DRAFT

Unlicensed Spectrum Subcommittee Report

November 1, 2010

Overview

The allocation of segments of the radio frequency spectrum for unlicensed applications offers the potential of improved frequency sharing, for more efficient use of the radio frequency spectrum, and for the creation of new services, all of which are in the public interest. Radio Technological advances under development can potentially transform the provision of wireless service by enabling efficient frequency sharing and protocol management to the ultimate end of eliminating the need of exclusive spectrum licensing. There are, however, dangers in premature allocation decisions based on such a regime before appropriate technology is available and before there is a complete understanding of how all use of the radio spectrum will evolve. On the other hand, there is also a need to ensure that as technology for more efficient use of the spectrum evolves and matures, there are sufficient spectrum resources available in which they can flourish.

This report reviews the opportunity and challenge presented by allocating spectrum for unlicensed use and includes recommendations for future activity by the Department Commerce. The focus of these recommendations is the creation of a national plan for evolution of both the user requirements and the technologies.

"Unlicensed Spectrum" Described

Unlicensed spectrum refers to radio frequency bands in which technical rules are specified for both the hardware and deployment methods of radio systems such that the band is open for shared use by an unlimited number of unaffiliated users. 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 FCC and operated in conformity with Part 15 of the Commission's rules. In contrast with most licensed assignments of spectrum use rights, devices or systems operating on an unlicensed basis 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 WiFi Alliance's 802.11 family of protocols) mitigate interference, users must accept any interference caused by other radios on the band.

Historically, the United States has had a permissive policy toward unlicensed usage as non-primary under Part 15 of the Commission's rules. The NTIA has been similarly supportive of unlicensed sharing spectrum assigned to federal users. Part 15 rules permit unlicensed usage in all frequency bands except those specifically identified in Section 205 of Part 15, which is attached as appendix A.

In addition, the FCC has promoted unlicensed use in certain bands by relaxing some of its rules. The bands with significant spectrum allocations for unlicensed devices 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) – lite-licensed
- 5 GHz (5150-5350, 5470-5825 MHz)
- 60 GHz (57-64 GHz)

Bands designated for unlicensed access can also be subject to other constraints designed to protect licensed, primary services operating on the same or adjacent channels. Unlicensed spectrum can, in fact, be highly regulated spectrum since users who operate on the same frequency band are not necessarily cooperative. For example, in the upper 5 GHz band, WiFi devices share a band with military radar subject to the condition that the devices are capable of spectrum sensing and Dynamic Frequency Selection; if radar is detected, the unlicensed user must vacate the channel immediately.

It should not be assumed that, because unlicensed bands lack regulatory protection, that unlicensed services are necessarily lower in quality or more subject to interference. Various techniques, some already deployed, can mitigate interference and organize spectrum usage such that quality of service may be as good as and in some instances, better than in licensed services. National governments currently allocate bands of spectrum (sometimes based on guidelines from the ITU) for use by anyone so long as they respect certain technical limits, most notably, a limit on total transmission power. Unlicensed spectrum is decentralized: there are no license payments or central control for users on a band. However, depending on the band, sharing spectrum on an unlicensed basis requires that mitigation techniques (e.g.: power limitation, duty cycle, dynamic frequency selection) are imposed to ensure that these devices operate without creating interference for licensed services. . Centralized coordination is not incompatible with unlicensed use, however. In September, 2010, the FCC finalized rules for unlicensed use of unassigned TV channels (so-called TV White Spaces0, which requires devices to have GPS capability and to check a national database to acquire 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 how incumbent users register for protection in the database.

Traditional users of unlicensed spectrum mostly authorized under Part 15 of the FCC rules include cordless telephones, garage door operators, and baby monitors and microwave ovens. More recently, a rapidly evolving collection of new technologies is taking advantage of unlicensed spectrum including Wi-Fi, Ultra Wideband spread spectrum, software defined radio, cognitive radio, and mesh networks.

Unlike most licensed assignments of spectrum, unlicensed band are generally open for shared access by a wide variety of services, devices and technologies. Open spectrum advocates promote provision by the Federal Communications Commission of more unlicensed, radio frequency spectrum that is available for use by all. But even when shared, some services may be given priority or precedence over others. In contrast, some proponents of the "commons model" of open spectrum advocate a future where all spectrum is shared, and in which cognitive radios use cooperative Internet protocols to coordinate to avoid harmful interference and optimize the communications capacity of the spectrum as a whole. Proponents of the "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. In this view, everyone would be given equal opportunity to use the airwaves for their own radio station, television station, or even broadcast their own website.

