Wireless Telecommunications Policy for American Leadership in the 21st Century

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Within a single generation, human connectedness has become radically more intense, purposive, and far-ranging than ever before. Early forms of desktop computers and mobile cellular telephones were successfully introduced in the United States in the 1980s; smartphones, tablets, mobile broadband internet, and Wi-Fi appeared in the 2000s. Today 90% of adult Americans own a mobile phone (mostly smartphones), 70% own a desktop or mobile personal computer, 45% own a mobile tablet, and 75% of households have high-speed internet (65% with Wi-Fi); and all of those technologies are ubiquitous at work and in public places.

With them, we exchange more than 7 billion text and email messages every day, routinely correspond at social-media sites, shop and bank and navigate, conduct business, share documents and photos and videos, report emergencies, access news, sports, entertainment, and personal health information, and through internet search have the entirety of recorded human knowledge at our fingertips and voice command. On average, we are online six hours a day.[118]

This transformation has profoundly affected personal, family, and social life, business and finance, science and engineering, and politics and government. It has powered innovation in critical fields such as the biological sciences and energy exploration and development. And it is at the heart of many innovations now under development, such as autonomous cars and other vehicles, long-distance medicine and learning, and the "Internet of Things"—the deployment of remote sensors throughout transportation networks, water systems, farms, factories, buildings, hospitals, households, the electric grid, and the atmosphere for purposes of continuous monitoring, coordination, and adjustment.

The communications revolution is, however, being hobbled by outdated government policies. All wireless communications, whether between persons or things, employ channels of the electromagnetic-frequency spectrum, which have long been allocated and regulated by the Federal Communications Commission. FCC policies crafted in the age of radio broadcasting have proven wholly inadequate to the far more intense spectrum demands of universal high-capacity wireless networks. The commission has responded with important policy innovations — since the early 1990s, it has liberalized the terms of certain of its spectrum licenses, which has made way for the construction of our current cellular telephone and broadband infrastructure; conducted spectrum auctions, which have moved unused and underused spectrum into the new wireless economy; and reserved ample "unlicensed spectrum" for short-range uses such as Wi-Fi. Yet regulatory innovation has not kept pace with wireless innovation and is falling progressively further behind.

The time is ripe, and urgent, for the fundamental next step in spectrum liberalization — all-purpose spectrum licenses. Holders of licenses would be permitted to use their frequencies for any purpose. Current license restrictions, which limit each holder to a narrow purpose, would simply be removed. The reform would dramatically extend and accelerate the FCC's recent reforms. Its social and economic benefits would be immediate and palpable. It is politically feasible and could be accomplished in a stroke.

BACKGROUND

"Radio waves" is the conventional term for the portion of the electromagnetic spectrum suitable for transmitting information (with much lower frequencies and longer wavelengths than those of visible light).[119] Radio waves are the medium for all wireless communication — radar, broadcast television, garage-door openers, sending photo images from Pluto back to Earth. Almost all uses require a spectrum license from the FCC (not including garage-door openers, an example of "unlicensed spectrum"). License details vary from case to case, but they typically specify the spectrum frequency band and, within it, the bandwidth the licensee may use; the forms of signal modulation and other methods for encoding and transmitting information on the designated spectrum; transmission power ("electromagnetic energy radiated"); the type of transmitter and antenna equipment (sometimes down to a particular brand and model);

the location (by geographic coordinates), ground level, height, radiation pattern, and geographic range of transmission; and (sometimes) hours of operation.

In addition, licenses are limited to specific purposes, such as television and radio broadcasting, mobile telephone and smartphone service, various satellite links (satellite to ground, ground to satellite, satellite to satellite), and a host of narrower purposes such as police radio, maritime navigation, and meteorological satellites.[120] Finally, licenses specify licensees' organizational and business forms—such as amateur radio, non-profit educational, for-profit corporation, and advertising versus subscription supported.[121]

Spectrum licenses are regularly bought and sold, but the restrictions on a seller's spectrum continue to apply to the buyer—so that, for example, the license of an AM radio station may be sold only for AM broadcasting by someone else. If you want to transmit a certain kind of information from A to B, but the FCC has already allocated all of the spectrum it has "zoned" for that kind of information in that place, and the incumbent license holders are not interested in selling, you are out of luck.

Different radio frequencies are better suited to different applications, depending on such variables as distance, transmission capacity, power availability, and "propagation properties" (lower frequencies generally transmit information more slowly but travel further and are better at penetrating walls and other objects, but these tendencies are affected by transmission power and other factors). The FCC's zoning scheme takes account of these technical considerations but is also based on estimates of market demand for various uses. Thus, the commission allocates spectrum between television broadcasting and mobile broadband, meteorological and geostationary positioning satellites, and a host of other competing uses of technically suitable spectrum according to its assessment of the need for each service. It maintains more than 100 "high level service categories."[122]

This "economic planning" feature of spectrum licensing has proven increasingly problematic with the emergence of many new forms of wireless communication and many new techniques for sharing and combining frequency channels. In recent years, the problems have become severe. The fantastic growth of smartphones, tablets, and laptop computers and the now-routine use of video-streaming, personal navigation, internet "cloud" storage, and other data-intensive applications have far outstripped the FCC's spectrum allocation for wireless broadband.

At the same time, the growth of cable and satellite television, which now reach the vast majority of households, has left a great deal of spectrum for old-fashioned broadcast television underused or dormant. (The TV-broadcast zone, first established in the early 1950s, still maintains generous allocations for local UHF, or ultra-high frequency, television stations, which are now little used outside some rural areas.) The spectrum designated for broadcast TV is ideal for wireless broadband, yet much of it is lying fallow. In addition, federal agencies have exclusive use of one-third of the most suitable spectrum (administered by the National Telecommunications & Information Administration, part of the Department of Commerce), and much of it is lightly used.[123]

Recent and current FCC spectrum auctions are designed to alleviate these imbalances by taking unallocated spectrum, underused federal spectrum, and spectrum purchased from television broadcasters and selling it to wireless-broadband suppliers through competitive bidding. The auctions have helped, and indeed have been a landmark improvement over previous schemes of allocation by administrative hearings or lotteries. But, as we shall see, they have been highly complex and slow moving, and are falling increasingly behind the explosive growth in demand for wireless broadband.

