SDR Technology Directions for Public Safety Communications

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ABSTRACT

The Public Safety community is responsible for a variety of community level police and fire functions to ensure the safety and well-being of citizens. Historically, voice communications have been the primary means of communication with units in the field.

With current advances in information technology, however, the need for data in the field is exceeding the ability of installed systems developed around voice requirements. Also, due to the highly diverse range of organizations that may respond to a given emergency, it is often possible that they may have difficulty with communications interoperability.

This paper briefly describes the history of Public Safety communications, offers a business model of the marketplace, and examines the applicability of SDR technology to the problems facing Public Safety organizations. Some suggestions for system-level solutions are offered.

1. INTRODUCTION

The Public Safety community is the United States is very fragmented. Some 50,000 organizations are maintained by a variety of local governmental bodies and special districts. Although the Federal Government has extensive resources, they are only brought to bear when requested by local government, and the question of local jurisdiction can be quite complex.

As a result the Public Safety market, although similarly fragmented, has been served by a small number of vendors offering proprietary technologies, with systems tailored to the needs of Public Safety organizations and independent municipalities.

Equipment designed specifically for Public Safety is relatively expensive, and has a relatively slow rate of obsolescence. Voice communication has been the primary medium, with extensive flexibility offered through trunked radio technology. Standards, such as P25 in the US and TETRA in Europe, have been slow to emerge, and are still in the process of being adopted.

Recent developments in communications technology are presenting a problem to the Public Safety community. The large volumes associated with consumer electronics and communications facilities, such as commercial wireless telephones, offer extensive capabilities in wireless data and video transmission at exceptionally low cost. They do not, as a rule, meet the quality of service (QoS) levels that Public Safety organizations have come to expect.

The concept of a "System of Systems", coupled with cognitive radio capabilities has been suggested as an approach to optimizing the cost-performance-QoS trade space for Public Safety.

2. HISTORY

Over the many centuries that local communities have made provisions for officials to maintain peace and order and conduct fire-fighting operations, there has been a continuing requirement for maintaining contact with those individuals. Before the advent of communications technology, contact was made by blowing a whistle or banging a nightstick on the curbing. Telephone lock boxes and fire alarm boxes were later provided as technology emerged to support them.

An early application of radio broadcast technology was to deliver orders to police units, introducing the well known phase "Calling all Cars!" A return link was soon added, with transmissions started with the word "Ten", as in "Ten-Four" to acknowledge receipt, in order to give time for circuits to settle.

Public Safety radios emerged as a distinctive line of radio development in the decades after world war II. A common configuration was a centrally located base station operating at relatively high power and connected to a dispatch center. Sometimes repeaters or remote transmitter/receiver sites were deployed. Transmissions were normally half-duplex, meaning that at a point in time one transmitter is active at a time on a given channel.

Vehicles were equipped with land mobile radios, while individuals had belt-mounted units with a microphone and controller that clipped to their uniform. These radios also operated at power levels higher than those of a cellular system.

A further development was trunking, a system in which all the radios in a talk group would switch, under central control, to a common traffic frequency. This approach allowed sharing a group of frequencies to avoid needing a dedicated channel for each group. It also allowed a given radio to participate in more than one talk group.

One drawback of these systems was lack of a general provision for interoperability. It was common for units to respond to an emergency, such as a train wreck or plane crash, in a remote location, and find that they could not communicate with other responders because the radios were not compatible.

Software Defined Radio offers a solution to interoperability either by rapid reconfiguration of one of the radio types, or by bringing a bridging unit to the scene that relays traffic between nets.