An Idealistic Model Of Effective Unlicensed Spectrum

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

1) The bandwidth required,
2) For only the time required,
3) Occupying only the geographically defined space required, and
4) Using 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 by trillions of times. While this may appear to be an exaggeration, it is rather an indicator of how inefficiently spectrum is used today. When even a small part of this potential is achieved, today's concept of spectrum shortage will dissipate and the need for traditional frequency regulation will disappear. Elements of this technology are already in use in the form of smart antennas, and other tools, such as dynamic spectrum access and radio defined software technologies are in development. An evolutionary path toward unlocking the full potential of our spectrum resources and addressing today's looming spectrum crisis is necessary, but that path has to be mindful of real world limitations.

Experts offer widely varied views of when technology will be available to enable this transformational model. Given these divergent opinions, the report starts by describing the existing limitations in order to offer 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 fulfilment of a "commons model" regulatory-free spectrum regime,.

Wi-Fi as an Example

Wi-Fi is often a 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 in which it is ineffective. Wi-Fi is an inherently short range service as limited by the low power output that is required under Part 15 of the Commission's rules to minimize interference between users. Wi-Fi is designed to provide relatively high bandwidth to users with 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 terrestrial connection. Larger areas are sometimes covered by Wi-Fi mesh networks that use access points to bridge gaps between terrestrial connections and users but these networks are spectrally inefficient. When used to cover a home or a portion of an office building, Wi-Fi is 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 WiFi 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.

Another emerging and rapidly growing use of WiFi 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 WiFi connections when and where available. For example, a reported 40 percent of iPhone data traffic travels over WiFi connections, relieving AT&T's network. While most of these WiFi connections are provisioned by consumers themselves (at home, work or in public spaces), AT&T has acquired and expanded a network of 25,000 WiFi hotspots it opens freely to its smartphone customers in high-traffic areas, from Starbucks stores to sports stadia. The carrier is also building out mesh WiFi networks on unlicensed spectrum that provide high-capacity coverage across locations such as New York City's Times Square and Wrigley Field, the Chicago baseball stadium.

WiFi technologies currently play a more limited role in enabling wide area coverage. For example, although thousands of Wireless Internet Service Providers (WISPs) rely on WiFi technology to provide Internet access it is generally confined to mostly rural and remote areas. Wi-Fi is unsuitable for robust wide area coverage in densely populated areas for the very reasons that make it so effective for homes and offices. Extending robust coverage, that is with the order of 95% or greater coverage in populated areas, is prohibitive and impractical. Further, while existing spectral efficiency of Wi-Fi networks is acceptable by today's standards, the contention-based and non-coordinated protocols that characterize WiFi seem likely to limit future improvements in spectral efficiency. Cell-splitting, still an effective spectrum multiplying tool in cellular systems, is not viable with Wi-Fi. Because spectral efficiency is limited, and because the consumer demand for bandwidth is exploding, the Wi-Fi frequency bands will become congested. 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 instructive to examine an example of how existing or developing tools have the potential for important increases in the capacity of the radio frequency spectrum to offer services in the public interest. 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 impinges on 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 spectrum inefficiencies that prevents others from using the radio spectrum that could be shared.

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 within the cell. Using (MAS), it is no longer necessary to avoid using radio channels and the adjacent cells. The net result in this example is a 21 times increase in the capacity of the spectrum.

The (MAS) technology described above is commercially available and has been used in hundreds of thousands of base stations and over 20 countries for over 10 years.

Similarly, cognitive and Software Defined Radio technologies currently being developed and tested by 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. While the utility of these new, potentially more spectrum-efficient technologies are by no means restricted to either unlicensed or licensed bands, we believe it is quite possible that like WiFi technologies, their development could be accelerated and diversified by allocating additional unlicensed spectrum access, whether on a shared (secondary) or exclusive basis. This would be particularly the case to the extent that promising cognitive and/or cooperative radio technologies could not operate well in the current unlicensed bands heavily populated by contention-based WiFi radios and/or ‘dumb’ consumer appliances (e.g., cordless phones, microwave ovens).

There are at least two promising new technologies for more efficient spectrum access that did not exist even as recently as the initial flourishing of the WiFi 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 where cognitive radio technology can be employed 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 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.

