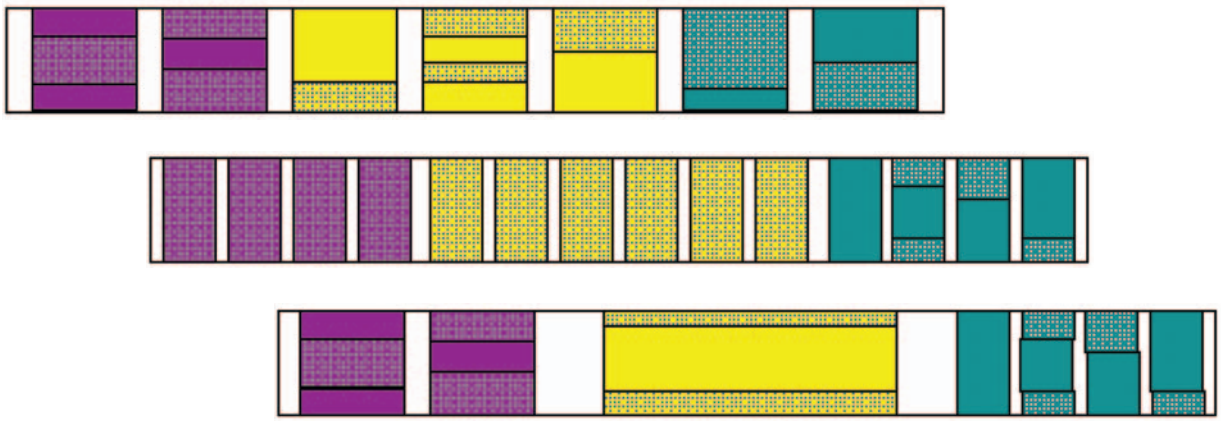


Spectrum Paradigm Shift

Policy reforms and user innovation can bridge next-generation cognitive-radio technology's use in LMR spectrum.

By Nancy Jesuale and Bernard C. Eydt

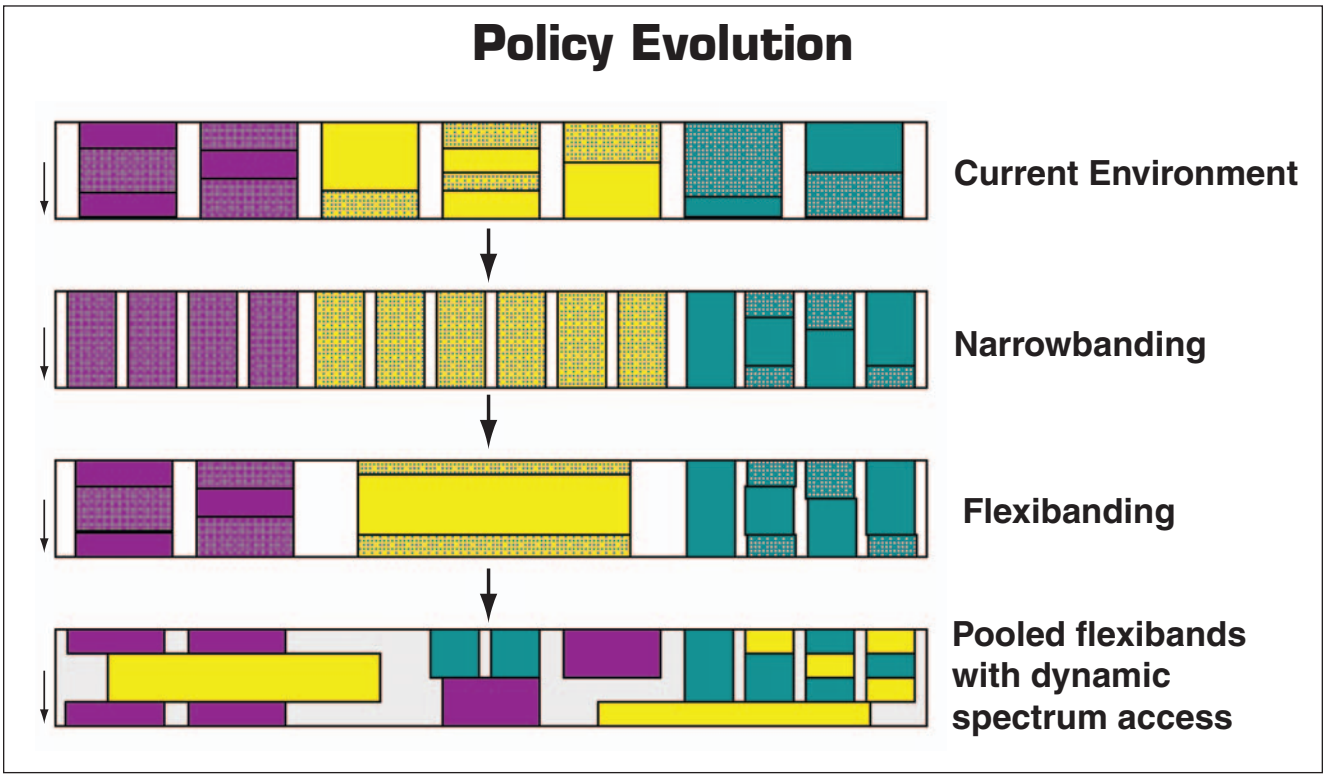
Managing a mission-critical radio communications system means facing a number of critical operational challenges such as interoperability, coverage problems, narrowbanding or rebanding, and increasing system costs. These challenges are exacerbated by outmoded spectrum policies that continue to carve spectrum access rights into increasingly smaller slices. Achieving radio system reliability, capacity and coverage with a reasonable investment using existing LMR technology under the FCC's Part 90 rules is nearly impossible. New spectrum policies recognizing emerging wireless technologies are needed — and they are coming. The question is, will system managers embrace new operating models? Skeptics and traditionalists aside, paradigm-shifting technology and spectrum access models are currently in research labs, and commercialization is around the corner.

