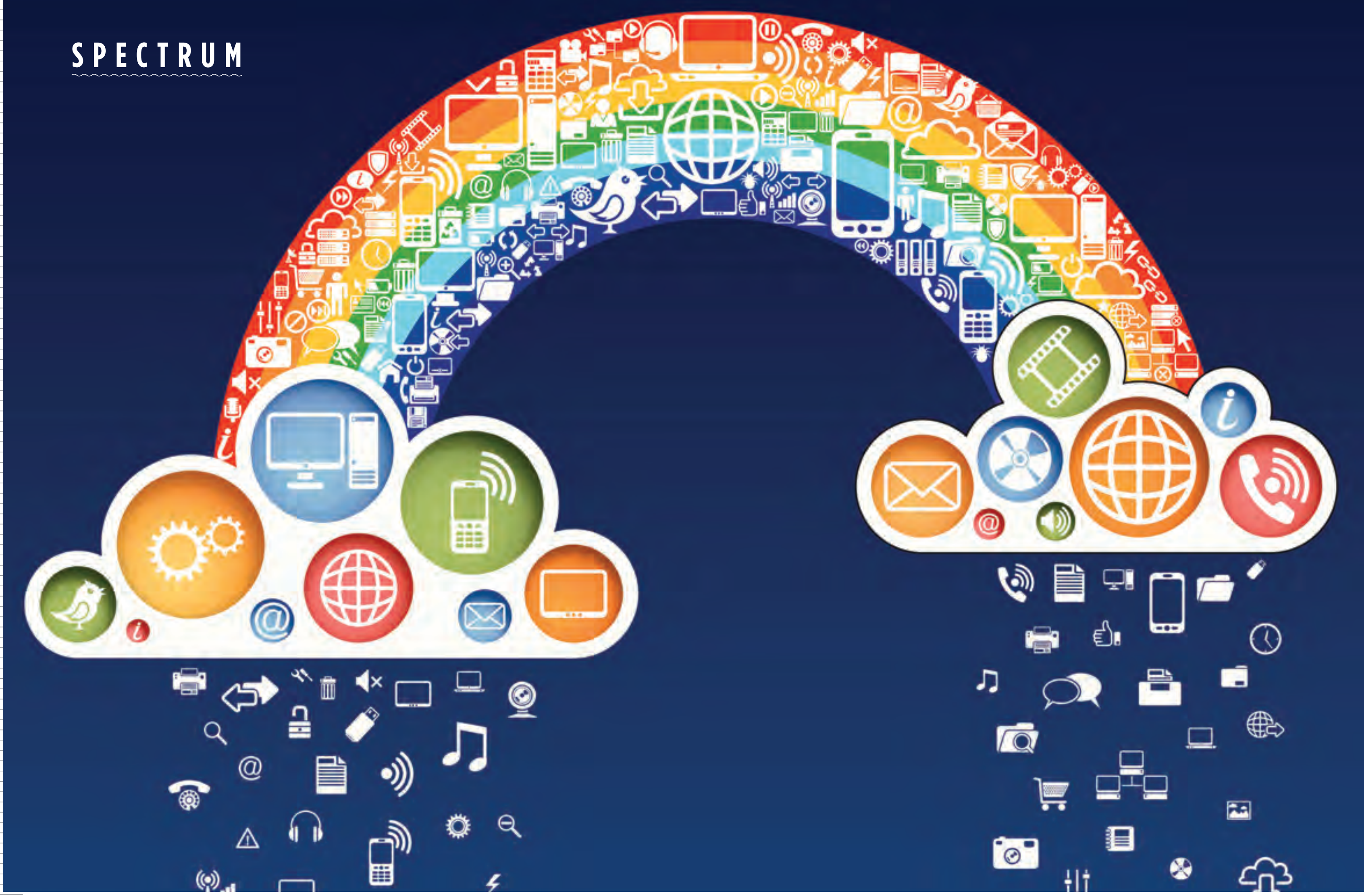

TOWARDS A SHARING PARADIGM

In the second article in their two-part paper, **BRYAN TRAMONT** and **ADAM KRINSKY** discuss sharing strategies from a US viewpoint

The exponential growth in demand for spectrum-based services in the US has stretched the limits of today's networks and the spectrum on which those networks rely. President Obama and the Executive Branch, the Congress, and the Federal Communications Commission (FCC) have all stepped up to the plate to explore new measures to increase the efficiency of spectrum use. This requires new ways of thinking about repurposing and sharing spectrum.

