A Cognitive Policy Management Framework for DoD

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***Abstract*— Cognitive Radios and Networks have become a focus of attention commercially and within DoD. Technologies such as Dynamic Spectrum Access (DSA) can greatly improve spectrum utilization and can even address issues such as Anti-Jam. One of the most difficult tasks ahead of us is to manage these cognitive systems. Rules or "policies" must be used to control them, but these policies must be balanced with the intelligence innate within cognitive systems so as not to thwart performance. Typical network policies use an event-condition-action (ECA) format. But cognitive policies are often written using a "permissive / restrictive" format that is declarative stating the type of behavior desired rather than how to implement the behavior. How such policies are developed, distributed, and maintained is an active area of investigation within DoD. This paper will present work investigating the components required in a DoD system to implement a policy management framework for DSA systems and it extensibility to other cognitive systems. [1]**

Keywords-Cognitive, Policy, Dynamic Spectrum Access, DSA

I. INTRODUCTION

Recent efforts in cognitive radio have focused on "White Space": Spectrum that is allocated for use by others but is locally unoccupied at the current time. A critical technology for accessing white space is dynamic spectrum access (DSA). US Department of Defense (DoD) efforts such as the DARPA XG program [1] and commercial standards efforts such as IEEE 802.22 [2] and IEEE 1900.4 [3] have placed a focus on DSA technology. However, the roots of DSA stretch farther back.

For many years commercial standards such as 802.11 have had the ability to detect systems such as military radars, and relocate the wireless data network in response [4]. Such systems meet some definitions of DSA and cognitive radio [5]. What differentiates current DSA efforts is the emphasis on reprogramability via policy, and how DSA systems are managed [6][7] .

DSA systems present a number of challenges for control and management. One is that as policies become more complex a simple imperative "set/get" approach to controlling radios is no longer appropriate. Rather declarative approaches are preferred.

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For instance, in a traditional radio system, the operating frequency would be programmed via an external interface. In a DSA radio, a set of operating frequencies and conditions would be provided. The radio system then determines what specific frequency to use based on its environment and state.

The selection of operating frequency could be based on many criteria. Some examples would be propagation conditions, received interference, interference to other systems, current location, current time, mission constraints, etc. The specific criteria may vary over time. The desire to express complex constraints leads to a "declarative" approach to controlling DSA radios. The type of behavior desired is expressed rather than how to achieve that behavior.

Another management and control issue is that many different entities may have an interest in influencing the radios behavior. Regulators, spectrum planners, network planners, mission planners, and the immediate user may all want to influence the behavior of the radio. A framework and architecture are required to ensure effective control and management of DSA radios. For DoD networks, the framework should reflect the command and control structure innate within DoD.

To address these issues a study was conducted by the authors to identify an appropriate framework and architecture for policy management of DoD DSA systems. While the results were targeted for application to DSA radios, they are sufficiently general that they could be applied to the control of many cognitive systems. This paper reports some of those results from that study [8]. The rest of this paper is organized as follows.

Section II reviews some relevant issues pertaining to policy engines and languages. Section III reviews the use cases developed for the study. Section IV reviews a tiered policy distribution architecture developed on the study. Section V presents the generic policy framework that was developed. And Section VI provides a summary and some conclusions.

II. POLICY ENGINES AND LANGUAGES

Two core components of any policy management framework are the policy engines used to process policy, and policy language or languages used to express policy. A wide variety of architectures for policy engines exist (e.g. [4]-[7], [9], and [10]). No single authoritative definition of a policy engine seems to exist today.

