Cognitive Radio Use Cases and Spectrum Policy Issues for Public Safety and State and Local Government

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ABSTRACT

This paper describes challenges faced by local and state governments in providing advanced technical infrastructure for efficient delivery of public services, under current federal spectrum and telecommunications policy. The potential impact of new wireless communications technologies, particularly cognitive radio and broadband convergence are discussed. Within this context, the spectrum policy issues important to state and local governments are highlighted.

1. Introduction

Today, usable radio spectrum has been nearly fully allocated. Consumer and industry demand for wireless communications and networking is accelerating. Technological advances in communications are focused on two key capabilities: **mobility** and **bandwidth**. As demand for more mobile bandwidth grows, spectrum is the key resource. As mobile networking grows, proper spectrum allocation and usage becomes more challenging and more critical. Currently outside the spectrum policy debates, but clearly a key concern of states and municipalities, is the need to protect the competitive health of their local economies by insuring that mobile broadband access is available for local businesses and residential use. However, competing national telecommunications policies create barriers to the most efficient development of state and local communications by limiting networks built for one purpose to serve other purposes.

Local and state governments are the primary providers of government services to citizens. Schools, fire and rescue, policing, courts, jails, health clinics and services, housing, streets, sewers, water and electricity, airports and ports, economic development, and the policies that govern all of these services are primarily housed in local and state government. Within states, local municipalities (cities and counties) provide the most fundamental services and infrastructure for the quality of life of citizens.

State and local governments in the US have very large investments in land mobile radio (LMR); wireless public safety infrastructure that serves their first responders, but provides little if any benefit to any other sector of the community. Cognitive radio technology coupled with spectrum reform could allow local and state governments to leverage their large investments in both wireless and wireline infrastructure to accomplish strategic local and regional telecommunications policies. Cognitive capabilities such as multi-networking, policy-based operation, ad-hoc and mesh network architectures, and frequency agility, can enable robust next generation public safety platforms that serve economic development, education, and rural health agendas with the same or smaller levels of investment.

2. Current Public Safety Radio Systems

The first spectrum band for public safety was allocated in 1922, and each successive allocation has been in a different part of the spectrum band. Current public safety bands exist at 50, 150, 450, 700, 800 MHz and 4.9 GHz. Today's radio technology designed to operate in any one band cannot operate in any other band[1]. In major cities and populous counties, public safety agencies may have licensed most of these bands over time, and may be operating separate radio systems in each band to serve a specific

[1] There are dual-band 700-800 MHz radios available. However, most cities cannot license the 700 MHz channels reserved for public safety because they are still occupied by television broadcasters, who are supposed to move off these frequencies during the delayed digital television conversion.

function. Public safety radio technology was designed to provide only voice communications, and only recently has added data functionality. Most major cities have very slow mobile data systems, operating at maximum speeds of 19.2 Kbps. Rural areas generally use no data, or if available, use cellular systems. Because of licensing rules for spectrum in these bands, and the technical development paths of the dominant vendors, most public safety systems do not support Internet Protocol (IP).

Over time, proprietary technology for the public safety radio market has kept end-user devices and networks coupled, so that only two manufactures are dominant[2]. A single police radio costs about $3500, in comparison to an advanced cell phone which may cost about $200. A police radio cannot talk to a cellular network, or any network but its local network, except through elaborate and expensive matrix switches that must be deployed at transmit locations. It cannot roam. It cannot text message. It cannot transmit or receive images. It cannot access the Internet. Today an urban police or fire vehicle is likely to have $10,000 of communications equipment on board, and still be unable to talk to other agencies reliably. A large municipality is likely to have $30-100 million in radio system infrastructure deployed, and still be experiencing severe interoperability issues.[3]

The "interoperability" problem for first responder communications networks is directly related to the dispersed discontinuous public safety spectrum allocations and limited interest in adapting commercial wireless technologies to public safety. American first response organizations such as the Association for Public Safety Communications Officers (APCO), National Public Safety Telecommunications Council (NPSTC) and the Department of Homeland Security (DHS) have bootstrapped public safety communications policy to an isolationist technical standards path (the P-25 standards) that ignores the significant developments in cellular and Internet technologies over the past twenty years. The P-25 standards process, initiated eighteen years ago, has instead veered off into a "common air interface" which further isolates public safety land mobile radio from the benefits of the larger efforts of technology design for commercial carriers.

