Public Safety Radios Need to Pool Spectrum

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ABSTRACT

The Dynamic Spectrum Access (DSA) research and development community is maturing technologies that will enable radios to share RF spectrum much more intensively. Adoption of DSA technologies by the public safety community can better align systems with the future of wireless services more generally and can contribute to making next generation public safety radio systems more robust, capable, and flexible.

A critical first step toward a DSA-enabled future is to reform spectrum management in order to create spectrum pools that DSA-enabled devices such as Cognitive Radios (CRs) may make use of under the control of more dynamically flexible and adaptive prioritization policies than is possible with legacy technology. Appropriate reform will enable spectrum portability, facilitating the decoupling of spectrum rights from the provision of infrastructure.

This article examines the economic, policy, and market challenges of enabling spectrum pooling and portability for public safety radios.

I. INTRODUCTION[i]

Dynamic Spectrum Access (DSA) technologies, including Cognitive Radio (CR) technologies, are in development for the next generation of commercial, military, industrial *and* public safety networks. These technologies hold the promise of delivering more flexible and adaptive radio architectures, capable of sharing the RF spectrum much more intensively than is feasible with today's currently deployed technologies. The current landscape of wireless networking reflects the legacy of a world premised on static network architectures and spectrum allocations. In this world, public safety networks have traditionally been designed to meet capacity and reliability "standards" that are based on user requirements at the "worst case" level – that is the capacity and reliability necessary during an emergency or catastrophe. It is not assumed that the network will ***always need*** these levels of capacity and reliability during "day to day" operations. But it is assumed that the network must ***always have*** these levels of capacity and reliability available when needed. Such worst-case planning implies that significant spectrum and equipment resources need to be "stockpiled" and remain unused most of the time. This creates significant *artificial* spectrum scarcity, especially in the public safety bands, which are small allocations fragmented across multiple bands and many system owners.

The wireless world is changing. The needs for wireless systems of all types, and for public safety systems in particular, have greatly expanded. This increases the costs and collective infeasibility of continuing worst-case planning and the wasteful allocation of resources it implies. The radio future, of necessity, will require shifting to more DSA-friendly modes of spectrum usage. Besides being inevitable, the transition to DSA will offer many significant benefits for the public safety community and wireless users more generally. These benefits will include better mission responsiveness, expanded capabilities, and ultimately, lower costs. However, getting to this future will also entail overcoming important challenges. A number of complementary innovations are required. These include further technical developments, public policy reform, and changing industry and end-user attitudes. While further technical research and product development is certainly needed, our focus here is on the policy and business practice challenges of developing DSA technologies for use by public safety systems.

II. CHANGING ENVIRONMENT FOR PUBLIC SAFETY RADIOS

While the precise shape of the radio future may be difficult to discern, certain key aspects appear certain. The future radio environment will include lots more wireless of all kinds, greater demand for mobility and portability and more heterogeneous wireless networks. These future developments will have concrete implications for radio network design, including the need for more broadband capacity, enabling more dynamic and flexible services and spectrum sharing.

A. Policy Based Radio

Cognitive radio (CR) captures the flavor of these advances: a CR is capable of sensing its local radio environment and negotiating modifications to its "waveform" (modulation scheme, power-level, or frequency/channel access behavior) in real-time with other CRs, subject to "policy constraints" (e.g., that may limit the range of waveforms allowed). The policy constraints are enforced by the radio's policy engine. Policies may include authorization to transmit in specific locations and frequencies at specific times, or may include access protocol constraints (e.g., listen-before-talk). These policies may be static and hard-coded into the radio, downloaded from a database, or may be dynamic and subject to updating in real-time in communication with a network operator or other CRs. DSA/CR devices typically require location awareness capability in order to support the policy engine and because interference is a local phenomenon occurring at a receiver's location. Finally, CRs are inherently multi-band radios, allowing the radio to transmit or receive in a wider range of frequencies than might be used in any specific communication environment. This allows CRs to opportunistically make use of unused spectrum and facilitates their interoperability with legacy radio systems.

While significant technical work remains to be done in academic research and commercial product development laboratories to field a commercially viable CR, prototypes already exist and many aspects of the technology are already embedded and working at scale in commercial systems. In this paper, we do not focus on the technical developments that still must be made, but rather on the policy innovations that are required to make commercialization viable.