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14. ABSTRACT

Cognitive Radios and Networks have become a focus of attention commercially and within DoD. Technologies such as Dynamic Spectrum Access (DSA) can greatly improve spectrum utilization and can even address issues such as Anti-Jam. One of the most difficult tasks ahead of us is to manage these cognitive systems. Rules or "policies" must be used to control them, but these policies must be balanced with the intelligence innate within cognitive systems so as not to thwart performance. Typical network policies use an event-condition-action (ECA) format. But cognitive policies are often written using a ?permissive / restrictive? format that is declarative stating the type of behavior desired rather than how to implement the behavior. How such policies are developed, distributed, and maintained is an active area of investigation within DoD. This paper will present work investigating the components required in a DoD system to implement a policy management framework for DSA systems and it extensibility to other cognitive systems.

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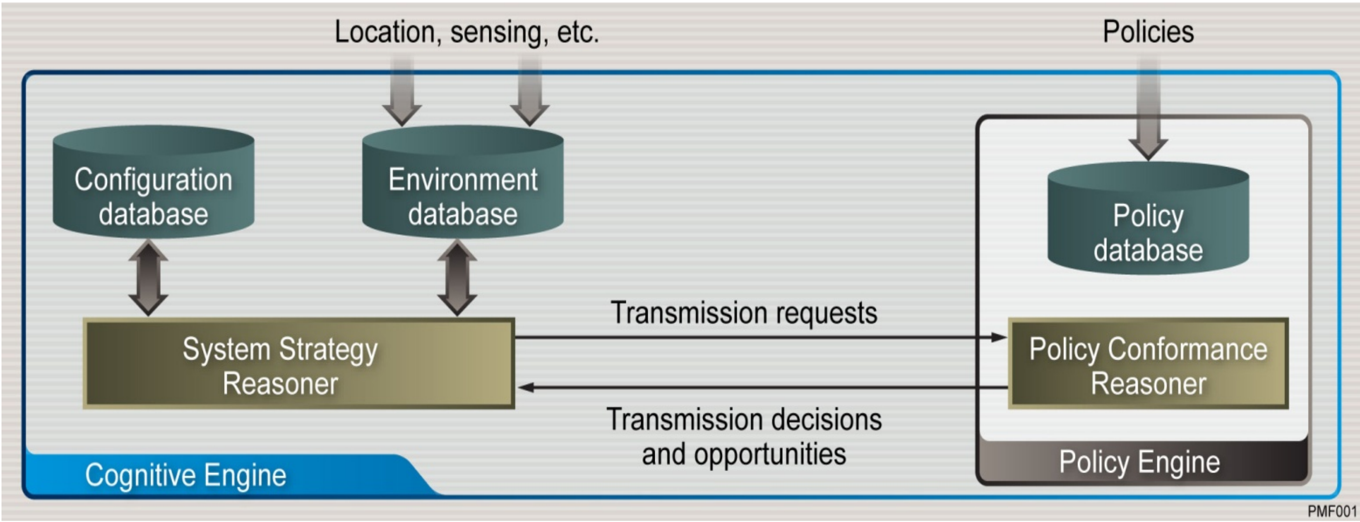

Figure 1. Example Cognitive Engine Model

A good general reference for terms relating to DSA and cognitive radio is [5]. There the term "policy engine" does not exist, with the closest equivalent being "policy based control mechanism". This is defined as:

"A mechanism that governs radio behavior by sets of rules, expressed in a machine-readable format, that are independent of the radio implementation regardless of whether the radio implementation is in hardware or software."

The policy based control mechanism is described as a component of a 'cognitive engine" which itself is part of an "adaptive radio" (see Figure B.5 of [5]). However, the concept of a policy engine is well established (e.g. [6] chapter 6). Within DoD circles most cognitive radio architectures have a portion of the radio allocated to dealing with policy, which we here term a policy engine. Most of these are derivatives from the cognitive engine concepts developed on the DARPA neXt Generation (XG) program. A reference model was required for our investigations, and we adopted a model based on [8] which is derived from the XG cognitive engine. The essence of this model is shown in Figure 1.