The dominant strategy in American public safety thinking continues to enforce the concept that prioritization of emergency response communications must be accomplished by isolating the first responder traffic on its own network infrastructure and architecture, and on its own channels (frequencies). Most public safety networks do not have the ability to implement security and control using V-LANs or QoS techniques, because they do not transmit IP packets. Security and control are accomplished by isolation on a private network at the physical layer. Public safety networks overbuild and exist in tandem to public communications systems, and do not allow public access to any of their infrastructure.

Thus, the City of Los Angeles, for instance, operates five distinct LMR radio systems; [2] It is currently developing plans for a 700 MHz system. Operating costs top $6 Million per year. It also spends another $20 Million per year on telephone services, cellular telephones, pagers and other communications services. These costs do not include the vast radio and fiber optic facilities built to support the operations of the municipal water and power utility (Los Angeles Department of Water and Power), or those used by Los Angeles County, both in the same geographical footprint. This example is repeated in major urban areas across the Country. The local tax base supports each of these separate infrastructures, and the costs are staggering.

Today's public safety interoperability techniques, such as trunking and "overlays" such as gateways or bridging do not produce appreciable gains in bandwidth, in fact they waste spectral resources. Yet, the public safety community has documented its needs for **broadband** data capabilities and more spectrum.

3. Municipal Broadband Development

Fiber has been placed along most major state, federal and county highways to support transportation systems and utilities but is almost always dedicated only to the use of one sector. To date, many major cities including New York, Los Angeles, Seattle, San Francisco, Portland and Washington DC and several States have built their own fiber telecommunications infrastructure to serve the fixed data, telephone and video requirements of their main buildings and

[2] Motorola and MA/Com

[3] An "interoperability problem" occurs when first responders at a scene are unable to use their radio networks to communicate with each other.

facilities. When municipalities provision data or voice services to themselves over these networks, they are referred to as **Municipal Broadband Networks.** Municipal broadband networks most often include a fiber optic/microwave "backbone" network carrying high speed Ethernet traffic, some leased circuits, and often some wireless last mile for mobile uses.

Municipal broadband networks are being extended and augmented by unlicensed Wi-Fi, mobile cellular data, high speed digital microwave radio and meshed network solutions, designed to reach mobile workers and smaller fixed location facilities. With advances in voice over Internet protocol (VOIP) and compressed video over Ethernet, municipal network architects are developing very robust and economical strategies for wide-area voice and video service over their municipal broadband network architectures. This has helped some of the more progressive public safety radio operators to begin to look at existing wide-area IP networks for public safety uses requiring higher bandwidth. But physical convergence of public safety, government, transportation and utility traffic in a region is not recognized as possible, valuable or desirable in current policy debates about "mission critical" public safety spectrum and networking design. Instead, public safety needs are characterized to be so singularly demanding of reliability, that only separation on the physical layer can guarantee capacity, coverage and availability. Clearly, a new technical and operational strategy is required to accomplish affordable broadband infrastructure development and efficient spectrum use.

4. Spectrum use and spectrum policies in local government are not limited to fire and police

Other major municipal and state spectrum users include transportation agencies, public utilities (including electric utilities, water, sewer and storm water, security, parking enforcement, highways, light rail and transit, corrections, health and human services and public education). As all of these local and state government entities move toward IP-enabled technologies, including VOIP and mobile computing, and move away from proprietary protocols and standards the most visionary local governments are converging critical infrastructure services onto municipal, state and regional broadband networks designed for multiple uses. Public safety, however, lags behind any convergence strategy, mainly because of the dominant policy principle that it should be isolated and separate from these other administrative uses. A second reason often given for segregating public safety from other users is the need to establish coverage in remote and least populous areas, where conventional networks rarely have coverage. However, these are the very areas from which we hear separate cries for rural broadband initiatives. If public safety networks were designed to support broadband IP, the infrastructure placed primarily for public safety coverage could "open its doors" to the broadband and mobile needs of the entire community.