SHARING WITH INCUMBENT GOVERNMENT USERS

In the US, the FCC is responsible for overseeing allocations and licensing of non-federal government spectrum, and the Department of Commerce manages federal government use of spectrum. Government agencies use spectrum for a wide variety of critical purposes, including law enforcement and national defence.

However, nearly 60% of the 'beachfront' (high value) frequencies are predominantly allocated to federal government uses, and there is an opportunity to make more efficient and intensive use of those frequencies. Accordingly, in 2003, the Department of Commerce started the Spectrum Initiative, which convened a government-wide spectrum task force, including representatives of the FCC, to develop a new framework for spectrum management. As a result, the Department of Commerce Spectrum Management Advisory Committee (CSMAC) was established to provide advice on needed reforms to domestic spectrum policy to enable new spectrum-dependent technologies, including expediting the public's access to broadband.

In the following years, CSMAC working groups have examined, among other things, a variety of ways in which spectrum could be shared between government and private sector users in order to use spectrum more efficiently, most of which involved sharing rather than simple reallocation, given that many of the federal users cannot readily be relocated. As a result, the Department of Commerce has turned to sharing as an alternative to relocating some government spectrum users, such as meteorological satellites, controllers for drones, surveillance operations, and shipboard radar.

Sharing took on new emphasis in 2012, when the President's Council of Advisors on Science and Technology (PCAST) report on spectrum found that "the traditional practice of clearing government-held spectrum of Federal users and auctioning it for commercial use is not sustainable", and urged the President to facilitate sharing of government spectrum because of challenges posed by clearing and reallocation, namely "the high cost, lengthy time to implement, and disruption to the Federal mission". The PCAST report declared that "the norm for spectrum use should be sharing, not exclusivity", advocating use of a "new 'dynamic sharing' model" that would allow establishment of a "three-tier hierarchy" of spectrum sharing: federal primary systems to be protected from harmful interference, commercial secondary licensees registered in a database with some degree of protection, and "general authorised access" users with opportunistic access to the spectrum.

The assistant secretary of commerce and National Telecommunications and Information Administration (NTIA) administrator, Larry Strickling, endorsed this recommendation, saying, "We need to find a new way of making spectrum available for commercial broadband, and that new way has to embrace the sharing of spectrum between federal agencies and industry."

Subsequently, President Obama, in his 2013 presidential memorandum on spectrum, took action to accelerate the process of such spectrum sharing. And the FCC has initiated a proceeding to consider PCAST's three-tiered hierarchy of dynamic spectrum sharing in the 3.5 GHz proceeding, as discussed further below. As Strickling recently said: "The report has provided a tremendous boost to changing the paradigm of how we go about allocating spectrum for commercial use," with particular emphasis on use of 'coordination zones' to enable commercial access to areas with federal use, rather than 'huge exclusion zones' which would simply ban commercial use within those areas. In addition, the FCC has fostered sharing approaches as part of its rules governing the 1755-1780 MHz band, which is currently occupied by federal government users but has been described as "especially appealing for commercial wireless use" by the FCC.

TRADITIONAL STATIC SHARING

Sharing can be accomplished statically by employing what economists call 'electrospace' dimensions. Assuming a common frequency or channel is to be shared, traditional sharing mechanisms have included temporal, geographic, and angle of arrival sharing. In addition, under some circumstances, some 'underlays' have been established on a finding that an alternative spectrum use can coexist with incumbents' use of spectrum without interfering.

Temporal sharing. Spectrum can be statically shared on a temporal basis. The FCC has long exercised the statutory power to establish the times of operation of stations. For example, because AM radio signals travel farther at night, the FCC requires some stations to reduce power or go off air after dark to avoid interfering with distant stations. Similarly, multiple licensees have historically shared a single channel for services such as paging by alternating their use of the channel sequentially.