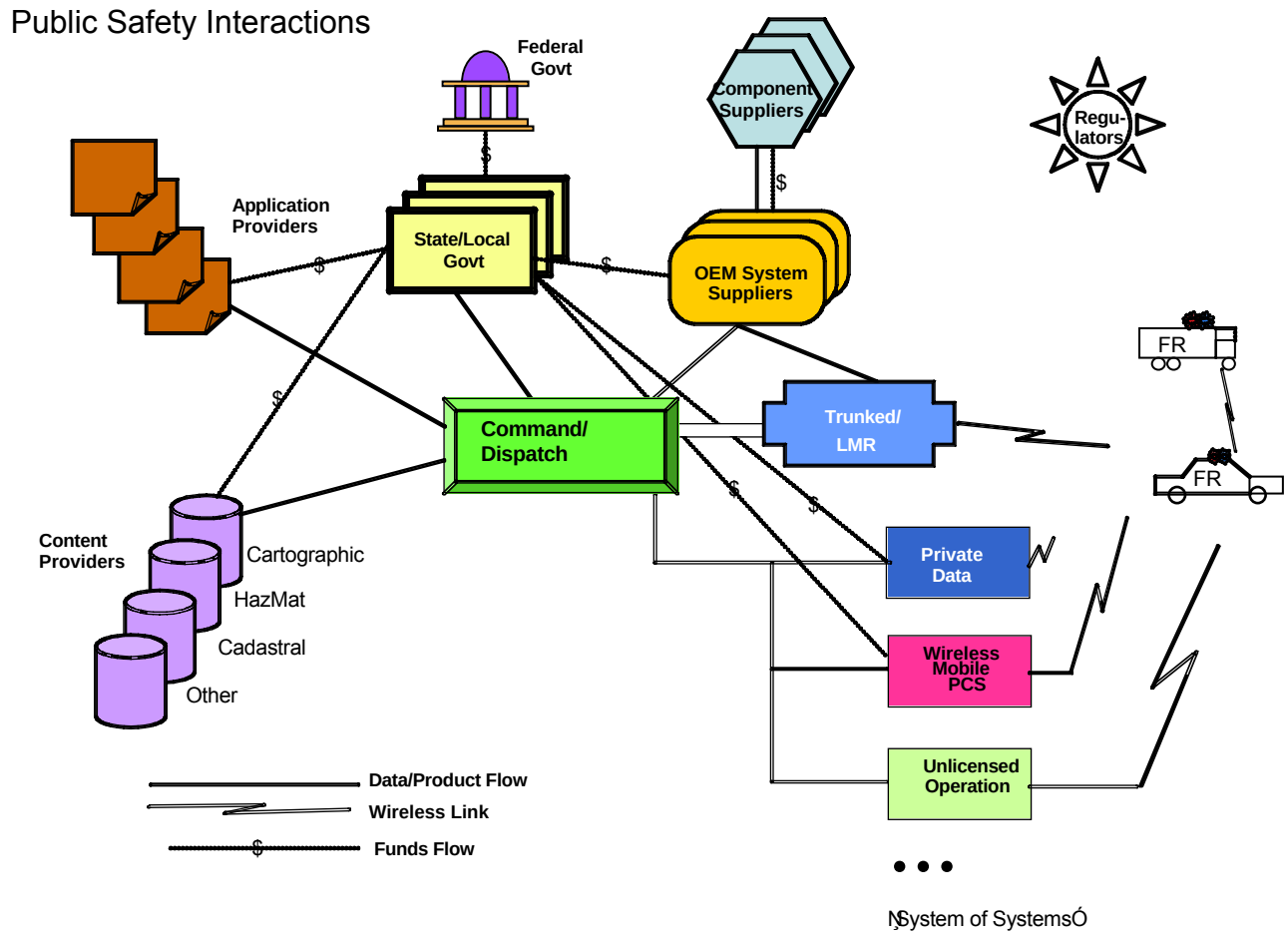

Figure 1. The Public Safety Business model

3. THE PUBLIC SAFETY BUSINESS MODEL

Figure 1 shows the Public Safety business model. In the center is the command facility for an individual Police, Fire, or other Public Safety organization. There are some 50,000 of these organizations in the US, extremely diverse in size and in range of problems with which they deal. The Command function manages operations, while routine communications, most commonly voice, connect Dispatchers with First Responders in the Field.

First Responders (FR) have a variety of communications facilities available to them, both in their vehicles and on their persons. Land Mobile Radio (LMR), often trunked for efficiency, is their primary means of communication with the Dispatch Center, where telephone calls for assistance are taken, and with each other.