5. "Wi-Fi" capabilities have not gone unnoticed by first responders

Many of the more visionary local governments, including Portland, Seattle and San Francisco are looking at Wi-MAX and mesh network technologies [5] to solve the distance limitations of Wi-Fi, and to expand their communications capacity for data, image and video. Once the transmit distance of an 802.11 access point can be measured in miles rather than feet, and mesh technology can fill in coverage gaps, these mobile access technologies could augment (and may eventually completely replace) conventional public safety LMR systems. Though it is a dramatic shift away from traditional isolation-by-design of public safety network infrastructure from all other communications infrastructure (both commercial and government-provided), public safety radio communications is moving toward becoming another local government *application* rather than another network.

6. Convergence of Networks Using Licensed Bands

However, using commercial, off the shelf (COTS) "Wi-Fi" and WiMAX, which operate in unlicensed bands today, creates serious interference and congestion concerns for public safety and municipal government. The lack of protection from interference, lack of security, certain congestion in unlicensed bands, and the uncertainty of continued protection of their licensed bands are among the deterrents to developing further public safety uses of these technologies.

7. Agile, Adaptive (Cognitive) Radio Technology Could Provide Impressive Economical and Technical Efficiencies

Cognitive or adaptive radios are currently in development. These radios can "sense" the radio environment and reconfigure themselves to transmit on available frequencies based on rules and policies provided to the radios. Cognitive radios, once developed and deployed, will allow the disparate frequency bands used by public safety to be "stitched" together and available in a single end-user device. Tunable *spectrally adaptive* radios and devices that can sense available transmit and receive frequencies, will provide stunning improvements in interoperability and channel capacity for systems in a region and in a State.

In the state of Oregon for example, where wildfires are common disasters; urban firefighters who use 800 MHz trunked systems, can not communicate on those radios when providing aid at a rural wildfire scene, because available radio transmit infrastructures are likely to be in the 50-150 MHz range. To the degree that cognitive radios could be deployed in existing public safety spectrum bands spread from 50 MHz to 4.9 GHz, firefighters and public safety responders could arrive on scene, with radios that could "know" how to communicate and interoperate in any available band.

Rural and wilderness areas are likely to prefer lower frequency bands (50, 150 MHz) because they propagate over long distances very effectively. Urban areas are more suited to the capabilities and economics of systems in the higher bands. There is no clear benefit to public safety to lose either the preferred characteristics of the lower frequencies for wilderness and remote areas, or the propagation and coverage characteristics of the 700-900 MHz bands in the urban environment. This is one reason why retaining the disparate bands from very low to ultra high frequencies could be useful for public safety agencies. But first responders are increasingly more mobile, and as they move from metro to rural environments or even from city to suburb, their radio needs to be on, and transmitting. Therefore, a radio that can sense where it is, and what frequencies are available to it, would be extremely useful as the mobility of responders increases and during incidents where interoperability across bands is necessary.

Commercial devices that are adaptive to licensed frequencies will greatly decrease the cost per device, and cost per radio system for local government. Their primary user (public safety) as well as their secondary users (other municipal departments) will benefit from the economies of scale of being able to use the same, or only slightly adapted equipment developed for the commercial and consumer sectors.

If base stations and devices can dynamically re-tune across all public safety bands, they will solve interoperability problems between first responder networks within a region, between regions, and even across the country. The current problems cities and counties face of adding frequencies in an already congested band will be relieved if they can add frequencies from a different, non-contiguous band, and the electronic devices in the system can adjust. Finally, as system controller devices use more sophisticated, yet standardized user prioritization, or Quality of Service (QoS) schema, one could imagine that spectrum usage could grow far more efficient within public sector systems.

8. Cognitive Radio, combined with new Spectrum Policies, including the Development of Secondary Markets and Time Dimension Spectrum Leasing will benefit local government under three distinct policy paradigms:

1) Secondary Market for Public Service Agencies: The FCC defines a secondary market for spectrum, as the ability of a license holder to find an entity that wishes to lease its spectrum rights for its own purposes. Perhaps the most obvious first foray into secondary markets for local government is serving its own "secondary market". In other words, local governments holding public safety spectrum rights could lease them to other government sectors. Currently, FCC rules prohibit public safety licensees from providing public safety spectrum to non-public safety users. However, as local government requirements for mobility and real-time access to data networks and mobile workers increases, it is likely that a public sector market could emerge for spectrum access on public safety networks, especially if capacity could be made available dynamically on the time dimension.[4]

[4] The time dimension would allow licensing or use on a dynamic basis by assigning a frequency to a transmission and then reassigning that frequency after the transmission is complete. A

During normal day-to-day functioning, a trunked public safety network uses only about 10-40% of its channel capacity at any given time. Because public safety networks must not "busy-out" during emergency events, network managers engineer their networks to stockpile spectrum resources for use in emergency and disaster situations. Therefore, public safety networks have fallow spectrum "time" available and waiting on a day-to-day basis.