Geographic sharing. Geographic sharing can be accomplished by establishing geographic limits, coupled with power or signal strength criteria to prevent interference to another spectrum usage across the geographic boundary. For example, the National Radio Quiet Zone is an area of about 13,000 square miles in Virginia and West Virginia surrounding the Naval Radio Research Observatory and the National Radio Astronomy Observatory, with strict limits on radio transmissions inside the established boundaries; there are other geographically defined quiet zones in a number of locations as well. Another example of geographic sharing is the use of geographic protection zones to permit wireless broadband use of government spectrum in areas where government has specific needs for access to spectrum without interference. For example, the Department of Defense reached agreement in late 2013 on sharing the AWS-3 (advanced wireless service) bands under a provision that maintains its exclusive use of certain spectrum in limited areas. Of course, area-wide commercial wireless licences are another example of co-channel geographic sharing.

> **This new commitment to sharing is a significant shift from flat exclusions on commercial access based on interference.**

Directional sharing. Directional sharing, based on angle of arrival, is used to allow spectrum to be reused intensively in services where directional antennas isolate two co-channel signals. For example, separate co-channel fixed microwave transmissions can be received at a given tower from transmitters in different directions, provided the receive antennas are sufficiently directional to prevent the two signals from interfering. Likewise, satellite earth stations can receive signals from space stations using directional antennas, while the same frequency is used for terrestrial communications.

Underlays. Spectrum can also potentially be shared statically through use of a spectrum underlay. A spectrum underlay permits a very low-powered, short-range transmitter to coexist with much higher-powered transmitters by spreading its signal over a very wide range. One example of an underlay authorised by the FCC is the ultra-wideband (UWB) service, which the FCC allows to be used within specified technical limits, without any need to consider its potential effect on licensed services. The FCC found such devices' interference potential to be, at most, *de minimis* at the authorised power levels and related criteria.

DYNAMIC SPECTRUM ACCESS (DSA)

Given the ever-growing demand for spectrum, the US is exploring various ways to enable spectrum sharing to further more efficient and intensive spectrum use – with a growing focus on sharing techniques that provide varied access as spectrum usage demands change over time. These dynamic spectrum access models can be applied to sharing both between government and commercial users and between multiple commercial users. A key element is providing sufficient interference protection for incumbent uses. As stakeholders are discovering, dynamic spectrum access can be accomplished through a variety of means, including cognitive radio systems employing spectrum sensing, database and geolocation systems, and complex spectrum access systems.

Dynamic spectrum access models

Dynamic spectrum access permits spectrum to be shared dynamically, ie. in ways that change over time, instead of only statically. There are three basic models for implementing dynamic spectrum access:

- A dynamic variant on the exclusive use model
- Open sharing, via the commons model
- A hierarchical access model, such as dynamic overlays or underlays.

There are also innumerable variables and variants involved.

Dynamic exclusive use. This model maintains the existing exclusive use structure (eg. PCS or WCS [personal or wireless communications service], and to some extent cellular), but allows licensees to sell and trade spectrum use rights, through a variety of mechanisms.

Some engineering experts see the current FCC secondary market leasing rules as a theoretical way of implementing dynamic exclusive use. However, the FCC process for obtaining leases makes this 'dynamic' in name only, because of the time needed to implement a spectrum lease through FCC notifications or applications.

A more realistic way of implementing dynamic exclusive use may be to allow exclusive use licensees to share spectrum in real time. Some engineers have described this as the 'spectrum property rights' approach, presumably because it allows an exclusive use licensee the option to exercise its spectrum property rights more efficiently in response to demand for spectrum.

A model similar to the band manager leasing concept could also be used, wherein a non-facilities-based spectrum access provider would make spectrum from a new band available to facilities-based radio network infrastructure providers on a dynamic basis. This approach would avoid the delays that can result from the FCC leasing process.

A further variant on dynamic exclusive use that has been briefly mentioned in the literature would allow providers in different services, such as cellular, public safety, TV etc. to share their spectrum dynamically, on an instantaneous basis, subject to interruption in the event the primary licensee requires the spectrum.

Open sharing. This model uses a spectrum commons – unlicensed spectrum shared among peers in accordance with accepted protocols – to allow an unlimited number of providers to dynamically share a given block or blocks of spectrum.