Centralized administrative allocation of rights to radio transmission was first conceived by Secretary of Commerce Herbert Hoover in the mid-1920s, in response to the first appearance of commercial radio broadcasting stations, and was then legislated in the Radio Act of 1927 and the Communications Act of 1934. Federal regulation displaced the development, then underway, of property rights in radio spectrum and legal rules to settle conflicts among different users and interference between users of adjacent spectrum channels. Many experts in communications technology and economics believe the regulatory approach was a mistake (the economist R.H. Coase received the Nobel Prize in 1991 in part for demonstrating that this was so).[124]

It was, however, an understandable mistake. Radio was then a strange new phenomenon, useful mainly for public purposes such as broadcasting, maritime navigation, and military communications: It was an invisible frontier that, Hoover and many others believed, the government should develop for the national good, just as it had the western physical frontier. Moreover, the known uses for radio were few in number, so designating frequencies for particular uses was a simple matter.

But radio has long since become well developed and ubiquitous. Almost everyone uses it several times every day, mostly for purposes that are private and personal—searching, scheduling, reading, listening to music, watching movies and videos, networking and sharing with family, friends, and colleagues. Even radio and television programming is now distributed mainly through dedicated wireless channels and landline networks rather than traditional broadcasting. And 80 years of experience and discovery have generated innumerable new uses of more and more spectrum (at progressively higher frequencies), along with new methods for data compression, sharing frequency bands for multiple purposes, and combining different frequencies for the same purposes.[125] The effort to limit particular frequencies to unique uses and transmission methods is increasingly out of step with the dynamics of communications and information technology, and has become, as a practical matter, simply unmanageable.

THE WIRELESS-BROADBAND SHORTAGE

In recent years, the problem of spectrum misallocation has centered on the shortage of spectrum available for smartphones, tablets, and other devices that rely on wireless broadband. (Technically, "broadband" means a radio channel that encompasses a range of adjacent frequencies used to transmit multiple signals simultaneously, but it is now generally used to refer to internet-access standards of increasing speed and capacity—3G, 4G, 4G-LTE, and now 5G and even faster ones to come.) The broadband shortage has generated task-force reports, agency blueprints (in particular the FCC's 2010 "National Broadband Plan"), industry white papers, congressional hearings, and presidential proclamations.[126] Everyone agrees that the shortage is seriously retarding innovation in a critical sector of the economy. But all of the proposed solutions are highly complex and many are highly partial—addressing only part of the problem, and doing so in ways that serve its proponent's interests.

The shortage of spectrum for wireless-broadband applications is indeed serious. It is needlessly raising the costs and retarding the speed and quality of personal communications. Wireless providers such as Verizon and AT&T have been obliged to raise prices and reduce speeds selectively for heavy users of video and data applications, leading to charges of "discrimination" that the FCC has taken seriously in its net-neutrality and other initiatives. It is also fostering wasteful commercial strategies, such as AT&T's ill-fated 2013 attempt to acquire T-Mobile, which was really a desperate attempt to acquire spectrum. At the same time, the shortage is slowing the introduction of long-distance learning and medicine, improvements in air- and highway-traffic control, and innumerable business applications, all with immense potential for social betterment.

The current evolution from M2M (Machine-To-Machine, meaning point-to-point connections among integrated machines and between sensors and controllers) to the Internet of Things (wide sharing and analysis of data transmitted from machines and sensors, usually through the internet cloud) is making the problem much more severe, for devices can be proliferated far beyond the size of the human population. Many on-the-horizon applications, such as continuous remote monitoring of medical patients, self-driving cars, and greatly strengthened cybersecurity for personal and commercial data, simply will not get beyond the pilot stage without large additions of spectrum.[127]

New techniques for sharing and combining spectrum and speeding transmission are sometimes touted as cures for the spectrum shortage.[128] Their effects, however, are actually ambiguous, because they lead to new uses for spectrum and increased competition in the supply of spectrum-dependent services, which increase spectrum demand. To date, improvements in transmission technology have been accompanied by huge increases in wireless-broadband demand, with causation surely running in both directions.[129] But the steady increase in prices paid for broadband spectrum in recent (post-2007) FCC spectrum auctions, properly controlled for other factors affecting price, suggests that the demand for spectrum is outpacing improvements in transmission efficiency.[130]

The wireless-broadband shortage points to a problem that is larger still. A central administrative agency such as the FCC cannot possibly know the relative values, among multifarious and ever-changing uses, of a resource as pervasive and versatile as radio waves. The commission has erred many times in the past. In the 1940s and 1950s, it delayed the introduction of FM radio (with vastly superior quality to AM) by more than a decade;[131] in the 1970s and 1980s, it delayed the introduction of mobile cellular telephones even longer.[132] Even when its judgments are approximately correct for the time being, it lacks the flexibility to take account of varying local circumstances — its usage zones are nationwide, so a given frequency generally cannot be employed, for example, for financial exchanges in Manhattan and mountain-rescue in Colorado.

