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Unlicensed Spectrum Subcommittee Report

January 6, 2010

Overview

The report examines the policy options to expand the role of devices delivering services utilizing spectrum that is allocated solely for unlicensed use or designed to be shared among licensed and unlicensed users. Increased use of unlicensed spectrum bands enhances the public interest as it expands spectrum capacity (through frequency re-use) and offers lower entry barriers into the wireless market, providing more competition and consumer choice.

Within the segments of the radio frequency spectrum that can be shared by unlicensed and licensed applications, there is the potential for improved frequency sharing, for more efficient use of the radio frequency spectrum, and for the creation of new services.. Radio technology advances under development are expected to transform the provision of wireless service by enabling spectrally-efficient frequency sharing and protocol management. These technology advancements may permit the greater use of unlicensed devices with less complex regulation. Consequently, there is a need to encourage development of these technology advancements and to ensure that, as technology for more efficient use of the spectrum evolves and matures, there are sufficient spectrum frequencies exclusively allocated to unlicensed, or frequencies with rules designed to facilitate efficient sharing among unlicensed and licensed uses, in which technology advances can flourish. The danger of stranding scarce spectrum resources exists, however, in premature allocation and rules decisions based on such a regime before appropriate technology is available and before there is a comprehensive assessment and understanding of a long-term radio spectrum strategy.

This report reviews the opportunity and challenge presented by encouragement of unlicensed use and includes recommendations for future activity by the Department of Commerce. The focus of these recommendations is the creation of a national plan for evolution of both user requirements and related technologies. This report attempts to present long range thinking beyond the current regulatory scheme with the full understanding that NTIA faces, as well, many short term challenges in this area.

"Unlicensed Spectrum" Described

Unlicensed spectrum refers to radio frequency bands in which technical rules are specified for both the hardware and deployment of radio systems that are open for shared use by an unlimited number of compliant users. The term "unlicensed spectrum' is interpreted to include frequency bands in which the FCC allows sharing with licensed services as well as proposals for possible future unlicensed frequency allocations. Any person or entity may use unlicensed spectrum for either private or public purposes so long as the user's equipment is certified by the Federal Communications Commission ("FCC" or "Commission") and operated in conformity with Part 15 of the Commission's rules. In contrast with most licensed spectrum use, unlicensed spectrum users enjoy no regulatory protection against interference from other licensed or unlicensed users in the band. Although FCC device certification rules and standardized protocols (such as the Wi-Fi

Alliance's 802.11 family of protocols) help to mitigate interference, users must accept any interference caused by all compliant devices in the band.

Historically, the FCC has permitted unlicensed use as a lawful, use governed by Part 15 in all frequency bands except those specifically identified in Section 205 of Part 15 (attached as Appendix A). The National Telecommunications and Information Administration ("NTIA") similarly has been supportive of unlicensed use by federal users. Internationally, many governments currently allow operation in bands of spectrum (sometimes based on guidelines from the International Telecommunication Union) for use by anyone so long as they respect certain technical limits, including a limit on total transmission power. Unlicensed devices mostly authorized under Part 15 of the FCC rules include cordless telephones, garage door openers, baby monitors and microwave ovens. More recently, a rapidly evolving collection of new technologies is taking advantage of the FCC's allowance for unlicensed use including Wi-Fi, ultra-wideband, spread spectrum, software defined radio, cognitive radio, and mesh networks.

In addition, the FCC has adopted rules allowing operation of higher power unlicensed devices in certain bands resulting in significantly more unlicensed usage. The bands with significantly higher power unlicensed devices are in use include:

- 902-928 MHz
- 1920-1930 MHz (UPCS)
- 2.4 GHz (2400-2483.5 MHz) – Industrial, Scientific, and Medical band
- 3.6 GHz (3650-3700 MHz) – Licensed-Lite
- 5 GHz (5150-5350, 5470-5825 MHz)
- 60 GHz (57-64 GHz)

Bands designated for unlicensed access may be subject to constraints designed to protect licensed, primary services operating on the same or adjacent channels. Unlicensed devices are not permitted to cause interference to licensed operations or other operations that have a higher priority.

