Efficient Dynamic Spectrum Access Implementation

Filip Perich, Edward Morgan, Olga Ritterbush, Mark McHenry, and Salvador D'Itri
Shared Spectrum Company
Vienna, Virginia, USA
{fperich, emorgan, oritterbush, mmchenry, sditri}@sharedspectrum.com

Abstract*—Shared Spectrum Company developed Dynamic Spectrum Access (DSA) technology that enables military radio communication systems to deliver robust, non-interrupted wireless connectivity to tactical networks technology. DSA allows network operators to adapt to last minute spectrum assignment planning changes as well as changes made after deployment. DSA also allows the radios to overcome even unplanned, unexpected interference sources. The technology was initially developed for the DARPA XG program, and now several military radio platforms are currently being extended to integrate the technology. We present a case study of dynamic spectrum access software technical and operational integration challenges. We also present the benefits from developing and deploying a single core radio software application that follows commercial iPhone-like solutions. We describe an approach that obviates many problems by abstracting radio components into a set of device classes. We also define an open application-programming interface for interacting between the device classes and the dynamic spectrum access components. We have defined an open management interface for allowing consistent spectrum management across all platforms. This approach supports a scalable proliferation of the technology, future enhancements across platforms, and provides compatible spectrum management paradigm across platforms. This also enables upgrades performed in a consistent fashion. Our experience and results show that the approach performs well across heterogeneous military radio platforms with vastly varied hardware and software features. This software-only extension is achieved via adaptively collecting, analyzing, and responding to radio's spectral environment at runtime. This paper is a case study of lessons learned, challenges with network and waveform integration, and a roadmap for other dynamic access spectrum developers to consider in future applications.

Keywords-Cognitive networks; Mobile ad hoc networks

I. INTRODUCTION

In 2000, DoD had fewer than 50 unmanned aircrafts in its inventory; as of October 2009, this number has grown to more than 6,800. [1] This exponential increase in use of UAVs is just one illustration of how the DoD is in desperate need of additional spectrum to support its escalating communication needs from traditional soldier-to-soldier voice communication to collecting video feeds from aerial sensors. Unfortunately, there is no available spectrum left due to the current approach for spectrum assignment and management. Consequently, DoD, as well as commercial organizations facing similar shortage of spectrum, is looking into other wireless communication approaches that can support their growing demands.

This work was sponsored in part by the DARPA XG Program, Contract FA 8750-05-C-0150. Distribution Statement "A" (Approved for Public Release, Distribution Unlimited). DISTAR Case 15409

Cognitive frequency-agile radio devices offer the vision of virtually unlimited data and voice throughput for their users, thus promising to satisfy communication requirements for any application, anytime, anywhere, by intelligently managing locally available spectrum. The technology bases the premise on the ability of frequency-agile devices to communicate on any available frequency channel and on the devices' cognitive ability to select the right frequency channel from a finite pool of spectra that is currently deemed as available based on the devices' temporal, geospatial and spectral context.

Given the magnitude of opportunities cognitive frequency-agile devices would create – which range from improved spectrum utilization to spectrum sharing to spectrum pooling – there has been a vast interest in both researching and developing mechanisms for enabling such devices. To better understand the challenges and study the impact cognitive frequency-agile devices present to military and commercial applications, the U.S. Department of Defense Advanced Research Projects Agency (DARPA) executed the neXt Generation (XG) Communication Program [2] and selected Shared Spectrum Company as the prime contractor.

The result of the XG program was the development of the Dynamic Spectrum Access (DSA) technology, which was successfully implemented and field-tested using IEEE 802.16 based wireless networked radio devices [3,4].

Based on the XG successes, DoD has selected several military radio platforms to be integrated with the DSA technology. This includes DARPA WNaN radio platform, U.S. Army EPLRS-XF, DARPA MAINGATE, Harris, and Thales [5,6,7,8,9]. The objective was to develop a common DSA design and integrate the software with the vastly different hardware platforms and the very different protocols used to operate the various networks.

Our contributions in this paper can be summarized as:

- We present a case study of DSA software technical and operational integration challenges.
- We present the benefits from developing and deploying a single-core radio software application that follows commercial iPhone-like solutions. We describe an approach that obviates many problems by abstracting radio components into a set of device classes. We also define an open application-programming interface for interacting between the device classes and the dynamic spectrum access components.
- We define an open management interface for allowing consistent spectrum management across all platforms.