And the FCC's errors are not random: It is naturally attentive to incumbent firms that know the agency ropes and support its budget, and less so to newbies with unfamiliar ideas that could disrupt the settled plans of its licensees and its staff. Many of the past delays in disruptive innovations, and many of the distortions in current spectrum allocations, are the result of lobbying by incumbent licensees and FCC favoritism. Some of the commission's own efforts to counteract the inefficiencies of its zoning scheme have been defeated by political machinations. An example is its perennial proposal to charge license holders a substantial annual fee in order to discourage hoarding of unused or underused spectrum — a problem created by the narrow use restrictions in its spectrum licenses — which license holders have consistently quashed in Congress.[133] The FCC's initial moves toward spectrum auctions were obstructed by the television broadcasters, who feared that auctions would be a device for raiding their treasure troves of spectrum for reassignment to the new wireless applications.[134]

SPECTRUM LIBERALIZATION TO DATE

The FCC has nevertheless made significant progress in mitigating the harms and inefficiencies of its spectrum zoning system and rigid technical license specifications. It has done so through spectrum auctions, license liberalization, and unlicensed spectrum.

Beginning in 1994, the FCC has allocated most newly available spectrum licenses by competitive auctions. During the 21-year period ending in September 2015, it had completed 101 auctions of a total of more than 85,000 spectrum licenses, collecting $52.2 billion for the U.S. Treasury ($53.6 billion in auction revenues offset by $1.4 billion in auction expenses) with substantial additional receipts expected.[135] Allocating licenses by the price system, in place of the former approach of allocation by administrative hearings or lotteries followed by regulated secondary-market transactions, has undoubtedly speeded the movement of a considerable amount of spectrum to more productive, highly valued uses. In particular, the auctions have allocated approximately 600 MHz of highly valued frequencies to various cellular telephone and wireless-broadband uses — much of it in auctions after 2004 aimed at alleviating the broadband shortage, and much of it subject to the commission's new license-liberalization policies discussed below.[136] The commission's "broadcast incentive auction," begun in March 2016 — consisting of a reverse auction to purchase spectrum from TV broadcasters followed by a forward auction to sell that spectrum to wireless-broadband suppliers[137]—could transfer another 126 MHz of spectrum to wireless broadband, all of it under liberal licenses.

The FCC auctions have, however, been beset by a host of difficulties. They are highly bureaucratic and at least mildly politicized—involving hundreds of pages of rules, arcane restrictions on who may bid, special credits and preferences for certain bidders, special obligations for purchasers of some spectrum, and other features that have permitted or encouraged collusion and strategic behavior, suppressed bids, and led to lengthy delays.[138] The 2016 broadcast incentive auction, which is particularly complex, will take most of the year to execute, followed by at least another three years for the commission to relocate many of the selling broadcasters to other broadcast spectrum.[139] But there are deeper problems that cannot be remedied with improved procedures or larger FCC budgets and staffs. The auctions are conducted within the inherited structure of assigned usage zones and extreme spectrum fragmentation into scores of thousands of individual licenses, which complicates auction procedures, suppresses participation and bids, and severely limits the potential for moving spectrum to better uses.[140] And the auctions are absurdly over-centralized and episodic—as if sales and purchases of thousands of parcels of valuable real estate throughout the United States were restricted to occasional blunderbuss now-or-never dramas in Washington.

The greatest improvements in spectrum efficiency during the auctions era have come not from the auctions themselves but rather from the FCC's concurrent re-zoning of spectrum in response to new cellular and broadband technologies. Indeed, the auctions, with their elaborate and time-consuming procedures, have slowed the migration of spectrum to more valuable uses by years or decades compared to the alternative of all-purpose licenses proposed in this paper; at their current pace, the auctions may never catch up with the still-exploding demand for wireless-broadband spectrum. In the light of history, the auctions era will probably be viewed as a transition—an initial step from the commission's command-and-control traditions to full liberalization of spectrum usage, and one that eased the way forward by revealing the immense value of spectrum to the modern economy.

FCC license liberalization, which began in the late 1980s and continued through the 1990s, was a response to the development of cellular networks as the most efficient means of mass wireless communication, and to the rapid evolution of technologies of spectrum transmission and management within and around the cellular architecture. The commission's licensing regime had been designed for three primary types of communication: radio and television broadcasting, characterized by one-way transmission from a fixed point to innumerable passive receivers; point-to-point transmission in terrestrial microwave networks and among satellites and ground-stations; and a few precursors to today's personal mobile communications, such as radio dispatch and walkie-talkies, which operated in local environments rather than as parts of integrated networks. Its traditional license specifications of transmitter location, power, equipment, antenna direction, and other particulars were ill-suited to the construction of thousands and then tens of thousands (now well over 200,000) of communications cells of widely varying size and geography, each one populated by hundreds and then thousands of moving transmitter-receiver devices in constant use, and each cellular network requiring use and coordination of many different frequencies within and among cells. Traditional FCC specifications of bandwidths and methods of signal encoding could not keep pace with innovations in spectrum sharing, spread-spectrum jumping, and technologies for transmitting data at progressively faster rates. And the appearance of new uses and applications (from voice to data and video; social media; M2M) and a variety of commercial arrangements (fee-based, advertising-based, free), all of them coexisting on the same communications networks, made a hash of the commission's traditional zoning of spectrum "service categories."

The FCC's response took the form of (essentially) four kinds of license liberalization.[141] First, beginning with the appearance of digital-transmission technologies in the late 1980s, the commission permitted licenses designated for analog transmission to be upgraded to digital, and thereafter pursued a permissive approach to accommodating progressive improvements in transmission technologies. Second, in the early 1990s the commission established a broad new service category, "Commercial Mobile Radio Service" (CMRS), which subsumed several narrower categories such as Specialized Mobile Radio, Personal Communications Services, Business Radio, and Common Carrier Paging, and thereafter incorporated additional service categories into CMRS.[142] Third, the commission relaxed or abandoned many of its specifications of transmission power and equipment and antenna location, giving suppliers flexibility to adjust them to the varying demands of individual cells. Fourth, through auctions and other means, the commission permitted mobile-service suppliers to "overlay" existing licenses for point-to-point and broadcast services — to use portions of the allocated spectrum (so-called "white spaces") in ways that did not interfere unduly with the incumbents' uses. These spectrum-sharing policies set the stage for private transactions among incumbent and overlay licensees to adjust their business models, relocate to other frequencies, manage radio interference, and otherwise economize on the use of spectrum for competing uses.