The first key concept in developing a dynamic market for available fallow spectrum, would be the development of policies and technologies that allow the public safety network to instantly "recall" its spectrum from the available pool of "talk-time for lease" and return it immediately to the public safety users. The development and implementation of such preemption and recall rules might be most easily accomplished when the leasees, or secondary users are also sub-entities of the same municipality as the primary users (public safety) rather than a commercial entity (such as a cellular company). Potential customers of available "fallow" time-slots on a public safety network could include a variety of government users including schools, government offices, transportation and transit, health care clinics and hospitals, public universities and other public service entities.

The second key concept for developing a dynamic market for public safety spectrum is the need for inexpensive cognitive radios which can not only operate according to the secondary and primary use policies of a region, but which can use all of the licensed public safety bands, from 50 MHz to 4.9 GHz, and conform to power output and security requirements of both users and regulators. Radio technology will need to be relatively inexpensive, and allow for ad-hoc and mesh networking to reduce static infrastructure costs and create coverage "pockets" at incidents as needed. This will require the convergence of public safety radio system design with next generation cognitive radio technologies, and IEEE standards based system approaches.

2) Public Spectrum Leasing to the Commercial Marketplace: Once cognitive radios have been proven to operate according to secondary and primary use policies, it is likely that the stockpile of public safety spectrum could have commercial value. If communities could lease spectrum capacity to finance their consolidation and improvement program, there could be both financial and operational incentives to move to system consolidation among local governments including a source of cash for system modernization. However, leasing out fallow or stockpiled capacity to commercial entities, which unlike public sector entities operate without local government regulation or control, is an irrational option unless public safety users have the ability to take back resources with an immediate “ruthless preemption” during an event to accommodate the a real time surge in public safety traffic. Developing cognitive technologies could provide means for this type of just-in-time preemption of secondary leasee use, the impact of which would either be a data rate reduction or the temporary reduction in the number of channels/callers. Such a "secondary-use-with-preemption scenario would not require either the local government leasor or the commercial leasee to lose access to entire blocks of spectrum, or the complete spectrum resource.

3) Lights and Sirens Access to Commercial Networks: Today we currently segment public safety and commercial users at the physical network layer and then burden local government with the expense of massive network infrastructures. However, networking has advanced to the point where we could move the secure segmentation and prioritization of public safety to a higher network layer, and "de-couple" access from infrastructure. Cognitive radios which recognize and implement use-agreements could allow states and regional governments to provide first responders with priority access to any available transmit facilities across the nation. If public safety had cognitive radios that could transmit over commercial networks when first responder networks were busy or unavailable due to coverage "holes", the efficiency of public safety communications networks would be increased. Overall infrastructure needs among the commercial and public safety sector would be dramatically reduced due to economies of scale achievable by simply sharing. Just as police vehicles and commercial traffic can traverse the same roads and highways with different priority ("lights and sirens") public safety signals could traverse any electronic highways that offer the best route to transmit.

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user could be assigned any frequency that was not in use by another user at that moment in time.

One important characteristic of public safety traffic, especially voice traffic, is its density and compact nature—compared to most commercial public uses of spectrum for voice. While a typical cellular telephone call may be 20 minutes in length, the average length of a public safety voice transmission is well under 10 seconds. Police radios are used on-average for six calls in an hour. Nearly all calls are very local, and do not need to traverse many nodes, or cells. First responder traffic is bursty, short, and local. Thus, the profile of public safety spectrum access makes it easy to draw an analogy between the "lights" and "sirens" use of the streets by police and fire, and the potential for "lights and sirens" use of commercial cellular, television and data network infrastructure.

