Communications and Society Program

Preparing for a 5G World

Richard Adler, Rapporteur

THE ASPEN INSTITUTE

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Charles M. Firestone
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This report is written from the perspective of an informed observer at the Aspen Institute Roundtable on Spectrum Policy.
Unless attributed to a particular person, none of the comments or ideas contained in this report should be taken as embodying the views or carrying the endorsement of any specific participant at the Roundtable.

Foreword

Since the late-1970s wireless telephone communication has seen a steady progression in speed, bandwidth and services offered to the public. The next generation of wireless innovation, called 5G, promises a significant leap in what it will provide in capacity, speed and performance for wireless networks, massive machine communications and the Internet of Things. Many companies and organizations have already begun to create and test 5G technologies and have made commitments to early deployment. Yet, this shift in technology raises a number of legal and regulatory issues that will have to be resolved, both domestically and internationally, to realize the full potential of this technology.

To address these regulatory (and related) issues, the 2015 Aspen Institute Roundtable on Spectrum Policy (AIRS) met October 26-28, 2015 at the Aspen/Wye River campus on the Eastern Shore of Maryland. Leading communications policy experts took a close look at the range of needs that 5G is intended to address, attempting to understand what the technological options are for meeting those needs. Participants then focused on defining the key policy issues raised by the move to 5G and recommended actions to address these concerns. Recommendations include:

1. **Improving Spectrum Availability and Efficiency.** AIRS participants called for reducing the timeline for availability of federal spectrum; opening access to high frequency bands needed for 5G networks; a "Post Incentive Auction Incentive Auction;" increasing spectrum sharing with the federal government; speeding up development of service, licensing and tech rules; fast tracking license modifications; creating certainty in spectrum enforcement; and addressing receiver issues.

2. **Accelerating Development and Deployment of 5G Networks.** Participants made specific recommendations to improve and streamline the process of 5G deployment; investing in 5G research, including R&D on cybersecurity; and establishing a wireless model city.

3. **Ways to Promote Wide Adoption of 5G Offerings.** The final set of recommendations focused on actions to leverage Universal Service Funds to expand 5G adoption; providing federal funding for a BTOP II; and encouraging adoption of 5G networks within key vertical industry sectors.

In the advancement of improvements to mobile communications, policymakers will need to respond to the burgeoning increase in demand for mobile services with significant investments in research, building new and improved infrastructure, accessing and sharing new swaths of spectrum, and in expanding the accessibility of 5G technologies. The ideas and recommendations of this report highlight the technological possibilities and policy options to achieve the necessary improvements that 5G will offer to American society.

As in all our Communications and Society Program roundtables, the rapporteur, in this case, Richard Adler, aims to make the issues accessible to the lay reader and reflect the insights and recommendations of the participants at the conference. The group did not take votes and many of the recommendations stemmed from individual working groups that met during the Roundtable. Accordingly, not every recommendation or statement reflects the views of all attendees or their employers. Rather they are the rapporteur's view of the general sense of the group.

Acknowledgments

I would like to acknowledge and thank the entities represented in this conference who have also contributed to the Communications and Society Program. They are AT&T, Cisco Systems, Google, Inc., Intel Corporation, LightSquared, Microsoft, New Street Research, Time Warner Cable, T-Mobile USA, Inc., Vanu, Inc., Verizon Communications and The Walt Disney Company.

I also want to thank Richard Adler, our rapporteur, for his extensive and informative account of the conference discussions; and our participants for their contributions to these complicated topics. Finally, I want to thank Ian Smalley, Senior Project Manager, for producing the conference and Dominique Harrison and Kiahna Cassell for editing this report.

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The Aspen Institute
May 2016

PREPARING FOR A 5G WORLD

Richard Adler

Preparing for a 5G World

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> Few technological developments hold as much potential to enhance America's economic competitiveness, create jobs and improve the quality of our lives as wireless high-speed access to the Internet.
>
> — Barack Obama,
> *Unleashing the Wireless Broadband Revolution*[1]

> Mobile broadband represents the convergence of the last two great disruptive technologies—Internet computing and mobile communications—and may be more transformative than either of these previous breakthroughs.
>
> — National Broadband Plan[2]

The explosive growth of wireless communications is an indicator of its importance. According to Cisco's Visual Networking Index (VNI), which tracks the growth of digital communications, "Mobile data traffic has grown 4,000-fold over the past ten years, and almost 400-million fold over the past 15 years." In just the past year, wireless data traffic grew 74 percent, from 2.1 exabyte per month at the end of 2014 to 3.7 exabyte per month at the end of 2015.[3]

In 2015, penetration reached 111 percent, meaning that there were more cell phone subscriptions than people in the United States.

In fact, the growth of wireless communications in the U.S., and globally, over the past three decades has been remarkable. In 1985, just 0.1

percent of Americans owned a mobile phone. Ten years later, penetration of cell phone had grown to 11 percent, and by 2005, two-thirds of all Americans had a mobile phone. In 2015, penetration reached 111 percent, meaning that there were more cell phone subscriptions than people in the United States.[4] Perhaps even more amazing, in 2014, mobile phone subscriptions globally surpassed the total number of people on earth.[5] At the same time, the uses of mobile telephony have expanded from simple voice communications to voice plus data (initially, just text messaging) to wireless broadband increasingly dominated by video content, not to mention an ever-expanding universe of specialized apps.

From 1G to 5G

To support the growth of wireless traffic and the demand for higher and higher performance networks, providers have migrated through successive generations of cellular technology, each of which has delivered a substantial increase in capacity and performance. Beginning with so-called 1G service first introduced in Japan in 1979 (and in the U.S. in 1983), a new generation of wireless technology has been introduced roughly once every decade, with the most recent generation, or 4G, introduced around 2010.[6] And today, even as 4G networks continue to be rolled out globally—having reached approximately 635 million users by the beginning of 2015 and projected to reach one billion by the end of this year[7]—attention has begun to focus on the next generation of wireless, or 5G.

But what is 5G? Unlike the previous generations of wireless standards, 5G is likely to consist of a set of different technologies, which will be introduced over time to supplement rather than wholly replace earlier generations of wireless technology to support a variety of emerging use cases.

Defining the standard (or the components of the standard) is a multi-year, multi-national process that is not scheduled to be completed until the year 2020 (see sidebar, "Development of a 5G Standard: ITU and 3GPP"). Discussions are already underway in a number of forums about what technical capabilities 5G will need to support, which, in turn, are driven by ideas about how current uses of mobile wireless will evolve and what new uses are likely to emerge.

Development of a 5G Standard: ITU and 3GPP

(as taken from www.itu.int/en)

Two international organizations—the International Telecommunications Union (ITU) and the 3GPP (3rd Generation Partnership Project)—are actively involved, among others, with defining the standard for 5G networks.

The ITU is the United Nations agency responsible for information and communication technologies. It allocates radio spectrum and satellite orbits and develops global technical standards. The ITU's Working Party 5D (WP5D), which is part of the ITU's Radiocommunication sector (ITU-R), is responsible for standard for International Mobile Telecommunications (IMT).

In early 2012, the ITU embarked on a program to develop "IMT for 2020 and beyond," setting the state for 5G research efforts now emerging around the world. The ITU is committed to completing work on the 5G standard, IMT-2020, by 2020.

In 2016-2017, WP5D will define in detail the performance requirements, evaluation criteria and methodology for the assessment of new IMT radio interface. It is anticipated that the timeframe for proposals will be determined in 2018.

In 2018-2020 the evaluation by independent external evaluation groups and definition of the new radio interfaces to be included in IMT-2020 will take place. WP5D also plans to hold a workshop in late 2017 that will allow for an explanation and discussion of performance requirements and evaluation criteria and methodology for candidate technologies for IMT-2020 that have been developed by WP5D, as well as to provide an opportunity for presentations by potential proponents for IMT-2020 in an informal setting.

The whole process is planned to be completed in 2020 when a draft new ITU-R Recommendation with detailed specifications for the new radio interfaces will be submitted for approval within ITU-R.

The 3GPP is an industry-based, multi-national technical organization whose members are national telecommunications organizations from the U.S., Europe, China, Japan, Korea and India that encompass approximately 500 companies and government agencies. 3GPP is a "sector member" of the ITU-R and is an active participant in WP5D's standards development process, including IMT-2020.

3GPP is committed to submitting a candidate technology to the IMT-2020 process. Specifically, it will meet the following ITU-R deadlines:

- Initial technology submission before the WP5D meeting in June 2019
- Detailed specification submission before the WP5D meeting in October 2020.

3GPP will submit its final specifications at the WP5D meeting in February 2020, based on functionally frozen specs available in December 2019. This early submission will allow time for the transposition of specifications by members of 3GPP prior to their own submissions to the IMT-2020 process before October 2020.

Although much remains to be defined, the broad contours of a 5G standard are becoming increasingly visible.

According to early indications, 5G will not represent a smooth, evolutionary improvement over the current standard, but will involve significant discontinuities from the earlier generations of wireless technology. And rather than being a single cohesive standard, it will likely consist of an array of different types of technologies that will support different use cases. This shift will likely confront policymakers both domestically and internationally with a number of novel legal and regulatory issues that will have to be resolved if the technology is to realize its full potential.

[5G] …will likely consist of an array of different types of technologies that will support different use cases.

Even though a full-fledged 5G standard remains several years off, it will begin to take shape over the next few years both through the initial work of the major international standards-setting bodies and in field trials and demonstrations conducted in many countries. Therefore, it seemed particularly timely for the Aspen Institute Roundtable on Spectrum Policy (AIRS) to explore the challenges of "Preparing for a 5G World" at its 2015 meeting.

The AIRS meeting began by taking a close look at the range of needs that 5G is intended to address, then attempting to understand what the technological options are for meeting those needs (essentially, the pieces out of which the new standard will be constructed). With this information as background, the AIRS participants focused on defining the key policy issues raised by the move to 5G and then attempted to recommend actions to address these issues.

As is often the case with emerging technologies, the question of timing kept coming up in the AIRS discussions. On the one hand, anticipating potential issues and creating a clear policy framework can provide developers with confidence about what the rules of the road will be. On the other hand, rules that are overly restrictive or are set prematurely can be counterproductive, inhibiting or distorting the optimal evolution of technology. The AIRS participants, who represented a wide range of perspectives and interests, attempted to steer a middle course between these two extremes in order to agree on a set of recommendations that would promote development of a successful 5G standard.

Insatiable Demand for Wireless

The explosive growth of mobile broadband is, as the National Broadband Plan noted, the result of the convergence of two big trends that started separately: digital computing and wireless communications. At first, computers were stand-alone devices dedicated to data processing tasks. Then they got connected. The benefits of linking computers together led to all sorts of new uses ranging from email and time-sharing to e-commerce and social networking. The invention of the World Wide Web and search engines like Google simplified the process of getting online and finding useful resources. The advent of high-speed broadband networks provided access to rich media like music, photos and video. The world became increasingly digital.