A key aspect of the model is the partitioning of the reasoning between a "System Strategy Reasoner" (SSR) and a "Policy Conformance Reasoner" (PCR). The SSR focuses on deciding the appropriate behavior for the radio system. When a transmission (or set of transmissions) is required, the SSR queries the PCR as to whether the set of transmissions (with transmission parameters) conforms with all the policies the radio must meet. Minimally the PCR must respond with a "yes" or "no" answer. Other answers could include "yes if" where the SSR provides a incomplete set of parameters, and the PCR provides a response with what the missing parameters need to be to fulfill all policy requirements. One output of this study was that a "no, because" output should be considered. This would detail the specific policies that a requested transmission would be in violation of if allowed. Such a response would allow the SSR to more quickly converge to an acceptable set of transmission parameters.

Another potential component of the policy engine is the "policy enforcer" [7]. This component would have the ability to gate outgoing transmissions to confirm they are compliant with policy. As of the writing of this article, debate is still ongoing in standards bodies such as IEEE P1900.5 as to whether this component should be included in their reference model.

While the model in Figure 1 was adopted for this study and has been shown to be implementable [1], our sense is that the industry has not yet converged on a model for a policy engine. A primary motivator for the partitioning in the model seems to have been certification of the policy decision making [7]. One concern expressed in the study is that to be efficient the SSR and PCR need to be tightly coupled. The test results in [11] suggest that if the SSR and PCR are not tightly coupled, radios may not be able to make decisions in a timely manner. Also, if the "no, because" response were implemented, it is believed the SSR would benefit from direct interaction with the policies.

Based on our analysis, we believe the SSR and PCR need to interact heavily and deeply. The partitioning in the reference model should be considered a "logical" partitioning. It is not necessarily recommended for guidance in implementation. Further study in this area is required.

Another observation from the study was that the language selected to express policies and the reasoning used to evaluate the policies is coupled to some degree. Typical network policies use an event-condition-action (ECA) format (e.g. [6] chapter 6 and [12]). But as shown in Figure 1, the policy decisions are tailored around being allowed to transmit, or not allowed to transmit. Policies for current XG derived activities are written using a "permissive / restrictive" format that is declarative of whether the radio should or should not be allowed to transmit. Evidence (akin to conditions in ECA) is presented by the SSR for transmissions decisions. Based on the policies, evidence, and transmission requested the PCR then makes a decision on transmission.

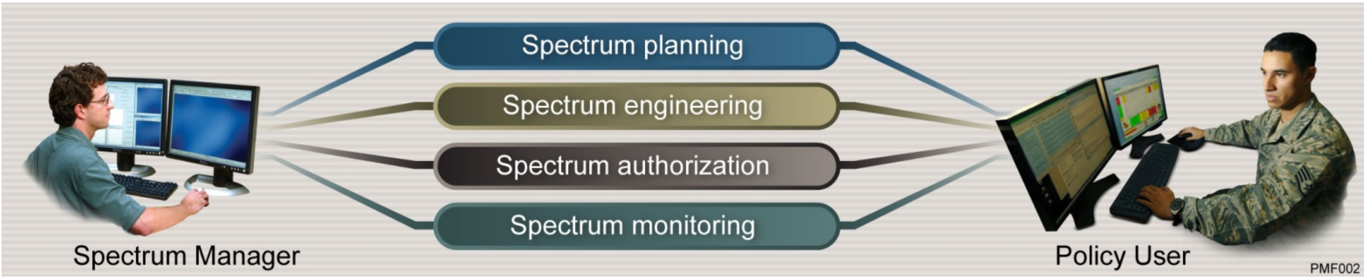

Figure 2. Use cases relating a spectrum manager to a policy user

To support the declarative nature of the policies and take advantage of the reprogramability assumed within the DSA radios, an ontology is used to define objects and relationships which are used to express the semantics of the policies. Today, the Web Ontology Language (OWL) augmented by various extensions is typically used for this purpose. However it is observed that these languages are tailored towards specific types of reasoning, such as description logic. As such they are limiting in the use of other types of reasoning.