Taken together, these policies have produced the closest approximation to date of a private property regime for spectrum allocation, where wireless service suppliers have been freed from narrow license restrictions to respond to evolving technology and market demand. Regulated only by straightforward recordkeeping and reporting requirements, suppliers have chosen their own transmission methods and equipment, service offerings, and business models; optimized signal power from location to location; shared and exchanged spectrum frequencies; deployed several generations of progressively faster and more proficient network technologies; and collaborated with (and subsidized) manufacturers of commensurately more proficient mobile phones, tablets, and computers that now continuously monitor network conditions and adjust frequencies and power levels.

It is difficult to derive a precise estimate of the economic value of license liberalization from trends in prices of CMRS spectrum at successive FCC auctions, given the importance of many independent variables such as geography, spectrum quantity, and improvements in transmission capacity and physical infrastructure.[143] It is clear, however, that, taking account of the independent factors, liberal licenses are substantially more valuable than traditional licenses with narrow specifications of use and technology.[144] This is strong evidence of the further benefits of extending the FCC's reforms to all-purpose spectrum licenses. In the meantime, liberal licenses for wireless broadband have been the *sine qua non* of the construction of a $1.4 trillion[145] communications network that has yielded continuously falling consumer prices for mobile services and devices[146] and is now the backbone of an economic sector that adds $1-2 trillion in value (5% to 10% of GDP) to the American economy each year.[147]

Not all of the spectrum is licensed; the FCC has long reserved portions of the electromagnetic spectrum for short-range, low-power uses such as microwave ovens and remote control of television sets and garage doors. The reserved portions are called "unlicensed spectrum" because manufacturers are not required to obtain licenses to transmit over the designated frequencies but must simply observe the commission's limits on range, power, and transmission methods. Users must accept any radio interference they receive and, on complaint, correct any interference they cause to others.

In 1985, the commission established expedited procedures and standards for a wider array of "Part 15" (unlicensed spectrum) devices, and in the 1990s a host of new applications were introduced, such as local-area wireless networks of phones and computers, cordless landline telephones, and wireless microphones. Then, beginning in 1999, computer and mobile-phone manufacturers began to introduce Wi-Fi and Bluetooth technology into their products — the former primarily for voice and data connection to the cellular network through local "hotspots" the size of a residence, business, or public facility; the latter primarily for shorter-range connections such as wireless computer keyboards and music speakers.[148]

Bluetooth and Wi-Fi proved to be immensely useful and popular, especially after the introduction of smartphones and tablets in the mid-2000s. With improvements in the speed and capacity of "last mile" landline connections from homes and businesses to cellular networks (such as through replacing copper wires with optical fiber), Wi-Fi became a good substitute for wireless-network subscriptions for many people — it was limited to places with Wi-Fi equipment but less expensive than more "nomadic" wireless service available throughout network cells. As Wi-Fi technology itself improved, and more and more businesses, commercial establishments (famously beginning with Starbucks), and transportation terminals and carriers installed the equipment, the locational limitations of Wi-Fi decreased. Soon tablets and smartphones were enabled to switch automatically between Wi-Fi and direct cellular connections depending on the availability of good Wi-Fi connections. And Wi-Fi, once installed, could be used for a growing number of additional purposes within homes and offices, such as connecting fixed desktop computers, music and video systems, and thermostat and security systems. Today, two-thirds of American households have their own Wi-Fi, as do more than 10 million shops, hotels, and other public facilities. Most wireless-broadband traffic connects to users through Wi-Fi (especially in urban areas), and wireless-service providers are beginning to employ unlicensed spectrum within their cellular networks of mostly licensed spectrum.[149] At the same time, Bluetooth and similar very-short-range technologies have increasingly replaced wires at desks and in cars and kitchens. In response to these developments, the FCC has allocated increasing spectrum for use by unlicensed devices — from 235 MHz of spectrum in 1985 to 955 MHz at the end of 2008, which was more than twice the spectrum it had allocated to liberal licenses for wireless broadband.[150]

These and other uses of unlicensed spectrum have been tremendous successes, and the emerging Internet of Things will make more intense use of it. The advantages of unlicensed spectrum have, however, been exaggerated by proponents of a "spectrum commons" — in which increasingly intelligent devices will put an end to spectrum scarcity and unlicensed spectrum will progressively displace and eventually replace licensed spectrum.[151] While unlicensed spectrum has employed many advanced, spectrum-economizing transmission technologies, such as spread-spectrum techniques for moving continuously among different frequencies, recently liberalized licensed spectrum has employed these technologies as well. For every example of creative use of spectrum sharing in unlicensed space, such as spectrum overlays in broadcasting "white spaces," there is an example of equally creative use in liberally licensed space (the latter include wireless delivery of Kindle e-books and iTunes music, and GM's OnStar navigation system, all of which piggyback on licensed broadband by private agreement). While unlicensed spectrum advocates emphasize that Wi-Fi has increased demand for wireless-broadband services and reduced the costs of cellular networks by offloading some of their traffic, the existence of the cellular networks has itself been a predicate for the demand for Wi-Fi to connect to them — in practice, the two are strong economic complements.[152]

We need not adjudicate the merits of the licensed-unlicensed debates in any detail. For purposes of evaluating the proposal to move to all-purpose spectrum licenses, three general, relatively uncontroversial propositions will suffice.