Ultimately, we demonstrate that this approach supports a scalable proliferation of the technology, future enhancements across platforms, and provides compatible spectrum management paradigm across platforms. This also enables upgrades performed in a consistent fashion.

Our integration experience and results show that the approach performs well across heterogeneous military radio platforms with vastly varied hardware and software features. This software-only extension is achieved via adaptively collecting, analyzing, and responding to radio's spectral environment at runtime. This paper is a case study of lessons learned, challenges with network and waveform integration, and a roadmap for other dynamic access spectrum developers to consider in future applications.

II. BACKGROUND

DSA technology enables users of virtually any radio device to utilize dynamic spectrum access techniques and thereby dramatically improve spectrum efficiency, communications reliability, and deployment time.

Fundamentally, a DSA-enabled radio, device or network node dynamically adapts to its RF environment to maintain reliable communications with other DSA-enabled devices, and it does so without interference to other DSA radios or to non-cooperative (NC) legacy radios. Furthermore, a DSA-enabled radio operates within prescribed policy constraints, which may vary depending upon the radio's geographic location, frequency band, the time of a day, spectrum activity, deployment scenario, and other anticipated or unanticipated factors.

A DSA-enabled radio achieves this by operating over a wide span of spectrum rapidly detecting non-cooperative or legacy radios, and adjusting, in real time, its operating frequency and other transmission parameters. Fig. 1 depicts the four key processes taking place in a DSA-enabled radio. This is based on the OODA approach [10].

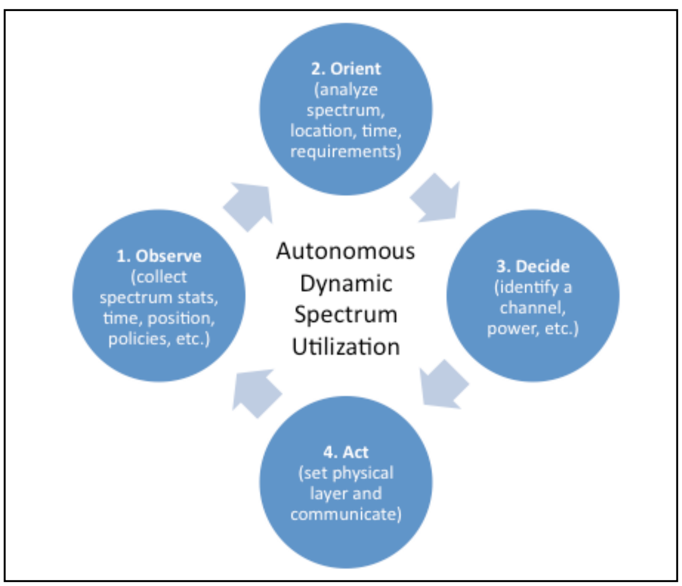

Fig. 1. Key DSA Processes

The Act process also referred to as the Reasoning process controls radio operations conformance to a set of policies governing spectrum access rules. Within the Reasoning process real-time DSA requirements metrics are generated and validated, and the best course of action is determined dynamically based on policies and performance evidence presented to Reasoning by other DSA processes. At the same time the Reasoning process acts a surrogate to spectrum stakeholders assuring a spectrum access requirement conformance.

The Observe process, also referred to as the Adaptation process, governs the real-time radio emission plan and generates optimal radio settings according to metrics and an action plan provided by the Reasoning process. The Adaptation process is aware of the radio's capabilities and characteristics. The Adaptation process utilizes the knowledge for optimally reconfiguring the radio.

The Orient process, also known as the Sensing process, governing spectrum monitoring, is essential in the evaluation of the radio RF environment. The Sensing process utilizes a variety of detection methods to support objectives formulated by the Reasoning process via sensing requirements metrics.

Finally, during the Decide process, also referred to as the Characterization process, the radio device is responsible for assessing its RF sensing results, and for classifying possible spectrum states. Based on this assessment, neighbors are found and spectrum access decisions are made.

The DSA-enabled radio then continues this loop indefinitely in order to maintain connectivity with its neighbors and in order to avoid any interference the radio or its neighbors may cause to other radio applications operating in the area as well as avoiding interference from those other radios in the area.

III. OPEN DYNAMIC SPECTRUM ACCESS DESIGN

Radio development is a difficult and very expensive system-engineering task. There are many requirements and it is difficult to analyze or simulate the radio performance. Additionally, there is a need to continually evolve and upgrade radios to tailor for new requirements. This is especially true for military radio communication platforms.