There was not sufficient time in the study to thoroughly evaluate and trade off different languages for use in expressing DSA policy. Rather a number of reason and language options were catalogued [8]. It is expected that the preferred format will evolve over time, but currently a combination of a version of Web Ontology Language (OWL) supplemented with the Semantic Web Rule Language (SWRL) encapsulated within Extensible Markup Language (XML) is believed sufficient and preferred. Further study is desirable in this area.

In addition, human readable format of policy along with translation to/from machine readable formats are required. It is believe additional work is still required in this area. Finally it is noted that the language used for evaluating the policies may be different than the language used to express them. It did not appear critical that the language for policy evaluation be specified, so it was not considered in developing the policy management framework discussed here.

III. USE CASES

The first step in developing a framework should be to develop use cases for the framework. Typical use cases for DSA focus on the RF environment and how radios react to that environment. But, for a policy management framework the use cases developed must focus on the development, deployment, and maintenance of policy rather than the specific behavior of the radios.

To develop use cases we first focused on identifying who the "Actors" are in the use cases. Who needs to interact with DSA policy as part of its use? While we normally think of regulators as being the primary creators of policy, spectrum managers actually play a more active role. While regulators such as the FCC, NTIA, or ITU create top level policy, spectrum managers must create additional regional or local policy that are consistent with regulatory policy. In addition, spectrum managers are likely to be responsible for distribution of policy. So the use cases we developed focused on the spectrum manager.

Creation of DSA policy is very much a part of spectrum management. To that end a useful document is "Pub 8" [13] which details a standard spectrum resource format, but more importantly here identifies typical relationships between spectrum planning entities.

In the end we decided there are 4 key activities a spectrum manager needs to do that can interact with policy. Those are planning, engineering, authorization, and monitoring. We see the needs of a regulator as being a similar but perhaps more constrained subset of the activities required for a manager. The relationship between a spectrum manager and policy user (really the policy itself) is shown in Figure 2. Ultimately we believe the DSA policy framework developed should support all the activities identified here.

IV. POLICY MANAGEMENT TIERS

One thing that became apparent in our study was the need to have a tiered architecture for DSA policy management. There are several reasons for this. The first is that spectrum management organizations are hierarchical. In the top tier are regulatory agencies such as at the FCC, NTIA and ITU. Regulatory agencies accept input from a number of advisory organizations and user groups. They tend to set policy in a very broad context, and not change it very often. The regulatory policies then flow down, normally to spectrum planners.

Under the regulators are spectrum managers or system operators. Typically there are multiple sets of managers / operators for different organizations that may interrelate as peers, or superordinate / subordinate. Spectrum managers must perform a planning function to allocate spectrum to users. They must also interact with other types of planners such as network planners and mission planners.

In the end it was determined that there should be two distinct tiers – A "regulatory" tier, and a "planning" tier. The planning tier is subordinate to the regulatory tier and only loosely interacts with it. Within the planning tier can be a complex array of interactions. But the ultimate outcome is a set of policy that must be pushed down to the policy users. Policy at this tier is generated and modified more frequently than at the regulatory tier, and must be generated in a machine readable format that can be delivered to the policy user. It is expected that human beings will be responsible for generation of policy at both this tier and the regulatory tier.