First, the proper reference point for evaluating unlicensed spectrum is not traditional, highly restricted licensed spectrum such as that for broadcast television — characterized by low spectrum usage, slow innovation, and inflexibility in the face of changing technology and consumer demand. Instead it is liberally licensed spectrum, which was introduced during the same time period as unlicensed spectrum, and in response to the same technological developments. Although liberal licenses for wireless broadband have been granted much less spectrum than unlicensed uses, they too have provided the framework for rapid innovation, much more intense spectrum usage, massive investments in physical infrastructure and devices, falling consumer prices, and very large consumer surpluses (the value consumers receive from goods and services above what they pay for them).[153]

Second, unlicensed spectrum is not an unregulated commons free of the constraints of property rights, but rather is regulated differently than licensed spectrum. The FCC regulates the power levels, transmission methods, and ranges of unlicensed spectrum devices to localize their use and control radio interference. Users own and manage the devices and, for almost all applications to date, the real property in which they are used. Residential and coffee-shop Wi-Fi is regulated by inherent limits on numbers of users and by precautions on use by neighbors. More expansive systems, such as those deployed throughout airports, hotels, buildings, and college campuses, are actively regulated by local administrators through such means as router placements; passwords; user fees or indirect charges; separate user categories of guests, employees, club or department memberships, and user location. Rural townships that have introduced unlicensed local systems have employed similar methods within their jurisdictions.

Third, unlicensed spectrum is to date almost entirely a phenomenon of small, short-range networks and "hotspot" cellular internet connections within privately (or municipally) owned premises. Most efforts to establish broader, public-use systems (such as "Muni Wi-Fi") have foundered on range limitations and difficulties in controlling use and radio interference among larger and less well identified numbers of devices; examples of successful deployments are strikingly few and far between.[154] Given this experience, it is a tall order to translate ideas about a wide-ranging communications commons into practical reality. A city, state, or nation blanketed by interconnected Wi-Fi hotspots begins to look like the cellular network that we have, and raises the question of whom, in the absence of proprietary owners of spectrum rights, would make the massive investments to build and manage the system.[155] A world where millions of far-flung device users simultaneously exchange millions of data-intense communications across unlicensed spectrum is a world in possession of technologies utterly beyond current knowledge. No doubt there will be many further, dazzling improvements in information and communications technology. But they will come in increments, each one with useful applications in both licensed and unlicensed spectrum architecture, and affecting the relative advantages of the two systems only at the margin. What we know so far is that unlicensed spectrum is advantageous for local connectivity but does not scale up easily, while licensed spectrum under liberal technical and usage rules exhibits large economies of scale and scope.

In sum, licensed and unlicensed spectrum have both come to play vital roles in modern communications and should be regarded as mutually beneficial rather than mutually exclusive systems. There is, of course, important competition between them — in *use*, when it comes to choosing one or another for a particular element of communications networks, and in *policy*, when it comes to allocating an additional increment of spectrum to one or the other. Allocating new spectrum to either system imposes costs on the other in the form of less available spectrum and greater radio interference from the favored system; the choice should be governed by judgments of the net benefits of new spectrum in licensed versus unlicensed uses. It is, however, impossible to make that comparison intelligently today, when only a small portion of licensed spectrum is subject to liberal, flexible-use rules. The relative benefits of licensed and unlicensed spectrum can be observed only when licensed users are as free as unlicensed users to deploy different technologies and different spectrum bands for different purposes.

THE NEXT STEP: ALL-PURPOSE SPECTRUM LICENSES

All-purpose spectrum licenses is a simple idea for a policy field rife with complexities, many of them unnecessary. The FCC would allow license holders to use their spectrum for any valid purpose, liberalize technical specifications as it has done for wireless-broadband licenses, and permit spectrum to be bought and sold with only minimal restrictions. The commission could do this immediately. While spectrum auctions require authorization from Congress, spectrum zones and technical license restrictions are the commission's own creations and can be revised as it sees fit (as it did in the case of wireless broadband). The commission would proposal a rule, which should take no more than a year to adopt through notice-and-comment rulemaking procedures, that removed the usage zones and most technical restrictions in practically all existing spectrum licenses, and the NTIA would take similar steps for government spectrum. From that moment on there would be no spectrum shortage.[156]

Broadcast-television licensees could sell spectrum to mobile-broadband providers, or not, or some spectrum but not all, depending on which application appeared more valuable to the parties involved. So could licensees in many other areas of misallocated spectrum that are not in the headlines and that the FCC doesn't even know about. Frequencies could be used for different applications in different locales and at different times of day. Or they could be used for different applications in the same place from minute to minute, relying on technologies that deploy spectrum among different uses in real time according to usage patterns. Or different frequencies could be used in tandem for purposes now forbidden because some of the frequencies are in the wrong zone. The FCC would continue with its auctions of unallocated spectrum, but without restrictions on use.

Over time, spectrum use would become akin to private property, just as it has for wireless broadband. It would be subject to the same laws — contract, nuisance, antitrust — that govern the use of land, buildings, and other tangible assets. The military, the police, and other government agencies would own and employ radio spectrum for public purposes and buy and sell increments as necessary, just as they do other resources. The FCC would operate the national equivalent of a county land-title office, where buyers and sellers could assure themselves of good title and register rights and obligations affecting other owners.[157] The entire process could be online and searchable, as could spectrum transactions themselves, whether by direct sale, auction, brokerage, or organized exchange.

All-purpose spectrum is entirely permissive. In contrast to the many proposals for top-down spectrum reallocation, it doesn't require anyone to do anything — it leaves it to license holders to bear the expenses and take the consequences, profit or loss, of whatever they decide to do. It simply opens up new opportunities. For this reason, and because of the explosive pace and unpredictability of innovation in communications and information technology, the social benefits of all-purpose spectrum cannot be estimated with any precision. From the prices paid in recent FCC auctions and private spectrum transactions, from the returns on recent investments in wireless services, and from empirical data on currently unused and underused spectrum, we can get a glimpse of the benefits of relieving the current shortage in wireless broadband.