In parallel, the introduction of mobile phones expanded phone service from fixed locations to anywhere there was a wireless signal. The first mobile phones, introduced in the 1980s were bulky and expensive and just supported voice communications. As handsets got smaller, more versatile and more affordable, personal phone ownership spread from business executives to young people to nearly everyone. Today, there are 111 mobile phone subscriptions for every 100 American citizens (which means that the U.S. ranks 48th in the world in penetration, just below Zimbabwe and just above Jordan).[8] As mobile phones became more popular, they began to replace landlines, and by 2015, nearly half of all U.S. households had become wireless-only, up from just four percent of households in 2003.[9]

The introduction of smartphones in the 1990s marked the beginning of a true convergence between phones and computers. Today, more than 80 percent of mobile phones in the U.S. are smartphones,[10] and there are nearly two billion smartphone users globally.

…more than 80 percent of mobile phones in the U.S. are smartphones, and there are nearly two billion smartphone users globally.

With the emergence of 4G networks, the distinction between wired and wireless networks for computer communications largely disappeared. For many, a smartphone is not only a substitute for a landline but for a computer. And even for many who own a computer, their phones have become their primary means for staying connected with, navigating through and conducting business in the world.

In fact, we are increasingly in a "mobile first" world. In 2015, for example, in ten countries, including the U.S. and Japan, more Google searches originated from mobile devices than from computers.[11] Entire industries that had already "gone digital" in response to the rise of the Internet have had to refocus their strategies to give higher priority to the needs of mobile users.

In addition to the growth of mobile phone users, the emergence of new applications with new requirements, have helped to fuel the increase in demand for wireless connectivity—and are driving demand for higher performance networks (although each type of use places distinctive kinds of demands on networks):

Cell Phones in Daily Life

Americans, collectively, look at their smartphones eight billion times a day according to Deloitte's 2015 *Global Mobile Consumer Survey*.[12] Other findings from the survey document the extent to which smartphones have implicated themselves into our daily lives, literally from dawn to dusk:

- Close to half of all phone users (48 percent) check their phones at least 25 times per day, while 4 percent look at them more than 200 times a day.
- Nearly two thirds of American consumers (61 percent) sometimes, if not often, consult their phones when out shopping.
- Nearly half (47%) of consumers use their smartphones while talking to friends and family.
- Each morning, 43 percent of adults check their phone within five minutes of waking, while 17 percent check them "immediately after waking."
- At bedtime, 33 percent of adults check their phone within five minutes before going to sleep, and 13 percent look at them "immediately before going to sleep."

- ***Social media:*** As of January 2016, 934 million of Facebook's 1.4 billion active monthly users accessed the service by a mobile device, and almost half of its users (823 million) were mobile-only.[13] Fast growing messaging services like Snapchat, with 200 million users, Instagram, with over 400 million users, and WhatsApp, with more than one billion users worldwide, are entirely mobile apps. Increasingly, we expect to stay connected with others at any time and from any place.

- ***Mobile commerce:*** In 2015, nearly one-third of all e-commerce sales were mobile and were growing three times as fast as overall e-commerce sales.[14] A service like Uber, which provides more than one million rides per month in more than 50 different countries, depends on a mobile app. Virtually every major bank now offers mobile banking, while smartphone-based point of sale payment systems are becoming increasingly common. Retailers have been working hard to develop apps that can track mobile users and offer them special deals depending on their location.

- ***Mobile video:*** The strongest single driver of mobile traffic growth is the increasing popularity of bandwidth-intensive video. More than half of video viewing on YouTube is mobile, and fully 65 percent of Facebook's video views are now on mobile devices.[15] Within four months of its launch in February 2015, the live streaming video app, Periscope, attracted 10 million mobile users who watched a total of 21 million minutes of video per day.[16]

…we are increasingly in a "mobile first" world… in 2015, more Google searches originated from mobile devices than from computers.

By the end of 2012, video content was responsible for half of total mobile data traffic and was projected to increase 13-fold between 2014 and 2019 when it will account for nearly three-quarters of all mobile data traffic.[17] The growing popularity of HD video with its higher bandwidth requirements will further drive the growth in video traffic, while even newer applications like virtual reality (VR) will add to the demand for greater capacity

- ***The Internet of Things:*** First networks connected computers. Then they connected people. Now they are beginning to connect "things" of all sorts—appliances in homes, machines in factories, crops and animals on farms, cars on the road, etc. The Internet of Things promises to create smart homes, smart grids, smart cities that will be more efficient and better coordinated, saving time and energy while improving productivity. Within a decade, there will be millions and then billions of wirelessly connected things that can be monitored and controlled remotely and that will generate vast amounts of data that can be crunched to improve performance in new ways.

- ***The Cloud:*** As broadband access becomes more pervasive, it makes sense to augment the intelligence of local computing devices by connecting them with computing power and data repositories "in the cloud." Access to cloud-based resources provides benefits to both businesses and consumers and has become an important driver of mobile data traffic. According to Cisco, cloud-based applications are already responsible for more than 80 percent of mobile data traffic, and are expected to account for 90 percent by 2019.[18]

- ***Proliferation of smart wireless devices:*** Smart devices drive greater data traffic. While these devices represented just 26 percent of all mobile devices in use in 2014, they accounted for 88 percent of total mobile data traffic. In 2015, an average smartphone generated 41 times more traffic than a basic non-smart phone. Projections indicate that half of all mobile phone users worldwide will have a smartphone by 2018.[19] Other connected devices, including tablets, wearables and portable computers, will generate even more traffic.

Taken together, these factors have resulted in steady, rapid growth of mobile data traffic. As reported by Cisco in the latest (2016) version of its Visual Networking Index:

- Mobile data traffic has grown 4,000-fold over the past 10 years. Mobile networks carried fewer than 10 gigabytes per month in 2000, and less than 1 petabyte per month in 2005, but were carrying 3.7 exabytes per month at the end of 2015. (One exabyte is equivalent to one billion gigabytes, and one thousand petabytes.)

- Global mobile data traffic will grow eightfold between 2015 and 2020, increasing at a compound annual growth rate (CAGR) of 53 percent over this period, reaching 30.6 exabytes per month by 2020.[20]

Improving Performance to Keep Up with Demand

Expanding network capacity to meet the ever-growing demand for wireless connectivity is an ongoing challenge. But just as a number of factors have been responsible for increasing mobile traffic, a number of technical developments have been responsible for expanding network capacity to keep pace with demand.

The maximum number of voice conversations or equivalent data transactions that can be conducted in all of the useful radio spectrum over a given area doubles every 30 months.
- Cooper's Law

Fortunately, progress in improving performance of wireless communication has been steady and reliable. Martin Cooper, the inventor of the first mobile phone, having observed that the efficiency of wireless communication had been increasing at a constant rate since Marconi's discovery of radio transmission in 1895, promulgated Cooper's Law:

> The maximum number of voice conversations or equivalent data transactions that can be conducted in all of the useful radio spectrum over a given area doubles every 30 months.[21]

Like Moore's Law, Cooper's Law is not a law of nature. Continuous improvement in wireless performance does not happen automatically; it is the result of large investments in research and development of new techniques and technologies. The million-fold improvement in spectrum use that has been realized over the past 45 years is based on three main factors: making use of more spectrum, enhancing modulation techniques and (especially) reducing the size of cells. Let's consider each of these:

- ***Increasing spectrum allocation.*** One obvious way to meet a growing demand is to increase the amount of spectrum available for this purpose. Finding more spectrum for wireless broadband communications has become a high priority globally. But the spectrum is a finite resource and the most desirable portions of the spectrum have already been allocated and are mostly in use, either by the government or by commercial users for many purposes including mobile communications.

Over the past two decades, the FCC has conducted auctions as a means of increasing spectrum available for wireless communications, but costs are going up. The AWS-3 auction for 65 MHz of spectrum, which ended in January 2015, attracted $44.9 billion in bids, far in excess of the pre-auction estimates of $10 to $20 billion.[22]

- ***Improving modulation schemes.*** Engineers have developed a variety of techniques, including time division multiplexing and frequency division multiplexing, to cram more data into a given amount of spectrum. For example, the introduction of OFDM (orthogonal frequency-division multiplexing) in LTE, the current 4G standard, resulted in a very large reduction in the cost per bit per second for data transmission compared with the previous 3G standard. Modulation schemes can also provide significant reductions in latency (delay), which is critical for certain applications.

- ***Reducing cell size.*** Shrinking cell size makes it possible to accommodate many more users in the same geographic area and also to improve wireless performance. Over the past several decades, the maximum size of cells has shrunk from a radius of five miles under the 1G standard to just 300 yards under the current 4G standard. Cell size will continue to shrink as we move from macrocells to microcells and from microcells to picocells and femtocells that cover a single room or even a portion of a room.

  The cost of smaller cells has fallen as has the cost of backhaul (routing wireless traffic to land lines for access to the "core" network) on a per bit basis. However, the civil engineering work involved with installing cells is not declining as cell size decreases and the density of cells increases. In addition, the challenge of providing sufficient backhaul capacity managing wireless networks with ever-larger numbers of smaller cells is substantial.

An online discussion of Cooper's Law[23] noted that each of these three factors has contributed to the realization of the million-fold improvement in the way we use spectrum over the past half century: the availability of more spectrum was responsible for about a 25-times increase; better modulation techniques contributed to another 25-times improvement; and the ability to re-use spectrum by shrinking cell size resulted in a 1600-fold improvement in efficiency.

Other Approaches for Improving Wireless Performance

In addition to the three strategies discussed above, there are others that can be used to improve performance, according to Dennis Roberson, Vice Provost for Research at the Illinois Institute of Technology. He noted that each offers attractive benefits, but also has limitations:

- ***Offloading cellular traffic onto Wi-Fi.*** If all wireless data traffic had to be accommodated on cellular networks, user demand for connectivity would almost certainly have outstripped the system's capacity. But fortunately, there has been a widely available alternative—Wi-Fi, which offers two main advantages: it typically supports higher connection speeds than cellular networks, and it is generally free. Since Wi-Fi uses unlicensed spectrum, there is no definitive count of the number of hotspots in operation, but there are certainly millions of them in homes, offices and public locations. In 2015, for the first time, more than half (51 percent) of all wireless data traffic was carried over Wi-Fi rather than cellular networks.[24]

  Wi-Fi is not only widely deployed (Roberson noted that from a middle floor of the Sears Tower in Chicago, it is now possible to "see" some 6,000 Wi-Fi hotspots!), but its performance continues to improve through repeated technology upgrades. A substantial amount of spectrum has been allocated for unlicensed use, and many mobile devices, including smartphones, have the ability to switch from a cellular to a Wi-Fi network.

Currently, portions of the spectrum where Wi-Fi operates—especially in the 2.4 GHz band—is congested, which limits the ability of Wi-Fi to offload more cellular traffic. However, more capacity will be added as 5 GHz Wi-Fi comes online, and the FCC is considering allocating additional spectrum for unlicensed uses such as Wi-Fi.

- ***Spectrum Sharing.*** An emerging option for increasing capacity is the shared use of specific spectrum bands by different users. The 2012 report from the President's Council of Advisors on Science and Technology (PCAST) recommended that the federal government take the lead in opening up portions of the spectrum that are under its control for sharing with non-governmental users. The report called on the government to identify 1,000 MHz of federally controlled spectrum to create "the first shared-use spectrum superhighway," and described a number of technical approaches and management schemes for sharing that would enable the U.S. to "move spectrum access from scarcity to abundance."