Although many view the term "unlicensed" to refer to services that are lightly regulated, since a licensed is not required, it is something of a misnomer since unlicensed spectrum use is, in fact, regulated to ensure that unlicensed devices do not cause interference to operations with a higher priority. Required regulatory mitigation techniques (e.g. power limitation, duty cycle, dynamic frequency selection) are imposed on unlicensed users to ensure that their devices operate without creating interference for licensed services. For example, in the upper 5 GHz band, Wi-Fi devices share a band with military radar subject to the condition that the Wi-Fi devices are capable of spectrum sensing and dynamic frequency selection; if radar is detected, the unlicensed user must immediately vacate the channel. While today unlicensed usage is largely decentralized with no license payments or central control, centralized coordination is not incompatible with unlicensed use. For example, in September 2010, the FCC finalized rules for unlicensed use of unassigned TV channels (so-called TV White Spaces). The rules require devices to use GPS to check a national database for a list of permissible channels based on the device's location – a list that varies from market to market, and even from day to day depending on use by incumbents in the band. And unlike bands such as 2.4 GHz, where Wi-Fi is most prevalent, to protect television viewers from interference, unlicensed devices will be required to operate at lower power limits (40 milliwatts) on channels immediately adjacent to licensed TV channels.

In addition, it should not be assumed that, because unlicensed users lack interference protection, unlicensed services are necessarily lower in quality or more likely to suffer from harmful interference. Various techniques, some already deployed and others under development can mitigate interference and organize spectrum usage such that the quality of service may equal and, in some instances, surpass licensed services that do not use these techniques. For example, a smartphone, table or notebook PC connected by Wi-Fi to a wireline local area network often provides considerably higher data rates than the connection over a far greater distance to the carrier's cell tower.

Consequently, the quality of service, a possible differentiator between a licensed and unlicensed regime may be mitigated by technology opening the possibility for consumers and providers to offer more services using unlicensed devices. Unlike licensed services, unlicensed usage is generally open for shared access to a wide variety of services, devices and technologies. Open spectrum advocates promote provision by the FCC of more radio frequency spectrum that is available for use by all, creating an ecosystem of both licensed and unlicensed spectrum access at a variety of frequency ranges with very different propagation characteristics. But, as discussed above, even when shared, it is possible to give some services priority over others. In contrast, some proponents of the "commons model" of open spectrum advocate for a future where all spectrum is designed to primarily be shared, and in which radios using dynamic spectrum access and multi-antenna systems coordinate to avoid harmful interference and optimize the communications capacity of the spectrum as a whole. Proponents of a pure "commons model" theorize that exclusive licensing could be phased out in most bands as technology evolves to a point where the effective carrying capacity of the airwaves is so abundant that there would be no justification for the government to ration access to spectrum or to give some services priority over others. In this spectrum abundant scenario, everyone would be given equal opportunity to use the airwaves to deploy a community broadband network or even to broadcast their own local radio or television station. Parties have raised concerns that such an approach might undermine investment in the extensive infrastructure necessary to provide reliable wide area services. This is because, unlike licensed services where investment in infrastructure and technology upgrades are realized by the licensee, there may be little incentive in the commons model for private sector investment in the infrastructure needed for higher-power and wide area wireless services where the benefit is shared by all users, including those that choose not to make such an investment. The evolution to a commons model even in limited segments of the radio frequency spectrum, would, of necessity, require a transition period allowing for creation, demonstration and deployment of the needed technology and for orderly obsolescence of legacy systems.

Although the discussion above may appear relevant only to telecommunications services, the principles apply to radar and other services where rapid technology advancement is also occurring. For example, the FAA "nextgen" system has less reliance on radar and more on data communications than existing systems.[1]

An Idealistic Model of Effective Spectrum Use

It is possible to hypothesize a self-organizing technology of the future that would provide spectrum access to any user who desires it but which would, for a given specific message, service, or transaction, utilize only:

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[1] FAA Roadmap for Performance based navigation – July, 206
http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/aaim/organizations/rnav_rnp/media/2006_roadmap.pdf

1) The bandwidth required,
2) The time required,
3) The geographically defined space required, and
4) The optimal frequency band for the nature of that message, service, or transaction.

When such technology is available, the capacity of the radio frequency spectrum will be multiplied exponentially. The extent of this gain is estimated by some to be many orders of magnitude. If even a small part of this potential is realized, today's concept of spectrum shortage may dissipate and the need for traditional frequency regulation based on licensing may be dramatically altered. Elements of this technology are already in use in the form of smart antennas and other tools, such as dynamic spectrum access and cognitive radio technologies, are in development. An evolutionary path toward unlocking the full potential of spectrum resources and addressing today's looming spectrum crisis is necessary, but that path has to be mindful of today's real world limitations.

