Incumbent Spectrum User's Dynamic Spectrum Access Requirements

Mark McHenry
Shared Spectrum Company
Vienna, Virginia, USA
mmchenry@sharedspectrum.com

***Abstract*— This paper discusses the Dynamic Spectrum Access wireless system requirements as viewed by incumbent spectrum users. Previously, DSA performance was primarily assumed to be based on the amount of interference the DSA system caused to incumbent radio systems. As DSA starts to mature, additional requirements have emerged. Incumbent stakeholders operate wireless systems that are critical to their operations and will only share spectrum when this basic goal is not threatened. Hence, the DSA entrant must develop a system to minimize the issues as viewed by the incumbent to facilitate spectrum sharing. They include the ability to accommodate changes in the incumbent's usage (amount and system types), enforcement and others.**

Keywords-Dynamic Spectrum Access, requirements, spectrum sharing

I. Introduction

This paper discusses the Dynamic Spectrum Access wireless system requirements as viewed by typical incumbent spectrum users. The requirements originated from conversations and meetings with multiple spectrum stakeholders including both commercial and incumbent groups. Additional insights were obtained from the DFS, AWS and TV white space spectrum rule proceedings.

Section II summarizes Dynamic Spectrum Access technology and provides a description of the "spectrum cube" vision where multiple types of wireless services efficiently share spectrum.

Section III describes the different DSA system requirements as viewed by the incumbent spectrum user. The goal of these requirements is to facilitate a "win-win" situation where the incumbent spectrum user will share spectrum and not enter into "life or death" struggles to prevent the entrant from using the spectrum. The different requirements focus on the incumbents' overall desire to be able to maintain and possible increase his spectrum use with high confidence. Many of these requirements are technical in nature. Some of the requirements are process orientated.

Section IV compares Shared Spectrum Company's DSA system to these requirements. While this system meets most of the requirements, there are some shortfalls that are currently being developed.

Section V provides a summary.

II. DSA Vision

Dynamic Spectrum Access (DSA) offers significant improvements in the amount of spectrum access compared to the present command and control, fixed spectrum access methods. DSA software technology dramatically improves spectrum efficiency, communications reliability, and deployment time. DSA software dynamically senses spectrum use and adapts to its radio frequency (RF) environment to maintain reliable communications with other DSA-software-enabled devices without causing interference to incumbent radios. The SSC DSA solution is a radio software solution comprising key radio software modules as depicted in Figure 1. DSA uses a variety of signal detectors and classifiers to characterize DSA signals from "Non-cooperative"/incumbent signals. When DSA signals are encountered, the DSA MAC determines the frequency selection strategy. When "Non-cooperative"/legacy signals are encountered, the DSA policy module follows FCC and NTIA rules to determine the operating frequency and power level. DSA technology was developed by SSC as part of the DARPA XG Program.