  Techniques for sharing spectrum range from the tried and true (e.g., separating transmitters by geography and/or frequency), to sensing (e.g., dynamic frequency selection technology that enables Wi-Fi to avoid government radars in the 5 GHz band) to versions of sharing where a transmitter is given directions from a central database to avoid interference (e.g., TV white spaces data base, LSA/ASA in the 2.3 GHz band), to combinations of the above.

  Some promising actions have already been taken: In May 2015, the FCC authorized the creation of a Citizens Broadband Radio Service (CBRS) that would enable multi-tiered sharing of up to 150 MHz of spectrum in the 3.5 GHz band, which has been used by Department of Defense radar systems and for non-DOD commercial satellite communications.[25] And results from early testing of sharing schemes known as Licensed Shared Access (LSA) in Europe and Spectrum Access System (SAS) in the U.S. suggest the possibility of further increases in spectrum capacity for cellular services.[26]

Given the need to make more efficient use of spectrum, sharing technologies are likely to continue to develop in sophistication and capability.

- ***Millimeter Wave (mmW) and Massive MIMO.*** The portion of the spectrum from 30 to 300 gigahertz is generally characterized as "extremely high frequency" or millimeter wave (mmW) bands. According to the FCC, these frequencies "have historically been considered unsuitable for mobile applications because of propagation losses…and the inability of mmW signals to propagate around obstacles. [However,] technological advances hold promise of unlocking the potential of using mmW bands for mobile uses."[27]

  In fact, the characteristics of mmW that had previously seemed unattractive—short transmission paths and high propagation losses—could usefully contribute to supporting high performance transmission in small cells that can accommodate larger numbers of users. In addition, Massive MIMO antennas (arrays made up of hundreds or thousands of small antennas) are well suited to mmW signals and can be easily adapted to fit conventional mobile devices. mmW is likely to be a key element of 5G to support applications requiring very high capacity.

  On the other hand, while mmW is evolving rapidly, the technology is still in its infancy and is currently expensive to deploy and use. Although mmW will play a prominent role in improving wireless performance, particularly in areas with concentrated high demand, it will not fully replace the need for additional low band spectrum for 5G services.

- ***Bi-directional transmission.*** The ability to support full-duplex (bi-directional) operation on a single channel immediately doubles the data carrying capacity of an existing channel. The capacity has now been demonstrated for a radio to cancel out a high powered local transmit signal, enabling it to "see" a weak signal from a distant transmitter. The technique promises large gains in spectral efficiency, but the technology is relatively immature and still expensive. In addition it is unclear how

> broadly applicable this technique will be, for example, in environments where transmission is primarily in one direction (i.e., asymmetrical, as in the case of streaming video content).

Other potential approaches to expanding capacity and increasing performance include carrier aggregation, which combines multiple, smaller bands of spectrum into a single bigger band; hybrid services, such as LTE-U and LAA, that augment cellular services operating in licensed spectrum with unlicensed spectrum to improve performance; and updating policies that set limits on interference to reflect the use of new technologies to enable closer packing of wireless systems in terms of frequency, space or time.[28] Other innovations such as Software Defined Networks (SDNs) and Network Function Virtualization (NFV) that operate at higher levels of the wireless telecom protocol stack hold promise of granting additional flexibility for 5G networks, enabling them to support advanced services and provide capacity on demand.

Looming Deficits

Despite the promise of these technical and regulatory approaches to improving spectral efficiency and expanding the availability of spectrum, mobile usage will have to overcome shortages of some key wireless resources. For example, a few years ago, the FCC projected that strong, wireless data growth would lead to a "spectrum deficit" as early as 2013. Another looming problem is a shortage of backhaul—the side of the network that connects wireless users (usually by a wired connection) to the core network. A 2013 study by the firm Strategy Analytics projected a potential shortfall of up to 16 petabytes in backhaul capacity.[29]

Growth in wireless traffic has primarily been met by implementation of succeeding generations of technology, each substantially more capable than the previous generation. Two key performance metrics for these standards are the maximum *data rate*, which has moved from narrowband to broadband speed, and *latency*, the inherent delay between the time a signal enters and exits a network. Data rate determines the type of media that can be supported by a network, with rich media like video requiring broadband speeds (and lots of capacity). Latency is directly connected to the "naturalness" of communication between parties on a network, and also determines the responsiveness of online games. And it is critically important for applications related to such things as support for autonomous vehicles, which obviously depend on very quick response times to operate safely.

Wireless Network "Generations"

Generation	Technology Standard	Capabilities	Maximum data rate	Latency	Year introduced
1G	AMPS	Analog voice	<10 Kbps		1979 (Japan) 1983 (US)
2G	GSM, CDMA	Digital voice	64 Kbps		1991 (Finland)
2.5G	GPRS, EDGE	Digital voice + data	144 Kbps	600 ms	2001
3G	WCDMA, EvDO	Circuit switched data	2 Mbps	200 ms	2002 (S. Korea, US)
3.5G	HSDPA	Packet switched data	20 Mbps	170 ms	2008
4G	LTE	Wireless broadband	450 Mbps	<100 ms	2009 (Sweden)
5G	IMT-2020	Flexibility to address multiple use cases	> 1 Gbps	< 1 ms*	2020

** This is envisioned RAN latency, not e2e*

Moving Toward 5G

Much of the technical work involved with development of standards for cellular network technology in the United States is conducted through the 3rd Generation Partnership Project (3GPP) that brings together national standards-development organizations from the United States, Japan, China, India, Korea and Europe (the U.S. is represented by ATIS, the Alliance for Telecommunications Industry Solutions, which, in turn, is made up of 150 private companies, industry groups and government agencies). 3GPP's most important output has been a series of "releases" which contain the detailed specifications for each generation of wireless technology. For example, Release 8 in

2007 provided the basis for the LTE standard, while subsequent releases (9-11) have described enhancements and extensions to LTE.[30]

…among the high priority requirements for 5G are enabling "massive machine communications"….

3GPP is still primarily focused on further evolving LTE by incorporating new technologies such as channel aggregation, MIMO and dense heterogeneous networks. But even as the current standard continues to evolve (perhaps to a 4.5G standard), increasing attention is being given to the effort to develop the next-generation 5G standard. 3GPP kicked off this process in 2013 with a Future Mobile Summit that concluded that among the high priority requirements for 5G are enabling "massive machine communications" and supporting "ultra-reliable/low-latency communications" as well as "enhanced mobile broadband." The conference ended with a call for a network that can provide "perceived infinite capacity."[31]

Getting a Head Start on 5G Development

Even before a 5G standard is completed, many companies and organizations are actively developing and testing 5G technologies and have even made commitments to early deployments. As one observer noted, "Everyone is rushing to demonstrate they are a leading player for 5G."[32]

In the U.S., both Verizon and AT&T are testing advanced high-speed wireless technologies that will lay the groundwork for 5G, and Verizon announced that it will begin limited commercial deployments in 2017. In early 2016, Facebook announced that it was launching the Telecom Infra Project, an "engineering focused" effort to support open source development of 5G technologies by a consortium of companies that includes Intel, Nokia, Deutsche Telekom and SK Telecom.[33]

In Japan, NTT DoCoMo conducted a demonstration that used beam forming and millimeter wavelength bands to achieve transmission speeds in excess of 2 Gbps.[34] In the UK, University of Surrey opened a 5G Innovation Centre in 2015 that includes industry partners such as Huawei, O2, Vodafone, Samsung and Fujitsu. In China, the Academy of Telecommunication Research announced that it is undertaking a three-year program of 5G experimentation beginning in 2016, and plans to conduct field trials in 2018.

Beyond R&D projects, high profile 5G demonstrations are being planned by telecom providers to take place at major international sporting events, including the 2018 World Cup in Russia, the 2018 Commonwealth Games in Australia, the 2018 Winter Olympics in PyeongChang, South Korea and the 2020 Summer Olympics in Tokyo, Japan.

There are a number of basic questions related to a future 5G standard that remain unanswered. These include:

- Will 5G be revolutionary or evolutionary?
- Can a single standard effectively address the breadth of technical requirements?
- What will be the architecture for integrating low-, mid- and high-band spectrum?
- What new protocols, interfaces, channel models, security enforcement mechanisms, etc., will be required?
- Is a single 5G international standard feasible?

In reference to the last question, Mary Brown, Senior Director, Technology and Spectrum Policy of Cisco suggested that, given its size and global ambitions, "China will always do its own thing" when it comes to setting standards. Even though equipment vendors very much want a single international standard, China is likely to insist on having its own "flavor" of 5G for its domestic market. The U.S. has been working to achieve at least regional harmonization, particularly in the area of spectrum allocation and favors the creation of a relatively flexible framework that will allow different parties to make different choices within it.

One challenge to achieving global harmonization is that different countries "want so many different bands" that it will be difficult to accommodate all of them in a single schema. Hopefully, technical studies will provide a basis for guiding future choices. But there was considerable pressure for different countries and different interests to stake out positions at the ITU's 2015 World Radiocommunication Conference (WRC15) that took place in November 2015, in anticipation of the next iteration of the Conference in 2019 that will play an important role in shaping the 5G standard.

Another challenge to development of a unitary standard is that the wide range of use cases that have emerged for wireless communications may require a variety of technical solutions that will be difficult to encompass in a single standard. For example, Jeffrey Carlisle, Executive Vice President for Regulatory Affairs at LightSquared, questioned whether extremely high frequency mmW spectrum will be able to provide the density and ubiquity of access needed for applications such as autonomous vehicles, drones or the Internet of Things. Dennis Roberson responded by stating that while mmW technology is "new and shiny"—and will certainly be an important component of 5G—there will still be a need for lower frequency "beachfront spectrum," and 3G- and 4G-based networks will still be widely used for many years after introduction of 5G networks.

Dale Hatfield, Senior Fellow at the Silicon Flatirons Center at the University of Colorado, pointed out that there is inevitably a conflict between squeezing out the maximum capacity from a given bit of spectrum and providing for flexibility of use. Deciding on how usage of various parts of the spectrum will be regulated will require making decisions about that tradeoff, and may entail regulators abandoning strict neutrality. Peter Pitsch, Executive Director for Communications Policy at Intel, added that making such decisions is difficult as long as the ultimate uses for spectrum remain unclear. A regulatory agency like the FCC can encourage companies to invest in 5G technologies by developing a framework that gives them flexibility to balance business and technical tradeoffs as they become more apparent in the future, while eliminating regulatory uncertainty in the present.

Regulatory and Policy Goals for 5G

To provide a framework for recommendations for useful steps that government agencies and other key stakeholders could take, the Roundtable took a high-level look at goals for communications regulation that should help to shape regulators' actions related to development of a 5G standard.

Harold Feld, Senior Vice President of Public Knowledge, identified five sets of policy goals, some of which overlap or are redundant with others: 1) the goals of policy makers generally; 2) the public interest goals spelled out in the Communications Act of 1934 that still provides the basis for current regulation; 3) specific goals for regulation of wireless communications as spelled out in Section 309(j) of the 1934 Act; 4) newer goals that have emerged at the FCC in recent years in response to new challenges and new opportunities; and 5) goals of the National Telecommunications and Information Agency (NTIA) and other federal entities that contribute to determining the role that government should play.