The modular hardware architecture is the best way to support DoD's radio development goals. There are many different DoD radio applications, including tactical ground vehicle, soldier carried, robot, UAV, or telemetry, all that need to be tailored and optimized for each application. A good design for a specific application is significantly different than the design for another application. Therefore, there is no single frequency range, medium-access-control (MAC) design, transmit power level, or prime power requirement for all military radios.

At the same time, all radio devices are used for the same goal, i.e. to provide means to exchange data with others, and therefore from user's perspective, they appear the same. As such all radios also provide similar means for their configuration.

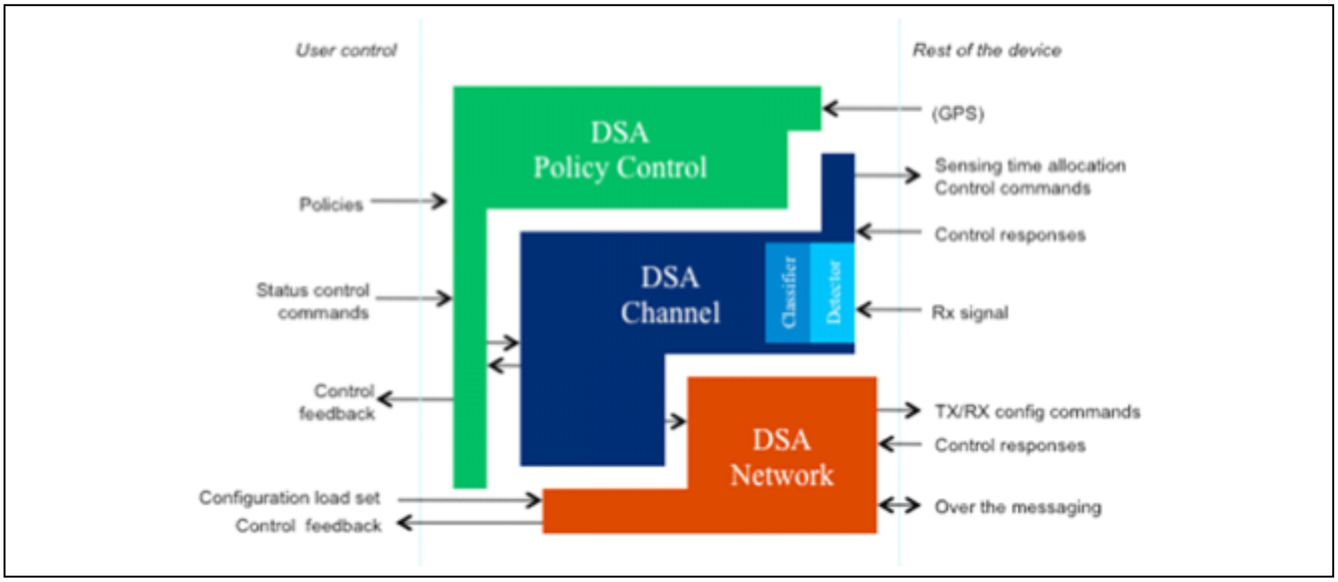

Fig. 2. Complete fully-integrated DSA implementation consists of a policy control module, channel module with detector and classifier, and network modules.

In the most simplified model, DSA is nothing more than automated reconfiguration of radio's transmission and reception configuration parameters. The challenges arise from the facts that the reconfiguration may have to be performed as fast as once per every frame in a TDM based MAC or once per every packet in other MAC implementations. Additionally, the challenges arise from the facts that the decisions to perform a reconfiguration are done based on dynamic spectrum access control policies, based on currently sensed environment, and based on coordinated messages exchanged with other collaborating neighbors. Finally, the challenges arise from the fact that while the user expects the same DSA behavior on any military platforms each platform offers varied computing resources and operates using different networking protocols.

In order to satisfy this heterogeneity, we have divided the DSA design into a set of module components. Fig. 2 shows the DSA module components, including the DSA Policy Control, DSA Channel, which includes detectors and classifiers, and DSA Network.

The DSA Policy Control component includes reasoning software for processing spectrum access control policies. The policies can vary in their complexity from simple frequency range allotments to complex rules expressed in a declarative language [11]. Regardless of their complexity, the spectrum access control policies can be generated by many stakeholders and are supplied by an authorized network operator to the DSA. The DSA Policy Control component merges and analyzes the complex policies or simply extracts the simple frequency ranges in order to identify DSA operational opportunities. The opportunities may differ based on the current location or time of the day as reported by, for example, a GPS device. The opportunities may also differ based on messages received from other neighbors as well as on spectral knowledge collected about the radio's spectral environment. The opportunities are then provided to the DSA channel module component.

