Cognitive Radio Implications for Public Safety Communications

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ABSTRACT

The Public Safety community is caught between two cross-currents. On the one hand they have a need for more spectrum, significantly enhanced communication of data, economies of scale associated with volume production, and information technology resources to better support first responders. On the other hand their requirements for area coverage, reliability, and response-time characteristics are met by their existing equipment, but exceed that currently available in commercial systems.

This problem has considerations in political, regulatory, technological, operational, and business/economic domains. While Cognitive Radio has much to offer to satisfy those needs, there has been a notable lack of consensus on many of the issues associated with spectrum allocation, architecture, and implementation.

This paper provides a conceptual framework to aid in understanding the problems, and examines the current state of progress in fulfilling the needs and meeting the requirements identified above. It also reviews the concept of the "Super Base Station", previously introduced as "Network Oriented Base Station",[i] a facility that combines extremely high radio frequency performance with Software Defined Radio and Cognitive Radio capabilities to enhance the options available to system architects.

1. INTRODUCTION

The Public Safety (PS) community has a long[ii] history of adopting developments in communication technology.[iii] These systems have evolved since the middle of the twentieth century to provide dependable, reliable, secure, and efficient systems to support the needs of first responders.

In the US the Public Safety community is very diverse, with some 60,000 individual organizations supported by communications systems with a total replacement cost estimated at $45 billion.[iv] The world-wide number is probably several times that size. A typical individual terminal costs over a thousand dollars.

Cellular telephone systems were introduced commercially around 1980[v]. By dispersing infrastructure around the service area, and operating with precise power control, these systems replicate groups of channel frequency assignments in different locations, dramatically increasing spectrum utilization. Operators make an ongoing set of trade-offs of investment, coverage, call quality, and charges to optimize their revenue.

With two billion subscribers, mobile phone utilization is now ubiquitous around the world, resulting in total annual turnover of more that $1.0 trillion[vi]. It also provides the dramatic economies of scale so well suited to price reduction in the semiconductor industry. The result is that individual handsets cost from fifty to several hundred dollars, often subsidized by the carrier in the US. Users typically incur a cost of $.10 to $.20 per minute.[vii]

Commercial wireless systems have drawn ahead of the older Public Safety systems in terms of development investment and low unit cost, but with a resulting lower level of Quality of Service (QoS). The Public Safety challenge is to find a way to take advantage of the commercial cost structure while maintaining the necessary capabilities and performance.

Many aspects of the Public Safety and commercial wireless are very divergent, while others seem to be complementary. In this document we will explore these characteristics in some detail, and attempt to identify means to promote cooperation to their mutual benefit.

2. A TAXONOMY FOR COMMUNICATION SYSTEM COMPARISON

To compare the characteristics of these two quite different systems, we propose to parse them in terms of the following characteristics:

- Political
- Regulatory
- Technological
- Operational
- Business/economic

Comparing Public Safety and commercial systems on such a point-by-point basis can provide a basis to suggest a solution to resolve the dichotomy.

2.1 Political

In the US, Public Safety organizations exist at the local, county, state, and federal levels. Although each of these entities has a high degree of individual autonomy, they operate primarily from tax revenues, and face substantial financial constraints. The result is a decision making structure that is low in coherence, and, in conjunction with relatively low purchase volumes, finds it difficult to achieve economy of scale. It also results in acquisition of communication systems that do not include a requirement to interoperate with other organizations that fall outside their planning horizon. Problems with interoperability have been identified as a significant problem in recent major disasters.

This diversified structure is a hindrance to exploration of possible means of cooperation. As yet there is no Public Safety central organization that can convincingly say "NO" or authoritatively say "Yes" to any given remedial proposal.

The federal government has several avenues of recourse to improve this situation. One is to fund system development and make grants to assist in purchase of standardized systems. Another is through legislative or administrative mandate (laws and rules), but that can be both difficult and unpopular.

Commercial service providers operate in the private sector, and their commercial viewpoint is very different from the way the public sector thinks and talks about their communications systems. This divergence complicates dialog between the two.