Policy and Regulatory Goals that Could Inform Actions to Promote 5G

I. "Headline" goals for policymakers

   a. Ensure that the U.S. leads the world in development and deployment of new networks

   b. Support new opportunities in 5G, Internet of Things (whatever they are)

   c. Promote competition (however it is defined)

   d. Encourage "innovation" (whatever that means)

   e. Provide sufficient spectrum to support continued growth (500 MHz by 2020)

   f. Use mechanisms like auctions to optimize allocation of spectrum

II. Broad public interest goals of the Communications Act of 1934

   a. Provide service to all Americans

   b. Encourage use of new technologies

c. Support development and deployment of high-performance networks

d. Promote competition

e. Encourage diversity of ownership

f. Ensure public safety

III. Specific goals for wireless networks (Section 309j[35])

a. Development and rapid deployment of new technologies, products and services for the benefit of the public

b. Promote economic opportunity and competition and ensure that new and innovative technologies are readily available to the American people

c. Support efficient and intensive use of the electromagnetic spectrum; expand availability of spectrum for multiple uses

d. Promote diversity of ownership

IV. Additional FCC goals that have emerged over time

a. Increase flexibility and general use spectrum

b. Encourage spectrum sharing in line with the PCAST report (2012)

c. Improve service to underserved and traditionally marginalized communities

d. Improve affordability of communications services

e. Attempt to forecast new technologies and new uses

V. Goals for NTIA and other federal agencies

a. Protect public "assets"

b. Expand shared use of spectrum (PCAST model)

c. Pursue recommendations of Commerce Spectrum Management Advisory Committee (CSMAC) for enhancing efficiency of federal spectrum use[36]

d. Conduct research into new wireless technologies (including national security applications)

Some of these goals may, in fact, be inconsistent if not directly in conflict with others. For example, there is a potential for conflict between the desire to accelerate innovation with technology and efforts to provide for inclusiveness in the use of technology. Nicol Turner Lee, Vice President and Chief Research and Policy Officer of the Multicultural Media, Telecom and Internet Council (MMTC), noted that as technology keeps evolving, members of minority communities often have difficulty keeping up and run the risk of being excluded from full participation in society. She asked whether, as we move toward 5G, there are uses that will be particularly critical economically and socially that may need to be subsidized.

At the same time, other groups maintain that policies should not impose obstacles or burdens on providers that could inhibit investment and slow the process of development and deployment of new technologies. According to Carl Povelites, AVP for Public Policy at AT&T Services, Inc., policymakers should be aware that strategies such as requiring spectrum to be shared could act as a disincentive for investment. It is also important not to create barriers that will discourage new participants from entering the market.

…spectrum will certainly remain the most valuable asset, and the best way of dealing with it is by encouraging a "diversified portfolio" of uses, including both licensed and unlicensed users.
–Blair Levin

Avoiding playing favorites. Policymakers should avoid the temptation to create a single master plan for development of 5G. Michael Calabrese, Director of the Wireless Future Program at the New America Foundation, warned against trying to envision a "single integrated future" for 5G. Technology has evolved in unexpected ways and will continue to do so: no one foresaw the iPhone and the dominant role it would play in shaping the wireless environment, nor the way that cellular and Wi-Fi networks have played complementary roles for each other. Policy should create an environment that encourages innovation but should not try to anticipate the course that technology will take. Blair Levin, Non-Resident Senior Fellow at the Brookings Institution, added that spectrum will certainly remain the most valuable asset, and the best way of dealing with it is by encouraging a "diversified portfolio" of uses, including both licensed and unlicensed users. In essence, policymakers need to assure license holders that "they can win," and assure users of unlicensed spectrum that they can win as well.

The value of incentives. One way for policymakers to encourage "good things" to happen is by providing incentives. Even though nothing in the Communications Act explicitly addresses this topic, incentives are one concrete way to operationalize public policy goals. In terms of 5G, the question is "Incentives for what?" It may make sense to provide incentives to expand access for underserved communities (as the FCC's E-Rate does in subsidizing Internet access for schools and libraries), but policymakers should be wary of favoring specific technology applications over others. One of the most effective ways of supporting innovation is by supporting "general purpose networks."

The tricky issue of physical access. There are currently approximately 300,000 cell sites in the U.S.[37] But as 5G networks are deployed, and particularly those that make use of millimeter wave frequencies, sites will shrink in size and will grow exponentially in number of locations, perhaps to several million, with multiple sites within a single building.

A specific challenge to policymakers will be to ensure access for this vastly increased number of sites. Preston Marshall, Principal Wireless Architect at Google, argued for the importance of identifying and addressing existing institutional barriers that could interfere with deployment of the small cells that will be key to 5G's ability to increase wireless broadband capacity. As 5G cell size shrinks, it may well be necessary to establish access points not just on towers and/or on the tops of buildings, but to provide access on every floor in a building or within a single room. Thus, it may be necessary to ensure access to building interiors, including individual apartments in multi-dwelling units (MDUs). According to Dale Hatfield, getting access to real estate may be "the biggest policy problem in making high frequency spectrum useful." Michael Calabrese noted that some building owners may wish to maintain control over connectivity in their buildings and may not want to provide unrestricted access to their premises for commercial network providers. From a practical perspective, it may not be feasible to provide multiple access points in a single space. As Preston Marshall noted, "It is hard to imagine accommodating four different [5G] providers in each room." A more practical solution may be to provide some sort of shared facilities or to have one dominant provider in each space.

Tom Hazlett, Professor of Economics at Clemson University, noted that there is a difference between barriers provided by local governments and by individual property owners. The latter generally want the best technology available to their tenants since having good cell phone service is important to tenants, while local governments generally do not necessarily experience any painful opportunity costs for supporting a monopoly in service provision. With 80,000 local jurisdictions, each of which has the power to complicate 5G access, some sort of pre-emptive policy may be needed to prevent the erection of barriers to timely deployment of 5G networks. One possible precedent for ensuring access is the FCC's Over-the-Air Reception Devices (OTARD)–Rule, in effect since 1996, that pre-empts restrictions imposed by either landlords or zoning laws on the installation of antennas for satellite, broadband radio or broadcast TV service for personal use.[38]

A related challenge is expanding backhaul capacity to keep pace with the growth of wireless connectivity. Beyond simply establishing 5G points of presence in multiple locations, backhaul requires pathways to link these POPs with the core network, which will require additional investment. (Part of the solution for providing sufficient backhaul capacity may be to use portions of lower frequency bands to provide fixed wireless "infill backhaul.")

A final bottleneck that will need attention arises from the need to locate data near end users in order to reduce network latency—one of the key benefits of 5G networks. While this potential problem is "non-trivial," it may not be one that can or should be addressed by policymakers.

Roundtable Recommendations

To help the U.S. prepare for a 5G world, the Roundtable participants developed a set of recommendations in three categories—actions to increase the availability of needed spectrum; government policies to encourage deployment of 5G networks; and actions designed to promote adoption by underserved populations in order to create a more inclusive 5G "highway." Participants also identified potential vehicles to enable these changes. Before making specific recommendations, the participants spelled out a set of core principles or assumptions that provide a rationale for action:

> ***Demand is growing exponentially.*** As the number of users and uses continues to grow, there will continue to be strong demand for greater wireless capacity and higher performance networks. Policymakers need to act to provide additional spectrum and create an environment that encourages investment and innovation to meet this demand.
>
> ***Maintaining U.S. leadership is important.*** The U.S. was one of the first countries in the world to deploy 4G (LTE) technology on a large scale and currently has one of the highest rates of 4G penetration. Being a leader in 4G networks has promoted innovation in mobile services, which has resulted in substantial economic benefits for the U.S. For the U.S. to remain economically competitive, the country needs to maintain its leadership role in deployment of next generation networks.
>
> ***5G will be a platform for other platforms.*** As mobile access becomes important for more and more uses, wireless broadband provides the infrastructure that supports these applications. For example, a large portion of news and entertainment is now accessed by mobile devices and the "app economy" was made possible by the availability of wireless networks, and the same is true of the emerging Internet of Things. As pointed out previously, the world's "mobile first" world, and with their enhanced capabilities, 5G networks are likely to further accelerate this trend. The ability of 5G to serve as a "platform for other platforms" represents a factor that substantially increases its strategic importance.

Higher frequency bands and new technologies raise new issues. One portion of 5G will use the same bands and similar technologies as the current generation (4G) of wireless networks, which means that traditional technical and policymaking approaches will continue to be relevant. But the ability of 5G to keep up with growing demand and to support advanced services will depend on the use of higher frequency bands with distinctively different technical characteristics than existing services (including much greater capacity along with much shorter range), which offer new challenges for policymakers. For example, how should geographic territories be defined in licensing 5G networks (e.g., Does granting licenses for designated "regions" still make sense)? What does it mean to have exclusive rights to a frequency band in an environment where signals are transmitted by narrow "pencil" beams over relatively short distances? What are the implications for allowable power levels? What are the best ways to avoid interference while promoting maximum efficiency in spectrum use? What are new opportunities for spectrum sharing?

Uncertainty vs. Need for action. Timely action by policymakers will be important to allow the U.S. to maintain its momentum in wireless innovation. But many questions about characteristics of and requirements for 5G networks remain unanswered. Therefore, a key challenge for policymakers will be to act in a timely manner in a way that does not prematurely lock in (or lock out) particular technology options and that encourages experimentation with and investment in development of multiple, competing services.

Specific recommendations from the AIRS participants are as follows:

I. Recommendations Related to Improving Spectrum Availability and Efficiency

One of the clearest yet most challenging tasks for policymakers involves providing sufficient spectrum to support robust development of 5G networks and to ensure that it is being used as efficiently as possible. It is important to keep in mind that 5G will involve a combination of licensed and unlicensed spectrum, in both low frequency and high frequency bands, and that the rules governing 5G will need to address all of these alternatives. The AIRS participants made a number of recommendations for actions to A.) increase the availability of spectrum, especially in the higher frequency bands, and B.) improve the efficiency of spectrum use.

A. Expanding Availability of Spectrum

The response to recent FCC auctions clearly demonstrated the extent of the demand for additional spectrum. The government may need to do more to identify additional opportunities for reallocating or sharing spectrum in order to fulfill President Obama's 2010 directive to the NTIA, in consultation with the FCC, to take the lead in making a total of 500 MHz of Federal and non-Federal spectrum available by 2020. Recommendations from the AIRS group focused on efforts to spur additional action by agencies or commercial spectrum users, and on initiatives on specific bands, particularly for higher frequency spectrum that will be needed for 5G networks.

Reducing Timeline for Availability of Federal Spectrum

The Spectrum Relocation Fund (SPF) has played an important role in encouraging Federal agencies to repurpose spectrum and move applications to new bands by reimbursing them for costs associated with these activities. The recommendation from the AIRS group to further leverage the fund was incorporated in the Spectrum Pipeline Act of 2015 that was part of the end-of-the year budget deal between Congress and the Administration. The Act broadens the scope of reimbursable expenses, enabling agencies to use funds from the SRF to pay for research and related up-front activities that promise to increase spectrum efficiency and that could lead to repurposing of additional spectrum for commercial use. These modifications provide an additional $500 million in funding along with a mechanism to replenish the funding pool with proceeds from future actions.