Experts offer widely varied views of when technology will be available to enable this transformational model. Given these divergent opinions, this report starts by describing the existing limitations to establish a framework for proposing an evolution. There is a genuine danger that premature allocation of large swaths of spectrum to unlicensed use before the technology to use that spectrum efficiently is available will, in the long run, delay the full potential of a "commons model." At the same time, many continue to believe that licensed spectrum, with appropriate technical and service flexibility, provides for the most efficient use of spectrum. Whether the licensed or unlicensed models prevail, or a combination of these models, there is agreement that evolution of spectrally efficient technology and advanced sharing methods are in the public interest and that these methods should be encouraged and stimulated.

Wi-Fi as an Example

Wi-Fi is often presented as a model of successful unlicensed frequency deployment. In fact, there are some services that are very effectively performed by Wi-Fi and others for which it is ineffective. Wi-Fi is an inherently short-range service that is limited by the low power output that is required under Part 15 of the Commission's rules to minimize interference between users. Although some Wireless Internet Service Providers ("WISPs") mostly in rural areas have successfully deployed wide area subscription-based services, generally Wi-Fi is designed to provide relatively high bandwidth to users separated from their access point by two or fewer walls between the user and the access point that serves that user. Each access point requires a high bandwidth connection to the Internet, usually by a dedicated wired or wireless connection. Larger areas are sometimes covered by Wi-Fi mesh networks that use wireless access points to relay traffic and bridge gaps between terrestrial connections and users, but these networks are less spectrally efficient since each "hop" in a mesh network reduces the total available throughput. When used to cover a home or a portion of an office building, Wi-Fi can be cost effective if high bandwidth connections are available. In home or office application, Wi-Fi can be spectrally efficient since interference is limited by the physical structures that define these locations. It is not uncommon for 10 or 12 different home and/or office Wi-Fi networks to be operating within range of each other, permitting multiple computing devices in each discrete location to share a single wired connection to the Internet. This achieves a high degree of spectrum reuse.

Another emerging and rapidly growing use of Wi-Fi technologies operating on unlicensed bands is to offload data traffic from licensed carrier networks. The FCC's October 2010 Mobile Broadband Spectrum Forecast projects that the rapid adoption of smartphones with full Internet capability, together with increased tethering of laptops, tablet PCs and other devices to mobile networks, will increase mobile broadband traffic on the order of 35 times present levels within five years. In response, carriers increasingly are encouraging consumers to use Wi-Fi connections when and where available. For example, a reported 40 percent of iPhone data traffic travels over Wi-Fi connections, providing an outlet that leaves more bandwidth available for other users on AT&T's licensed network. While most of these Wi-Fi connections are provisioned by consumers themselves (at home, work or in public spaces), AT&T has acquired and expanded a network of 25,000 Wi-Fi hotspots that it opens freely to its smartphone customers in high-traffic areas, from Starbucks stores to sports arenas. The carrier is supplementing its services offered on its licensed spectrum by building out mesh Wi-Fi networks on shared spectrum which provide high-capacity coverage across locations such as New York City's Times Square and Wrigley Field, one of Chicago's baseball stadiums. Wi-Fi connections are also able to reduce voice traffic and improve in-home coverage. T-Mobile customers are able to use Wi-Fi not only for data, but also for voice. In early 2010 T-Mobile reported some 1.6 million voice calls per month over Wi-Fi.

While use of Wi-Fi is an effective way to reduce the load on commercial networks, , it does not replace the need for dedicated licensed spectrum or improved spectral efficiency on existing spectrum to provide reliable commercial service consistent with current business models and network architectures. As a result, Wi-Fi technologies currently play a more limited role in enabling wide area coverage. For example, although thousands of WISPs rely on Wi-Fi technology to provide Internet access it generally has been more prevalent in rural and remote areas where wireline broadband service is unavailable or uneconomical. Further, while existing spectral efficiency of Wi-Fi networks is acceptable by today's standards, the contention-based and non-coordinated protocols that characterize Wi-Fi seem likely to limit future improvements in spectral efficiency. Cell-splitting, an effective tool in use to multiply spectrum capacity in cellular systems, is not viable with Wi-Fi. Given the exploding consumer demand for bandwidth and the limitation in spectral efficiency with Wi-Fi, bands in which they operate may be expected to become congested over the long term. Either a new generation of technology will be necessary or more open spectrum will be needed, or both.