Also very diverse are the many state and local governments that use their legal authority to authorize, recruit, equip, and make policy for their Public Safety units. The sheer magnitude of the numbers of organizations operating independently make this a very fragmented market. In the US, Federal government is also a major player in this picture, although both through legislation levying requirements on individual municipalities and Public Safety organizations and by directing funding into specific areas.

In the past, voice communications systems provided by OEM suppliers have been the primary or even sole

communications facilities available to support the FRs. Those OEM suppliers integrate a number of components from component suppliers, and assume system responsibility for effective operations.

Increasingly the "System of Systems" concept is coming into play. FRs are provided with cell phones, data radios, and unlicensed devices using WiFi, Bluetooth, and other commercial communications capabilities. The philosophy of System of Systems is "use what works" rather than the "it has to work every time" architecture that characterizes the primary voice systems. The diereses indicate that any number of communications capabilities have potential to support some aspect of Public Safety operations.

On the left side of the diagram are depicted a number of applications and data resources. These applications, some commercially available and some dedicated to Public Safety needs, are used to deliver information and direction to FRs responding to an event. A cartographic data base contains detailed map data for the jurisdiction, data that is displayed using a geographical information system that can change parameters to meet the needs of specific incidents. Hazardous materials (HazMat) are often present at the scene of an incident, and FRs are trained in how to handle them, given detailed data on the characteristics of materials encountered. Cadastral data describes property lines, building ownership, and related legal information about a jurisdiction.

Regulators make rules to implement legislation, and recommend legislative changes. They also enforce applicable regulations.

The picture also shows some of the flows of funds, products, data and wireless communications existing in this market. Sate and Local Government receives money from taxation, the Federal Government, and other sources. They lease or purchase communications systems from the OEM suppliers, and the systems are installed in local facilities. They also purchase application, data, and a variety of services used to support Public Safety operations.

Wireless links enable mobility of FRs and their vehicular units. Both dedicated Public Safety systems and commercially available services are used.

4. WIRELESS TECHNOLOGIES FOR PUBLIC SAFETY

A number of new technologies have emerged in recent years, many of them with potential use by Public Safety organizations.

4.1 Cellular Services

These commercial services originally had the intent of providing telephone service without need for a landline connection. Now offering facilities for both data and pictures, they have been wildly successful, growing to nearly one trillion dollars in twenty years.

Cellular differs from Public Safety radio systems in that a large number of base stations are deployed using the lowest possible power levels. Communications are normally full duplex, although half-duplex capability is offered by some suppliers. Coverage is a more important criterion that QoS.

There are several potential roles for commercial wireless is Public Safety service.

4.1.1 Normal wireless telephone service

Although the "telephone Call" format does not conform to the half-duplex call-group format of normal Public Safety communications, there are a number of circumstances under which a telephone call can be useful. It is, for example, more suitable than police radios to call a store owner whose property has been broken into.

Although cellular system are not engineered to the same coverage standards, they are useful for a variety of administrative communications. Cellular telephones are sufficiently low cost that they are commonly used as a supplemental communications facility by Public Safety personnel. Where they function well they provide an excellent low-cost option.

An additional option is "hardening" of cellular infrastructure. Potential risks at a given cell site are analyzed, and additional mechanical, electrical, and system-level facilities installed. For example, protected underground electrical generators with extended fuel capacity can insure a power source. In the event of backhaul disruption, some air channels can be diverted from subscriber use to provide over-the-air emergency backhaul.

One possibility in the US is optional Federal funding for the incremental Capex involved. Another consideration is the flexibility offered by SDR-based infrastructure to provide additional flexibility and implement additional options.

4.1.2 SDR Equipped Cellular Infrastructure

Cellular infrastructure is widely available, and may be equipped with SDR Base Stations. When available, portions of the system capacity could be made available to serve as bridges for Public Safety communications in an emergency situation. By offering air interfaces to incompatible radio systems and a repeater link between them, emergency interoperability can be offered.

4.1.3 Universal pilot channel

A problem associated with system interoperability is distribution of software, keys, and channel assignments from a central authority. These services are a potential application for cellular service providers. Under this proposal, a Public Safety unit arriving at the scene of an emergency would access the network using a pilot channel using a standard air interface. Then, after confirmation of identity, the necessary provisioning can be provided, enabling the unit to operate in an local network, interoperating with other, normally incompatible, equipment.