Additional incentives may be needed to encourage federal agencies to do more. For example, proposed legislation titled Making Opportunities for Broadband Investment and Limiting Excessive and Needless Obstacles to Wireless (MOBILE NOW), introduced after passage of the Spectrum Pipeline Act at the end of 2015, would encourage agencies to move more rapidly in identifying spectrum that could be repurposed by requiring them "to quantify the 'opportunity cost' of holding onto their spectrum rather than putting it into the hands of the private market."[39]

Opening Access to High Frequency Bands Needed For 5G Networks

In the past year, the FCC has turned its attention to higher-frequency spectrum bands that will be needed for 5G networks. In October 2014, the FCC issued a Notice of Inquiry (NOI) on "Use of Spectrum Bands above 24 GHz for Mobile Radio Services"[40] that included both licensed and unlicensed bands. In the introduction to the NOI, the FCC noted that:

> Industry and technical groups are beginning to examine the use of higher frequencies sometimes known as millimeter wave (mmW) bands for mobile use. This examination of the possible uses of the mmW bands for mobile use takes place within the context of broader efforts to develop technical standards for so-called Fifth Generation (5G) mobile services. In view of the technological and marketplace developments outlined in this item, we seek to discern what frequency bands above 24 GHz would be most suitable for mobile services, and to begin developing a record on mobile service rules and a licensing framework for mobile services in those bands.

The NOI went on to explain that even though the specifics of a 5G standard were not yet defined, it was expected that it would support much higher performance with a 1000-fold increase in capacity along with much higher transmission rates and much lower latency times. But the Commission acknowledged that achieving these benefits will involve exploring unfamiliar territory and raise novel regulatory issues since 5G:

> …will likely require the development of new system architectures to include heterogeneous networks that will deliver service through multiple, widely-spaced frequency bands and diverse types of radio access technologies, including macrocells, microcells, device-to-device communications, new component technologies, and unlicensed as well as licensed transceivers. In

this context, bands above 24 GHz are typically considered not for stand-alone mobile services but as supplementary channels to deliver ultra-high data rates in specific places, as one component of service packages that will likely include continued use of lower bands to ensure ubiquitous coverage and continuous system-wide coordination.

Just one year later, on October 22, 2015—at almost the same time that the AIRS meeting was taking place—the FCC issued a Notice of Proposed Rulemaking (NPRM)[41] that focused on several bands above 24 GHz that had been tentatively identified in the earlier NOI, portions of which are currently allocated for federal government use while others are allocated for commercial use.

The FCC's overall goal in the NPRM is to "develop a flexible regulatory framework that will accommodate the widest possible variety of compatible services and will allow the market to determine the best possible uses of the mmW bands." The FCC also explained that it had selected specific bands for action that 1) offered at least 500 MHz of continuous spectrum; 2) were being considered internationally for mobile services; 3) would be compatible with existing users and uses; and 4) were suitable for establishing a flexible regulatory framework that would accommodate a wide variety of uses.

Participants in the AIRS meeting, who were cognizant of the FCC's pending action, made a series of recommendations for licensing changes in specific high frequency bands that were largely consistent with the FCC's goals and generally paralleled the proposals in the NPRM (see "Recommended Spectrum Licensing Actions: AIRS and FCC").

Recommendations from the AIRS participants related to these specific bands:

28 GHz and 39 GHz Bands. The portion of the 28 GHz band that the FCC is proposing to make available for "flexible use" (27.5-28.35 GHz) is primarily being used today for satellite uplinks and Local Multipoint Distribution Service (LMDS), a fixed, wireless point-to-multipoint technology that the FCC originally envisioned being used for digital television and data distribution ("wireless cable"), but eventually became a point-to-point wireless backhaul service.[42] In 1998 and 1999, the FCC

Recommended Spectrum Licensing Actions: AIRS and FCC

Band	Authorized uses/users	AIRS Recommendation	FCC NPRM October 22, 2015
28 GHz	Local Multipoint Distribution Services (LMDS) Fixed Satellite Services (FSS) No Federal use	- Should remain licensed - Give existing licensees greater flexibility - Auction very large overlay license for unassigned portion	We propose to authorize mobile operations in the 27.5-28.35 GHz band (28 GHz band) and the 38.6-40 GHz band (39 GHz band) with county-sized geographic area licenses. These bands could be suitable for deployment of high-capacity, high-throughput small cells as part of mobile broadband deployments. At the same time, we propose rules that would provide licensees with the flexibility to conduct fixed and/or mobile operations.
39 GHz	Fixed & Mobile Service Fixed Satellite Service (FSS) 39.5-40 GHz is co-primary for federal use, both fixed and mobile satellite	*Need mechanism for hold-outs	
37 GHz	Fixed and mobile Service Space Research Service Fixed Satellite Service NASA, NSF and military satellite ground stations	- FCC grants secondary rights regarding indoor use to real property owners (or in the alternative, create an unlicensed band) *Lawyers can litigate condo situations	We propose a hybrid licensing scheme that would grant operating rights by rule to property owners, while establishing geographic area licenses based on counties for outdoor use. This licensing mechanism would facilitate the deployment of advanced enterprise and industrial applications not suited to unlicensed spectrum or public network services, while also providing additional spectrum for more traditional cellular deployments.
Above 60 GHz	65-71 GHz authorized for Inter-Satellite Services (ISS), but none licensed now No authorized non-Federal uses in 64-71 GHz; non-licensed use authorized in 57-64 GHz Multiple Federal and non-Federal allocations	- Keep it as unlicensed - Adopt Enhanced Experimentation Regime - Allow greater experimentation in sensing and variable power *Because it is localized, related to geography *E.g., raising power level according to geographies - Build on what FCC has done in 60 GHz band	We propose to authorize operations in the 64-71 GHz band under Part 15 of our rules [for unlicensed low-power transmitters] based on the rules we recently adopted for the adjacent 57-64 GHz band. This action will provide more spectrum for unlicensed uses such as Wi-Fi-like "WiGig" operations.

held auctions for two LMDS licenses in each of 493 "basic trading areas" (BTAs) across the country. But despite high initial expectations for the technology, LDMS was not particularly successful and has been largely superseded by LTE (4G cellular) and WiMax services. Fixed satellite service (FSS) that involves transmission of programming from geostationary satellites to radio or television stations is designated as a secondary use for the band, and the FCC has granted licenses for 47 ground stations that serve as FSS gateways or uplinks. There are currently no primary Federal government allocations in this band.[43]

The 39 GHz band (38.6-40 GHz) has "co-primary allocation" for both fixed and mobile services, although the FCC previously held off authorizing mobile uses "until it conducted a separate proceeding to resolve…interference issues." Among other things, the band is currently used to provide fixed wireless backhaul. The Department of Defense and NASA have fixed (FSS) and mobile satellite systems (MSS) in 39.5-40 GHz.

The AIRS participants recommend that these bands should remain licensed, but that commercial license holders should be given additional flexibility to add mobile services, which was consistent with the proposed FCC rules. (In early 2016, Verizon leased LMDS and 39 GHz licenses from XO Communications in a number of markets in order to use for 5G testing.)

In addition to granting mobile rights to existing fixed service operators, the AIRS group noted that there is still a lot of unassigned spectrum in this band, and therefore, the FCC should make available a large overlay license for the unassigned portion of the band. (Such a license would grant the right to operate in the band in a given geographic region but would require the recipient to protect existing licensees' operations from harmful interference.)

37 GHz band. The 37 GHz band (37 GHz to 38.6 GHz) has no commercial users and the FCC has not adopted any terrestrial services rules for non-Federal operations in this band. It contains 1.6 GHz of contiguous spectrum that could support high data-rate transmissions. Current Federal users include NASA, which operates receiving earth stations in the band; NSF, which supports receiving stations for scientific observations; and the military. Although there are currently no commercial satellite users in this band, satellite operators have expressed opposition to mobile uses to protect their interest in possible future use of this band.

The AIRS group proposes that the FCC should grant secondary rights (in relation to Federal users) to real property owners for indoor use. Participants acknowledged that determining exactly how such rights would be implemented could be complicated, particularly in the case of condominiums where multiple owners live directly adjacent to one another and share ownership of common spaces. (Some AIRS participants questioned whether this concept was a good idea.)

60 GHz and Above. Unlicensed operations are allowed by the FCC in the 57-64 GHz band under Part 15 of its rules, while the band from 65-71 GHz has been identified as available for ISS satellite licenses (although none are currently in use). The AIRS recommendation is to keep this band unlicensed, but also to develop an "enhanced experimentation regime" that would encourage experiments in such things as the use of signal sensing and variable power levels. For example, it could be interesting to test the value of raising power limits in rural areas where there are few competing services. Because these very high frequency signals will be very short range, trying out such experimental uses should carry little risk of causing damage to others.

Establishing a "Post Incentive Auction Incentive Auction"

The FCC's first "incentive auction" is intended to encourage broadcast television license holders to voluntarily relinquish their spectrum usage rights in exchange for a share of the proceeds from the auction. First proposed in the 2010 National Broadband Plan and authorized by Congress in 2012, the Broadcast Incentive Auction is taking place in 2016. The total number of television stations that will end up selling their spectrum and going off the air depends on a rather complex set of formulas that the FCC is using to conduct the "reverse auction."[44] In some markets, just one station may be involved, while in other markets, up to half the stations in operation may be affected.

This auction will play a useful role in expanding the amount of spectrum available for other purposes, including 5G services, but it is unlikely to completely satisfy the demand for additional spectrum because it will not provide large amounts of very high frequency bandwidth. Therefore, the AIRS group recommends two further actions to follow this auction: First, immediately after conclusion of the Broadcast Incentive Auction, the FCC should commence a new proceeding to determine if action is needed to actively encourage private transactions between broadcasters who retain spectrum and other potential users. Second, not less than five years after the commencement of the Broadcast Incentive Auction, the Commission should schedule a date for another auction—a Post Incentive Auction Incentive Auction (PIAIA)—in coordination with a proceeding that would set a new broadcast standard that would enable broadcasters to deliver next generation (4K/8K) video while reducing bandwidth requirements for broadcast TV. The group also proposed that if the FCC found that over-the-air transmission of television programming accounted for less than a specified portion of all video distribution (including online video distribution), all remaining broadcast spectrum would be put up for mandatory auction, with the proceeds split between the license holders and the Federal Government under a formula for auction revenue sharing determined by the FCC. (This last proposal was somewhat controversial with some participants expressing concern about the impact of such an action on even a relatively small number of people who remain dependent on access to over-the-air broadcasts.)

B. Improving Efficiency in Spectrum Use

In addition to making more spectrum available, the AIRS participants made several recommendations related to improving the use of existing spectrum:

Increasing Spectrum Sharing with the Federal Government

The concept that portions of the spectrum should be, and can be, shared in order to meet the demand for wireless connectivity is now well accepted. As Paige Atkins, Associate Administrator for the Office of Spectrum Management at NTIA, put it, "As I think everyone is aware, the way forward is largely sharing." Although exclusive licensing will continue to be preferable for some uses, the ability to optimize spectrum use across the entire user base will almost certainly involve expanded sharing between federal and non-federal users. The Spectrum Relocation Fund (discussed above) provides incentives for federal agencies to clear portions of spectrum they control and make it available for other uses.