The Technological Basis for Claims of Future Potential Improvement

It is important to examine how existing or emerging tools have the potential for significant increases in the capacity of the radio frequency spectrum so policy can be designed to promote services that mitigate the spectrum scarcity that has contributed to the recurring need for additional licensed allocations. Cellular radio is the most advanced widely deployed radio technology. Compared to previous techniques for wide area coverage, cellular radio is more efficient by orders of magnitude. Yet, consider that when a cellular base station listens to receive a signal from a handset, it listens over the entire area of the cell even though, once the handset starts transmitting, the base station knows precisely where the handset is located. Further, when a cellular base station wishes to communicate to a user handset, it transmits energy (an RF signal) that blankets an area that comprises an entire cell or sector of that cell even though, once again, the base station knows precisely where the handset is located. Almost all of that energy is wasted; the only useful energy is that which arrives at the antenna of the handset. The base station interacts with a handset, by creating a frequency channel for the exclusive use of the handset, effectively preventing all other potential users from accessing those frequencies within the cell or sector until the handset session is completed. This process results in wasted energy and unused spectrum capacity that may prevent others from sharing the radio spectrum.

MAS Technology: There are a variety of technologies available that may increase spectral efficiency. A technology known as "smart antennas," but more accurately "Multi-Antenna Signal Processing" ("MAS"), uses an array of antennas and enormous processing power at each base station site to concentrate the transmitted signal directly to the user handset antenna and perform the ask and listen process in a similarly concentrated matter. Further, MAS technology avoids transmitting energy to other receivers in the same cell and avoids listening to other handsets in that cell. As a result, it is possible to use the same radio channel (that is, the same frequency and time slot) several times more efficiently within the cell than current technologies. Using MAS, it is no longer necessary to avoid using radio channels and the adjacent cells. The net result in this example may be a 21 times increase in the capacity of the spectrum[2]. Alternatively, cellular operators have configured their network and technology to deal with this by using smaller cells in densely populated areas, thus increasing spectral efficiency but at the cost of additional sites. The MAS technology described above is commercially available and has been used in hundreds of thousands of base stations serving and in 20 countries for over 10 years.[3]

Dynamic Spectrum Access (DSA): DSA technologies currently being developed and tested by the Defense Advanced Research Projects Agency ("DARPA") and several commercial firms offer the potential for opportunistic, non-interfering use of underutilized spectrum capacity, as well as more intensive spectrum re-use, especially when combined with MAS technology. While the utility of these new, potentially more spectrum-efficient technologies are by no means restricted to either unlicensed or licensed bands, it is possible that like Wi-Fi technologies, their development could be accelerated and diversified by providing additional unlicensed and licensed spectrum access. This would be particularly the case to the extent that promising new technologies may not operate well in the current unlicensed bands heavily populated by contention-based Wi-Fi radios and/or 'dumb' consumer appliances (e.g., cordless phones, microwave ovens). Identifying spectrum for such uses, however, must be weighed against the need for additional licensed spectrum and considered on a case-by case basis as to the appropriateness of a specific band for licensed or unlicensed use.

There are at least two promising new technologies for more efficient spectrum access that did not exist even as recently as the initial emergence of the Wi-Fi 802.11 family of standards less than a decade ago. These technologies could be implemented separately, or in combination.

One example is "cooperative" radio systems that employ cognitive radio technology to enable all radios certified to operate within a band to coordinate their operation and spectral use with each other in a manner that materially increases spectral reuse, minimizes transmit power, and limits emitter co-interference. In a mobile, ad hoc wireless network (MANET) the radios can be designed to share information with unaffiliated users within range, to "whisper" rather than "shout," and even to relay packets. This potentially allows for as many parallel transmit operations as possible in a network to drive the highest possible spectrum utilization in a given time-frequency slot. Radios with the capability to self-organize into peer-to-peer networks could intensively re-use spectrum by relying for backhaul primarily on an association with wired connections ("opportunistic

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[2] The interference rejection capabilities of a MAS smart antenna system using eight antennas at each base station allow an average of three or more conversations to occur on each frequency and time slot in every cell of a system so equipped. Further, in this example all frequencies can be used in every cell in contrast with typical cellular systems where less than one-seventh of frequencies may be used in each cell.