Academic and industry studies using these data find short-term economic benefits of many hundreds of billions of dollars.[158] There are large ranges of uncertainty in these estimates, but if one looks at expenditures and economic value (to both consumers and producers) in the initial stages of wireless growth, and at the many high-value, technically feasible applications now under development, the estimates are more than plausible. In any event, the economic benefits of all-purpose spectrum licenses would be much greater, because the reform would improve spectrum use throughout the spectrum and permit continuous improvements over time that the current system insensibly obstructs.

Most of all, the social, economic, and personal gains of all-purpose spectrum licenses would begin to be realized almost immediately, rather than years in the future as under the FCC's desultory auction program. They would be large enough to show up in aggregate measures of national economic performance. And, because they would arise from the uncorking of new opportunities, they would not be subject to the zero-sum political wrangling that dooms so many beneficial regulatory reforms.

OBJECTIONS TO ALL-PURPOSE SPECTRUM LICENSES

All-purpose spectrum proposals build on recent FCC reforms that have acquired substantial constituencies and political momentum, but its potential for unleashing new rounds of disruptive innovation means that it would be sure to generate controversy. Fortunately, the recent experience of spectrum auctions, license liberalization, and unlicensed spectrum provides answers to the most important objections that might be made. What might have been considered a radical departure 25 years ago is today more evolutionary and grounded in practical experience.

Consider first the objection that all-purpose licenses would "privatize" an invaluable national resource — permitting license holders to profit from spectrum that belongs to the public, and to abscond with government revenues the FCC's spectrum auctions could raise. The first part of this argument is a fallacy. Whether they paid for it or not, licensees have always profited from whatever economic value they could produce with spectrum (from their own use or sale to others). Their increased returns from the lifting of service and narrow technical restrictions from their licenses would depend on their using the flexibility to find more complete and valuable uses for the covered spectrum, and consumers would realize a substantial share of that increased value.

The second part is misguided — good policy aims to increase social welfare, not just government revenues. In any event, simply permitting all-purpose spectrum licenses by rule would almost certainly generate higher revenues than the alternative of attempting to auction the removal of license restrictions. The $52 billion raised to date from 21 years of FCC spectrum auctions (in recent cases known by bidders to be accompanied by license liberalization) must be a small fraction of the taxes paid on the higher-valued commercial activities that they permitted. Tax revenues from capital gains on all-purpose licenses, sales taxes on goods and services that better-used spectrum made possible, and taxes on added personal and corporate income would probably far exceed auction revenues as well, and would continue with the flexibility to repurpose use over time across the radio spectrum.

And we know from the auction experience that those revenues would be collected years or decades sooner than if all-purpose licenses were enmeshed in auction procedures. The demands of government revenue collection often conflict with private-sector productivity, but there is no such conflict in the choice between spectrum auctions and all-purpose licenses, because the taxable private gains from the latter would come sooner and be orders of magnitude greater than auction revenues.

A second objection is that license holders, freed of the FCC's usage zones, would employ spectrum in ways that created radio interference with other licensees in adjacent spectrum bands or geographic areas. But radio interference is technical phenomenon, not an artifact of one or another allocation scheme. It is legally actionable and can be resolved by direct negotiation among users of adjacent spectrum. This already happens under the current zoning scheme and has become routine in the build-out of cellular broadband networks under liberal licenses, where transactions to move or share frequency bands have become everyday business, often conducted by engineers.

In contrast, the FCC's traditional approach to radio interference has been clumsy and terribly wasteful, requiring the preservation of large "white spaces" — buffers of unused spectrum between active bands. That approach led to the commission's 2012 decision, based on radio-interference objections from GPS service providers, to revoke Lightsquared's permission to establish a new wireless broadband network after the firm had already invested $4 billion in the venture.[159] It was a policy debacle of the first order: The social value of the new broadband network would have been vastly greater than the costs of resolving any GPS interference problems.

With all-purpose licenses, spectrum that is now warehoused as buffer would be deployed much faster and more completely than under FCC auctions or administrative procedures, and border conflicts would be left to straightforward commercial and technical resolution rather than lobbyist-infested political resolution. Spectrum-sharing and other technologies plus the law of contract would move much more spectrum into productive use — and reveal, through experience, the most practical approaches to managing radio interference among competing uses.

While the FCC's recent policy reforms have diminished the force of privatization and interference objections to all-purpose licenses, they have raised a potential new one. Exclusive spectrum rights, it might be objected, should not be liberalized but rather supplanted by unlicensed spectrum with no exclusive usage rights at all — an extension of the arguments for unlicensed spectrum discussed in the previous section. But these arguments have focused mainly on the waste and inefficiencies of traditionally restricted licenses, and the experience with liberal licenses has cast the licensed-versus-unlicensed question in a new light. Although many influential corporations and industry leaders have favored increased allocations of unlicensed spectrum, this has been in the context of the FCC's established regime of narrow, inflexible licenses for most spectrum. When the comparison is instead to all-purpose licenses across the spectrum, the balance of advantages for different technical and commercial circumstances will change.

As a general matter, almost everyone in the communications industry wants a regime of flexible, decentralized decision-making where spectrum frequencies may be employed according to considerations of technology, economic combination with non-spectrum factors of production, and market demand. Unlicensed spectrum offers these advantages — but exclusively licensed all-purpose spectrum does as well. So current preferences for more unlicensed spectrum do not logically translate into opposition to all-purpose spectrum licenses, and may translate into support. In any event, as the practical possibilities of all-purpose licenses sink in, industry positions as well as those of government officials and academic analysts should shift toward the more informed comparison of incremental licensed versus unlicensed spectrum suggested at the end of the previous section.

It appears that this may already be happening. In late 2014, the Aspen Institute convened a two-day roundtable on spectrum policy with 26 leading industry, government, and academic experts, and asked them to evaluate a "general-purpose spectrum regime" (their term for all-purpose spectrum). By design, the participants included vigorous, knowledgeable proponents of licensed spectrum, unlicensed spectrum, and "shared spectrum" (where, as mentioned earlier, frequencies are licensed but transmission rights are shared by more than one party).