The IEEE 802.11 family of WiFi protocols shows how this can be accomplished. However, the FCC does not mandate compliance with such protocols in unlicensed spectrum, and so there is always the possibility that an alternative use of a given unlicensed band that is consistent with FCC Part 15 unlicensed rules will result in a 'tragedy of the commons', with efficient usages being drowned out under an open sharing model, given that no interference protection is afforded to unlicensed open sharing.

Hierarchical access. The third dynamic model is hierarchical access, wherein primary and secondary users coexist, with perhaps several tiers of secondary users having varying degrees of protection.

In some cases there are multiple tiers of primary and secondary users. For example, in the television channels, TV broadcasters have primary access to spectrum where they are licensed, but the spectrum can also be used for broadcast auxiliary purposes (such as communications related to television production) on a licensed secondary basis and for TV 'white space' data communications and unlicensed wireless microphones on an unlicensed secondary tier. Moreover, the PCAST report has recommended a three-level hierarchy for sharing of government spectrum between federal government primary users, secondary priority licensed users, and unlicensed users at the lowest tier. Currently, there are secondary users of many bands of spectrum, in the form of Part 15 unlicensed intentional radiators, including baby monitors, WiFi access points, Bluetooth devices, and remote controls.

Dynamic spectrum underlays. An underlay is an example of hierarchical access that could potentially be deployed differently from the static underlay described above, such that the secondary underlay user's right to operate depends on the primary operator's operational status, in which case a dynamic spectrum access technique may be necessary. For example, a static underlay may be appropriate at any time, based on a strict power limit or duty cycle limitation, but a higher power limit or duty cycle could be permissible on a dynamic basis based on the activity (or lack thereof) of primary users.

Spectrum overlay or opportunistic spectrum access. The most commonly discussed implementation of hierarchical access dynamic spectrum access is a spectrum overlay, or opportunistic spectrum access model. In such a system, the secondary user is allowed to use the spectrum only where there are gaps or white spaces in the primary users' coverage, such that the secondary user can transmit without causing harmful interference. The secondary users seek out opportunities to employ frequencies not already in use in a given area by higher-priority users. A spectrum overlay implementation requires a means for the secondary user's radio to determine whether it is located in a primary coverage gap such that it may use the spectrum. As discussed below, the principal means for accomplishing this are spectrum sensing and database/geolocation.

An example of a hierarchical access spectrum overlay is a portion of the 5 GHz band used for IEEE 802.11 WiFi. Part of this band overlays a band used by federal government operations, and the unlicensed non-government portion of the band is known as the U-NII band, and is subject to rules designed to avoid interference with government spectrum use. In particular, in portions of the band devices are required to incorporate dynamic frequency selection (DFS), which implements dynamic spectrum access by sensing the spectrum for the presence of radar and switches the transmitter to another frequency if it is present.

The cognitive radio and spectrum sensing DSA solution

The DFS protocol is an example of a form of dynamic spectrum access known as cognitive radio. From an engineering perspective, cognitive radio today has two key characteristics: (1) cognitive ability, which uses spectrum sensing to detect usage by primary users, performs spectrum analysis to determine whether there is a 'spectrum hole' permitting operation, and then makes a spectrum decision concerning the appropriate spectrum for transmission; and (2) the ability to reconfigure dynamically.

A cognitive radio may engage in spectrum sensing, analysis and decision-making independently (a 'non-cooperative' environment) or 'cooperatively', in which case multiple cognitive radios work together to decide on spectrum access based on the constraints on spectrum use, either coordinating directly with each other or using a central controller to manage spectrum usage.

In short, a cooperative cognitive radio environment can provide for inter-user sharing by taking advantage of similar management techniques that are used within systems under network control, such as frequency selection and power control. Indeed, the FCC has acknowledged in its 2005 order on cognitive radio that some cellular networks have already incorporated "cognitive capabilities to sense spectrum use and/or to adjust transmit power to allow more efficient spectrum use".

While the FCC, CSMAC and PCAST all generally use the term 'cognitive radio' to mean a radio or radio network that uses sensing to select the appropriate spectrum for transmission, the term is occasionally used more loosely to describe dynamic spectrum access more generally, including systems using database and geolocation techniques (described below), rather than sensing spectrum use.