2.2 Regulatory

The Federal Communications Commission (FCC) is the primary regulator of spectrum for both Public Safety and commercial wireless applications in the US. It has the ability, subject to rule-making procedures, to grant or withdraw license to use spectrum, and to dictate operating rules. (They also designate spectrum for unlicensed operation.)

Channels for public safety are allocated to specific governmental units, who do not pay for their assignment or use. Commercial wireless organizations often acquire spectrum rights through auction, bidding large amounts for bandwidth in designated geographic areas. They are then free to use that spectrum to provide services for a fee to recover their costs and make a profit.

FCC actions have considerable influence on how both types of system are implemented. At present there is significant activity in the process of reallocation of spectrum in the 700 MHz band[viii] formerly designated for analog UHF TV. FCC is heavily promoting a combined public-private approach to a nationwide broadband network.

2.3 Technological.

Public Safety communications systems have fewer towers, and operate half-duplex at relatively high high power, to provide the coverage they need. Urban areas, with multi-path propagation and in-building operations, often present a severe challenge, as does signal strength in remote areas. Public Safety operations have long[ix] relied heavily on half-duplex voice communication, and require immediate response times.

Commercial wireless systems have been implemented with a relatively small number of different air interfaces with sophisticated access and channel assignment protocols, providing comprehensive interoperability (roaming). Operation is full-duplex, and power levels are carefully constrained. They have a history of upgrading to new architectures and better equipment at frequent intervals.

The commercial coverage strategy is based on having enough capacity to meet the presented revenue-generating load with a 98% rate of successful connection. Customers have come to accept a significant reduction in quality below that provided by legacy "plain old telephone systems" in order to have the freedom to talk from a distance longer than a phone cord.

The two environments have significant differences in spectrum loading and access priority characteristics. Some Public Safety emergency or backup channel assignments may go unutilized for some period of time until a major incident occurs. The Commercial Wireless industry, on the other hand, goes to great lengths to maximize the load on the bandwidth they paid for at auction. For common use of facilities, a key requirement will be a strong mechanism for priority interrupt and an effective upgrade in QoS for designated users.

In addition to voice, commercial systems are becoming increasingly capable of delivering wide-band data. Public Safety systems, even those using the latest P-25 technology, currently have very limited ability for data communication and even future developments of Public Safety technologies, such as TETRA 2 and derivatives such as TAPS, although "broadband" as defined in the Public Safety sense, will not able to match the rate of development and introduction available in the commercial world Data connectivity introduces the ability to provide video, pictures, maps, and database access directly to a unit in the field, rather than to a dispatcher for verbal relay.

2.4 Operational

Public Safety organizations, where threats to human life are regularly encountered, very properly place a high value on the performance of their voice systems. Commercial wireless effectively operates on a "best effort" basis. Revenue generation is the primary concern, and customer satisfaction has a lesser priority level. Competitive pressure in the commercial world, and need of the operators to maintain strong brands, means that customers may be compensated for dropped calls, hence strong efforts are made to maintain a network of good quality As perceived network quality can increase churn, and impact the bottom line.

Delivery of data has different operational characteristics than voice. Verbal communication provides a very direct physiological and psychological connection to an individual. Even data that is directly related to an event, such as a chemical hazard level, mug shot, or license plate identification, has a different delay dynamic; there is both a system retrieval interval, and an assimilation time after non-verbal information is delivered to the responder. And, if the information provided is next week's duty roster, its urgency is not high.

Data can be considered an incremental enhancement. It can be very valuable, and there are already instances of the crossover between Public Safety and commercial wireless technologies. For example, a $500M contract[x] was awarded Northrop Grumman for the deployment of a private broadband data network across New York City for all Public Safety first responder organizations and also NYC Civic departments. It utilizes TD-CDMA technology from IP Wireless which was developed initially for UK operators to make use of the 5MHz time division duplexing (TDD) spectrum awarded with the 10MHz paired W-CDMA in the 3G auctions.

As voice communications are much better suited to meet time-critical requirements, the area of data offers the most promise for joint utilization of commercial systems. Correspondingly, it is important to recognize that requirements for data communication will vary from those appropriate for time-critical voice.