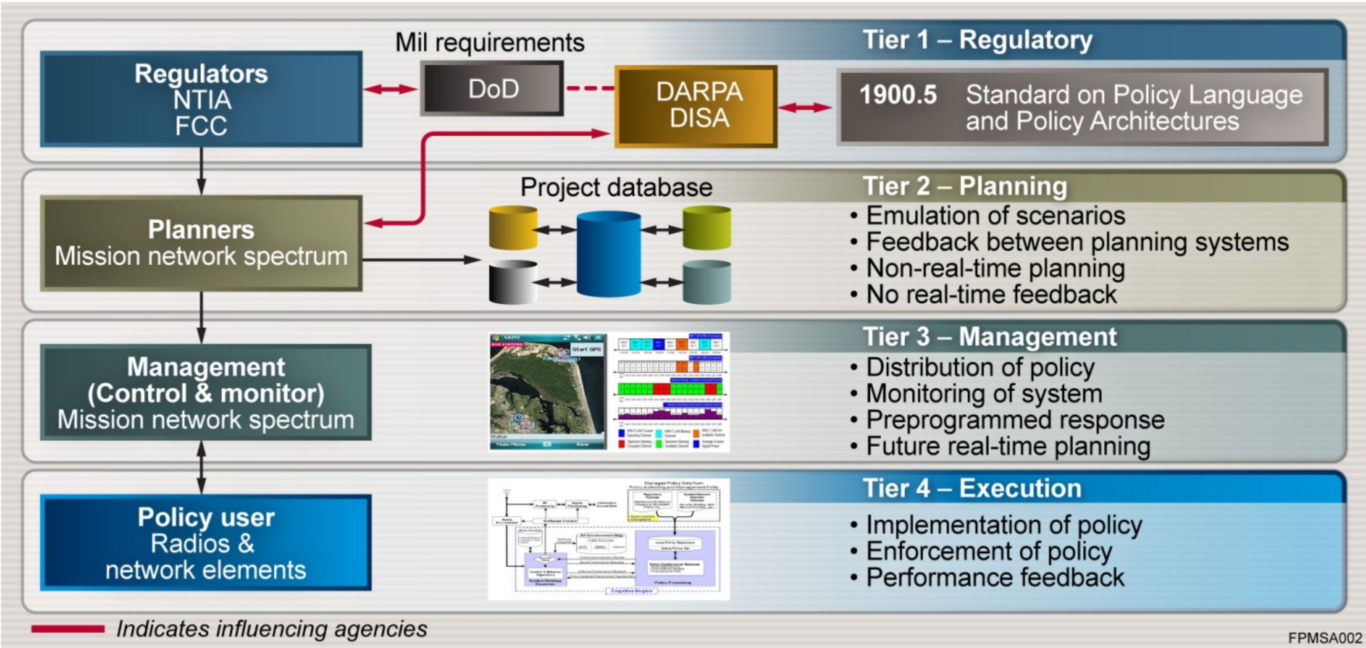

Figure 3. The recommended tiered policy distribution architecture

Once generated, policy must be delivered to the policy users. Generally a network of some sort will be used to accomplish the distribution of policy. However, more than distribution is generally required. Control and monitoring functions are typically required as well. There may be different versions of policy that must be tracked in terms of which users have received which version of policy. In addition, feedback on policy / radio performance may be desired. Feedback could be acted upon if corrective actions are required. This feedback may or may not be pushed back up to the planning tier. So it seems a tier for monitoring / control needs to exist as well.

To accommodate these needs a "management" (command and control) tier is recommended, that may be loosely coupled to battle command and control, or network management. This tier would exist below the planning tier. It is seen as primary reactive rather than proactive, and will ultimately require response times that cannot be accommodated with a human being in the loop. Little to no changes in policy are expected at this tier today. However it is envisioned that as spectrum planning becomes more automated real time spectrum planning will become possible. Proactive management of DSA Policy (detecting in advance when changes to DSA policy configuration are required) may also be incorporated. If real time spectrum planning and proactive management of DSA policy do occur, they may be incorporated at the "top" of the management tier, or alternatively at the "bottom" of the planning tier.

At the lowest level in this tiered distribution architecture are the policy users or end points. We call this the "execution" tier because it is where policy is implemented and enforced. Policy users accept and enforce policy, but today don't have the ability to change policy. The sum result of this analysis is shown in Figure 3 where the recommended tiered policy distribution architecture is presented.

V. A Policy Management Framework

While the distribution architecture gives a sense of the flow of policy, it does not address the components required to implement a DSA policy management system. Identifying those components is critical if a DSA policy management system is to be specified and procured.