4.2 WiFi, WiMax

These wideband technologies are being widely deployed to provide network access to portable computers. Commercial production volumes make them inexpensive. A number of Public Safety organizations have implemented systems using commercial equipment to enable computer applications from field units. By filing routine reports from remote locations, police officers can maintain a presence in the field, reducing less productive trips back to the central location.

4.3 Ultra-Wideband, Bluetooth

These short-range wide-band services are largely used for personal and short range communications. They have potential for connecting different equipment within a unit.

4.4 Satellite

Satellite communications do not operate well from within buildings, require special antennas and are relatively costly. The do have the substantial advantage of providing connectivity in remote areas where nothing else is available.

4.5 Military Radios

Military radios are among the earliest services to adopt SDR technology. Their capabilities include the ability to load software enabling interoperation with Public Safety equipment. Although these radios are generally more expensive than is acceptable for Public Safety organizations, they do enable interoperability with them.

4.5 FRS/CB/Amateur

Although family radio service and citizen band radios are widely available, and have potential for communicating with the public, they are not sufficiently reliable for more than casual use. Amateur operators have a long tradition of emergency service, but use the relatively unreliable HF bands for long distance communications. Connectivity with these services is appropriate, but newer technologies have largely supplanted them for most Public Safety applications.

4.6 Mesh Networks

Mesh networks are organized on an ad hoc basis to implement local area networks by establishing links between nodes. Any air interface that enables link establishment will work, but wide-channel capability increases the net's functionality. Conversley, a narrow-band interface may have greater range and be more robust. Units in the mesh that can see fixed infrastructure provide connectivity to terrestrial wired facilities.

In order to establish the net all of the participating radios need to have the same compatible air interface. If they are SD radios, they can come up initially on a universal pilot channel, and receive software for the designated protocol.

One application for mesh networks is for intelligent transportation (IT) systems enabling connectivity along a highway. Such a system has significant potential for traffic control, traffic condition reporting, and facilitating response to emergencies.

Another capability is to provide coverage for remote areas by stationing units at intervals between base networks and a remote emergency site.

4.7 Cognitive Radio

Cognitive radio is a different category of technology that can be used with any of the transmission protocols, and optimize selection of system use to optimize users' capabilities to satisfy requirements of a specific situation.

Cognitive capability makes a unit aware of its surroundings, and provides it with an ability to select protocols, channels, and arrange connectivity to optimize its objective function. Acceptance of these facilities in the Public Safety community will require careful consideration of what functions are optimized by the cognitive radio and those that remain under human control.

5. SYSTEM OF SYSTEMS

As described above, there are a number of different communications systems available to meet the first responders' mission critical and support needs. These resources have widely varied characteristics in areas such as coverage, reliability, QoS, bandwidth, and cost.

There is no reason to reject use of a facility because it is not capable of supporting all possible emergency conditions. With proper sysem planning, the facilities used in a particular situation can be selected from a portfolio of those available at a given location, and connected in an ad hoc fashion to best meet current specific needs.

Two phases of introduction of the System of Systems can be envisioned.

5.1 Introductory Phase

As some of the System of Systems concepts are already in use, it can be said that this phase is already underway. In this phase the capabilities of various systems are evaluated, and equipment installed to take advantage of them. For example, several WiFi systems are in operation in the State of Arizona to bring high speed connections to laptop computers installed in Police vehicles.

Additional system planning can evaluate needs for new equipment and software. It can also establish policy describing the circumstances under which specified facilities are to be used, and those procedures incorporated in user training.

With operational experience, additional system facilities can be established as requirements, and vendors encouraged to provide products to meet the requirements. Higher level system facilities can also be established to facilitate interconnection, provide interoperability, and improve the capability of an integrated System of Systems to meet user needs.

5.2 Consolidation Phase

The System of Systems concept provides an intellectual framework under which future developments can be planned to improve communication system capability and reduce costs.