2.5 Business/Economic

This area is another where there are many benefits to common use, but differences between the fundamental concepts of commercial and Public Safety systems complicate efforts to cooperate. A commercial service provider can measure quite accurately the volume of traffic carried by a given base station. The capital expenditure to install it and the operating expense to run it are also easily obtained from normal accounting operations. So return on investment (ROI) is easily obtained. And if a base station is running at peak capacity during the daily busy hour, then some callers are not given access, and revenue is not realized. The solution is assignment of additional channels, or adding base stations.

On the Public Safety side, cost numbers, including equipment acquisition cost and salaries can be obtained. But the benefits are difficult to quantify. Adding one channel to a given dispatch center is not likely to have significant impact, except in cases of severe overloading. The result is that the business case for shared use of facilities is not easy to quantify specifically.

Intuitively, it seems obvious that some use of commercial wireless would have value if it eliminated the need for a major new installation with duplicate coverage and provided the commercial service provider an additional source of capacity and revenue. In fact, of course, there are already significant amounts of such use – many Public Safety individuals carry and use mobile phones. Rather than dwelling on why commercial networks fall short of meeting Public Safety needs, the need is to develop new system architecture concepts to meet both those needs and the revenue generating requirements of the private sector.

2.6 Evaluation of Opportunities to Cooperate

Of these five areas, the *business case* is the most compelling reason for cooperation. Spectrum has substantial economic potential, and Public Safety systems on average have a great deal of unused spectrum.

Under proposals being considered by the FCC, the commercial sector would pay for the capital cost of building out infrastructure in return for the opportunity to use part of the capacity to provide services. Public organizations are provided with communication capacity without a requirement for added capital. Commercial services obtain access to added system capacity, which they can use to make more money. The attraction of the shared network is much stronger if the overall cost to both parties can be optimized and is potentially more acceptable than the experience with the UK Airwave Network where a

Commercial company with their own funding and government subsidy has built and operates a network solely for Public Safety and other related entities.

In the case of Airwave, the government department responsible for Public Safety (the Home Office), has mandated the use of a common TETRA network installed and operated by Airwave as a commercial operation. It originally was intended for adoption by Police, but now there is pressure on Ambulance Services of each Health Authority to adopt this – somewhat unwillingly - and also the Fire Brigade. There are concerns about marginal data performance, particularly with the Ambulance and Fire Service who are strongly biased towards data communication in their day to day operations. The Business Model for Airwave is that the infrastructure is provided by Airwave and they charge a license fee in excess of £1000 per annum for each mobile. There were significant problems in gaining support for this approach among the 42 Police Forces and similar problems are currently seen for the Ambulance Services as this is not an inexpensive solution. The UK is a relatively small country and when this approach is scaled up for a country the size of the USA there would be many issues to be resolved in the engineering of a nationwide network

In Europe, and particularly the UK, the Airwave model and also cooperation with existing Commercial Wireless Networks is also important from a spectrum perspective There are discussions that the Public Safety organizations should compete and pay for their spectrum in the same way as other players to force them to optimize their spectrum usage. The Digital Dividend Review is also being carried out across the EU to review analog TV Bands. The intent is to move existing users, including some Public Safety channels into different bands so as to form a block of technology neutral continuous spectrum for auction.

These issues are certainly major incentives to examine a more flexible business model and technological approach

A further incentive is the cost efficiencies derived from increased production of the hardware used. To the extent that common hardware is used, a substantial cost reduction can be realized.

Within the US the *regulatory* climate is very favorable. The FCC sees that the complementary structure of these two services presents an opportunity to combine them, with a concomitant reduction on the pressure to provide additional spectrum for innovations as they emerge.

Technological obstacles are not severe. These two communities are served by different vendors, or, in some cases, quite independent design organizations within the same corporate structure. A communication system developed by two different engineering organizations, even though using the same set of requirements, will always have differences. Not only will there be different implementations of hardware and software, but the architecture, terminology, and even mindset will not be congruent.

An architectural requirement to field a system with two different operating modes is quite technically feasible. Public Safety operation could operate with a higher priority structure, different power control parameters, data delivery, and a choice of half or full duplex operation.