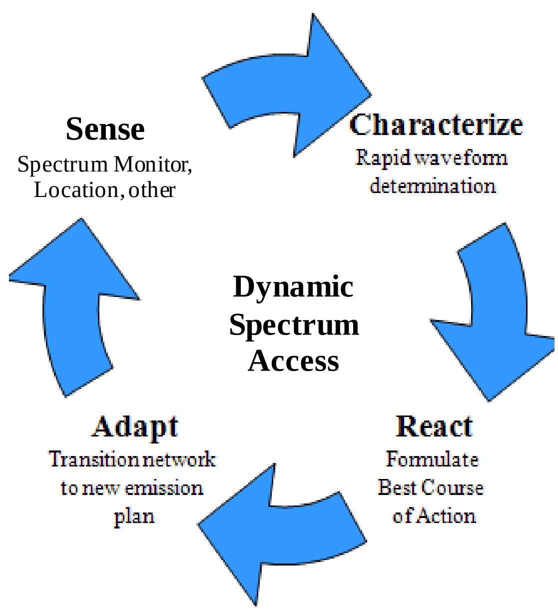

Figure 1. Dynamic Spectrum Access (DSA) Technology

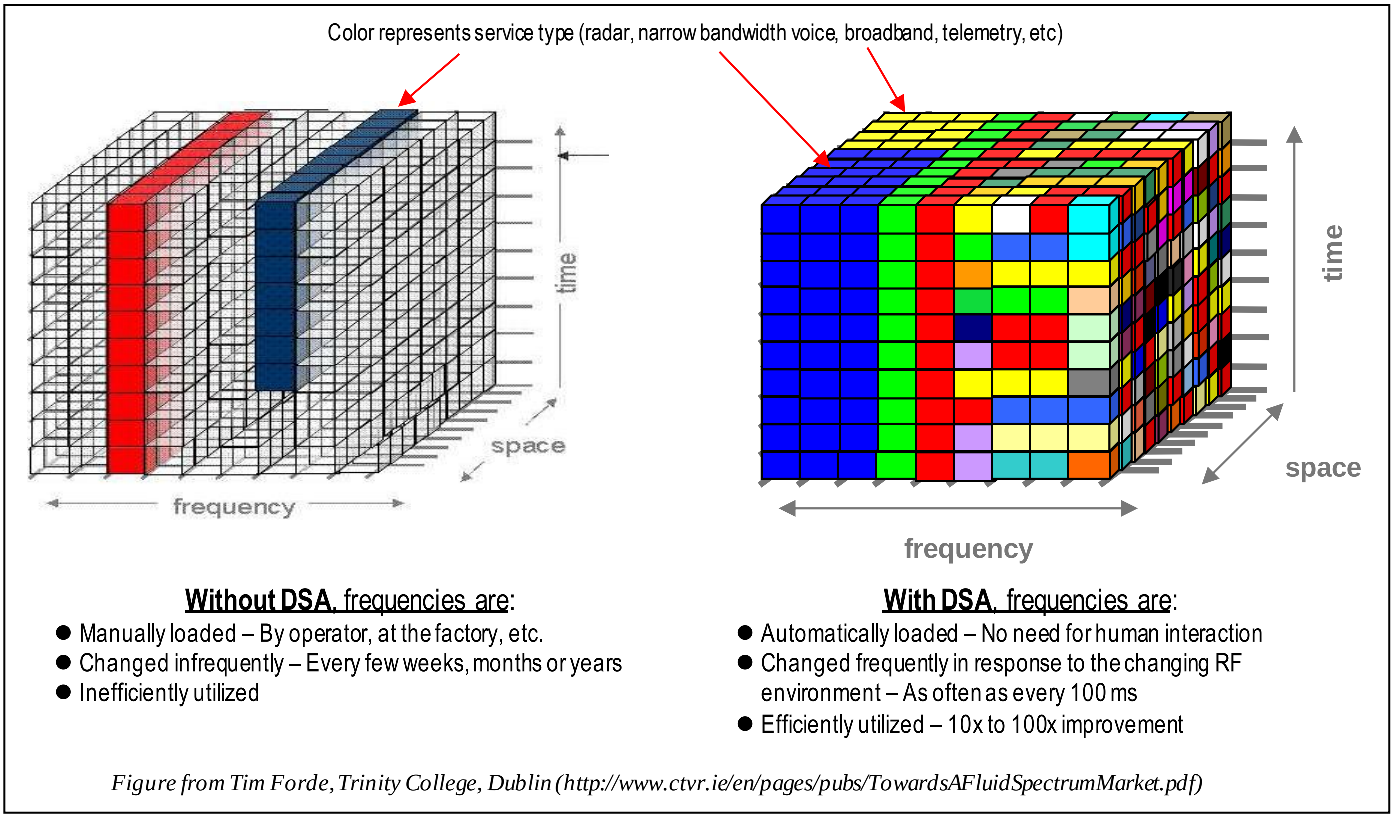

Figure 2. The "Spectrum Cube" vision is for a dense use spectrum use with diverse services sharing with minimal frequency, space and time spaces.

DSA improves spectrum efficiency by enabling efficient spectrum use as illustrated by the spectrum cube shown in Figure 2. Without DSA (left side of figure), there are large separations in frequency, space, and/or time between different users. These separations are used to minimize interference between the users with a minimal amount of coordination between the users. As the number of users has increased, the frequency, space and time separations represent a very large spectrum user inefficiency, which needs to be utilized if the wireless capacity is going to grow. With DSA (right side of figure), the amount of frequency, space, and time separation between users is minimized.

In the past, similar types of services were grouped in frequency bands to reduce coordination efforts. However, in the future, different services will share the frequency bands. Examples include the Dynamic Frequency Selection (DFS) rules which allow low power, unlicensed communication devices to share spectrum with high power radar systems, the TV white space (TVWS) rules which allow low power DSA devices to share spectrum with TV broadcast systems.

The question is what process will be used to develop rules and process that enable users to share spectrum. The DFS and the TVWS rules processes were protracted (5 to 10 years in length), adversarial approaches where a set of fixed rules were developed. The entrants and incumbents spent large sums on lawyers and lobbyists, conducted expensive (and inconclusive) tests, and finally resolved the rules through largely political means. If the entrant's top leadership had not personally contacted congressional and senior FCC leadership, the DFS and TVWS rules would still be pending in the government offices.