To date, most of the discussion around spectrum sharing has been focused on encouraging government agencies to share spectrum they control with private sector users. For example, the AWS-3 auction that took place in 2014/15 included bidding on shared use rights in two bands (1695-1710 MHz and 1755-1780 MHz),[45] and following the auction, NTIA set up an online portal to facilitate sharing of the 1695-1710 MHz band between carriers and federal agencies.

"As I think everyone is aware, the way forward is largely sharing." - ***Paige Atkins***

But spectrum sharing could be a two-way street: The AIRS participants called for the creation of incentives that would encourage private sector users to share their bands with the Federal Government. Such sharing would potentially lead to greater opportunities for repurposing spectrum for additional commercial access and could be used to satisfy localized Federal spectrum requirements that cannot be met by current Federal allocations. Possible incentives for private users to share with the government could include making such sharing count toward build out or renewal milestones for FCC licenses, or perhaps providing some kind of bidding credit or other financial incentive in exchange for making spectrum available for sharing. Another avenue could be to provide for secondary market leases for government access to commercially licensed spectrum via some kind of standardized agreement and nominal cost.

Speeding Up Development of Service, Licensing and Tech Rules

As the rate of technological change has increased, government agencies have struggled to develop and implement regulations quickly enough to keep pace. As a result, private sector companies eager to move ahead with new initiatives may be forced to wait until the regulatory environment is clarified. Although the government will not drive development of 5G technologies, at a minimum it should be responsible for making decisions in a sufficiently timely manner as to not hold back investments in its development. And as discussed below, government can also play a useful role in removing obstacles to the deployment of 5G networks.

Fast Tracking License Modifications

Since so many spectrum bands could potentially be part of 5G networks, for which demand seems virtually insatiable, the practical effect of 5G is to put all licenses in play. One means of promoting continued innovation is to provide greater flexibility in licensing schemes. Making it easier to modify an existing license to accommodate changing requirements will encourage new investments, reduce rent seeking behavior from incumbents, and shorten the time required to get to a final decision.

The AIRS group proposed development of a new License Modification Scheme that would allow any license holder to petition the FCC for a modification which would be deemed granted unless it were denied within six months. In cases where the proposed modification raised "complicated engineering issues," the Commission could extend the deadline for action by an additional three months.

Creating Certainty in Spectrum Enforcement

The problem of spectrum interference has become more complicated as the wireless operating environment has become more complex and dynamic, and changes may be needed to make spectrum enforcement more effective. A 2013 meeting of spectrum experts convened by the Silicon Flatirons Center at the University of Colorado noted that technological advances have led to the development of systems and devices that "operate with virtually unlimited numbers of waveforms…make concurrent use of multiple system architectures…and produce more 'noise-like' broadband digital signals that are often harder to detect, decipher, identify, and locate at a distance"—all of which can complicate the problem of enforcement. The group concluded that "the FCC's Enforcement Bureau is under resourced to adequately address radio spectrum issues, more resources must be committed to interference enforcement, and better distinctions need to be made about jurisdiction." Finally, the Flatirons meeting called for development of a new "a taxonomy of spectrum interference" to help guide the development of new regulations and new enforcement mechanisms.[46]

Addressing Receiver Issues

Interference problems in wireless communications often come from transmissions on an assigned band that "leak" or "spill over" into an adjacent channel. In order to optimize spectrum use and avoid the need for wide separation between spectrum users, the FCC requires manufacturers to incorporate filters in transmitters designed to minimize interference. However, even when adjacent signals that are operating legally within their assigned bands, interference can also arise due to poor filtering in receivers. But the FCC has never regulated the performance of receivers.

Improving efficiency of spectrum use will require dealing with the performance of receivers as well as transmitters. But regulating 5G receivers will be challenging since they will be increasingly complex: they will operate over multiple bands spread out widely in frequency, will operate over a far greater number of channels with widely different types of signals within these dispersed bands, and will even receive more than one channel simultaneously in order to improve performance by combining data being received on two channels (i.e., channel bonding). This means that to be effective, filters will need to be more complex, but they can play an important role in improving spectrum use.[47]

II. Recommendations Related to Accelerating Development and Deployment of 5G Networks

Beyond providing additional spectrum, the government can play other roles in facilitating the development new technologies in order to meet a range of policy goals. As noted above, the large and continually growing role of wireless communications in the country's social, political and economic lives provides a particularly strong rationale for action to encourage timely development of 5G networks. The AIRS participants developed specific recommendations for government action that would focus on promoting investment in 5G technologies, and facilitating deployment of 5G networks, mainly by removing unnecessary barriers.

Investing in 5G Research

The U.S. government can help accelerate the development of 5G through the direct investment of public funds in some targeted areas:

- ***Basic research.*** The U.S. government has traditionally provided support for basic research in many areas, a number of which are relevant to 5G. For example, the National Science Foundation is funding "fundamental research in wireless communications and wireless data networks [that is] paving the way for 5G wireless data networks and beyond."[48] Similarly, DARPA has sponsored a number of efforts aimed at achieving major breakthroughs in wireless communications such as the DARPA Spectrum Collaboration Grand Challenge announced in March 2013, that offers prizes for "developing smart systems that collaboratively, rather than competitively, adapt in real time to today's fast-changing, congested spectrum environment" through the use of advanced machine learning capabilities.[49] According to Doug Brake, Telecommunications Policy Analyst at the Information Technology and Innovation Foundation, another particularly promising area for basic wireless research is in the development of technology to support full-duplex communications.

- ***R&D on Cybersecurity.*** Threats to security represent a real Achilles Heel for the Internet, and wireless data communications bring with them additional vulnerabilities, including the ability of hackers to intercept mobile phone communications and the prospect of autonomous vehicles being compromised.[50] Unfortunately, increases in the sophistication and the frequency of breaches have outrun the ability to protect wireless users. Both the Department of Homeland Security and the Department of Defense have been actively involved in funding research related to cybersecurity, but much more remains to be done in this important area.

- ***Wireless Model City.*** The 2012 PCAST report recommended that a Wireless Model City be established in one or more urban locations to explore how "new technology will perform in an actual metropolitan setting with all of its related challenges, understand and define harmful interference, measure spectrum usage efficiencies and study propagation characteristics and waveforms"[51] of wireless networks. In addition to serving as a testbed for new concepts and new approaches, a Model City could be an ideal place for public/private partnerships. Although a workshop held by the FCC and NTIA on this topic in April 2015 generated interest in the concept, no funding has yet been made available to implement the program. AIRS participants agreed that the Wireless Model City project should be funded as a way to speed development of 5G technologies.[52]

Facilitating 5G Deployment

The 5G networks of the future will be different in some important ways from previous generations of wireless technology. For one thing, there will be distinct differences between those portions of 5G networks that operate below 6GHz and components that operate in the bands above 6GHz. Below 6 GHz, they will be relatively similar to existing 4G networks; but above 6 GHZ, the physical properties of higher frequency bands will lead to different economics, including higher costs, and greater device demands.

One of the most distinctive challenges of building out 5G networks will involve extending the current practice of "densifying" 4G networks by deploying much small cells. With 5G, there will be a need to deploy an unprecedented number of small cells in addition to deploying additional cellular towers that provide wide area wireless coverage. Network providers will need greater access to individual buildings, and very likely to multiple locations within buildings—to install high performance network points of presence which will need to be supported by high capacity backhaul facilities.

Because of these considerations, deployment of 5G may be much less uniform than previous generations of wireless networks, with the highest performance (and highest cost) elements likely to be limited, at least initially, to locations where demand for service is greatest. This could include commercial facilities, hospitals, stadiums, etc., rather than blanketing a given geographical area.

Specific recommendations to improve and streamline the process of 5G deployment are:

- ***Remove barriers to local siting of small cells and deployment of backhaul facilities.*** The problems caused by delays in decision making by local governments on the siting of cell towers is likely to be even greater with decisions on siting much larger numbers of small cells for 5G networks, as well as the need for much greater backhaul capacity in a much larger number of locations. While this is fundamentally a local problem, there was considerable discussion of the need for and appropriateness of higher-level action. One proposal was to have state governments to pre-empt local governments and give decision making authority to state public utility commissions—a step that would require legislative action by each of the states. Another option would be for the Federal Communications Commission to extend "shot clock" rules on the siting of cell towers that it enacted in 2009 to apply to decisions to cover 5G networks. (Under those rules, local or State governments have 90 days to act on collocation applications [that involve modifications to existing facilities] and 150 days for siting applications other than collocations, after which time service providers can commence legal action to force a decision.[53])

- ***Leverage rights of way.*** A "dig once" rule that requires installation of conduit to accommodate high speed transmission cables whenever highway or other construction work is being done has been described as a "no brainer policy" that would more than pay for itself by dramatically lowering the costs of laying new cable.[54] Blair Levin, lead author of the National Broadband Plan agreed that "dig once" is a good idea, but noted that it has been proposed many times (including by the 2010 NBP and most recently by the Broadband Opportunity Council Report[55] released in September 2015) without having been enacted. However, an executive order issued in 2012 did direct "federal agencies to ensure that broadband infrastructure projects coincide with highway construction whenever possible to reduce companies' costs of expanding their high-speed Internet networks," and a bill introduced in the last session of Congress that would "require states to consider installing broadband conduits at the same time federally funded highway projects are under construction" has attracted bi-partisan support.[56]

III. Recommendations to Promote Wide Adoption of 5G Offerings

Concerns about a "digital divide" have persisted for many years. As with earlier technologies, there are a number of groups who are likely to be "left behind" by the emergence of 5G networks. Among those who will be most affected are:

- Consumers for whom affordability is an issue and by whom the value proposition for 5G is not clearly understood
- Consumers who lack trust in the technology and in the marketplace
- Isolated and low-density population areas, i.e., rural residents impacted by a rural-urban "capacity divide" (as with 4G and landline broadband).

The introduction of new higher performance access that depends on high-frequency, shorter-range technologies will raise additional issues: the economics will change and potentially contribute to increased subscriber costs; mechanical access to premises becomes more complicated, as do demands on access devices; and backhaul becomes more expensive. As a result, developing business cases for use, particularly by "ordinary" consumers, will become more difficult, and we are likely to see more uneven deployment of 5G networks based on highly localized needs.

These new technological factors may further exacerbate the disparities between those who benefit from the technology and those who are left behind, with particular concern for:

- Those with lower income and in more remote locations
- Communities without access to sufficient backhaul capacity
- Communities where 5G could be beneficial (beyond video) for uses such as telemedicine or economic development, but that lack the market size to justify private investment.

A final set of recommendations focused on actions to address these concerns and to ensure that all segments of society, especially underserved populations and regions, have opportunities to adopt and use 5G networks.