B. Next Generation Public Safety radios need to embrace DSA

The same forces that are shaping the future for commercial wireless apply with even stronger force to public safety wireless systems.

First, public safety first-responders are more likely than most other users of ICT to require mobile, wireless access. In many first-responder scenarios, the only option is wireless.

Second, first-responders who are dealing with life-and-death situations are perceived generally as meriting higher priority in the event of competition for resources.

Third, first-responders may be more likely to deal with adverse environments. This increases their need for flexible, adaptive systems (e.g., capable of supporting ad hoc or mesh networking in the absence of other supporting infrastructure). First-responders are likely to suffer from localized congestion: disasters typically happen in specific places and at specific times. The demand for all wireless services by all first-responders are likely to be concentrated in time and place, increasing the peak-provisioning problem.

Finally, public safety system capabilities are still woefully inadequate, even compared to the services available to commercial users (e.g., 3G mobile telephony v. legacy LMR systems). The public safety community shares this conclusion.[ii]

Public safety cannot rely on LMR designs "getting better." There is both the need and opportunity to replace outmoded legacy infrastructure with leapfrogging technology to enable the wireless future needed by public safety. Rather than continue development of static, private, and expensive narrowband digital LMR network infrastructures, public safety is in need of a network architecture where privacy, reliability, capability, adaptability and flexibility are built in, no matter whose infrastructure their radios traverse, or even when infrastructure is damaged or non-existent. The future of public safety radios needs to be much more adaptive and responsive to its environment (spatially, temporally, and situationally) to account for the greater demands placed on first responders. A public safety responder should be able to take his radio, his authentication and security, his spectrum rights, and his priority with him to any incident in the country, power-up the radio, and be recognized and admitted to whatever incident command network he is authorized to support.

Table 1 summarizes our vision of the past, present, and future for public safety radio.

Table 1: Past, Present and Future for Public Safety Radios			
	Past	Present	Future
Key characteristics of public safety radios	Proprietary, single user, single channel, single locale	Multichannel, trunked, narrowband (voice only) Regional Proprietary	Multichannel, multimedia (voice, data, integrated) National Open Interoperable Broadband (data) Mesh/Ad hoc
Shared infrastructure?	No. All dedicated to single user/department	Yes. Shared access infrastructure and base stations via trunking. Channels shared within trunk group but not otherwise.	Yes. Shared access infrastructure and radios. Pooling of spectrum for sharing among multiple trunked groups.
Shared spectrum?	No.	Channel sharing within trunk calling group only.	Yes. Sharing of spectrum across bands. Pooled spectrum.
Infrastructure/ Spectrum tied?	Yes. Closely coupled, closed systems. Limited interoperability via gateways, tying up additional spectrum	Yes. Spectrum still tied to infrastructure. Gateways used to link systems.	No. DSA facilitates unbundling of infrastructure and spectrum. Infrastructure shared across multiple bands.
CPE	Single channel radios	Multichannel radios	Multiband radios and flexible CPE

III. PUBLIC POLICY IS ON COURSE TO FACILITATE DSA IN PUBLIC SAFETY

Today's public safety radio systems are fragmented, overly expensive, under-capacitated, and limited. This is due, in part, to the legacy regime of dedicated, narrowband, and overly restrictive spectrum policy. However, regulatory reforms such as the consolidation of licensing eligibility, approving the certification of software radios, and allowing secondary trading for some licensed spectrum demonstrate that progress is being made. In contrast to the case for commercial wireless services that depend more directly on market-based processes, reform of public safety spectrum management will depend on non-market institutions to coordinate cooperative evolution. Over time, a number of policy reforms have helped to make spectrum pooling and DSA more feasible in public safety applications.

A. Cooperative role-and policy-based institutions are developing

The national system of Frequency Coordinators, the Regional Planning Committees (RPCs) and the introduction of the National Incident Management System (NIMS) within the National Response Framework (NRF) provide the institutional foundation needed to enable the transition to DSA and spectrum pooling.[iii1] These relatively new institutions are positioned to enable public safety managers to define global/local priorities, and static/dynamic rules and policies that can assist in self-regulation of spectrum use. The development of appropriate user-based prioritization and policies that reflect accepted practices in emergency management and incident response are essential to support developing CR and DSA technologies.