5.2.1 Universal Radio

The concept of a "Universal Radio" does not propose a single piece of equipment to meet all needs. Rather is suggests that there are significant potential gains to be derived from consolidating requirements from widely disparate application areas and satisfying them with a common software defined radio design.

Telematics, or equipment for vehicular application is a case in point. In the future all vehicles will incorporate radios that provide a number of different communication facilities. If those radios are software defined they can be used in a variety of different applications, and several of them installed in some vehicles for use in different applications, and perhaps with different antennas for specific channels. By having a common design instead of a number of specific designs, the economies of scale realized can provide significant incremental functionality and flexibility at a given price point. If a common radio could be installed in ten million automobiles in a given year a much lower cost unit could be provided than one installed in only one hundred thousand police vehicles.

5.2.2 Universal Infrastructure

Again, the concept of "Universal Infrastructure" means looking for areas where requirements can be met with a common infrastructure, not a single system for all applications.

The Cellular market has seen a significant consolidation of cell site towers, where a third party organization leases tower space to more than one Service Provider. There are also a number of Virtual Network Operators, who sell wireless service under their own terms and conditions, with network connectivity provided under contract with another Network Operator.

The operational concept involves implementation of network infrastructure with very capable software defined radios, supporting a wide variety of different applications, not just a specific cellular service. A Network Operator providing cellular service in a metropolitan area, for example, could implement additional channels outside the designated cellular spectrum to support taxi dispatch, bus control, traffic congestion, and even meter reading.

The essence of this proposal is to encourage thought across application areas previously considered totally independent, and explore economies and efficiencies that might be profitably realized.

6. CONCLUSIONS

A number of new communications technologies have emerged in commercial markets that have potential for supporting and improving Public Safety operations. In considering potential application of these capabilities, the Public Safety community will need to adjust some of the criteria it has applied to communications in the past.

We have introduced the concepts of System of Systems, Universal Radio, and Universal Infrastructure to facilitate such considerations. We have also introduced a Business Model to aid in understanding interactions in the Public Safety market.

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Overview

- 1. Introduction
- 2. History
- 3. Public Safety Business Model
- 4. Wireless Technologies for PS
- 5. System of Systems
- 6. Conclusions