Leverage Universal Service Funds to Expand 5G Adoption

The concept of providing "universal service" for all Americans is an old one, dating back more than a century. The 1934 Communications Act provided the FCC with the mandate of ensuring that communication services were available to "all the people of the United States," and the 1996 Telecommunications Act created the Universal Service Fund (USF) and directed the FCC to use these funds to "increase nationwide access to advanced telecommunications services." In 2014, the USF fund distributed a total of $7.8 billion.[57]

The AIRS group identified several ways in which the USF could be leveraged to expand access to 5G networks. In particular, they focused on two components of the USF, the Lifeline and E-Rate programs:

- ***Enhance Lifeline program to cover 5G networks.*** The lifeline program provides a subsidy to low-income Americans for a landline or cell phone service. As of 2012, 17 million households received a subsidy through the program. As wireless broadband becomes more important in people's lives and as the use of landlines continues to decrease, it makes sense for the Lifeline program to help pay for more advanced services such as 5G, perhaps by expanding the FCC's Low-Income Broadband Pilot Program.[58] (Another possibility would be to encourage private sector programs for 5G network access similar to Comcast's Internet Essentials program that has provided more than 500,000 low income families with low-cost broadband Internet connections.)

- ***Modify E-Rate rules to expand 5G infrastructure reach and adoption.*** The FCC's E-Rate program has played a significant role in enabling virtually all public schools and libraries in the U.S. to get connected to the Internet. But these institutions often become islands of connectivity in communities where broadband access remains limited. To overcome this problem, the AIRS participants recommended that the rules for E-Rate subsidies for fiber construction (self-provisioning) be modified to incentivize anchor institutions like schools and libraries to serve as interconnection points for the private sector or others in their communities in need of fiber access. These institutions would be allowed to sell their excess fiber at market rates in order to fund programs that close the "homework gap" by helping students who lack connectivity at home to get online, providing digital literacy training, or paying for tablets or other access devices for students.

Provide federal funding for a BTOP II

The Broadband Technology Opportunities Program (BTOP), which was part of the American Recovery and Reinvestment Act enacted in 2009, provided $7.2 billion to support expanded deployment of broadband networks in the U.S. The largest portion of these funds was devoted to infrastructure grants to "deliver broadband service through last mile or middle mile facilities to unserved and underserved [i.e., mostly rural] areas." As next-generation 5G networks begin to be rolled out, it may make sense to establish a new fund that would help ensure that these advanced facilities are deployed across the entire country.

One possibility suggested by the AIRS participants for areas that lack adequate access to fiber where there is no economic case for private investment in building backhaul capacity was for the government to provide public funds to pay for construction of middle mile fiber on an open access basis. Funding could come from a "leaseback program" where users would pay back the construction costs to enable the program to operate with no loss.

Encourage Adoption Of 5G Networks within Key Vertical Industry Sectors

Much of the value that advanced 5G networks will provide will be realized by enhancing the connectivity within specific sectors of the economy—healthcare, education, manufacturing, energy, agriculture, hospitality, transportation, etc. Think, for example, about the impact of rapidly emerging Internet of Things that will allow all sorts of companies and organizations to connect with and coordinate vast networks of devices or other elements on which their operations depend. Or the benefits of providing pervasive, seamless high-speed connectivity throughout a hospital or medical center, or within a large university or corporate campus. Or the potential gains in efficiency that will come from linking multiple systems in "smart cities."

Although use cases and adoption curves will differ greatly from sector to sector, they all share a common interest in taking advantage of the new capabilities that 5G networks will offer. And while each industry bears responsibility for advancing its own interests, it may make sense to support targeted pilots that can help assess the 5G value proposition for verticals (such as healthcare or education) that clearly have pubic interest benefits, as well as in industry segments that drive economic development.

IV. Vehicles for Action

Finally, the AIRS participants identified several possible mechanisms, other than already well-established regulatory rulemaking procedures, that could be helpful in focusing attention of 5G issues. One option would be a report on the potential of 5G that would update the National Broadband Plan (NBP) that was released by the FCC in 2010. Although the original Plan did deal with wireless issues—its recommendations included expanding spectrum access, implementing a "dig once" policy, and establishing a Mobility Fund—it was published at a time when the prevailing wireless standard was 3G and just before 4G was launched in the U.S. The AIRS group took note of the fact that a written report has several inherent limitations: it is not dynamic and cannot adopt to changing circumstances (which is why an update of the NBP may now be needed), and a plan is not self-executing and runs the risk of simply being put on a shelf to gather dust. Still, a plan that contains specific actionable recommendations and has constituency to back it can be an effective tool for galvanizing action, as was the case with several spectrum recommendations from the NBP that were successfully implemented.

An alternative strategy that might be more impactful would be to task a multi-stakeholder group with identifying needed actions and then working to support the timely development, deployment and adoption of 5G networks. Several different types of groups were identified: One option would be to create a high level public/private executive committee to recommend actions by the FCC and other agencies and the administration as well as to propose needed legislation in support of 5G network development. A second option would be to establish a joint federal/state/local board that would be specifically charged with recommending actions for overcoming potential obstacles to the deployment of the large number of small cells that will be a distinctive component of 5G networks.

A third option would be to continue to build on the accomplishments of the Commerce Spectrum Management Advisory Committee (CSMAC), whose stated mission is to provide NTIA with "advice and recommendation on a broad range of spectrum-related issues." The Committee, which is made up of approximately two dozen "spectrum policy experts" from private industry, academia, and public interest groups, was set up in 2004 but made its most important contribution when it was asked by the NTIA Administrator to make recommendations for reallocating significant amounts of federally-controlled spectrum for commercial use. The Committee formed working groups, each of which focused on specific spectrum bands (including 1695-1710 MHz and 1755-1850 MHz). In 2013, the working groups issued a set of reports to the FCC that contained detailed roadmaps for reallocating spectrum in those bands.[59] These efforts provided the basis for the FCC's AWS-3 auction, which represented an important step in opening new spectrum for private use. Going forward, this group could be asked to focus on key spectrum issues related to 5G, including making additional federal spectrum available and addressing issues related to the compatibility of shared spectrum.

Conclusion

The full specification of a 5G standard is still several years in the future, but a good deal of effort is already underway to lay the groundwork for its implementation. Domestic and international bodies are already at work on defining the standard, with a goal of completing their work in 2020. Regulatory bodies have started to free up additional spectrum, particularly in the higher frequency bands that will be needed for 5G networks. A number of R&D efforts and field trials of key 5G components have been undertaken or planned by equipment makers and network operators, and more will get underway in the near future. But as this report has shown, 5G will raise a number of novel policy issues that have not yet been adequately addressed. If the U.S. is to retain its role as a global leader in wireless communications in a 5G world, the time for action is now.

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APPENDIX

Preparing for a 5G World

Queenstown, Maryland
October 26-28, 2015

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Richard Adler is a Distinguished Fellow at the Institute for the Future, Palo Alto. He is also president of People & Technology, a consulting firm located in Silicon Valley. His research and writing have focused on the impact of new technologies on fields including business, education, healthcare and aging.

Richard is the author of numerous reports for the Aspen Program on Communications & Society, including: *Rethinking Communications Regulation* (2013); *Updating Rules of the Digital Road: Privacy, Security, Intellectual Property* (2012); *News Cities: The Next Generation of Healthy Informed Communities* (2011); *Media and Democracy* (2009); *m-Powering India: Mobile Communications for Inclusive Growth* (2008); and *Minds on Fire: Enhancing India's Knowledge Workforce* (2007). He wrote the initial draft of the report from the Aspen Institute Task Force on Learning and the Internet, *Learner at the Center of the Networked World* (2014).

Richard is also the author of the reports from each of the Aspen Roundtables on Institutional Innovation: *Navigating Continual Disruption* (2015); *Fragmentation and Concentration in the New Digital Environment* (2014); *Connecting the Edges* (2013); *Institutional Innovation: Oxymoron or Imperative?* (2012); *Solving the Dilbert Paradox* (2011); *Leveraging the Talent-Driven Firm* (2010); and *Talent Reframed* (2009).

Other publications include *Catalyzing Technology to Support Family Caregivers* (NAC, 2014); *After Broadband: Imagining Hyperconnected Futures* (Wharton, 2012); and *Healthcare Unplugged: The Evolving Role of Wireless Technology* (California HealthCare Foundation, 2007) as well as two articles on the future of higher education co-authored with John Seely Brown. In 2014-15, he contributed a series of columns to Computerworld on the future of broadband technology.

Richard is Fellow of the World Demographic Association and serves on a number of local and national boards. He holds a BA from Harvard, an MA from the University of California at Berkeley, and an MBA from the McLaren School of Business at the University of San Francisco.

About the Communications and Society Program

www.aspeninstitute.org/c&s

The Communications and Society Program is an active venue for framing policies and developing recommendations in the information and communications fields. We provide a multidisciplinary space where veteran and emerging decision-makers can develop new approaches and suggestions for communications policy. The Program enables global leaders and experts to explore new concepts, exchange insights, develop meaningful networks, and find personal growth, all for the betterment of society.

The Program's projects range across many areas of information, communications, and media policy. Our activities focus on issues of open and innovative governance, public diplomacy, institutional innovation, broadband and spectrum management, as well as the future of content, issues of race and diversity, and the free flow of digital goods, services, and ideas across borders.

Most conferences employ the signature Aspen Institute seminar format: approximately 25 leaders from diverse disciplines and perspectives engaged in a moderated roundtable dialogue, with the goal of driving the agenda to specific conclusions and recommendations. The program distributes our conference reports and other materials to key policymakers, opinion leaders, and the public in the United States and around the world. We also use the Internet and social media to inform and ignite broader conversations that foster greater participation in the democratic process.

The Program's Executive Director is Charles M. Firestone. He has served in this capacity since 1989 and also as Executive Vice President of the Aspen Institute. Prior to joining the Aspen Institute, Mr. Firestone was a communications attorney and law professor who has argued cases before the United States Supreme Court. He is a former director of the UCLA Communications Law Program, first president of the Los Angeles Board of Telecommunications Commissioners, and an appellate attorney for the U.S. Federal Communications Commission.