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. These radios are typically described as being "cognitive" and require spectrum sensing capability in the PHY layer and policy controls in the MAC layer. For example, in its September, 2010 Order implementing unlicensed access to certain unassigned "white space" channels on the terrestrial TV band, the FCC left the door open for the possible certification of such devices – relying on spectrum sensing – to detect and avoid interference with TV broadcasts and wireless microphones without reliance on access to the geolocation database that will otherwise provide devices on the unlicensed channels permission to operate.

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 opportunistic basis. The FCC anticipated this as far back as it's Spectrum Policy Task Force Report in 2002:[1]

> 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. . .
>
> 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

Just a few years later, the Department of Defense (DoD) agreed that this approach would allow unlicensed sharing of substantial military radar bands at 5.6 GHz based on requirements that devices certified to operate there operate at low power, follow a sense-before-transmit protocol, and have the Dynamic Frequency Selection (DFS) capability to periodically re-scan and switch channels in under one second if radar is detected.[2]

A third 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. Access to additional unused or underutilized bands for unlicensed access can be managed in the

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[1] FCC, Spectrum Policy Task Force Report, Washington, DC: November 2002, at 3, 4, 14.

[2] 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 Governmment Spectrum," Wireless Future Program Issue Brief #25, New America Foundation (June 2009), at 4-6.

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. 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. The combination of advanced antenna (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. Spectrum allocation policies that promote the development of spectral re-use through these and other emerging technologies will be far more important in the medium-to-long-term in meeting the rapidly growing demand for mobile data than will be the inevitably diminishing returns from reassigning finite spectrum among exclusive users.

The Challenge

The promise of improved spectral efficiency resulting from widespread use of unlicensed spectrum 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, but one which 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 edict. For example, the land mobile industry evolve from citywide use of single frequency channels with bandwidths of 250 kHz or more to trunked systems with as little as 3 kHz bandwidth for voice channel. This improvement evolved over a period of 40 years but progress was continuous and effective and stimulated simply by the fact that the users had no choice. The adoption of cellular technology was a continuation of this effort but was also stimulated by government edict that stated that spectrum for public switched personal communications would simply not be available without such spectrally efficient technology.

The reallocation of new spectrum, whether licensed or unlicensed, without conditions requiring improved spectral efficiency will only delay creation and adoption of new generations of technology. New technologies will be created only when entities who introduce new applications have no easier alternative. Further, users will not adopt improved operating systems unless they, too, have no practical alternative.

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, that the unlicensed 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. In contrast, in the 900 MHz and 2.4 GHz unlicensed bands, stand-alone consumer devices such as cordless phones and baby monitors, as well as most WiFi 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.

Because of the inevitability and desireability of the technological developments described above, these legitimate concerns need not deter future allocations of unlicensed spectrum. The "assignment" of bands for unlicensed or opportunistic access need not 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. Access to new unlicensed bands can be conditioned in ways that reserve the flexibility to reallocate a band in the future or to change its operating rules. 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 Database in that particular local market area. Opportunistic access presumes that devices will increasingly be multi-band and capable of frequency hopping. No devices certified for use on new unlicensed bands need to be tied to a particular frequency, even though this may make the devices more expensive than they otherwise might be. Bands can be opened or closed for sharing – nationally, regionally, or locally – and even on short notice, without "stranding" any users or equipment.

Another distinct advantage of using a geolocation database to manage new unlicensed bands 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 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 will 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.

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. 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 numerous technology efficient project including SmartGrid, Health Care Monitoring and DOT vehicle systems could provide early adoption of innovative RF dependent technology. For example the programs used by DOT in advancing the technology of robotic vehicles offer prices and annual contests that are resulting in extraordinarily productive, innovative and low-cost results.

It is further recommended that NTIA in concert with the Federal Communications Commission engaged in a long-term effort to create a National Spectrum Technology Roadmap. 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 in which all future spectrum allocations would be made. Regulating agencies would have the basis upon which future spectrum users would be required to accommodate spectrum efficient technologies.

The allocation of limited unlicensed spectrum allocations dedicated to RF technologies that facilitate the development of sharing technologies will accelerate their evolution. The encouragement and (requirement) that licensed spectrum users tolerate some sharing in limited instances will align their interests and resources around efficient sharing technologies.

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, cognitive radio technologies and/or protocols that might thrive on a currently unlicensed bands dominated by contention-based 802.11 standard devices/networks.

Finally, we recommend that where feasible, that NTIA and the FCC open 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			