[3] For data on MAS performance in deployed systems, *see* ArrayComm Web site, http://www.arraycomm.com/serve.php?page=proof. For Worldwide deployment of spectrally efficient MAS system with performance data, *see* http://www.itu.int/ITU-D/imt-2000/Meetings/MoscowNovember2007/Presentations/Presentation_Moscow_KYamaguchi_Part1.pdf. China has over 1 million PHS base stations (peak user number is 100 million). The network is being replaced by a more advanced MAS network. *See* http://translate.google.com/translate?hl=en&sl=auto&tl=en&u=http%3A%2F%2Ftech.sina.com.cn%2Ft%2F2008-06-13%2F07272255320.shtml (translated article).

infrastructure") in homes, enterprises and public spaces. These devices could also be connected to more conventional wide area networks (traditional "tower and power" connectivity). Practical variants could include public safety networks which, like the DARPA ad hoc device networks currently being field-tested by the U.S. Army, permit a peer-to-peer network to be formed on the fly; or enterprise and institutional networks where ad hoc radios are tethered to enterprise infrastructure for backhaul; or consumer networks where the backhaul is handled through opportunistic access to the DSL, cable or fiber connection that is already provisioned at the location.

DSA Advances: A second, more established new approach to band-sharing and unlicensed access incorporates "cognitive" radio technologies that permit frequency and protocol agile devices to sense other transmissions and share unused spectrum capacity more effectively. The concept of dynamic spectrum access networks ("DySPAN") is premised on devices that follow "listen before talk" protocols. They scan the spectrum environment and adjust their operation to take advantage of spectrum holes and/or to comply with built-in policy rules designed to minimize the risk of harmful interference.

Whereas spectrum sensing on unlicensed TV white space channels would be used primarily to detect licensed local broadcast transmissions on neighboring channels, spectrum sensing technology can be particularly useful for working around a primary licensee (e.g., military radar) to share unused capacity on the same frequency – albeit on a secondary and other non-interference and opportunistic basis. The FCC anticipated this as far back as its Spectrum Policy Task Force Report in 2002:[4]

> Preliminary data and general observations indicate that many portions of the radio spectrum are not in use for significant periods of time, and that spectrum use of these "white spaces" (both temporal and geographic) can be increased significantly.
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> Often technologies such as software-defined radio are called "smart" or "opportunistic" technologies because, due to their operational flexibility, software-defined radios can search the radio spectrum, sense the environment, and operate in spectrum not in use by others . . .
>
> That is, because their operations are so agile and can be changed nearly instantaneously, they can operate for short periods of time in unused spectrum

DFS: Opportunities and Challenges: Just a few years later, in 2006, the Department of Commerce, on behalf of federal licensees operating at 5.25 – 5.35 GHz and 5.47 to 5.725 GHz agreed that this approach could support unlicensed sharing of frequencies used by government radar systems based on requirements that devices certified to operate there operate using Dynamic Frequency Selection ("DFS") technology. DFS technology is designed to: (1) avoid frequencies in use by radars on initial start up; (2) once initiated, to perform in-service on-channel monitoring to determine if a radar has started transmissions; and (3) if so, to move to a clear channel without causing harmful interference to the radar system. [5] While the ability of DFS to detect and avoid many radar emissions is well documented, the success of this technology has not been as universal as hoped. Interference to Terminal Doppler Weather Radar (TDWR) systems has underscored the need to ensure adequate enforcement mechanisms are in place when new technologies are

[4] FCC, Spectrum Policy Task Force Report, Washington, DC: November 2002, at 3, 4, 14.
[5] For a brief history of how DoD shares radar bands with the private sector, and a proposal describing how federal agencies can take affirmative steps to facilitate expanded and more efficient band sharing, see Michael J. Marcus, "New Approaches to Private Sector Sharing of Federal Government Spectrum," Wireless Future Program Issue Brief #25, New America Foundation (June 2009), at 4-6.

introduced that could create harmful interference. This is particularly the case because once unlicensed equipment is sold to end users and service providers, it is difficult to locate the source of harmful interference and to quickly rollback the deployment of devices causing prohibited forms of interference *(see discussion of enforcement recommendations in .the Interference and Dynamic Spectrum Access Subcommittee report.)*

In the case of unlicensed 5 GHz outdoor network equipment, the FCC has documented cases in which interference was caused to the Federal Aviation Administration's TDWRs from fixed wireless transmitters operated by WISPs outdoors in the vicinity of airports at high elevations that are line-of-sight to the TDWR installations.[6] The Commission found that in some cases, the interference was created by equipment that was not certified or otherwise compliant with FCC rules. In some cases, equipment that met certification standards still created interference, as the result of several factors, including the configuration of the transmitter, its height and azimuth relative to the TDWR, gaps in the database created by Federal users, and "the device's failure to detect and avoid the radar signal," according to a 2010 FCC memorandum.