Select Publications from the Aspen Institute Communications Policy Project

Skirting Bottlenecks: Policies to Support Network Evolution, Digital Inclusion and Data Security, by John B. Horrigan

The Thirtieth Annual Aspen Institute Conference on Communications Policy, titled "The Future of Broadband Competition," took place on August 12-15, 2015 in Aspen, CO. Robust competition among communications providers has always been a crucial goal for policymakers, leading to robust, innovative and efficient delivery of services. But what does the competitive communications marketplace of the future look like? 32 leading communications policy leaders and experts gathered in Aspen to investigate policy goals that can ensure this robust, competitive marketplace, and consider how broadband markets can promise delivery of economic and social benefits that improve the quality of life in America for all. The report, written by rapporteur John B. Horrigan, offers five recommendations for the future of broadband competition. 2016, pages, ISBN Paper: 0-89843-643-5 , $12.00

Making Waves: Alternative Paths to Flexible Use Spectrum, by Dorothy Robyn

The 2014 Aspen Institute Roundtable on Spectrum Policy (AIRS) gathered 26 of the top telecommunications policy experts at the Aspen Wye River Conference center in Queenstown, MD, to investigate whether the U.S., in light of recent progress in alternative approaches to spectrum allocation, should make the more drastic move to a regime that has all spectrum, other than some carved out for specific public benefit, to be considered general use spectrum eligible for the highest and best use available. The report, written by Roundtable rapporteur, Dorothy Robyn, tackles the task of describing what general purpose spectrum actually is; discusses the practical, political and institutional limits and ways to overcome them; and details the necessary technical advances and regulatory actions to make general purpose spectrum a reality. 2015, 68 pages, ISBN Paper: 0-89843-625-7, $12.00

The Atomic Age of Data: Policies for the Internet of Things, by Ellen P. Goodman

The Twenty-Ninth Annual Aspen Institute Conference on Communications Policy, titled "Developing Policies for the Internet of Things," took place August 13-16, 2014 in Aspen, CO. As the world becomes increasingly connected and more objects become embedded with sensors, the Internet of Things is poised to explode, with estimates of 25 billion connected devices by 2020. 35 knowledgeable participants gathered to examine how specifically should communications policies accommodate the new Internet of Everything? This report explores the nascent promises and challenges of the IoT. In examining the interplay between the vast increase in data created on the Internet of Things (IoT), and the resultant strain on the networks that carry this information, and the group came to a realization. Data needs to be thought of as "infrastructure." 2015, 72 pages, ISBN Paper: 0-89843-623-0, $12.00

Video Veritas: Building a 21st Century Video Platform for a High-Performance Society, by John B. Horrigan

The Twenty-Eighth Annual Aspen Institute Conference on Communications Policy focused on the future of video regulation. The resulting report, written by John B. Horrigan, looks at the changing landscape of video regulation and the fundamental shift in how video is being viewed. While cable and broadcast television continue to be the dominant modes of transmission, over the top delivery of content via the Internet provides new ways to distribute personalized and targeted programming directly to the viewer. This, and the proliferation of mobile devices and tablets can deliver video to the viewer anywhere, anytime. As a result, the advertising-based broadcast business model is undergoing significant challenge and change. This report examines the evolving video ecosystem and offers recommendations for policy that can accommodate the new video market. 2014, 54 pages, ISBN Paper: 0-89843-603-6, $12.00

Spectrum as a Resource for Enabling Innovation Policy, by William Webb

The 2012 Aspen Institute Roundtable on Spectrum Policy (AIRS) convened shortly after the presidential election to consider ways that spectrum policy could improve the economy through innovation. The

32 leading communications policy experts in attendance focused on how spectrum policies could help create an environment that makes it easier to use spectrum as a resource for innovative new goods and services. The participants first identified problems facing new entry and innovation today, and then recommended solutions, looking specifically at the interstices among licensed and unlicensed approaches, spectrum sharing and flexibility, and new institutional arrangements to manage these solutions. The report, written by British spectrum expert William Webb, sets forth 11 recommendations that he gleaned from the conference dialogue to guide future spectrum policy development with regard to facilitating innovation. 2013, 45 pages, ISBN Paper: 0-89843-584-6, $12.00

Rethinking Communications Regulation, by Richard Adler

As the Internet and other information and communications technologies grow exponentially, and as a new ecosystem is emerging that could conflate previously distinct methods of communication into a single digital medium, questions arise as to whether the traditional silos of regulation are still appropriate. The report resulting from the 27th Annual Aspen Institute Communications Policy Conference addresses the overarching concern as to whether the Communications Act needs a radical revision. Written by rapporteur Richard Adler, the report considers the key goals of a new communications regime and offers regulatory and non-regulatory approaches for achieving these goals in a digitally connected world. 2013, 65 pages, ISBN Paper: 0-89843-583-8, $12.00

The Reallocation Imperative: A New Vision for Spectrum Policy, by Preston Marshall

The report resulting from the 2011 Aspen Institute Roundtable on Spectrum Policy addresses new ways of allocating, clearing, using and/or sharing spectrum controlled by private parties and government agencies. Written by rapporteur Preston Marshall, the report attempts to step back and establish a broad vision for reallocating spectrum in the United States in the public interest, discussing new approaches that will facilitate more effective and efficient spectrum use. A number of recommendations are laid forth to guide future spectrum policy development, Congressional actions, and technology explorations. 2012, 54 pages, ISBN Paper: 0-89843-570-6, $12.00

Updating Rules of the Digital Road: Privacy, Security, Intellectual Property, by Richard Adler

Given the current growth and importance of the Internet, the report of the 2011 Aspen Institute Conference on Communications Policy titled *Updating Rules of the Digital Road: Privacy, Security, Intellectual Property*, highlights the elements that will allow for greater use of broadband as the common medium: security, privacy and intellectual property regulation. Written by rapporteur Richard Adler, the report explores a range of threats that plague the use of today's communications media and provides a series of recommendations which aim to ensure that users' communications are secure, private and protected.

The report reflects the issues and ideas raised by business leaders, academics, and policy experts at the Twenty-Sixth Annual Aspen Institute Conference on Communications Policy. 2012, 70 pages, ISBN Paper: 0-89843-563-3, $12.00

Spectrum for the Next Generation of Wireless, by Mark MacCarthy

Spectrum for the Next Generation of Wireless explores possible sources of spectrum, looking specifically at incentives or other measures to assure that spectrum finds its highest and best use. It includes a number of recommendations, both private and federal, of where and how spectrum can be repurposed for wireless use. In November 2010, the Aspen Institute Communications and Society Program convened the Aspen Institute Roundtable on Spectrum Policy, where 31 experts and leaders addressed the consequences and solutions to the increasing demand for spectrum. Spectrum for the Next Generation of Wireless is the report resulting from the Roundtable discussions. 2011, 68 pages, ISBN Paper: 0-89843-551-X, $12.00

Rewriting Broadband Regulation, by David Bollier

The report of the 25th Annual Aspen Institute Conference on Communications Policy in Aspen, Colorado, considers how the United States should reform its broadband regulatory system. Participants looked at international models and examples and examined how data and communications should be protected in the international arena. The resulting report explores a range of policies for U.S. broadband regulation, many of them derivative of the National Broadband Plan adopted by the Federal Communications Commission only a few months before the conference.

Participants also ventured into new and interesting territory with the novel concept of "digital embassies." They saw this as a way of dealing with jurisdictional issues associated with the treatment and protection of data in the cloud, i.e., data that is provided in one country but stored or manipulated in another. The concept is that the data would be treated throughout as if it were in a kind of virtual embassy, where the citizenship of the data (i.e., legal treatment) goes along with the data. This policy seed has since been cultivated in various other regulatory environments. 2011, 37 Pages, ISBN Paper: 0-89843-548-X, $12.00

Scenarios for a National Broadband Policy, by David Bollier

The report of the 24th Annual Aspen Institute Conference on Communications Policy in Aspen, Colorado, captures the scenario building process that participants used to map four imaginary scenarios of how the economy and society might evolve in the future, and the implications for broadband policy. It identifies how certain trends—economic, political, cultural, and technological—might require specific types of government policy intervention or action. 2010, 52 pages, ISBN Paper: 0-89843-517-X, $12.00

Rethinking Spectrum Policy: A Fiber Intensive Wireless Architecture, by Mark MacCarthy

Rethinking Spectrum Policy: A Fiber Intensive Wireless Architecture is the report resulting from the Aspen Institute Roundtable on Spectrum Policy, held at the Aspen Wye River Conference Center in November 2009. Written by rapporteur Mark MacCarthy, the report captures the insights of the participants, exploring innovative ways to respond to the projections of exponential growth in the demand for wireless services and additional spectrum. In addition to discussing spectrum reallocations, improved receivers, shared use and secondary markets as important components for meeting demand, the report also examines opportunities for changes in network architecture, such as shifting the mix between fiber and wireless. 2010, 58 pages, ISBN Paper: 0-89843-520-X, $12.00

ICT: The 21st Century Transitional Initiative, by Simon Wilkie

The report of the 23rd Annual Aspen Institute Conference on Communications Policy in Aspen, Colorado addresses how the United States can leverage information and communications technologies (ICT) to help stimulate the economy and establish long-term economic growth. The report, written by Roundtable rapporteur Simon Wilkie, details the Aspen Plan, as developed in the summer of 2008, prior to the economic meltdown beginning in September 2008 and prior to the election of Barack Obama as President. The Plan recommends how the Federal Government—through executive leadership, government services and investment—can leverage ICTs to serve the double bottom line of stimulating the economy and serving crucial social needs such as energy efficiency and environmental stewardship. 2009, 80 pages, ISBN Paper: 0-89843-500-5, $12.00

A Framework for a National Broadband Policy, by Philip J. Weiser

While the importance of broadband access to functioning modern society is now clear, millions of Americans remain unconnected, and Washington has not yet presented any clear plan for fixing the problem.

Condensing discussions from the 2008 Conference on Communications Policy and Aspen Institute Roundtable on Spectrum Policy (AIRS) into a single report, Professor Philip Weiser of the University of Colorado at Boulder offers a series of specific and concrete policy recommendations for expanding access, affordability, and adoption of broadband in the United States. 2008, 94 pages, ISBN Paper: 0-89843-484-X, $12.00

The Future of Video: New Approaches to Communications Regulation, by Philip J. Weiser

As the converged worlds of telecommunications and information are changing the way most Americans receive and relate to video entertainment and information, the regulatory regimes governing their delivery have not changed in tune with the times. These changes raise several crucial questions: Is there a comprehensive way to consider the next generation of video delivery? What needs to change to bring about a regulatory regime appropriate to the new world of video? The report of the 21st Annual Conference on Communications Policy in Aspen, Colorado, outlines a series of important issues related to the emergence of a new video marketplace based on the promise of Internet technology and offers recommendations for guiding it into the years ahead. 2006, 70 pages, ISBN Paper: 0-89843-458-0, $12.00

Clearing the Air: Convergence and the Safety Enterprise, by Philip J. Weiser

The report describes the communications problems facing the safety enterprise community and their potential solutions. The report offers several steps toward a solution, focusing on integrating communications across the safety sector on an Internet-Protocol-based backbone network, which could include existing radio systems and thus make systems more dependable during emergencies and reduce costs by taking advantage of economies of scale. The conference participants stressed that the greatest barriers to these advances were not due to lagging technology but to cultural reluctance in adopting recent advances. Writes Weiser, "The public safety community should migrate away from its traditional reliance on specialized equipment and embrace an integrated broadband infrastructure that will leverage technological innovations routinely being used in commercial sectors and the military." 2006, 55 pages, ISBN Paper: 0-89843-4, $12.00

Reforming Telecommunications Regulation, by Robert M. Entman

The report of the 19th Annual Aspen Institute Conference on Telecommunications Policy describes how the telecommunications regulatory regime in the United States will need to change as a result of technological advances and competition among broadband digital subscriber lines (DSL), cable modems, and other players, such as wireless broadband providers. The report proposes major revisions of the Communications Act and FCC regulations and suggests an interim transitional scheme toward ultimate deregulation of basic telecommunications, revising the current method for universal service subsidies, and changing the way regulators look at rural communications. 2005, 47 pages, ISBN Paper: 0-89843-428-9, $12.00

Reports can be ordered online at *www.aspeninstitute.org/publications* or by sending an email request to *publications@aspeninstitute.org.*