If first responders were to access commercial systems for spectrum resources, they would be subject to the survivability and reliability of those systems. A significant policy consideration for public safety will be the reliability and survivability of any system resources it accesses. Since a lights and sirens preemption would take place during a surge of public safety communications activity, it would include events that may have compromised commercial systems abilities to operate; either because their facilities have been damaged (for instance, in a hurricane or earthquake) or when consumer use is also high (which will happen in a riot, a natural disaster, an attack). Where cognitive infrastructures are possible, public safety would benefit from technology that would allow commercial systems to "hear" a public safety "siren", and allocate those users priority access to spectrum and infrastructure.

The combined application of these concepts; 1) Secondary markets for public service agencies, 2) public spectrum leasing to the commercial marketplace; and 3) Lights and sirens access to commercial networks, could create a flexible co-existence of prioritized first responder/critical public service traffic with commercial/consumer traffic on both industry and government deployed infrastructures. First responder use of spectrum would expand as necessary for rescue, law enforcement and public protection, and during its contractions, consumers and commercial entities would benefit from additional spectrum availability. Contracting and expanding spectrum rights would be enabled by cognitive radio technology, new spectrum policy, and local contracting between buyer and seller of spectrum.

9. Conclusion

In contrast to many nations, the American form of government protects the rights of States and municipalities to decide all forms of local issues. Decision-making concerning telecommunications infrastructure that supports first responders, public utilities and the operation of local government has historically been viewed in the city halls of America as the local responsibility of local officials. The localism and diversity of American communities are important factors to understand and respect while considering sweeping national changes in spectrum policy. Regional differences, including geography, income and tax base, density, and availability of basic infrastructure significantly impact local decision-making on all kinds of policy, and play a significant part in local telecommunications policy and local spectrum policy. At the local level of government, activism plays a very key role, especially in matters of consumer protection, public finance and the use of public funding. Top-down state or Federally mandated policies that are aimed at restricting local authority to decide when and how to implement local infrastructure, especially when the infrastructure is locally funded through the local tax base are controversial and often opposed by cities and counties. Therefore, it is extremely important to involve local decision-makers in national spectrum policy revisions, particularly when discussing the needs and requirements of citizens, public institutions, utilities, local economies, education and public safety. As the spectrum policy debate moves from the concerns and needs of an amorphous "market" or "industry" to the more personal needs of "citizens" or "communities," diverse local interests are going to surface.

Spectrally adaptive technologies could greatly enhance public safety communications coverage, reliability and interoperability, but they are not a complete answer. To create efficient, affordable and interoperable public safety communications infrastructure, federal policies that restrict local governments from behaving efficiently and reacting to the same technological advancements, convergence principles and economies of scale that commercial network providers respond to must be revised.

The greatest gain in effectiveness and efficiency for local government networks will come when secure public safety communications systems can be constructed, secured and operated using commercial, off the shelf technologies (COTS) tunable to licensed local government public safety frequency bands. Dedicated spectrum for public safety will always be important to national homeland security goals and effective first response, and cannot be displaced by providing subscription service for first responders on commercial systems. However, dynamic access to commercial system capabilities and infrastructure on a "lights and sirens" basis could provide a temporal, on-demand surge in available spectrum capacity and capability for public safety when and where it is needed, without requiring band set-asides, if concerns for security and reliability can be addressed.

Municipalities and states may also have incentives to share dedicated licensed spectrum if trusted technical mechanisms are developed to dynamically lease and retrieve spectrum in the secondary market. These mechanisms must protect first response networks from the potential harm of not being able to retrieve spectrum from a leasee during a crisis. If trusted mechanisms are developed, secondary spectrum leasing could provide a source of funding for first response network infrastructure and operations that is badly needed. Moreover, spectrum leasing by local government should allow the local government spectrum leasing policies to be determined locally, rather than imposing a top-down national generalization. National policymakers must remember that public safety, ambulance and fire-fighting agencies are divisions of state and local government, and accountable to local officials, who are in turn, accountable to local voters. These local city councils and state governments should have the flexibility to invest their resources in the most efficient telecommunications solutions for their region, and should retain the ability to maximize the effectiveness of their infrastructure for other public purposes, including health care, education and economic development.

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