B. Regional Planning for Public Safety Band Management

Since its creation, the FCC has licensed public safety spectrum by segregating uses/users into eligible and non-eligible categories in order to control radio interference. Eligible users compete for very small slivers of available spectrum. "The results are: (a) a set of narrow slots spread throughout the spectrum that users of different eligible classes cannot traverse; (b) a body of super-expensive technologies designed to serve specific channel assignments; and (c) a patchwork of non-interconnected transmission facilities serving single-use licensees. Each user/licensee is compelled to build its own infrastructure, and jealously guard its spectrum allocation and existing licenses."[iv] This fragmentation of the public safety spectrum results in artificial spectrum scarcity. As we discuss below, the spectrum pooling concept will help correct this problem.

In 1982, Congress provided the FCC with the statutory authority to use frequency coordinators to assist in developing and managing the LMR spectrum. Frequency coordinators are private organizations that have been certified by the

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Commission to recommend the most appropriate frequencies for applicants in the designated Part 90 radio services. In general, applications for new frequency assignments, changes to existing facilities or operation at temporary locations must include a showing of frequency coordination. Although the FCC issues the actual license, frequency coordinators perform essentially all of the spectrum acquisition activities on behalf of licensees. Each community of users in the LMR bands has at least one frequency coordinator entity that is owned and operated by its trade association, or in the case of the Federal Government, by the Department of Defense (DOD).

In the newer 700 and 800 MHz bands designated for public safety, the FCC has required that RPCs be formed to create policy and prioritize uses for the band on a regional basis. The RPCs must submit detailed regional plans to the FCC which are developed by consensus in each region, and which serve to pre-coordinate access to the band for all eligible public safety entities in a region.

The essential role of both frequency coordinators and RPCs is to organize the access to spectrum so that interference is avoided and communications needs (both present and future) are planned for and accommodated. Frequency coordinators and RPCs also perform the valuable function of communicating with existing licensees about plans for new facility construction and they provide a valuable consensus and peer review function. Additionally, RPCs can establish prioritization for the band via a consensus-based process.

The RPCs and frequency coordinators are federally sanctioned and empowered, trusted local user-owned and controlled agents who implement group (pool) policies to manage spectrum and avoid interference. If the RPCs were authorized and empowered to implement more extensive and flexible policies that could be enforced by better technologies, public safety spectrum management could move out of a spectrum scarcity paradigm and into a world where communication was always available and portable across both geography and spectral bands.

C. NIMS and ICS Supply the Dynamic Cooperative Policy Framework

The recent adoption of the National Incident Management System (NIMS) and the Incident Command System (ICS) within the National Response Framework (NRF) provide an excellent working basis for the new paradigm for dynamic policy-based spectrum management. NIMS is a set of generic protocols for incident preparedness, management, response and recovery that all US first responders must conform to. NIMS includes the ICS, which defines the specific way incidents will be managed, from very small and local to major nationwide disasters. The ICS and NIMS include planning, response and recovery protocols for day-to-day, tactical and emergency activities.

With national frequency coordinators managing knowledge of license rights granted in all bands across the nation, with RPCs empowered to create static regional prioritization rules and access protocols, and with the NIMS and ICS systems to ensure hierarchical consistency and to guide local layer dynamic prioritization and localized tactical network formation "on the ground," the federal, state and local public safety communities have a significant amount of the institutional framework in place to enable public safety spectrum pooling.

D. Transferring these developing incident management values to spectrum management is key to DSA development

DSA/CR and associated radio technologies will provide the technical solutions to allow spectrum rights and authentication to be transferred dynamically, and to allow radios to follow the policies associated with more complex spectrum transfers and authorizations. Facilitating the commercialization of these advanced radio technologies, however, *requires* the creation of spectrum pools. This is a classic chicken/egg problem. Without spectrum to share dynamically, the value of deploying DSA/CR technology is reduced. Without commercially available DSA/CR equipment, incentives to invest in the business relationships and policies needed to share spectrum are reduced. Pooling of public safety spectrum can address this conundrum.

IV. SPECTRUM POOLING EXTENDS RADIO RESOURCES FOR INCIDENT RESPONSE

In the most general sense, spectrum pooling is the situation wherein multiple users share access rights to a common "pool" of spectrum. We envision a context in which holders of exclusive-use licenses for public safety spectrum would voluntarily agree to contribute their spectrum to a common pool. Access to the pool would be "closed" relative to an unlicensed regime of open-access to all/any complying devices. In essence, the license rights would transfer to the pool from the individual. Any use of the spectrum would be in compliance with pool policies.

