum-Dependent Technologies

This report bases its references to disruptive technologies on a May 2013 study by McKinsey & Company.[71] The report identified a dozen "disruptive technologies" and their industries. The definitions and categorization of these technologies as provided by McKinsey serve in this report as a baseline for understanding spectrum-dependent technologies and their role in the U.S. and global economies.

Mobile Internet

Advances in wireless communications technology have fostered a large and growing market for mobile broadband services, also referred to as the mobile Internet.[72] The mobile Internet is defined by the McKinsey report as a combination of mobile computing devices, high-speed wireless connectivity, and applications. Wireless devices support voice, text and video communications providing information and entertainment. An increasing amount of mobile communications is through social media, exchanging information among virtual communities. Mobile Internet devices and networks are enhanced by the use of the Internet Protocol for interoperable connectivity and applications development. The impact of the Internet on retailing, banking and payments, education, health services, and other public and social services is well advanced and projected by the McKinsey report to increase and expand. The development of software applications (apps) for the mobile Internet may be a separate disruptive technology.

Increasingly, as this report discusses, licensed spectrum for the mobile Internet is used for LTE cellular technology on networks owned and operated by wireless carriers. These networks cater primarily to markets for the mobile Internet but are currently expanding their customer bases in the Internet of Things, near-autonomous vehicles, and cloud technology.

Cloud Technology

Cloud technology, as described by the McKinsey report, allows the delivery of potentially all computer applications and services through networks or the Internet. Many commonly used Internet services are delivered using cloud resources, such as online searches, and streaming media. The cloud and the mobile Internet contribute to each other's growth, and cloud technology is an enabler for the Internet of Things and other wireless innovations. One of the advantages of the cloud model is elasticity. With cloud technology, notes the McKinsey report, capital-intensive investments for infrastructure can be turned into "asset light" operating costs because, for example, peak demand loads can be distributed throughout the cloud. The ability to shift demand easily throughout cloud resources provides another advantage: greater reliability. These benefits contribute to cloud technology's potential to disrupt existing business models.

[71] McKinsey Global Institute, *Disruptive Technologies: Advances that will transform life, business and the global economy*, May 2013, available at http://www.mckinsey.com/insights/business_technology/disruptive_technologies. Note that projections are for global growth and may not accurately represent a technology's role in the U.S. economy.

[72] See, for example, "Remarks of Ruth Milkman, Chief, Wireless Telecommunications Bureau, FCC," prepared for delivery at Georgetown Center for Business and Public Policy and PCCA Workshop, June 14, 2013.

The development of cloud technologies might be the source for new services and applications for mobile users. Decreased reliance on fixed infrastructure for data processing and storage might also include less dependence on fixed network infrastructure, such as the base stations that serve cellular towers.

Internet of Things

The Internet of Things, also known as machine-to machine communications, is defined in the McKinsey report as the use of sensors, actuators, and data communications technology built into physical objects, enabling the objects to be tracked, coordinated or controlled across a data network or the Internet. The three main components for the Internet of Things are: the sensors and actuators that detect and communicate information; programming and analytical software; and data communications links. Wireless sensors, including Radio Frequency Identification (RFID) chips, usually operate on designated unlicensed spectrum. Wireless connections might be by cellular networks or microwave, using licensed frequencies, or over unlicensed frequencies.

The McKinsey report includes Intelligent Transportation Systems (ITS) as part of the Internet of Things. ITS relies heavily on sensors for vehicle-to-vehicle and vehicle-to-infrastructure communications. It uses spectrum assigned to the Department of Transportation (DOT) for ITS and other programs in DOT's Research and Innovative Technology Administration (RITA). The ITS program currently focuses on development of the connected car.[73] Applications for trucks and automobiles are oriented toward traffic safety, using vehicle-to-vehicle and vehicle-to-infrastructure, short-range communications systems.

Autonomous and Near-Autonomous Vehicles

An autonomous vehicle is defined by the McKinsey report as a vehicle that can move with little or no human intervention. Some autonomous applications are already familiar, such as autopilot in airplanes and self-parking cars. Key technologies for autonomous vehicles are machine vision systems, artificial intelligence, and sensors. The signals from machine vision and sensors are integrated through artificial intelligence to provide directions to vehicles. Similar applications are used to guide robots. The images captured through machine vision can be sent over wireless communications technologies such as gigabit Ethernet. For autonomous guidance systems, Ethernet operates on unlicensed WiFi frequencies or on higher frequencies for fixed (point-to-point) connections.

Unmanned Aerial Vehicles (UAV, or drones) are categorized by the McKinsey report as an autonomous or near-autonomous vehicle. UAVs are supported by Unmanned Aerial Systems (UAS), a complete system of communications and guidance technologies using terrestrial networks and satellites, and their radio frequencies. UAS technology is also, or can be, applied to maritime and terrestrial vehicles. Commercial UAS in the United States, where allowed, currently

[73] The Federal Highway Administration and other agencies within DOT are preparing for technology concept pilots. The Connected Vehicle Pilot Deployment Program will test innovations in connected vehicle and mobile device technologies with one or more pilots in 2015, https://www.federalregister.gov/articles/2014/03/12/2014-05414/connected-vehicle-pilot-deployment-program-request-for-information

operates over spectrum assigned to the Department of Defense and some frequencies assigned for amateur radio operators.[74]

Trains are another example of an autonomous or near-autonomous vehicle. They use guidance systems such as Positive Train Control (PTC), which is designed to use dedicated spectrum to communicate information and guidance to trains.

Advanced Robotics

According to the McKinsey report, robots excel at tasks that require superhuman speed, strength, stamina, or precision in a controlled environment. Advanced robots have greater mobility, dexterity, flexibility, and adaptability. They may have features such as high-definition machine vision and advanced image recognition, and can learn from and interact with humans. Robots can improve efficiency and safety in a variety of tasks as varied as sorting produce, performing high-precision, minimally invasive surgical procedures, or transporting heavy objects. A robot may be stationary, operated on a tether or track, or mobile. Communications requirements vary from environment to environment. A mobile robot operating in open spaces, for example, has different communications and spectrum needs than one controlled within an indoor space. Mobile robots operating with wireless sensors and communications connections have the potential to perform dangerous tasks that potentially jeopardize human life or health, including military combat.

Some advanced robotic systems incorporate existing wireless technologies that have spectrum allocations on unlicensed frequencies used for WiFi or RFID, or over infrared electromagnetic spectrum.

Policy Considerations

Some of the barriers to deploying new technologies are described in detail in the McKinsey report. Briefly, some of the main policy concerns—in addition to spectrum access—deal with

- Privacy.
- Data security.
- Education and training.
- Shifts in labor markets.
- Interaction of state and federal laws and regulations.
- Research and development.

These topics are outside the scope of this report but may need to be addressed in order to provide a hospitable environment for innovation in mobile technology.

[74] As required by Congress, the FAA has taken steps to accommodate the development of commercial UAS operations in the United States. For example, it has created a road map to plan for and document future UAS uses. Six sites have been chosen to test the possibility of allowing commercial drones and aircraft to share airspace, http://www.faa.gov/about/initiatives/uas/.

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