III. Incumbent DSA Requirements

This section describes the DSA system requirements related to satisfying incumbent spectrum stakeholder's concerns. Incumbent stakeholders operate wireless systems that are critical to their operations and will only share spectrum when this basic goal is not threatened. Hence, the DSA entrant must develop a system to minimize the issues as viewed by the incumbent to facilitate spectrum sharing.

A. Accomidate Changes in Incumbent Use

There needs to be a mechanism for the incumbent user to change their radio equipment types or parameters that doesn't significantly impact the entrant DSA user. An example is in the DFS band where a certain type of weather radars were not considered in the original DFS rules and the fielded DFS devices didn't detect these radars. It was very difficult for the government to go back to the commercial users to fix this problem.

DSA Implication – The DSA classifier and other spectrum access rules needed to be easily changed in fielded DSA radios. This software update must be done with the DSA radios that are in the field at an insignificant cost. DSA radios that don't get the update must cease operations after a certain time period.

B. Backup DSA Operation Bands

The entrant DSA user needs to have one or more backup spectrum bands to accommodate the incumbent user's potential increase spectrum use. The incumbent user might originally have a low spectrum use, but may later decide to increase their use. The incumbent user's fear is that the entrant DSA user's system will not function well when the incumbent user increases their usage, and then the entrant DSA user will go to the regulators to force the incumbent user to reduce its usage.

DSA Implication – DSA needs to be implemented on multi-band radios with at least three spectrum bands to enable robust "backup" secondary usage. The initial DSA radio operators need to seek two or more incumbent bands with dissimilar incumbent users in the initial pilot programs to demonstrate "backup" operation. Or, the entrant DSA spectrum band must augment the commercial system's existing spectrum bands. The DSA system should not solely operate in a single incumbent user's spectrum band(s).

C. Enforcement

If interference occurs, there needs to be a way for the incumbent user to easily identify which entrant DSA users are causing interference, and to then correct the problem or shut them down. For example, an interference issue occurred in the DFS band where the weather radars starting getting interference [1]. It occurred because the weather radars had a waveform that was not in the initial DFS rules. The incumbent users contacted the FCC and asked them to shut down the interfering DFS users. The FCC said that they would if the incumbent user told the FCC the owner's names and locations of the interfering radios, the FCC would shut them done. The incumbent user didn't have a method to do located the interfering the DFS users. Hence, the incumbents had to expand significant engineering resources to identify the source of the interference to correct the issue.

DSA Implication – The DSA system should implement a method to identify and shutdown suspected interfering DSA radios when the spectrum managers don't have information on the location and identity of the DSA radios in the field. This could be accomplished by transmitting new spectrum policies that shut down DSA radios in a certain geographic region and frequency band to isolate the DSA radios causing the problem. Then the DSA operators would incrementally change the policy parameters to determine the specific reason why the interference is occurring. The DSA system needs to include a function for the DSA radios to identify to the spectrum managers that the DSA radios are in the area being suspected of involved in an interference event.

To support enforcement, the DSA system needs to support a wide range of spectrum access rules as shown in Figure 3. These rules are needed to both localize what DSA radios are causing interference and to restrict use. For example, a sense-based (Listen-Before-Talk) DSA radio must also support spatial access rules to facilitate determining what DSA radio is the source of an interference complaint. Temporal type rules are required to enable rules to age out so that if a rule is changed, that this rule change is promulgated out to all users within a reasonable amount of time. Device based type rules are needed to support changes in incumbent radio types.

D. Unauthorized and Accidental Use

Incumbent users are concerned about unauthorized and accidental spectrum use by DSA systems. This includes both accidental and malicious situations.