Enforceable restrictions on who gets to use pooled spectrum and strong limits on what constitutes acceptable secondary use are likely to be important. At the radio system level, there need to be technologies and access policies/protocols that assure that the radio will learn and confirm that spectrum is (1) accessible, (2) that access is allowed (and the terms governing such access), and (3) that its use is appropriate (i.e., there isn't a better alternative available). Additionally, the radio systems must include the capability to signal/learn when conditions change (e.g., when the primary user needs to preempt/reclaim pool spectrum) and allow the radio to release the spectrum when it is no longer needed or the radio is no longer allowed to use the spectrum.[v] This makes it feasible to allow the intended use to dictate the best choice of spectrum usage, based on factors including the radio environment and location ("I am underground"), the application ("I need to stream video"), the incident (fire, hurricane, interstate pile-up, chemical spill), the role ("I am a paramedic"), and the permissions ("I have authority").

Pooling can enable DSA/CR radios to opportunistically combine narrowband channels to support broadband access. Pooling provides not only a way to access spectrum without individual licenses, it creates the mechanism for spectrum policies to be authored, adopted and transmitted to DSA/CR radios. Pooling is the first step in dynamic spectrum management.

To fully realize the benefits of sharing on a large, national scale, standardized approaches toward sharing need to be developed to simplify negotiating multilateral sharing agreements and to facilitate the design and production of equipment that can take advantage of pooled bands. Standardized approaches are also important to enable users to roam more widely, even nationally.

A. Necessary Standardized Elements for Pooling

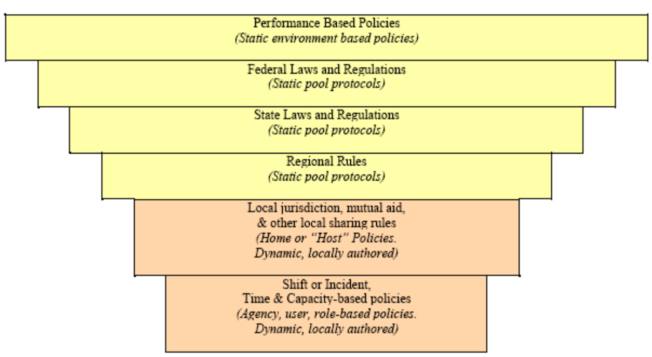
A number of core systems/elements will be needed to appropriately manage spectrum pool access and usage policies.

1) Structured Pooling Policies

Spectrum access policies are needed both for placing frequencies into a pool, and for accessing them from a pool. Some policies may be static, some may be universal, and some may be dynamic or regional. Some policies may only be invoked in certain circumstances, and at certain locations. Some static policies may be hard-coded into the CRs when they are manufactured, while others may be downloaded periodically from a database. We envision a hierarchy of spectrum pool policies, which will guide the radio to the best choice for channel selection based on its ability to resolve available options within a structure of rules.

Figure A below, represents a possible policy hierarchy for pooling and accessing spectrum. Once the radio learns the static policies that apply in any location, it can resolve dynamic user requests for spectrum based on more situational policies, dependent on such factors as the application, the user's role in the incident, or the developing incident command system as an incident grows and wanes.

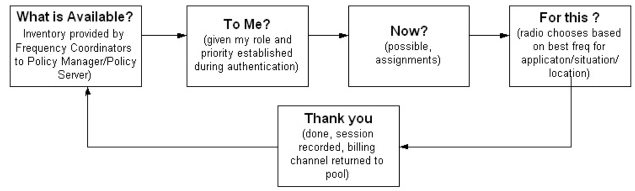
Figure A: Hierarchy of Pooling Policies



2) Policy Servers

Policy servers will be the primary "infrastructure" element of a DSA/CR radio network. Replacing radio system controllers, which control channel trunking and channel assignments in an LMR network today, policy servers will sit at multiple locations in a network, including the incident area to allow local incident command to issue specific policies to responder radios (e.g., to set up a tactical network). As the radio powers up and authenticates, it asks the server for its policy update, role, and tactical assignment information as shown in Figure B below.