Government officials have been regularly meeting with industry to address the issues. While the final chapters on this matter are not yet written, the outcomes initiated or under consideration include revising the certification test to better reflect TDWR emissions characteristics, use of a registration database to assist in locating master devices (and responsible parties) when interference is found, and revised rules for the operation of DFS devices to avoid interference to FAA weather radar operations.

Geolocation Databases: A development that holds promise for opening additional unused or underutilized bands for either unlicensed or even licensed access is more in the realm of governance: the geolocation database that the FCC will soon authorize as a means of providing a list of available unlicensed TV "white space" channels based on the specific GPS-determined location of a user's device (or operator's base station). Under the Commission's Order, both fixed and mobile TV band white space devices ("WSDs") will be required to query a national database to determine available channels at their current location before transmit capabilities are engaged. In the future the functionality of the TV bands database, or a separate database, may not be limited to the TV band frequencies. Moreover, it is possible that access to additional unused or underutilized bands for unlicensed access can be managed in the same manner, which could facilitate more intensive use of spectrum, particularly in bands where sensing technologies alone may offer insufficient protection to incumbent or primary users. Pending further technical analysis of the feasibility of this approach across other bands, including the operational impact to incumbent users, both federal and non-federal bands could be added to the Database, with access to each band subject to conditions that are tailored to avoid harmful interference to existing licensed use. Furthermore, the introduction of these services will need to be balanced against the harmful impact on the public interest that could result from any reduced flexibility for incumbent licensed services and the negative investment and innovation incentives created by access by third parties.

The combination of MAS technology, dynamic spectrum access technology, and technology-enabled governance innovations like the TV Bands Database offers the promise of multiplication of spectrum capacity by hundreds of times and with the potential for continued improvement. Policymakers should consider the real not theoretical increases in spectrum capacity resulting from these advancements when making allocation decisions. Spectrum allocation policies that promote

[6] FCC Memorandum to Manufacturers and Operators of Unlicensed 5 GHZ Outdoor Network Equipment, July 27, 2010, concerning "Elimination of interference to Terminal Doppler Weather Radar."

the development of spectral re-use through these and other emerging technologies will be important in the medium-to-long-term in meeting the rapidly growing demand for mobile data. However, policymakers have few long-term objective sources which they can use to determine the validity and timing of future advances in the technology of the various uses of spectrum. The availability of a National Spectrum Technology Roadmap, created and maintained by an organization such as the National Academy of Engineering would offer a valuable tool for policymakers to evaluate and place in perspective the ever increasing variety of technologies that will, over the coming decades, provide the multiples of spectrum capacity the requirements for are now being predicted.[7]

The Challenge

The promise of improved spectral efficiency can only be achieved by first, developing technologies that make effective use of unlicensed spectrum and second, evolving applications that provide improved access to the spectrum by users. Each of these is a major challenge that must be undertaken if genuine progress is to be made in the future.

Historically, new spectrally efficient technologies have arisen by virtue of necessity or by government stimulation. For example, the land mobile industry evolved from citywide use of single frequency channels with bandwidths of 250 kHz or more to bandwidths of 25KHz or less. This improvement evolved over a period of 40 years but progress was continuous, effective and stimulated simply by the fact that the users had no choice. Stimulation by the FCC resulted in application of trunked systems that use as little as 3 kHz bandwidth for a voice channel. The adoption of cellular systems was a continuation of this effort. Since that time, however, cellular technology has evolved at a rapid pace driven by the business need to increase capacity given a limited amount of spectrum and market-based incentives. As a result, commercial carriers are implementing, or have implemented fourth generation technologies with no government mandate to do so.

Policymakers allocating new spectrum to licensed or unlicensed use should carefully examine spectrum users' incentives to use that spectrum efficiently. Spectrum users with expanded capacity demands may choose to acquire additional spectrum, deploy more efficient technologies, or take other steps to manage demand. Some government polices are designed to drive spectrum use (such as the FCC's construction requirements[8]). In bands subject to command and control regulation, the government has mandated increased efficiency (such as narrow-banding[9]).

This report does not advocate government intervention in the planning and development of new technology but rather recommends that the government provide an environment that encourages

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[7] Cisco predicts a 39-fold increase from 2009 to 2014, or a compound annual growth rate of 108 percent. *See* http://news.cnet.com/8301-30686_3-10449758-266.html and http://news.cnet.com/8301-30686_3-10449758-266.html#ixzz1AKvYIqQB.