DSA Implication – The DSA system needs to implement a policy software certificate security management feature that

Listen-Before-Talk based types
LBT – Same up and downlink frequencies
LBT – Different, but known, up and downlink frequencies
LBT – Different, but known, up and downlink frequencies, band plan known
Spatial types
Geographic border field strength limits
Database geographic/ Coverage area based
Temporal types
Time of Day restrictions
Authorization for finite time duration (with periodic renewals)
Device based types
Classifier Capability – Certified ability to detect specific incumbent signal type to a certain sensitivity level
Device Capability - Ability to measure second and third harmonic
Device Capability - DSA TX power spectrum density limit

Connectivity based types
Beacon reception required to use band
Connectivity requirement for any policy (can use certain bands only if connected to Spectrum Manager)
Group Behavior based types
Type 1 Group Behavior - Abandon channel if any node in your "group" detects Non-cooperative signal at above specified level
Type 2 Group Behavior - Determine DSA TX power based on estimated interference probability using "belief maps" of incumbent receiver locations
Control based types
Automated policy updates if feedback indicates that existing policy is insufficient for non-interference operations
Automated policy updates notification of policy revocation or update by policy authority
Node Identify restrictions (e.g., use while airborne prohibited, use only in fixed applications, Red Cross use only)

Figure 3. A wide range of DSA rules are needed to support interference mitigation and enforcement.

prevents unauthorized use [2]. This feature should include certificates installed in the radio software by the manufacturer that validates spectrum access polices in certain spectrum bands. Regulators also define regulatory policies, which are applicable to specific applications and which are certified by the regulators for use. In this operating mode, the DSA operator purchases an open, certified device from a manufacturer and specifies the type of application the radio is used for by providing the radio software through a secure link with appropriate certified policies. The device now consists of two certified objects – (i) a policy component, as part of the certified radio, which ensures that the radio conforms to policies, and (ii) the certified policies, which clearly define what the radio can do and what the radio must not do. Therefore, security threads caused by malicious users are still prevented through enforced security guards on the device and on the interface links; however, the security threads caused by malfunctioning or modifying a device are eliminated by dynamically avoiding them.

This approach addresses concerns raised by any stakeholder that is affected by smart software-defined radios. The approach allows regulators and other points of control to continue controlling where and how software-defined devices are allowed to transmit, yet at the same time this approach allows DSA operators and users take the full advantage of the software-defined radio technology.

E. DSA System Diversity

There will be a wide range of DSA entrant user system parameters (transmit power, mobile/fixed, directional/omni antennas, bandwidth, antenna height, etc) as shown in Figure 4. Each of these has a different potential to cause interference to incumbent users. The incumbent users are concerned about the complexity of this problem. For them to understand the technical details of the different DSA radio types and DSA spectrum access rules that are used is expensive and difficult for incumbent users. Incumbent users are also forced to determine the worst case scenario and/or force all of the DSA users to a common system type. Forcing all DSA system to be homogenous (as occurred in both the DFS and TVWS rules) is highly disadvantageous for the DSA operator since this is likely to cause significant unfavorable equipment tradeoffs.

DSA Implication – The DSA operators needs to derive simple "cheat sheet" equations and probabilistic simulation models that be used to determine the appropriate DSA spectrum access technique for each scenario. The DSA operators need to illustrate how a policy-based language approach can be used to reduce the spectrum management workload and complexity of managing the different types of DSA users.

F. Proven Technology

Incumbent spectrum users correctly require that DSA technology be proven before it is deployed in their spectrum bands. They believe that there have not been enough field tests in realistic environments showing interference avoidance and other DSA features.

DSA Implication – The DSA community needs to conduct more interference avoidance field tests. The demonstrations must have sufficient technical rigor and scope to facilitate the acceptance of DSA by the specific incumbent spectrum community. Third-party validation from disinterested parties (government, testing companies, or academic groups) is required. Scenarios, test plans, requirements and equipment parameters are developed with and corroborated by all interested parties.

G. Incentives

There is currently no "upside" for the incumbent user to participate in sharing schemes. They have no funding to participate in meetings or to conduct technical analysis to support spectrum sharing. Federal spectrum user incumbents can't directly accept money from the entrant DSA user; this money would go directly to the US Treasury. The incumbent user might be able to accept "in-kind" exchange.