When a specific radio is unable to process spectrum access control policies locally, the DSA Policy Control module component can be removed and executed remotely to the radio on some proxy device, such as a network management console. In that case, a user is responsible to provide the DSA module with the specific frequency ranges that are currently permissible for transmission and the various parameters for other DSA components, i.e. the configuration load-sets.

When enabled, the DSA Policy Control component operates as the main entry point for user control.

The DSA Channel function stores spectrum measurements, manages the detectors, and performs the detection and classification. The main objective of the DSA Channel is to maintain several lists of channels, namely, the allowed, DSA-active, NC-active, and cleared channels. The allowed channels represent frequency ranges where the radio is now permitted to transmit. The DSA-active channels represent frequency ranges with detected friendly DSA activity. The NC-active channels represent frequency ranges currently used by other radio applications. Finally, the cleared channels represent channels that are either empty or DSA-active.

Additionally, the DSA Channel may provide spectrum statistics for other components on the radio but mostly for user operators for their logging purposes.

The DSA detectors include all of the detectors required to operate against existing signals in the spectrum. The detector types may include FFT detectors, cyclostationary detectors, specialized feature detectors such as for TV bands, or any multi-channel cross correlation detectors. The DSA detectors then work in tandem with DSA classifiers in order to classify the type of detected activity.

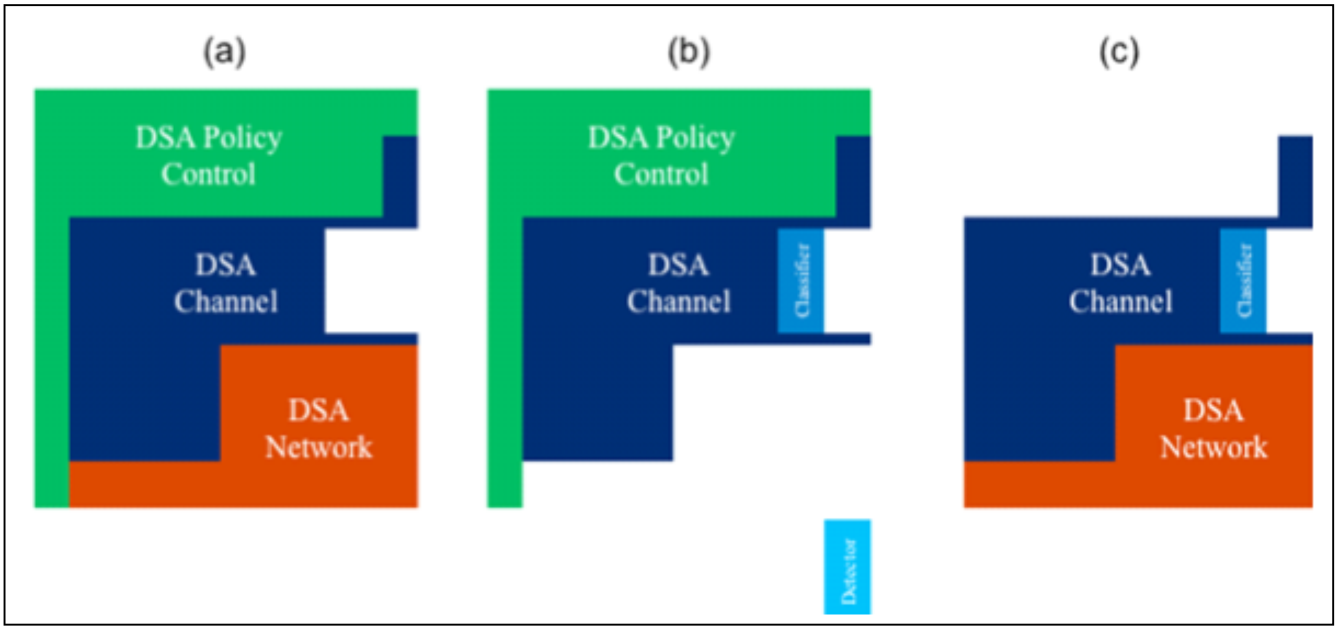

Fig. 3. (a) DSA implementation without detector and classifier; (b) DSA implementation with sepearte detector and no network module; (c) DSAimplementation without policy control and without detector.