[8] *See, e.g., Service Rules for the 698-746, 747-762 and 777-792 MHz Bands, Second Report and Order*, 22 FCC Rcd 15289, 15348 ¶153 (2007) ("In order to better promote access to spectrum and the provision of service, especially in rural areas, we replace the current 'substantial service' requirements for the 700 MHz Band licenses … with significantly more stringent performance requirements…. Licensees that fail to meet the end-of-term benchmarks will be subject to a 'keep-what-you-use' rule, under which the licensee will lose its authorization for unserved portions of its license area …. We expect that licensees will take these construction requirements seriously and proceed toward providing service with utmost diligence.")

[9] *See Implementation of Sections 309(j) and 337 of the Communications Act of 1934 as Amended; Promotion of Spectrum Efficient Technologies on Certain Part 90 Frequencies, Third Memorandum Opinion and Order, Third Further Notice of Proposed Rule Making and Order*, 19 FCC Rcd 25045 (2004) (requiring migration to narrowband (12.5 kHz) technology in the private land mobile radio services).

the adoption of new technologies including being prepared to make spectrum available when such technologies are ready to serve the public.

A closely related concern is that in the future, as new and far more spectrally-efficient technologies and governance mechanisms evolve and become cost-effective, both unlicensed and licensed bands will be littered with legacy devices that no particular entity has the ability or incentive to retire and replace with updated devices and infrastructure. For example, as digital PCS superseded analog cell phones, carriers were eventually able to offer replacement devices, over-build new infrastructure, and eventually stop analog transmissions (once the FCC eliminated the analog requirement). In contrast, in the 900 MHz and 2.4 GHz bands, stand-alone consumer devices such as cordless phones and baby monitors, as well as most Wi-Fi routers, are limited to a particular frequency band and could be "stranded" if the FCC reallocated the band – or determined that the technical requirements governing certified equipment should be very different. These concerns are mitigated by the business incentives users have to deploy the latest and most efficient technologies. The marketplace can be expected to generate competitive pressure that will drive many advances towards spectral efficiency. However, an important countervailing trend is that once unlicensed technology is deployed on a mass market basis in a band, there are few incentives to move toward more spectrally efficient, lower powered and potentially more expensive advanced technologies. A further complicating factor is the extent to which "first in" devices in a band often have a "presumed incumbency," based on operational realities but not regulatory protections, even if as less spectrally efficient operators they do not make "good neighbors" for more efficient technologies that seek to share spectrum. This has meant that as some unlicensed bands (e.g., 900 MHz) have become increasingly congested with older, less spectrally efficient unlicensed devices, more advanced technologies have migrated to other bands, in the absence of incentives for legacy consumer uses to upgrade to more efficient, advanced technology.

Because of the inevitability and desirability of the technological developments described above, these legitimate concerns need not deter future allocations of spectrum for exclusive unlicensed use. Some have recommended that the "assignment" of bands for unlicensed or opportunistic access may not need to be permanent, or even long-term. As the TV White Space Order suggests, opening new bands for shared or even exclusive access on an unlicensed basis need not preclude reallocation or reorganization of the band at a later date[10]. Access to bands by unlicensed devices could be conditioned in ways that reserve the flexibility to reallocate a band in the future or to change its operating rules.

For example, under the rules governing unlicensed access to the TV 'white space,' the Commission reserves the option to license additional TV stations, thereby "delisting" a vacant channel from the white spaces database in that particular local market area. Opportunistic access presumes that devices will increasingly be multi-band and capable of frequency agile. Devices certified for use on an unlicensed basis would not need to be tied to a particular frequency, even though this may make the devices more expensive than they otherwise might be. Bands may be able to be opened or closed for sharing – nationally, regionally, or locally – and even on short notice, without "stranding" any users or equipment.

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[10] This has not worked yet in a practical sense; there has not been a successful reallocation away from unlicensed.

Another distinct advantage of using a geolocation database to manage new unlicensed use is that access to different bands can be subject to different (and changeable) operating rules. Each listed frequency band can carry its own "rules of the road" with respect to maximum signal power, leakage into adjoining bands, or even the times of day or angle of transmission that would be allowed. This would permit the Commission, where appropriate, to factor in conditions that protect incumbent services, not only on the same frequency, but also on adjacent frequencies. It would also allow the Commission to foster innovation with respect to new network architectures – such as conditioning access to some bands on more spectrum-efficient protocols, as noted above.