Cognitive radio is a developing technology that bridges traditional LMR operating modes with advanced dynamic spectrum access — frequency-agile radio networking of the future. Cognitive radio coupled with supporting legal and institutional reform will solve spectrum scarcity and interoperability issues inherent in current operating models. Advanced cognitive radio systems are aware of their spectral environment and can make decisions about radio operating behavior based on that awareness and the software policy controls embedded in a radio and network infrastructure. The new 700 MHz national broadband operation is likely to provide a further catalyst for cognitive-radio deployment in both the network and user equipment for public safety. Cognitive and software-defined radio (SDR) will be used for efficient spectrum sharing, ruthless pre-emption for public safety of commercial traffic, and the requirements to build agility and flexibility into the infrastructure that recognizes local public-safety operations protocols and mutual-aid agreements.

The VHF, UHF and 800 MHz frequency bands that have been licensed to LMR services for decades are also a fertile field for deploying cognitive-radio technology. For example, a network of cognitive radios in these bands could sense which channels are available across all of the authorized LMR spectrum pools and then determine how channels could be temporarily assigned to meet a given objective, whether that be mission-critical voice or multiband, full-motion video. Yet several things need to happen for this future to be realized.

Pooling Spectrum

The current system of stovepiping different classes of users into different classes of eligibility — federal, public safety, business/industrial — different bands and then assigning frequencies to particular organizations within a class is in dire need of reform. The biggest drawback to the current system is its inefficiency; some users are desperate for more channels while neighboring spectrum is unused. Stovepiping is also a



serious impediment to interoperability because organizations that need to communicate with one another can't share the same frequencies.

Organizations eligible for LMR licenses, or "eligibles," have a great deal of difficulty finding enough available spectrum in any of their individual bands to deploy a multichannel, multisite, wide-area — citywide, regional or statewide — network. Negotiations to share, trade or acquire licenses from license holders are problematic because the community of license holders within a specific pool, such as the public-safety pool, includes dozens of separate organizations or jurisdictions with many historical institutional barriers to cooperation or commerce among them.

To look beyond a pool — for instance, for public safety to look to the business/industrial pool — complicates this "soup" even further. More layers of historic hands-off separation come into play. One concern with pooling is that nonessential uses could block an essential use.

Policy-based cognitive radio systems that recognize priority transmissions will be useful in addressing this issue. User class doesn't necessarily determine the criticality of a message. For example, many business LMR users are responsible for protecting "critical infrastructure" as defined in Homeland Security Presidential Directive 7. Their requirements for redundant, interoperable and reliable communications systems are approaching the same levels as public safety. They also have requirements for surveillance, intruder identification, background checks, hazardous materials data and other advanced radio applications similar to traditional first responders such as police and fire departments.