To help in the ultimate specification and procurement of a DSA policy management system a framework was developed which attempts to identify all the critical components that must exist to implement a working system. The framework is very generic, and further work is required to map it to specific architectural elements for a given implementation. The generic framework is shown in Figure 4.

Starting at the top left of Figure 4, it is expected that top level policy will be generated by people rather than machines. Tools to allow the creation and validation of DSA policy will be required. These tools ultimately need to generate policy in a machine readable format. It is expected that the preferred format will evolve over time, but currently a combination of a version of Web Ontology Language (OWL) supplemented with the Semantic Web Rule Language (SWRL) encapsulated within Extensible Markup Language (XML) is preferred. The tools will also need to be able to translate machine readable expressions of policy into a human readable format.

In addition to policy generation tools, policy based planning tools will be required (Shown at the middle top of Figure 4). Currently it is believe that mission, network, and spectrum planning tools will need to integrate DSA policy as part of their planning process. In addition to generating and viewing DSA policy, these tools may need to emulate the impact of DSA policy in various ways. This could include modeling the impact of running policies on specific radio platforms, and the impact on network performance / mission effectiveness.

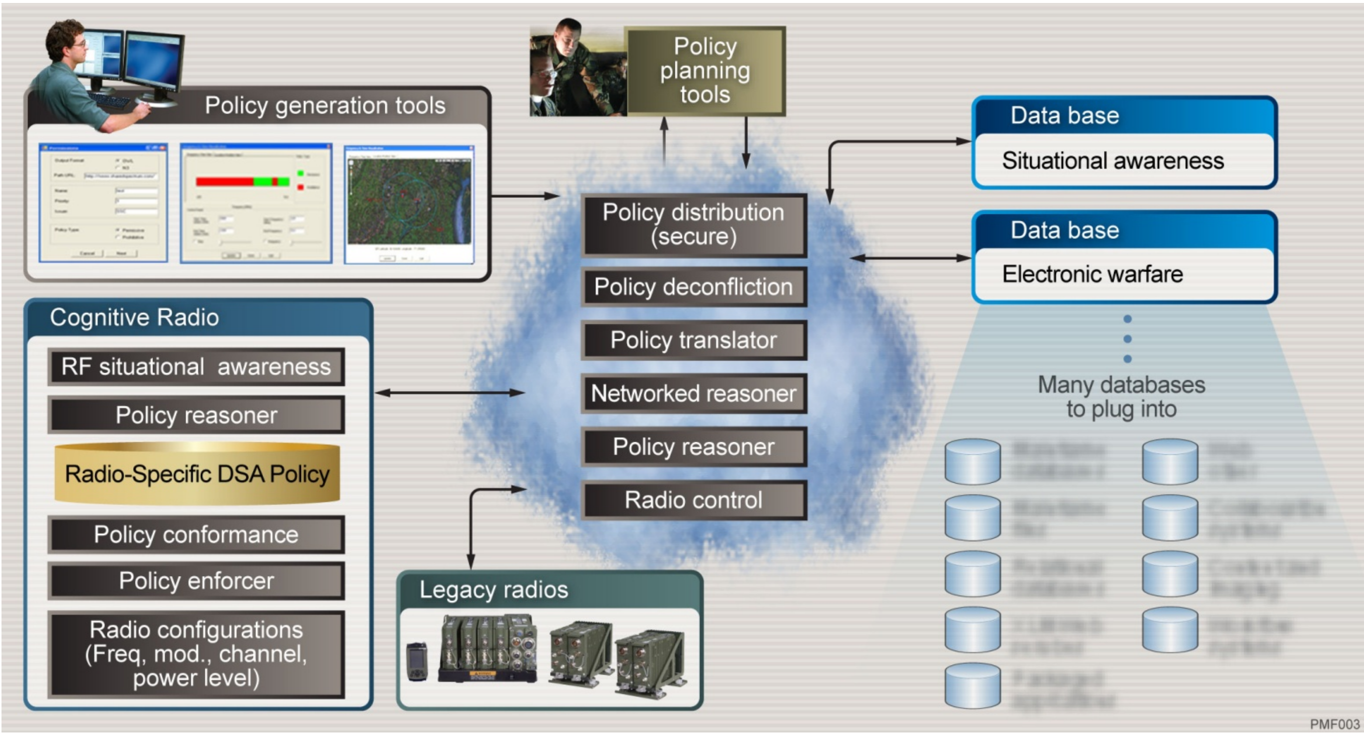

Figure 4. Use cases relating a spectrum manager to a policy user

Once created, DSA policy will need to be deployed. A secure policy distribution protocol is required that can safely operate over the Global Information Grid (GIG). The GIG is shown as the cloud in the middle of the diagram. A key point is that a wide variety of networked components may need to interact with DSA policy.

It is preferred that policy deconfliction occur prior to loading of the policies in radios. Policy engines that autonomously deconflict policy from different sources prior to final distribution to end points seems likely. In addition, a wide variety of DSA radios are expected to coexist in deployments. Some will have greater cognitive capabilities than others. To accommodate this, the format of the policies will need to be translated for different types of radios.

The U.S. Army Communications- Electronics Research, Development, and Engineering Center (CERDEC) under the RF ADaptive Technologies Integrated with Communications And Location (RADICAL) ATO-D [14] is developing a set of tools to assist in DSA policy generation. These include a "Configuration Generation" tool that will format a given policy set so that it can be properly accepted and interpreted by different types of DSA radios. This concept is shown on the bottom left of Figure 4.