Figure B: How policies resolve



3) Embedded CR Technology

CRs must include appropriate technology to allow them to "know" and "obey" DSA policies. For some policies, especially the most dynamic and location/context dependent, the CRs will need to know their location and specific characteristics of the spectral environment in that location. Other policies may be hard-coded.

4) Policy Authoring Tools

Standardized policy authoring tools are needed that will allow flexible policies to be designed and communicated to the radio infrastructure and managers. CR policies need to be rendered into appropriate machine readable formats and distributed to the radios and the band managers. Moreover, any conflicts among policies need to be detected and resolved.

5) Policy Enforcement

To ensure that policies are followed, and that all policies co-exist without conflict or interference, a policy enforcement system will be required.

6) Spectrum Portability

A user should expect the ability to roam with his radio across applications, locations, and networks. The ability for the radio to be served the best available channel for the user (based on role and authentication), use (applications, such as broadband video, or sensor data), and location (I am providing mutual aid to a community that is not my home base) is what we call spectrum portability. Our concept has important differences from current trunking practices. Today radio systems that can trunk channels, serve the next best available channel to the user requesting a talk channel. However, that only works in the user's home radio system, where the radio is hard coded with access to a limited number of talk groups, and the base stations are hard coded to specific frequencies. Since a DSA/CR radio will not rely on hard coded base stations, but will instead sense "white spaces" in a broad range of frequencies, it will, in theory, have the capability to transmit on any unused channel at any given time. Its decision about which channel to use will be determined not by hard coded information (having the "system key" installed in today's trunked system architectures) but by knowing and following the policy rules of the pools for each band. A public safety DSA/CR radio could be "told" to access only the public safety spectrum pools. But the policy servers and policy enforcers, must recognize and authenticate this radio as a public safety radio, before it receives its policy download. This recognition and authentication should be portable across the nation much like recognition and authentication of cellular phones is portable across national networks today. Such portability will involve the development of roaming agreements between infrastructure owners, allowing access to infrastructure resources, such as policy servers, backbone networks, switches, and frequencies.

The pool managers must be vested with the ability to represent pool members and commit pooled resources to binding mutual agreements between pool members and suppliers of network resources (such as infrastructure, additional secondary rights to other pooled frequencies, and application services). This is necessary to economize on transaction costs. It is impractical to expect individual licensees to negotiate individual agreements with each other. We believe that frequency coordinators are well positioned to manage this top level of DSA pool relationships and transactions.

V. OVERCOMING CHALLENGES TO SPECTRUM POOLING

Spectrum pooling and DSA represent elements of a cooperative spectrum management regime. This paradigm is very different from the prevailing "command and control" approach that underpins spectrum allocations and rights today. Because it is so different, the public safety community and wireless stakeholders more generally are not expected to embrace the concept, until it has been challenged and proven effective. Table 2 summarizes what we see as both real and perceptual challenges to spectrum pooling in public safety:

Table 2: Challenges for Spectrum Pooling in Public Safety
Real Challenges
Technology will not work as expected • Legacy services will work less well than with traditional technology • Prioritization will not work, Secondary uses not preemptible • Shared spectrum will have more congestion, less assured peak access than traditional model • Systems will fail to perform as predicted/promised
Government regulations will not permit • Necessary changes in regulatory framework will not occur • Political failure, Resistance of *status quo* vested interests
Early-adopter challenge • Pioneers face higher costs, lower benefits (network externalities) • Getting the adoption bandwagon started
Cost of NextGen Public Safety wireless systems • Learning, scale & scope economies accumulate over time, lowering costs • Managing cost recovery of shared systems • Incremental deployment and managing overlays
Perceptual Challenges
Risk of losing spectrum assets • Spectrum shared will not be reclaimable • Loss of ability to obtain additional spectrum allocations • Loss of control over radio networks
Systems will not be adequately reliable • Systems cannot be made robust (or as robust as legacy systems) • Cost of making systems adequately robust prohibitive for public safety radios • Systems will fail to meet standard of "worst case" planning which is necessary
Expanding pooling to wider communities • Sharing beyond narrow first-responder/public safety community infeasible, too risky

VI. Conclusions and Future Research Directions

The radio frequency spectrum will have to be shared much more intensively than has been possible with legacy technologies, business models, and regulatory policies. A paradigm shift is necessary to enable a wireless future of greatly expanded wireless usage and advanced capabilities required by our information-based economy and society.