Cognitive radios can be implemented using software defined radio technology at the physical level, but need not do so. Software defined radio is simply a radio whose frequency range, modulation type, maximum power or other operational characteristics can be modified through software without any change in hardware.

The database and geolocation DSA solution

Dynamic spectrum access can also be implemented without employing spectrum sensing by using a database of information about available frequencies in the area. The database is queried about the radio's location, determined by using geolocation (via GPS, WiFi, cell or Bluetooth). The database can be located in the radio, or it may be accessed via a fixed beacon or other technology. The device uses the database to determine whether it is safe to transmit by analysing the presence or absence of primary user spectrum usage in the area.

An example of a dynamic spectrum access system that uses a database and geolocation method is the FCC's TV white spaces regime, which provides for queries of a periodically updated database to determine whether it is safe to transmit, and on which channel. The FCC had originally required both the database/geolocation system and a sensing requirement, but later dropped the sensing requirement as unnecessary.

Under the TV white spaces rules, an unlicensed TV band device must determine its location and then access an internet database of protected services (including TV stations, broadcast auxiliary operations, and registered wireless microphones) to obtain a list of the permitted channels where it is located. Over a dozen database operators have been designated by the FCC, some of which are authorised to provide database services nationwide. The first commercial white spaces operation – a wireless ISP – went online in 2013.

The developing 3.5 GHz spectrum access system

The FCC is now considering even more complex forms of dynamic spectrum access as it seeks to allow non-government access to government spectrum, such as the 3.5 GHz band, where it is considering allowing two tiers of access to spectrum by non-government users, in addition to the government incumbents (and a limited number of non-government incumbents). Under the FCC's proposal, echoing the PCAST report, there would be incumbent access (primary), priority access (secondary to incumbent access) and general authorised access (secondary to both incumbent access and priority access).

The FCC has proposed to rely on one or more spectrum access systems (SAS) to govern the non-government users, employing a database to ensure that priority access and general authorised access users can operate at locations where they will not cause interference.

The FCC's proposal in its further notice of proposed rule-making calls for the SAS to direct non-government priority access users' use of particular frequencies and power levels in a given location, varying dynamically based on incumbent government users' activities. The FCC is continuing to seek additional information that will make it possible to avoid the need for what Larry Strickling calls "huge exclusion zones", and instead rely on DSA-managed coordination between government and commercial users to permit operational sharing in large portions of those areas.

CONCLUSION

Summarising this two-part paper, we have reported that the traditional command-and-control model of spectrum regulation has largely been replaced by an exclusive, flexible use model in the wireless sector, which has enabled more efficient and innovative spectrum use. Secondary market transactions – both acquisitions and spectrum leases – have acted as an engine for spectrum efficiency. Licensees have also adopted practices that facilitate expansion of the broadband ecosystem and efficient spectrum usage through resale, enabling machine to machine (M2M) communications, and development of the internet of things.

The government is in the midst of developing an exciting new tool, the two-sided incentive auction, which can move spectrum from command-and-control incumbent uses to flexible licences, enabling new services through the marketplace. The first incentive auction will involve transitioning television spectrum to commercial wireless services, but this tool can be applied to all types of spectrum, including government spectrum.

In another initiative, policymakers are opening up opportunities in government spectrum by providing new sharing mechanisms for commercial providers to access this spectrum, without disrupting the federal mission. This new commitment to sharing is a significant shift from flat exclusions on commercial access based on the theoretical possibility of future interference at some time and place.

Static sharing techniques, such as temporal, geographic, and directional sharing have some limitations, because they do not take into account actual operating conditions. Dynamic spectrum access models, including dynamic exclusive use, open sharing, and hierarchical access models such as dynamic spectrum overlays and underlays can be used to enhance the efficient and intensive use of government spectrum.

These models can be implemented through cognitive radio, which involves spectrum sensing, through use of a database and geolocation approach to permit operation only where it is safe to operate, or through use of an interactive spectrum access system that offers continuously updated access while ensuring the protection of sensitive government operations.

These are the latest tools in the spectrum policy toolbox, offering new ways to enhance spectrum use and meet ever-growing demand for spectrum-based services.

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