Depending on the platform, the detectors or classifiers may already exist on the radio and then the DSA would reuse the existing detectors or classifiers.

The final major module is the DSA Network. When enabled, the DSA Network function is responsible for instructing the radio when and what channels to use for transmission and reception. The DSA Network achieves that by negotiating with other DSA-enabled radio devices in order to identify a good communication link based on their common cleared, DSA-active, and allowed channels. The DSA Network is responsible for messaging between the other DSA radios, selecting operating frequencies, and for discovering other DSA-radios in the environment. Additionally, the DSA Network function is responsible for merging or splitting networks as DSA-enabled radios enter and leave the geographical area.

This design, as shown in Fig. 2, is truly modular. Depending on the existing capabilities and limitations of the target military platform, any combination of the five DSA module components can be integrated onto the platform. The newest platforms are likely to have sufficient resources and computing bandwidth to support all five components. Other platforms with lesser capability may delegate some of the components off-board or implement simplified approaches to specific components. For example, some radios may use frequency-range-based DSA Policy Control whereas others may use a full declarative policy support. Other radios may implement several detector types whereas some may implement just a basic FFT detector.

A. DSA Application Programming Interface

The DSA functionality from the user and device's perspective remains the same. From the control perspective, the DSA module accepts policies, status control commands, and configuration load-sets regardless of what components are implemented on the radio. The DSA module always responds with control feedback messages only.

There are two levels of control Application Programming Interface (APIs). The upper level API allows radio operators to distribute spectrum access control policy updates and monitor the performance of the DSA modules on each radio. This API consists of methods for adding, removing, activating, and deactivating policies. The lower level API allows radio operators to integrate the DSA with the underlying platform. This API consist of methods for configuring how the DSA can share transmitters with the MAC for sensing purposes, how the DSA can exchange messages with other radios, and how the DSA can instruct MAC to change transmitter's configuration.

From the radio device's perspective, the DSA Channel expects classifier's results. Should the DSA module have an inbuilt classifier then it expects detector's results. Should the DSA module have an inbuilt detector then the DSA expects raw signal. Should the DSA include DSA Network module, then the DSA issues TX/RX commands. Alternatively, the DSA only provides channel list updates and it is up to the radio's existing MAC to issue corresponding TX/RX commands.

IV. Integration Experience

In this section, we describe our experience with integrating the DSA module onto various military radio platforms. The success of applying the same DSA solution onto multiple drastically different platforms validates the benefits of the DSA modular design.

A. U.S. Army EPLRS-XF

In the U.S. Army EPLRS-XF project, we worked for Raytheon to integrate the DSA software onto the EPLRS radio device. Given the computing resources available on the radio, we have chosen the modular configuration shown in Fig. 3a.

The EPLRS-XF radio device implements its own detector and classifier as part of the platform. Therefore, the DSA did not require an internal detector or classifier. Additionally, the DSA version for the EPLRS-XF does not include the spectrum access control policy reasoner on the radio but rather the component is delegated to the off-device EPLRS Network Management (ENM) tool. Whenever the operator changes the policies on the ENM, all radios in the network receive the same updates.

Using this approach, the DSA enables EPLRS-XF radios to use additional spectrum in order to increase data bandwidth of the Tactical Internet (TI). The policy software in the ENM allows operations OCONUS where the 420-450 MHz bands have restrictions by country and local authorities. The radios, with properly updated policies, may be allowed to operate in the existing frequency band, when it is shown that the system no longer interferes with the resident users. Therefore, the availability of more spectra increases the performance of existing network operations.

B. MAINGATE

Also in the DARPA MAINGATE program, we worked for Raytheon, who is the DARPA MAINGATE prime, to provide DSA capability to the platform. MAINGATE provides secured, networked communications-on-the-move in heterogeneous environments. The MAINGATE radio system comprises of four major functional components: the Wireless IP Network (WIPN) MANET radios, the gateway network, the DSA technology, and the DARPA Disruptive Tolerant Networking (DTN).

Given the available resources and the demands on the spectrum for providing bridging capability to wireless networks, a decision was made to implement a complete full DSA module on the platform. Therefore, the MAINGATE radio platform contains the DSA Policy Control, DSA Channel, and DSA Network modules.