In the words of the group's rapporteur, Dorothy Robyn: "Roundtable participants were unanimous in embracing a general-purpose spectrum regime as a long-term, 'aspirational' goal, although they emphasized the importance of incremental gains, and individual participants viewed their preferred spectrum management model as providing the best transition path."[160] It is unclear from the report why the goal was regarded as long-term and aspirational rather than, as proposed here, immediate and actual. There appeared to be general agreement that the current regime of fragmented, narrowly defined, technologically limited spectrum is fossilized and is impeding innovation and competition in the here-and-now; that "exclusive, flexible rights has worked extremely well for CMRS carriers"; and that the distinction between unlicensed Wi-Fi and licensed CMRS is being eroded by new transmission technologies.[161]

When a subgroup of technical experts was asked about the continuing need for usage zones, they concluded that, from an engineering standpoint, "no applications will require single-purpose spectrum in the future."[162] And when the group as a whole was asked to specify what restrictions should be placed on general-purpose spectrum, they concluded that there is no need to limit a particular band to a specific use, and that the only technical requirements should be "operating rights" and "admission control."[163] By operating rights they meant transmission and interference standards based on system performance rather than technical inputs, and applicable to receivers as well as transmitters; by admissions control they meant procedures for determining who may access a spectrum band at any given time. Those, one might add, are exactly the issues for determination on a spectrum-wide, usage-indifferent basis in an FCC rulemaking proceeding to inaugurate all-purpose spectrum licenses.

THE POLITICS OF ALL-PURPOSE SPECTRUM LICENSES

The beneficiaries of all-purpose spectrum licenses would include producers who need spectrum now but lack the necessary licenses or use flexibility; consumers who would soon receive new, better, and lower-cost services; and producers and consumers of unforeseeable innovations stimulated by dynamic spectrum markets — effectively all of us. But the most immediate beneficiaries would be those who currently hold spectrum licenses with traditional use and technology restrictions who could now devote them, by use or sale, to a far wider range of purposes.

And therein lies an important political advantage. It is incumbent licensees who have been most threatened by previous proposals to improve spectrum use through annual spectrum fees, claw-backs of underused spectrum, and reduced spectrum buffers. The licensees have been highly effective in delaying or defeating those proposals, and some of them have been successful in gaming spectrum auctions and using administrative proceedings to selfish advantage. But all-purpose spectrum, by greatly increasing the economic value of currently licensed spectrum, turns the incentives around — transforming incumbent licensees into an interest group for what is also in the public interest. Its permissiveness turns the attentions of those most directly involved from political rent-seeking to economic value seeking.

All-purpose spectrum licenses hold the promise of promptly correcting a serious waste of one of nature's most valuable resources, generating profound economic benefits, and spurring new rounds of innovation in a field where recent innovations are widely understood and popular. That it is also highly feasible as a political matter makes it an opportunity not to be missed.

content/biopharma-keeps-roaring-ahead-full-speed-precision-medicine-race.

115. Alexander Gaffney, "FDA Withdraws 47 'Outdated' Guidance Documents," Regulatory Affairs Professionals Society, May 5, 2015, http://www.raps.org/Regulatory-Focus/News/2015/05/05/22102/FDA-Withdraws-47-Outdated-Guidance-Documents/.
116. Taha A. Kass-Hout and Elaine Johanson, "FDA Launches precisionFDA to Harness the Power of Scientific Collaboration," *FDA Voice*, December 15, 2015, http://blogs.fda.gov/fdavoice/index.php/2015/12/fda-launches-precisionfda-to-harness-the-power-of-scientific-collaboration/.
117. David Shaywitz, "PrecisionFDA: Why It Matters," *Inside DNANexus*, December 15, 2015, http://blog.dnanexus.com/2015-12-15-precisionfda-why-it-matters/.

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118. The figures in this paragraph are drawn from North America Statista, "Number of smartphone users in the United States from 2010 to 2019," Statista, www.statista.com/statistics/201182/forecast-of-smartphone-users-in-the-us; Thom File and Camille Ryan, "Computer and Internet Use in the United States: 2013," U.S. Census Bureau, November 2014, www.census.gov/content/dam/Census/library/publications/2014/acs/acs-28.pdf; Monica Anderson, "Technology Device Ownership: 2015," Pew Research Center, October 29, 2015, www.pewinternet.org/2015/10/29/technology-device-ownership-2015; Aaron Smith, "U.S. Smartphone Use in 2015," Pew Research Center, April 1, 2015, www.pewinternet.org/2015/04/01/us-smartphone-use-in-2015; and Mary Meeker, "Internet Trends 2015—Code Conference," Kleiner Perkins Caufield & Byers, May 27, 2015, www.smartinsights.com/internet-marketing-statistics/insights-from-kpcb-us-and-global-internet-trends-2015-report. The Pew Center's many excellent studies of Internet usage and other issues are listed at www.pewinternet.org/category/publications/report.
119. The portion of the spectrum suitable for wireless radio communication is usually described as running from frequencies of 3KHz (wavelength 100 km) through 300 GHz (wavelength 1 mm), although there are some technical uses for lower and higher frequencies. The best known forms of communication —commercial radio and television; mobile telephones, smartphones, and computers; short-range links such as Wi-Fi and Bluetooth; and satellite communications for navigation and other purposes—use intermediate frequencies from 1 MHz through 3000 MHz (or 3 GHz), with the 300–3000 MHz range considered "beachfront property." Frequency numbers are also used to designate *bands* or *portions* of spectrum—so, for example, when it is said that mobile

broadband services "need 200 MHz more spectrum," that does not mean that they need spectrum with a frequency *of* 200 MHz but rather that they need spectrum of any suitable frequency that *totals* 200 MHz in bandwidth. That might be spectrum running from 600 to 700 MHz plus that from 1750 to 1850 MHz or, more realistically, combinations of many more, narrower spectrum bands. In these cases, frequency numbers are used as a shorthand measure of capacity to transmit information.