Trunking has helped spur system sharing and create spectrum efficiency among first-responder agencies, but the shared systems seldom involve sharing between public safety and business/industrial users, and trunking doesn't involve pooling spectrum allocations. An opportunity exists to reverse the legacy of stovepiping frequency assignments by regulation and instead facilitate and encourage pooled frequency access and shared network architectures to relieve serious congestion and reinvestment pressure. The FCC has begun this reform by adopting a broader definition of public-safety eligibles, relaxing other LMR eligibility limits, facilitating secondary markets in spectrum licenses, including public-safety-to-public-safety spectrum leasing, and encouraging tower collocation and infrastructure sharing especially in rural areas. In fact, the 700 MHz Public Safety Spectrum Trust (PSST) has a mandate to employ interruptible spectrum leasing across the national public-safety broadband spectrum allocation. But what about the rest of the bands?

Radio Service Utilities

The expansion of spectrum access in LMR bands would be more easily implemented if network operators could serve multiple classes of customers, because network operators could dynamically

A frequency coordinator could act as the trusted agent to dynamically assign spectrum according to the policies of the pool.

allocate the total spectrum among all the real-time demands for spectrum. These radio service "utilities" could develop the ability to acquire and operate the facilities and spectrum of existing licensees and then lease cognitive-radio service on a subscription basis. This is essentially the vision of the FCC for the national public-safety licensee in the 700 MHz D block.

The LMR community generally holds the notion that the only way to achieve public-safety-grade reliability is for a public-safety user to own and operate its own radio infrastructure, but this doesn't have to be the case. Hospitals, banks and e-commerce businesses often create mission-critical information systems using leased infrastructure. The keys to success include well-crafted service-level standards, service-level agreements (SLA), proper assignment of liability and cost, customer visibility into operator systems, and independent third-party audits of technical, operational and management controls. In fact, if radio service utilities pool spectrum, negotiated SLAs could guarantee that customers will have at least as much, if not more, capacity than before without the limitations and burdens of accessing and maintaining their own capacity-constrained systems. Utilities can also leverage technical talent in ways not available to most public-safety agencies, particularly those in small towns and rural areas.

Shared infrastructure is also basic common sense. Federal, business/industrial and public-safety users in any region occupy the same or contiguous bands, their transmission facilities sit on the same hilltops, are often accessed by the same private roads, and in many cases, are trussed to the same towers. Collaborative or outsourced management of databases, routing, switching, authenticating and provisioning would negate the need for billions of dollars of duplicated facilities across the nation.

Regional planning committees (RPCs) and frequency coordinators could also be key enablers of the radio service utility model and cognitive radio. They have already developed policy databases that tell when a frequency is available and to what type of user, for what purpose and at what location (coverage contour). Their current roles could be expanded to provide trusted management of pooled spectrum on behalf of eligible users. A frequency coordinator could act as the trusted agent to dynamically assign spectrum according to the policies of the pool. The policies could include user priority, per-use compensation between pools, time-of-day pricing, and other rules or policies. Such pooling agreements could cover a portion or all of a region's spectrum allocation, depending on the ability of a region's eligibles to agree on what amounts of

Realizing the Vision of Cognitive Radio

Now	Future
Stovepipes Users are divided into different classes of eligibility and then assigned frequencies available only to that class. Users in different classes can't easily interoperate. Some users are desperate for more channels while neighboring spectrum is unused.	**Pools** Existing allocations are combined to give each user access to a broader range of spectrum. Users in different classes can communicate with each other on common frequencies as needed.
Fixed Frequency Assignments Users obtain licenses for exclusive use of certain frequencies, regardless of how often they use them.	**Dynamic Access** Users can access spectrum without a license when it is unused. Spectrum isn't left fallow just because it's "reserved."
Owner Operators Public-safety grade reliability is achieved by owning and operating all radio infrastructure.	**Shared Infrastructure** Collaborative or outsourced management of databases, routing, switching, authenticating and provision would negate the need for billions of dollars of duplicated facilities across the nation.
Single Network Access Generally roaming from one mission-critical network to another is not possible.	**Roaming** Radios can detect available channels and roam from band to band and network to network.
Narrowbanding Current mandate for VHF/UHF licensees to migrate to 12.5-kilohertz channels and then potentially to 6.25-kilohertz channels. The requirement forces users with broadband needs to higher frequencies with expensive buildout costs.	**Flexibanding** Users can negotiate both the bandwidth and the frequency band most appropriate for an application.