At the extreme, legacy (non-DSA) radios may be given DSA capabilities through the use of cognitive networking techniques. This is also shown towards the bottom left of Figure 4. Here a policy reasoner is placed external to the radio, along with software to control the radio via a management information base (MIB). External network databases (shown to the left of the figure) and sensors are used to help determine how to configure the radio. The policy reasoners would network with other policy reasoners controlling legacy radios to jointly configure a radio system.

In addition there may be other components monitoring and controlling the overall performance of sets of radios. These devices would also need access to DSA policy. They are identified as "networked reasoners" in Figure 4.

While this framework is targeted at DSA policy for DoD, many of the components identified would also be useful in commercial networks. Other types of policy (such as network policy) could be incorporated within the same framework. While the data based identified (situation awareness and EW) may not directly be relevant commercially, they are intended to be exemplary rather than strictly required. Commercially, "coexistence" or "geolocation" databases might be used instead. The rest of the framework has been specified in sufficiently generic terms that commercial analogs should exist as is.

VI. Summary and Conclusions

This paper has reviewed some of the results from a recent study to develop a DSA policy management framework conducted for DISA [8]. Key results reviewed included the identification of use cases, development of a tiered policy distribution architecture, and a recommended policy management framework. Other investigations in that study on related topics including policy engines and languages are not reported here.

Much work remains to be done in this area. If DSA systems are to be employed in the near term the generic framework described needs to be mapped to specific infrastructure that can be procured or developed. In addition, policy management approaches for cognitive radios / networks will continue to evolve. It is believed that a more generic policy management approach incorporating at a minimum network and spectrum management policy, but potential other policy needs such as mission policy is possible. It is an open question as to whether such an encompassing policy management approach is needed.

The tier policy distribution architecture and policy management framework have been geared for DoD. However they are quite generic. It is expected that they could both be applied commercially, but further investigation would be required.

Finally, there is much research yet to be conducted in policy controlled cognitive systems, particular concerning policy languages and engines. It is difficult today to forecast how policy management architectures will need to evolve in the long term to account for innovations that are likely to occur here. Policy management for DSA and cognitive networks / systems promises to be an exciting area of research for some time to come.

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