However, a significant amount of system work would be required to converge the two different legacy architectures to a common standard. So the technological area can be rated as neutral to slightly favorable toward cooperative operation.

Operational considerations are a significant potential problem that will need significant effort to resolve. Not only do public safety organizations have different operational procedures, they speak different languages and their nature is inherently different.

The commercial wireless service provider uses a very small portion of its product offering, and such use does not result in revenue. Rather, its service is used by a myriad of individuals, all of whom derive their own perssonal benefits from it. Mobile service is essential to both a real estate agent and a plumber, and each uses the provided connectivity to improve their operations. The service provider has no stake or even interest in how their product is used. The decision makers in a commercial wireless company focus on system growth, operation, product offerings, and the resulting revenue generated.

Public Safety organizations, as their name implies, improve the lifestyle and safety of the community. Decision makers focus on crime rates, response times, and deterrence of perpetrators. They depend on communications to improve their effectiveness, and have implemented and control systems tailored to their own needs. They make changes to the system to reflect changes in organization or operating procedures. Use of commercial systems is a major conceptual change.

It is no wonder that, when these two sets of decision makers interact, they have trouble maintaining effective communication. The service provider sees Public Safety as a very demanding customer. The Public Safety professional sees the service provider as reluctant and inflexible support function.

Another important actor in this situation is the Public Safety equipment provider. These organizations have built a whole market over many years based on providing complete systems that are responsive to Public Safety requirements and for which they assume performance responsibility. These vendors have little interest in promoting use of commercial wireless products by their customers.

The potential for cooperation will depend on measures to bridge the existing differences in operational perspective. One way to accomplish that is to have a "back to first principles" general systems activity involving both groups that considers both communications facilities and the operational environment to arrive at an architecture responsive to the needs of all of the stakeholders.

The most serious problems, however, lie in the *political* arena. Politics is the process by which groups of people make decisions.[xi] The political process is seen in both public and private organizations, but execution is so divergent as to make communication and negotiation very different. Viewpoints, attitudes, mindsets, and mores within the two spheres are essentially antithetical.

The political process leads to policy in both arenas. In the public sector policy is usually established by elected officials, who interact to enact laws, statutes, ordinances, codes, and other forms of legislation to document their policy. The legislative bodies also adopt budgets that provide funding to governmental organizations to implement the policies and provide public administration. They exercise power in the form of incentives for individuals who conform and discipline for those who do not.

Success of a government is measured by smooth functioning of operations, customer satisfaction with the services provided, successful resolution of problems, and, above all, a minimum of disruptive political activity aimed at changing policy or operations.

In the private sector policy takes two forms: administration and management. Administration is routine functioning of the organization to comply with legal and contractual obligations, such as payroll and accounting. Management is the process of accomplishing the goals of the organization, functions such as engineering, production, marketing, and sales. These processes are not rigidly structured, and motivation of individuals is an important function. Managers are assigned people, given budget, and accorded authority (or power) to operate within the bounds of direction from higher management and established policy. Range of authority varies widely from one organization to another, but most managers have considerable latitude to assign duties to individuals.

The "bottom line" is to execute so that the revenues derived from operations exceed funds expended. Profitable organizations are rewarded; others are redirected reorganized, or disbanded.

The key to successful interaction between the public and private sectors is development of new policy. If representatives from both sectors can interact in an open environment conducive to constructive resolution of issues, then the resulting course of action has potential to be acceptable to both sides, and have prospects for successful implementation. A situation in which one side coerces the other to conform has higher risk.

It is possible that such an interaction has prospects for developing an approach to provision of communications solutions by the private sector to meet the needs of the Public Safety community. There are proposals now before the FCC to implement a public-private solution to allocation of spectrum for a nationwide broadband system in the 700 MHz band. It is clear that changes in both commercial wireless systems and Public Safety requirements will be needed if they are to be implemented. Also needed is development of a cautious transition plan, so that the pace of introduction of new ideas is commensurate with the level of confidence in changes already implemented. If all goes well in these actions they may be a harbinger of significantly better future cooperation.