C. DARPA WNaN

In the DARPA Wireless Networking after Next (WNaN), we teamed with BBN and Cobham (previously M/A COM). The purpose of this project was to design, develop, and demonstrate low-cost wireless network nodes, which support adaptation by means of distributed network processing.

The challenge in this integration effort was to design and implement DSA that operates over the four transmission components provided by the WNaN radio. Additionally, the challenge was to integrate with a complex MAC that operates over the four transmission channels in both SISO and MIMO modes.

Consequently, we have chosen to implement the DSA modules shown in Fig. 3b. We have tightly integrated the DSA detector as part of the WNaN radio platform. We then decided to delegate the responsibility for selecting the proper TX/RX configuration to the WNaN MAC and instead focused on the DSA Policy Control and DSA Channel components only. The result is a robust declarative-policy controlled DSA component that continuously identifies available channels based on sensing knowledge, time of the day information, and location information.

D. JTRS Land Mobile Radio

Additionally, we ported the DSA software to two JTRS-certified tactical radios, the Thales JEM and Harris Falcon III (PRC148/152). Given the limited computing resources available on the two platforms, only the DSA Channel module with an accompanied classifier and the DSA Network module were added. Both radio platforms implemented their own DSA detector. Due to the limited resources, the DSA Policy Control module was not integrated. Instead the module was executed remotely in order to compute frequency range opportunities, which were then loaded into the DSA Channel module through configuration load-set interface.

V. CONCLUSIONS

Initially as part of the DARPA XG program, we have developed DSA technology that enables military radio communication systems to deliver robust, non-interrupted wireless connectivity to tactical networks technology. The DSA technology achieves this by operating over a wide span of spectrum rapidly detecting non-cooperative or legacy radios, and adjusting, in real time, radio's operating frequency or other parameters when it does so. Because DSA can detect and avoid many types of interference, DSA allows the radios to overcome even unplanned, unexpected interference sources. Additionally thanks to the use of declarative policies, DSA allows network operators to adapt to last minute spectrum assignment planning changes as well as changes made after deployment.

We presented a case study of dynamic spectrum access software technical and operational integration challenges. Our objective was to develop a single modular design that is applicable to all military radio platforms that are currently being extended to integrate the technology.

We described an approach that obviates many problems by abstracting radio components into a set of device classes. We also defined an open interface for interacting between the device classes and the dynamic spectrum access components. Using an open interface in terms of declarative policies allows the same policies be reused by all platforms.

This approach supports a scalable proliferation of the technology, future enhancements across platforms, and provides compatible spectrum management paradigm across platforms. This approach also enables upgrades performed in a consistent fashion.

Our integration experience and results show that the approach performs well across heterogeneous military radio platforms with vastly varied hardware and software features.

REFERENCES

[1] M. Cooney, "Is US unmanned aircraft biz too booming for its own good?", [Online], March 29, 2010, http://www.networkworld.com/community/node/59405.

[2] DARPA XG Program [Online]. Available: http://www.darpa.mil/sto/smallunitops/xg.html.

[3] F. Seelig, "A Description of the August 2006 XG Demonstrations at Fort A.P. Hill", in IEEE DySPAN, April 2007.

[4] M. McHenry, E. Livsics, T. Nguyen, and N. Majumdar, "XG Dynamic Spectrum Sharing Field Test Results", in IEEE DySPAN, April 2007.

[5] DARPA WNAN Program [Online]. Available: http://www.darpa.mil/STO/strategic/wireless.html.

[6] Raytheon EPLRS-XF Radio Description [Online]. Available: http://www.raytheon.com/capabilities/rtnwcm/groups/ncs/documents/content/rtn_ncs_products_eplrsi_pdf.pdf.

[7] DARPA MAINGATE Program [Online]. Available: http://www.darpa.mil/STO/strategic/maingate.html.

[8] Harris XG Radio Integration Description, "XG Near-Term Radio Integration Program Overview", Richard DeSalvo, MILCOM 2008.

[9] Thales XG Radio Integration Description, "Application of Dynamic Spectrum Access to the AN/PRC-148 JEM Tactical Radio (U)", Robert. Masucci, Mark McHenry, Todd Martin, MILCOM 2008.

[10] OODA The OODA loop (for observe, orient, decide, and act), http://en.wikipedia.org/wiki/OODA_loop

[11] F. Perich and M. McHenry, "Policy-based Spectrum Access Control for Dynamic Spectrum Access Network Radios", Journal of Web Semantics: Science, Services and Agents on the World Wide Web, 2008.