Skeptics and traditionalists aside, paradigm-shifting technology and spectrum access models are currently in research labs, and commercialization is around the corner.

spectrum could be pooled.

Policy makers also need to appreciate that under the current rules, many eligibles don't succeed in receiving licenses, either because they can't build infrastructure or because the licenses are already granted to others. These potential users are shut out even when their communications could be of great value to the communities they serve. Pooled spectrum operated by a radio service utility that permitted dynamic access would enable the potential users spectrum access they don't have and provide new infusions of revenue to cover shared infrastructure and radio utility management.

Roaming, Portable Spectrum

Another evolutionary step toward realizing the vision of cognitive radio is to permit users to roam from system to system, similar to how commercial mobile-phone users currently do, and band to band. Such a feature could provide critical interoperability in response to a major disaster and be useful for a variety of homeland-security operations. Cognitive radios can sense and detect available channels that roam from band to band and network to network. The key cognitive ability is to do so while adhering to local, regional and national policies for band and system access, across all three eligibility pools: public safety, business/industrial and federal/nonmilitary.

User devices would dynamically access spectrum and authenticate on network infrastructure, whether commercial, industrial or government owned. Cognitive radio policies, updated every time a radio is powered on or affiliates to a base station, would ensure that the device obeyed the regional terms of frequency sharing, network access, priority and compensation. Cognitive devices will adhere to these policies, while avoiding interference and provide users with multiband interoperability and national coverage.

Flexibanding

The narrowbanding mandate is a well-intentioned artifact of efforts during the past decade to improve the efficient allocation of spectrum. But in practice, it is precluding even more efficient solutions. Ideally, users should be able to flexiband — let a user device negotiate the bandwidth most appropriate for an application. Spectrum doesn't need to be contiguous, as cognitive radio systems could adapt to support a variety of configurations. For example, two communicating radios might support a wideband data service by selecting several channels that flank both ends of spectrum supporting a single priority narrowband voice session.

Many different arrangements are possible. For example, business/industrial and federal LMR users could flex into public-safety spectrum for transmissions as necessary, but on a secondary basis. In return, public safety could flex into the business/industrial and federal pools, under a "lights and sirens" type access agreement whenever their communications is critical and requires priority. Narrowbanding all channels in the VHF and UHF bands forces users with broadband needs to abandon these frequencies for higher bands. Unfortunately, achieving comparable coverage at the higher bands requires a much higher density of towers — at an average cost of more than $300,000 per site — which makes broadband solutions more expensive than they would be if implemented in the bands subject to the narrowbanding mandate. Indeed, the coverage contours of towers in the VHF and UHF bands can be 20 times larger than similar towers in the 800 MHz band.

An alternative to the current narrowbanding mandate approach would be to retain a deadline for returning spectrum to the pool, but then encourage flexibanding and the creation of dynamically pooled spectrum accessible over radio service utilities.

5 Keys to a Successful Radio Service Utility

1. Well-crafted service-level standards
2. Comprehensive service-level agreements (SLA)
3. Proper assignment of liability and cost
4. Customer visibility into operator systems
5. Independent third-party audits of technical, operational and management controls

Technical Feasibility

The technology required to implement most of the functionality described exists, but primarily in academic and military research programs. Nevertheless, it's likely to be commercially available prior to the current 2013 deadline for narrowbanding.

For cognitive radio to become a reality in the LMR bands, several developments must happen. Radio systems will need to be policy based or able to implement machine-interpretable policies to restrict

operating behavior of devices based on local rules. Unfortunately, a standard language for such policies doesn't exist, but trends are promising, particularly in LMR. Many, if not most, of the recent digital LMR user equipment and base stations are programmable, often supporting this feature over the air. Programmable radio is, in effect, a rudimentary form of policy-based radio. This programmability is limited to a radio's personality, such as subscriber IDs, available frequencies, talk groups, traffic encryption keys, etc. In the future, this programmability will be extended to incorporate knowledge of available pooled spectrum, pricing, regional and national access rules.