This taxonomy can provide understanding of the sources of differences in viewpoint as these proposals are subjected to the political process. It should be worth considerable effort to understand and resolve the operational and political issues in order to enjoy the resulting economic and regulatory benefits.

3. A SYSTEM SOLUTION

In the past twenty-five years the commercial wireless market has emerged to become a major part of modern society in most parts of the world. In that same timeframe, the architecture of Public Safety radio equipment has made incremental improvements characteristic of a mature technology.

If we look twenty-five years into the future, with some conjecture, we will find that once-separate information systems will have merged. The individual consumer in

2032 will have universal connectivity at home, in the car, while shopping, and at work.

Networking that is a commodity, readily available and inexpensive, will support that connectivity. The user will have a choice of different personal devices, ranging from light, compact, and portable to very large screen entertainment devices. Numerous services will be available for the user from a host of service and entertainment providers, each an application accessed through the network.

A key component of such a network is the infrastructure end of the wireless link. We can call that component a Universal Base Station (UBS).

At the heart of the UBS is the "Software Manifold". On one end is a network connection that accesses the remote ports of a large number of desired application domains. Along the manifold are links to all of the terminals currently connected, with all those individually tailored connections maintained by a very capable Digital RF front end[xii].

When a user wants to utilize a service it is called from the terminal. The terminal and the remote application work with the UBS to allocate radio resources appropriate to the application, ranging from simple voice to video clips, navigation, or database access.

There is a one-to-one mapping of service and terminal to application. Each user receives a connection package with bandwidth, reliability, and cost tailored to their specific circumstances, needs, and willingness to pay. The result is a Quality of Service level specifically tailored to individual requirements.

There are some signs that initial efforts to implement this approach is already being considered in the Cellular sector where operators have formed joint venture companies such as that between Vodafone and Orange in the UK to install shared 3G Radio Access Networks operating simultaneously at different frequencies to save on tower costs and site rental with both Operators becoming mobile virtual network operators (MVNOs) on their own networks.

This approach is being extended to different Radio Access Network (RAN) technologies as service providers become multiplay Cellular Operators, offering cellular home broadband fixed line and broadcast services.

The next step, where the radio access technologies supported by the commercial wireless infrastructure also support specialist Public Safety, is not a huge step. As already demonstrated in some Rural US areas, for example by Vanu, where GSM and Public Safety networks can operate from the same installation.

The concept of the UBS based on SDR and CR technologies has an important application for both Public safety and Commercial services, and can act as an enabler for crossover services .

4. CONCLUSIONS

We have decomposed the very complex interactions between the Public Safety community, and commercial wireless service providers for the use of the latter's networks to provide part of their communications facilities. We have explored different aspects through a taxonomy of characteristics. Some of the elements are very favorable to cooperation and interaction, while others present substantial obstacles. The SDR Forum offers a venue in which these opportunities can be considered.

We have also looked out to a future time when the Universal Base Station is a key component is a utility that provides universal connectivity. When that time arrives, there will no longer be any obstacles to public-private cooperation and coordination.

We have mentioned the current 700 MHz actions at the FCC, and observed that they provide an opportunity to demonstrate the efficacy of new policy making and system architecture development for overcoming the problems impeding such cooperation.

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[i] Cook, Peter G., Network Oriented Base Stations, SDRF-01-I-0057-V0.00. July 14, 2001.

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[iii] Cook, Peter G. and Stephen R. Hope, SDR Technology Directions for Public Safety Communications, SDRF 2006 Technical Conference

[iv] SDR Forum Market Studies, Task 4: The US Public Safety Market

[v] Wikipedia: Cellular Telephone

[vi] SDR Forum Market Studies, Task 2: The Cellular Industry

[vii] Author estimate.

[viii] Former UHF TV channels 52-69, 698-806 MHz

[ix] Wikipedia, Ten-codes: Voice operations often use "ten-codes", a system developed by APCO in 1937

[x] www.eetimes.com/showArticle.jhtml?articleID=192701357

[xi] Wikipedia: Politics. See also Political Power, Public Administration, and Management

[xii] HYPRES, Inc. offers Superconducting Micro Electronic technology to support Digital RF applications such as this.