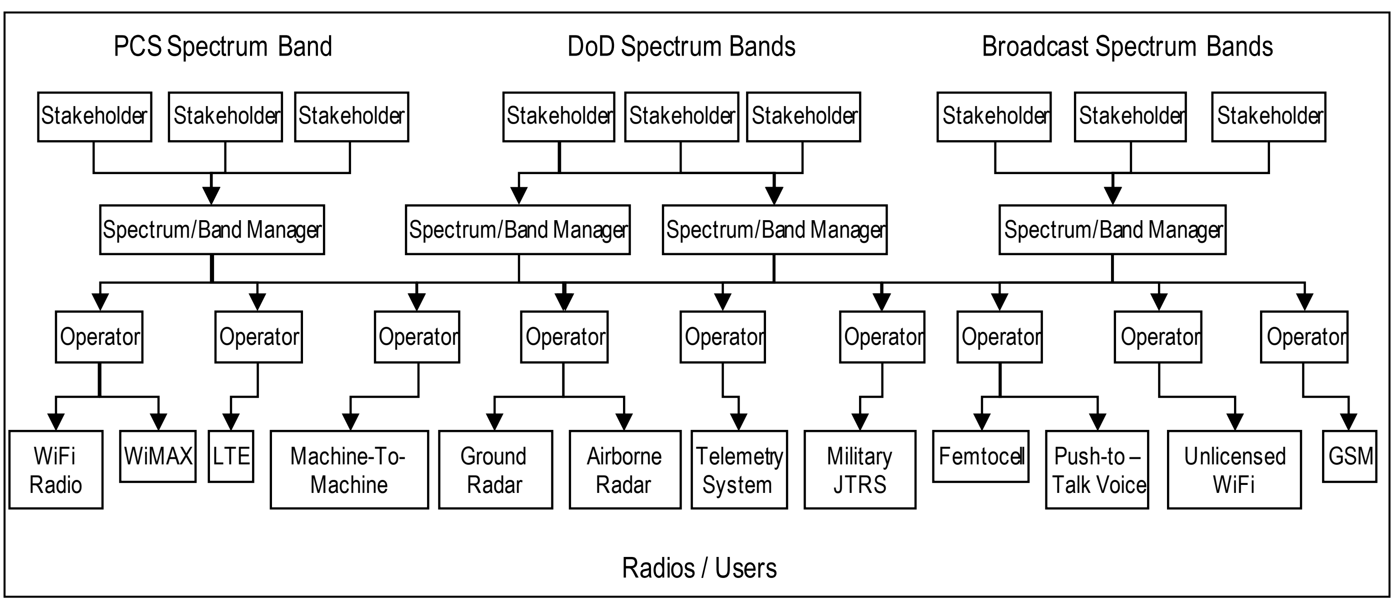

Figure 4. The wide range of DSA radio types and different types of DSA services creates undesirable complexity for the incument spectrum users.

DSA Implication – The entrant DSA operator needs to minimize the cost of the incumbent user in any spectrum sharing "deal". The entrant DSA operator needs to develop scenarios, legacy radio parameters, do field tests, etc with minimal input from the incumbent user. The entrant DSA operator needs to develop something to "give" to the incumbent user in exchange for use of the incumbent spectrum band. This could be incumbent use of commercial spectrum, free use of cellular networks, build out of cellular networks in remote DoD test ranges, free use of DSA radios operating in DoD spectrum bands for incumbent users, development of advanced DSA radios for DoD use, etc.

H. Keeping Commitments

The entrant DSA user needs to abide by its agreements with the incumbent user for a reasonable amount of time. Coming back several years to change "permanent" agreements is extremely upsetting to the incumbent users.

DSA Implication – DSA operators should avoid "challenging" the recent spectrum sharing agreements for in the initial DSA pilot programs. DSA operators should conduct pilot programs in bands where incumbent / entrant spectrum sharing is already going on. Examples are the TV band, 225-380 MHz band (for DoD-to-DOD DSA operations) and other spectrum bands.

IV. EXAMPLE DSA SYSTEM CAPABILITIES COMPARED TO THE REQUIREMENTS

Shared Spectrum Company (SSC) has developed and demonstrated a DSA radio system with most of the incumbent friendly features discussed in this paper [3], [4]. The SSC radio system spectrum access features are controlled by machine reasonable policy as shown in Figure 5. This radio system provides an existence tests that an "incumbent friendly" is feasible. The following describes the ability of this radio to meet the incumbent user DSA requirements.

- Accommodate Changes in Incumbent Use - The DSA spectrum access rules can be easily changed in fielded DSA radios by uploading a new policy file. The principal shortfall is the ability to easily change the DSA detector / classifier. At present, this requires a change of a portion of the radio's software.
- Backup DSA Operation Bands - The SSC radio operates over multiple spectrum bands depending on the RF card selected as shown in Table 1. This enables a DSA operator to use multiple spectrum bands and to avoid being dependent on a single incumbent spectrum stakeholder.

Table 1. The SSC DSA radio operates over multiple spectrum bands depending on the RF card selected.