The need for this paradigm shift is especially acute in the public safety community. The legacy regime severely limits interoperability among first responders and with those they need to communicate with. The fragmentation of infrastructure into incompatible silo-based networks drives up costs, reduces available capabilities and capacity, and ultimately, harms the ability of public safety professionals to do their jobs.

The traditional approach of over-provisioning static network infrastructure to meet worst-case scenario needs is neither feasible nor desirable. Luckily, it is also no longer necessary. Dynamic Spectrum Access (DSA) technologies like software/cognitive radio (CR) are making it feasible to share spectrum much more intensively. Transitioning to a radio future of DSA/CR will allow radio systems to be much more flexible and adaptable to local conditions. This will increase system capacity and capabilities, enhance interoperability and reliability, and will lower costs.

While the wireless future is bright, getting there will not be easy. Coordinating the design, investment, and deployment of new technologies without disrupting existing operations will be challenging. Even if all of the requisite technology existed and were commercially available at scale – which is far from the reality today – we would need to reform business models and spectrum management policies to enable use of the technologies.

One important and necessary first step toward building the wireless future is to transition to spectrum management based on spectrum pooling. With pooling, public safety users would expand their effective access rights and facilitate the adoption of DSA/CR wireless technologies.

Significant progress has already been accomplished toward establishing the institutional and policy-framework to successfully implement the spectrum pooling concept. The National Response Framework (NRF), the National Incident Management System (NIMS), the Incident Command System (ICS), frequency coordinators and the Regional Planning Councils (RPCs) provide some of the glue and apparatus needed to coordinate and manage pooled spectrum. Essential components (e.g., agreement on prioritization policies to manage shared access) still must be developed and challenges overcome (e.g., mobilizing coordinated adoption of DSA/CR technologies) to progress along the path to next generation public safety communication systems.

To maximize the likelihood of a successful transition, it will be important to move incrementally. If public safety professionals are to be convinced that spectrum pooling is indeed a concept whose time has come, they will need assurance that they will not experience any degradation in current capabilities or loss of resources. Future progress will build on early experience and learning. Over time, however, we expect the spectrum sharing concept to be accepted. All future wireless systems should be more dynamic and capable of interacting with expanded notions of priority in spectrum access rights. Public safety provides an important first test case for commercialization of these sharing ideas and success here will deliver positive externality benefits for the wider adoption of DSA/CR more generally.

Endnotes and References

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[i] For more detailed discussion, see Lehr, William and Nancy Jesuale (2008), "Spectrum Pooling for Next Generation Public Radio Systems," in *IEEE International Symposium on New Frontiers Dynamic Spectrum Access Networks 2008 (DySPAN2008)*, October 2007.

[ii] See http://www.psst.org/publicsafetynetwork.jsp, last accessed 7-14-08.

[iii] The NRF describes the national framework for responding to all hazard events, including describing who is responsible for what. The NIMS is the system/framework under the NRF for managing the reporting and tracking of domestic hazard incidents across all Federal, state, and local agencies. See National Response Framework (NRF), U.S. Department of Homeland Security, January 2008 (available at: http://www.fema.gov/emergency/nrf/) and National Incident Management System, U.S., Department of Homeland Security, March 1, 2004 (available at: http://www.nimsonline.com/docs/NIMS-90-web.pdf). The ICS is a management tool, originally conceptualized in the 1970s, intended to assist in emergency response. It identifies best practices and is an important element of NIMs (see http://www.training.fema.gov/EMIWeb/IS/ICSResource/index.htm or Incident Command System Review Materials (2005), available at: http://www.training.fema.gov/EMIWeb/IS/ICSResource/assets/reviewMaterials.pdf).

[iv] Quoted from Jesuale, Nancy and Bernie Eydt (2007), "A Policy Proposal to Enable Cognitive Radio for Public Safety and Industry in the Land Mobile Bands," in *IEEE International Symposium on New Frontiers Dynamic Spectrum Access Networks 2007 (DySPAN2007)*, April 2007.

[v] For discussion of how time-limited leased may be used to implement this functionality see Chapin, John and William Lehr (2007), "Time-limited Leases for Innovative Radios," *IEEE Communications Magazine*, June 2007.