120. A chart of the Commission's frequency allocations is posted on the website of the U.S. Department of Commerce, National Telecommunications and Information Administration, https://www.ntia.doc.gov/files/ntia/publications/january_2016_spectrum_wall_chart.pdf.
121. The FCC posts two searchable databases of its approximately 2,111,600 spectrum licenses — License View (http://reboot.fcc.gov/license-view/) and Spectrum Dashboard (http://reboot.fcc.gov/reform/systems/spectrum-dashboard) — which present some but not all of the specifications in individual licenses. Both postings are designated "beta"; Spectrum Dashboard, launched with fanfare in 1910, has not been updated since July 2014, but License View is evidently being kept current. The Commission's "License View Data Dictionary" (September 2010), downloadable at its License View site, details most but not all of its license terms and specifications.
122. See the FCC's "License View Data Dictionary," 13–16.
123. Brent Skorup, "Reclaiming Federal Spectrum: Proposals and Recommendations," working paper 13-10, Mercatus Center, May 2013, http://mercatus.org/sites/default/files/Skorup_FederalSpectrum_v1[1].pdf; Paige R. Atkins, "Why Sharing is the Answer to Rising Demand for Spectrum," National Telecommunications & Information Administration, February 12, 1912, https://www.ntia.doc.gov/blog/2016/why-sharing-answer-rising-demand-spectrum.
124. Thomas W. Hazlett, David Porter, and Vernon Smith, "Radio Spectrum and the Disruptive Clarity of Ronald Coase," *Journal of Law & Economics* 54, no. 4 (November 2011): S125–S165. This article also presents a meticulous analysis of the FCC's first 85 spectrum auctions running from 1994 through 2008.
125. Jeffrey Reed, Marius Vassiliou, and Syed Shah, "The Role of New Technologies in Solving the Spectrum Shortage," *Proceedings of the IEEE* 104, no. 6 (June 2016), http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7471536; ChunSheng Xin and Min Song, *Spectrum Sharing for Wireless Communications*, (Heidelberg: Springer, 2015).
126. Federal Communications Commission, "National Broadband Plan," March 17, 2010. Plan and related documents and research papers posted at https://

www.fcc.gov/general/national-broadband-plan; see especially FCC, "Mobile Broadband: The Benefits of Additional Spectrum," FCC Staff Technical Paper, October 2010, https://transition.fcc.gov/national-broadband-plan/mobile-broadband-paper.pdf. See also The White House, "Presidential Memorandum: Unleashing the Wireless Broadband Revolution," Presidential Memorandum, June 28, 2010, https://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution; Council of Economic Advisors, "The Economic Benefits of New Spectrum for Wireless Broadband," Executive Office of the President, February 2012, https://www.whitehouse.gov/sites/default/files/cea_spectrum_report_2-21-2012.pdf; Senate Committee on Commerce, Science, and Transportation, *Hearing on Removing Barriers to Wireless Broadband Deployment*, 114th Cong., 1st sess., October 7, 2015, http://www.commerce.senate.gov/public/index.cfm/hearings?id=d7b621c5-beb5-418d-b814-aebff10ffc21; Coleman Bazelon and Giulia McHenry, "Mobile Broadband Spectrum: A Vital Resource for the U.S. Economy," prepared by the Brattle Group for CTIA–The Wireless Association, May 11, 2015, www.ctia.org/docs/default-source/default-document-library/brattle_spectrum_051115.pdf.

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129. Coleman Bazelon and Giulia McHenry, "Substantial Licensed Spectrum Deficit (2015–2019): Updating the FCC's Mobile Data Demand Projections," prepared by The Brattle Group for CTIA–The Wireless Association, June 23, 2015, www.ctia.org/docs/default-source/default-document-library/brattle_350MHz_licensed_spectrum.pdf; Council of Economic Advisors, "Economic Benefits of New Spectrum for Wireless Broadband," 5–10.
130. Scott Wallsten, "Is There Really a Spectrum Crisis? Quantifying the Factors Affecting Spectrum License Value," Technology Policy Institute, Feb. 26, 2013, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2206466.
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132. Hazlett, "Allocating Radio Spectrum," 102–104.
133. Jeffrey Rosen, "The Future of Spectrum," Brookings Institution, Issues in Technology Innovation, August 2011, 4, www.brookings.edu/~/media/research/files/papers/2011/8/spectrum-rosen/08_spectrum_rosen.pdf; FCC, "National Broadband Plan," 82–83.
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137. Federal Communications Commission, "Broadcast Incentive Auction," https://www.fcc.gov/about-fcc/fcc-initiatives/incentive-auctions.
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150. Hazlett and Leo, "The Case for Liberal Spectrum Licenses," 1047–1049.

151. Examples of this "strong form" of unlicensed spectrum advocacy are Kevin D. Werbach, *Radio Revolution: The Coming Age of Unlicensed Wireless*, (Washington: New America Foundation, 2003), http://werbach.com/docs/RadioRevolution.pdf; and Thanki, "The Economic Significance of License-Exempt Spectrum." But many papers and reports simply document the virtues of unlicensed spectrum and spectrum sharing and call for more reallocation of underused licensed spectrum and government spectrum to the unlicensed domain — these include Milgrom, Levin, and Eilat, "The Case for Unlicensed Spectrum," and an influential government report, President's Council of Advisors on Science and Technology, "Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth," Report to the President, July 2012, https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf.

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153. See Bazelon and McHenry, "Mobile Broadband Spectrum," 15–17.

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157. Continued development of the FCC's License View and Spectrum Dashboard beta projects, see note 4, would be a step in this direction.
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161. Ibid., 11–12, 4, 6.
162. Ibid., 24.
163. Ibid., 25–27.