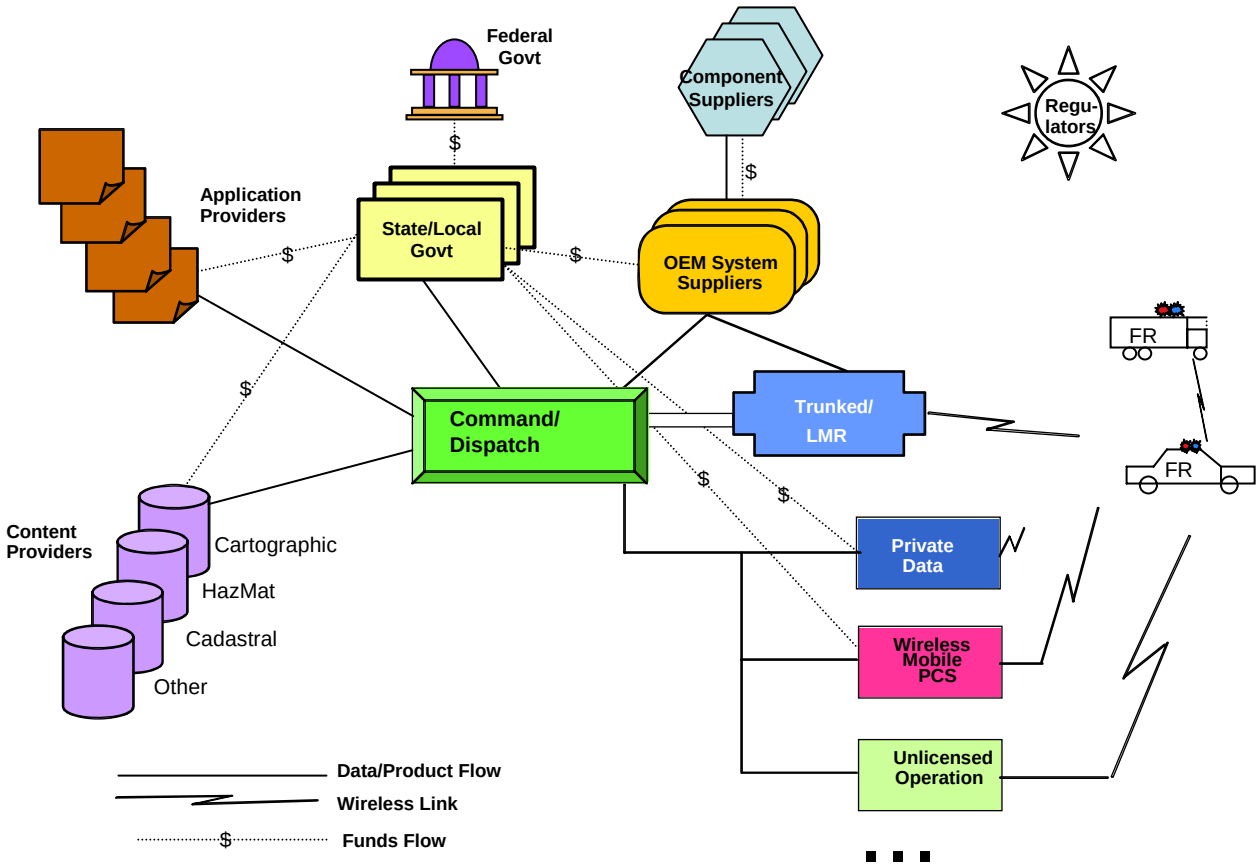
Introduction

- Public Safety community fragmented
  - 50,000 Organizations in US
  - Local jurisdictions
- Mobile radio products tailored to PS
  - Trunked LMR voice
- Want added functions, cost advantages of consumer electronics
- Question: To what extent are PS requirements driven by adopted technology?
- "System of Systems" approach to enhancement

History

- Whistles, bang nightsticks, call boxes
- Broadcast - "Calling all cars"
- Trunked talk groups
  - Keying moved all radios to available channel
- Need for interoperability
- SDR proposed for bridging

Public Safety Business Model



"System of Systems"

Other Technologies

- UWB/Bluetooth
  - Connectivity within a unit
- Satellite
  - Remote areas
- FRS/CB/Amateur
- Mesh Networks
- Cognitive Radio

Wireless Technologies for PS

- Cellular/PCS
  - Normal commercial offerings
  - SDR-equipped infrastructure
    - Bridging repeater
- WiFi, WiMax (802.xx)
- Military Radios
  - Adopting SDR
  - Equipped with PS waveforms
  - Expensive, exceed PS requirements

System of Systems

- Many communications facilities are available
- SoS concept:
  - survey and catalog resources
  - Introduce resources into response plan scenarios
  - Develop architectural approaches to use SDR and other technologies to cover shortcomings
- Two phases:
  - Introductory
  - Consolidation

SoS Introductory Phase

- Already underway
  - Graham County, AZ
  - I-19 AZ demonstration
- Build existing capabilities into plans
  - Cellular radios - notify store owners
  - FRS - hand out $20 units to coordinate lost child search at a picnic

SoS Consolidation Phase

- "Universal Radio" approach
  - Search across a wide range of applications for common requirements: e.g. telematics, police
  - Develop one or more SDR HW designs to meet needs AND achieve high production volume
  - Meet specific needs with software variations

SoS Consolidation Phase (con't)

- "Universal Infrastructure"
  - Use SDR and HYPRES's Digital RF techniques to establish an infrastructure capable of meeting needs of different services
  - Enable design of new facilities to meet needs
    - Cognitive Pilot Channel as a commercial application to permit non-compatible SDRs to authenticate and interoperate

Conclusions

- Many existing technologies can be applied to PS needs
- Some PS thinking may need to adapt
- New capabilities can be developed to further improve architectures
- HW designed to meet needs of variegated applications can lower costs

Conclusions (con't)

- Business model as aid to understanding market
- System of Systems to encourage expanded conceptualization
- Universal Radio
- Universal Infrastructure