Finally, we note that technologies and spectrum management mechanisms that facilitate both conditional and potentially temporary access to certain bands on an unlicensed or even secondary licensed basis may help to reassure band incumbents – particularly the military and other federal spectrum users – that opening a band to greater sharing will not preclude their future ability to reclaim exclusive use, or to accommodate technological and other upgrades in their own systems.

Recommendations.

1. It is recommended that Department of Commerce establish an organizational effort aimed at investigating effective ways of using spectrum more efficiently and sharing spectrum more effectively with unlicensed operations. The outcome of such an effort could define operating parameters and efficiency targets for developers of new radio systems.

Among the potential approaches to stimulating important advances in spectrum utilization is the use of government sponsored and funded programs to facilitate sharing technology advances. The potential areas for research include SmartGrid, Health Care Monitoring and DOT vehicle systems, which could provide early adoption of innovative RF dependent technology. For example, the programs used by DOT in advancing the technology of robotic vehicles offer prizes and annual contests that are resulting in extraordinarily productive, innovative and low-cost results. The effort could include examining incentives for legacy, inefficient spectrum-dependent technologies to upgrade to more advanced and efficient technologies in unlicensed bands. It would also assess methods for ensuring that enforcement measures are meaningful, adequately funded and methodically applied to assure incumbent operators that new entrants into an unlicensed band will not cause harmful interference.

2. It is further recommended that NTIA in concert with the FCC engage in a long-term effort to create a National Spectrum Technology Roadmap. As noted elsewhere in the document, spectrum technology advances have proceeded in the past as a result of evolving user requirements and new technology capabilities. This would be a continuing effort that could use resources like the National Academy of Engineering. The National Spectrum Technology Roadmap would provide a context for government entities in future spectrum allocations decisions. This roadmap could be developed in accordance with the strategic spectrum plan, which was recommended in the National Broadband Plan.[11] The roadmap would have added benefits in that it would provide objective benchmarks for agencies that have need to evaluate performance regarding adoption of spectrally efficient technologies and could inspire service providers and manufacturers to reach for more aggressive goals in solving the emerging crisis in spectrum scarcity. The Roadmap should not, in any way attempt to dictate technology decisions or distort the market forces that create these technologies.

[11] *See* FCC, Connecting America: The National Broadband Plan, Recommendation 5.3, at 81 (rel. Mar. 16, 2010), http://www.broadband.gov/plan/.

3. The Committee also recommends that one or more new bands designated for unlicensed access – whether on a shared or exclusive basis – be designed at least initially to encourage the development of more spectrum-efficient and/or higher-powered technologies that might not thrive in bands currently dominated by contention-based 802.11 unlicensed devices/networks.

4. Finally, we recommend that NTIA and the FCC consider opening unlicensed access to new bands, whether on a secondary (shared) or primary basis, subject to technical rules that will not create obstacles to future reallocation or reorganization of the band due to the risk of substantial stranded devices and infrastructure. Access to new unlicensed bands should generally be conditioned in ways that reserve the flexibility to reallocate a band in the future or to change its operating rules.

APPENDIX A

15.205 Restricted bands of operation.

(a) Except as shown in paragraph (d) of this section, only spurious emissions are permitted in any of the frequency bands listed below:

MHz	MHz	MHz	GHz
0.090–0.110	16.42–16.423	399.9–410	4.5–5.15
[1]0.495–0.505	16.69475–16.69525	608–614	5.35–5.46
2.1735–2.1905	16.80425–16.80475	960–1240	7.25–7.75
4.125–4.128	25.5–25.67	1300–1427	8.025–8.5
4.17725–4.17775	37.5–38.25	1435–1626.5	9.0–9.2
4.20725–4.20775	73–74.6	1645.5–1646.5	9.3–9.5
6.215–6.218	74.8–75.2	1660–1710	10.6–12.7
6.26775–6.26825	108–121.94	1718.8–1722.2	13.25–13.4
6.31175–6.31225	123–138	2200–2300	14.47–14.5
8.291–8.294	149.9–150.05	2310–2390	15.35–16.2
8.362–8.366	156.52475–156.52525	2483.5–2500	17.7–21.4
8.37625–8.38675	156.7–156.9	2690–2900	22.01–23.12
8.41425–8.41475	162.0125–167.17	3260–3267	23.6–24.0
12.29–12.293	167.72–173.2	3332–3339	31.2–31.8
12.51975–12.52025	240–285	3345.8–3358	36.43–36.5
12.57675–12.57725	322–335.4	3600–4400	([2])
13.36–13.41			