Further developments also are required for protocol specifications for predictable spectrum sensing and sharing. Standards such as CDMA, 802.11 and 802.16 have rudimentary forms of cognition that enable radios to select frequencies based on recent spectrum access experience, but current standards do not support the features needed for management of mission-critical systems. Further advancements from ongoing academic, government and industry research will likely produce robust, dynamic spectrum-sharing protocols soon, particularly if regulatory reform continues to facilitate the creation of a market for the technology.

For cognitive radio systems to achieve the promised benefits, radios must also be frequency agile or have the ability to operate over a wide range of frequencies and switch between them in near-real time. Most LMR radios are designed to support only frequencies in a single band because providing frequency agility increases the cost of a radio without any immediate benefit in the current LMR environment. Furthermore, power amplifiers in radios are efficient over a narrow range of frequencies. Consequently, frequency-agile radios may be less power efficient than current models, which may be a significant concern for radio applications that depend on batteries. Antenna technology also has similar limitations, as traditional antennas are efficient only within a certain range of frequencies. Several firms are competing to create frequency-agile transceiver chips — in one case promising support for frequencies from 150 MHz to 6 GHz. Developments in smart antenna technology tell a similar story. Multiband, multimode radios can be built, using arrays of front-end components with an interface to a common software platform for baseband signal processing.

Resources

Software Defined Radio Forum
www.sdrforum.org

IEEE Dynamic Spectrum Access Networks (DySPAN) symposium
www.ieee-dyspan.org

Neither regulators nor LMR users will embrace cognitive radio unless it's coupled with strong assurance mechanisms that ensure both the availability of emergency radio communications and minimize the likelihood of harmful interference. A variety of new security mechanisms will be needed to provide this assurance. Radio systems will need to authenticate policies before enforcing them; otherwise, the systems' adversaries could write destructive policies to achieve a number of malicious objectives. Similarly, any network messages related to spectrum availability would require authentication to avoid interference. The radio software supporting new protocols and cognitive functionality also require authentication.

Cognitive radio systems will facilitate reform of the way spectrum is accessed, its cost to use, and the types of network architectures, applications and equipment that can be deployed in mission-critical situations. Wireless communications managers need to understand the development of these technologies and advocate for reforms if they want to see their visions fully realized. As with other market disruptions, upsets may be ahead for parties invested in the status quo of the current LMR structure and big opportunities ahead for new entrants. ■

Nancy Jesuale has worked as a policy strategist and technologist in public-safety LMR, cable and telecommunications since 1978. She has undertaken a variety of other strategic-planning projects for governments throughout the United States as the president of NetCity. Jesuale is currently consulting to Shared Spectrum on developing next-generation cognitive radios for public safety on projects funded by the Defense Advanced Research Programs Agency (DARPA) and the National Institute of Justice (NIJ) and consulting on public-safety LMR rebanding and replacement projects throughout the Northwest.

Bernard Eydt is an associate at Booz Allen Hamilton, a global strategy and technology consulting firm. He also is chair of the SDR Forum's regulatory committee and an officer of the Institute of Electrical and Electronics Engineers (IEEE) standards coordinating committee 41, which focuses on dynamic spectrum access networks. E-mail comments to editor@RRMediaGroup.com.

RadioResource *MissionCritical Communications* delivers wireless voice and data solutions for mobile and remote mission-critical operations. The magazine covers business, public safety, and regulatory news; case studies; in-depth features; innovative applications; product information and comparisons; emerging technologies; industry reports and trends; and technical tips. In addition, each issue contains *Public Safety Report*, a special section devoted solely to the needs of the public safety community. Editorial content targets organizations in the United States and Canada with mobile and remote communications needs, including public safety, government, transportation, manufacturing, utility/energy, business, and industrial entities. To request a FREE subscription or get more information, go to www.mccmag.com. RadioResource *MissionCritical Communications* is published by the RadioResource Media Group. Pandata Corp., 7108 S. Alton Way, Building H, Centennial, CO 80112, Tel: 303-792-2390, Fax: 303-792-2391, www.rrmediagroup.com.