DSA 1000 / DSA 2000 /DSA 2100			
DoD RF Board (MHz)	**Public Safety RF Board (MHz)**	**Wireless (TV) RF Board (MHz)**	**Commercial RF Board (MHz)**
225 – 512 1215 – 1390 1435 – 1525 1755 – 1850 2200 – 2290	138 – 174 220 – 512 764 – 869	174 – 216 516 – 806	698 – 941 1390 – 1435 1670 – 2680

- Enforcement – The SSC radio is policy controlled and can execute a complete set of sensing, geographic and other rules as shown in Figure 4. With a properly constructed set of policies within finite time duration, interference events can be tracked down and eliminated at low cost. An example would be to have all sense-based policies time limited to a few days and require a re-authorization for continued use. If an interference event to an incumbent device occurred at a specific location, the cause could be determined using a set of geographically limited sense-based policies with different parameters.
- Unauthorized and Accidental Use - The SSC radios use a certificated-based policy system that provides a high level of security.
- DSA System Diversity - The SSC radio uses a policy-based system that is designed to isolate the incumbent users from the entrants.
- Proven Technology – The SSC radio was used in interference to incumbent systems field tests as part of the DARPA XG Project [5]. These field tests indicated the ability of the system to meet low interference to noise ratio values and rapid channel abandonment time values. These tests were performed in an isolated region. Additional tests in more realistic environments are needed to further increase the incumbent's confidence in DSA technology.

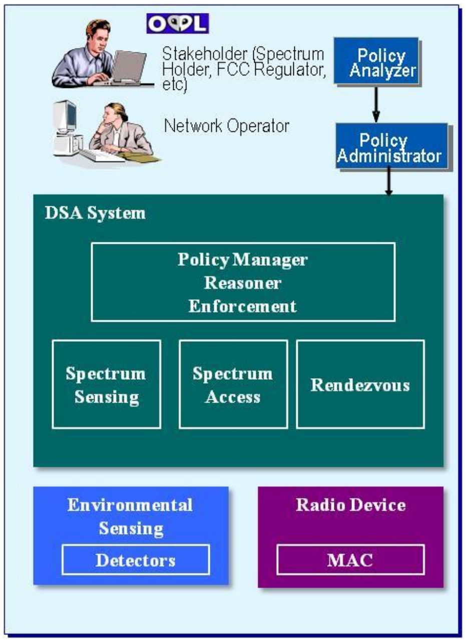

Figure 5. Shared Spectrum Company's DSA 2100 radio system is policy language controlled, which enables it to accomidate most of the incumbant DSA concerns.

V. Conclusions

To enable more rapid and less contentious deployment of DSA systems, the DSA system design needs to account for the valid incumbent spectrum users concerns. For example, the two DSA-related FCC rule proceedings (DFS and TVWS) were long difficult proceedings because they created significant perceived risks for the incumbent spectrum users. After fielding DFS devices, it was learned that certain incumbent devices types were not correctly accounted for during the rule making process, which led to interference events. Hence, the DSA devices needed to be "recalled" and modified. This caused significant expense for both the incumbent and the entrant entities.

Instead, we propose that DSA systems adopt incumbent friendly features. These include both technical and operational features. The specific entrant concerns and DSA features are as follows:

- Accommodate Changes in Incumbent Use - The DSA classifier and other spectrum access rules are easily changed in fielded DSA radios.
- Backup DSA Operation Bands - The entrant DSA user needs to have one or more backup spectrum bands to accommodate the incumbent user's potential increase spectrum use.
- Enforcement - If interference occurs, there needs to be a way for the incumbent user to easily identify which entrant DSA users are causing interference, and to then correct the problem or shut them down.
- Unauthorized and Accidental Use - The DSA system needs to implement a policy software certificate security management feature that prevents unauthorized use.
- DSA System Diversity - The DSA operators must take steps to isolate the incumbent from needing to understand the complexity of the many types of DSA systems. This includes developing simple representations of the DSA system interference performance and the use of policy language DSA command and control.
- Proven Technology - The DSA community needs to conduct more interference avoidance field tests. These tests need to be rigorous, well documented technical tests, and not "demonstrations".
- Incentives - The DSA operator needs to minimize the cost of the incumbent user in any spectrum sharing "deal". The DSA operator needs to provide funding, equipment exchanges or other compensation when possible.
- Keeping Commitments - DSA operators should avoid "challenging" the recent spectrum sharing agreements for in the initial DSA pilot programs. DSA operators should conduct pilot programs in bands where incumbent / entrant spectrum sharing is already going on.

SSC has developed a radio system that inherently meets most of these requirements because its spectrum access rules are policy language controlled using a certificate-based security policy. One shortfall is the ability to easily change the DSA detector / classifier. Presently this requires changing some of the software.

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