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IEEE DySPAN 1900.5 Efforts To Support Spectrum Access Standardization

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***Abstract*—The goal of IEEE DySPAN 1900.5 working group is to support the regulatory community and the wireless industry who rely on solutions for spectrum sharing. This group has created requirements and a flexible architecture for the proliferation of dynamic spectrum access policies. Current work is focused on defining a policy language and ontology as well as modeling spectrum consumption in an effort to create a suite of standards that support the formal representation of spectrum policy and usage in radio networks. Collaboration in standardizing solutions will improve the success and efficiency for all stakeholders in this ever changing environment. This paper will provide an overview of the current activities of the 1900.5 working group including its two current standards projects, P1900.5.1 and P1900.5.2 and interactions with regulatory bodies.**

Keywords—IEEE DySPAN-SC 1900.5, DSA, Dynamic Spectrum Access, Spectrum Sharing, Modeling Spectrum Consumption

I. INTRODUCTION

The rapid development of wireless communication systems places significant challenges on the efficiency of spectrum usage, yet also opportunities. Cognitive radios equipped with dynamic spectrum access (DSA) technologies are expected to be one of the critical solutions to improve spectrum usage, mitigate interference, and enhance communication performance.

The IEEE Dynamic Spectrum Access Networks Standard Committee (DySPAN-SC) among several key standards bodies aims to develop and standardize radio and dynamic spectrum management solutions. DySPAN-SC started as IEEE P1900 and evolved into the IEEE Standards Coordinating Committee (SCC) 41 before settling on the DySPAN-SC moniker. But the working groups (WG) still bear the 1900 identifier.

A prior MILCOM paper briefly outlined the work of then SCC41 and the 1900.5 WG in its "infancy" [13]. However, much as changed since then. This paper will address those changes relevant to the work of 1900.5.

Within the IEEE DySPAN-SC 1900 framework, working groups are focused on specific aspects of dynamic spectrum management. Of these, IEEE 1900.4 and IEEE 1900.5 both focus on policy based DSA radio systems (PBDRS), in which the radio systems are capable of real-time adjustment of spectrum utilization in response to changing circumstances and governing policies. The main focus of IEEE 1900.4 is the coordination and signaling protocols within a communications network practicing DSA. The internal functionalities and interactions within a network device have only been characterized on an as-needed basis at a fairly high level. On the other hand, the focal point of IEEE 1900.5 is specifically policy language and associated architecture for DSA throughout radio systems employing DSA.

IEEE 1900.5 intends to expose the detailed policy interactions required for DSA operation within a communications device. Furthermore, since IEEE 1900.5 focuses mainly on the internal architecture and interfaces of PBDRS, it can afford to be open and agnostic to various network architectures and/or topologies. Therefore, 1900.5 has the potential to be applicable to a broad range of communication systems and wireless networks.

The rest of this paper is organized as follows. Section II provides an overview of the published IEEE 1900.5™ - 2011 base standard and potential amendments. Next, Sections III and IV review the ongoing work in P1900.5.1 and P1900.5.2, respectively. Finally we outline the road map for the 1900.5 WG in Section V and conclude the paper in Section VI.

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II. AN OVERVIEW OF THE IEEE1900.5 BASE STANDARD

The P1900.5 working group began in 2008 to address the policy aspects of DSA in a cognitive radio network. Policy is not a new concept in networking systems. The primary application of policy based networking has been in the security and quality of service paradigms. Some policy standardization had been done by the Internet Engineering Task Force (IETF), but today's policy based networking requires a greater degree of awareness thus requiring an update of the policy concept. P1900.5 started with the intent of defining a policy architecture (loosely based on former standards) and a language for DSA related policies.

Initially the intent was that the IEEE 1900.5 base standard would in fact define a language for DSA Policies. However it became clear that a more incremental approach was appropriate. So the IEEE 1900.5 project was modified to focus on the requirements and architecture for a DSA policy language. The result was IEEE 1900.5-2011 providing policy language requirements and associated architecture requirements for interoperable, vendor-independent control of DSA functionality and behavior in radio systems and wireless networks. This standard also defines the relationships of policy language and architecture to the needs of at least the following constituencies: the regulators, the operators, the users, and network equipment manufacturers.

In 1900.5, a distinction is made between the policy reasoning that is accomplished within the Policy Based Radio (PBR) node and policy generation and validation that is accomplished through a policy generation system prior to provisioning the policy to the PBR node. Policy reasoning may be distributed, i.e., it may take place either within a PBR node or in other elements of a policy based radio communications network. Figure 1 [1] illustrates the defined architecture.

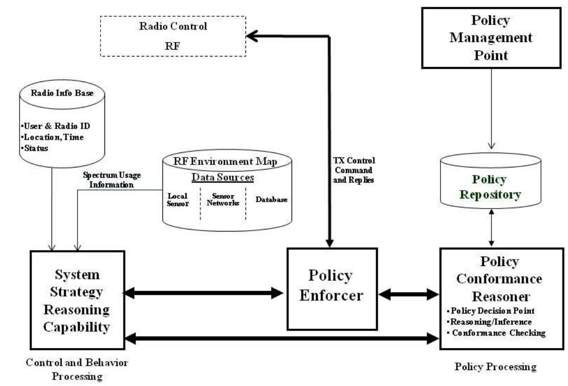

Figure 1. 1900.5 architectural overview

The key components of the architecture are:

- Policy Management Point (PMP)
- System Strategy Reasoning Capability (SSRC)
- Policy Conformance Reasoner (PCR)
- Policy Enforcer (PE)

The PMP operates in a manner very similar to what would be found in a typical network policy management system. Similarly the PE has a direct analog with the Policy Enforcement Point found in many network policy systems. The more interesting components are the PCR and SSRC. These do not have analogy in traditional network policy management systems.

The SSRC derives a set of behaviors for the DSA radio system and presents them to the PCR. These would be specified as "transmission opportunities". These opportunities would be evaluated by the PRC for conformance to relevant policies. The PCR would then identify which transmission opportunities are accepted or denied. More advanced behavior is also permitted such as the PCR requesting additional information of the SSRC to facilitate a decision. Additional details on the architecture and requirements can be found in IEEE 1900.5-2011.

III. THE 1900.5.1 STANDAND DEVELOPMENT

As a next step to IEEE 1900.5-2011, the policy language and interfaces need to be standardized. The 1900.5.1 standardization effort was launched in November 2011 to define the language component with expected completion of October 2014. The standard takes into consideration both the Policy Language Requirements of IEEE 1900.5-2011 and the results of the Modeling Language for Mobility Work Group (MLM-WG) within the Wireless Innovation Forum (SDRF v2) Committee on Advanced Wireless Networking and Infrastructure [4]. MLM-WG is developing use cases, an ontology, corresponding signaling plan, requirements and technical analysis of the information exchanges that enable next generation communications features such as spectrum awareness and dynamic spectrum adaptation, waveform optimization, capabilities, feature exchanges, and advanced applications.

As was discussed earlier in this paper, the requirements for a policy language have been specified in [1]. The P1900.5.1 standard being developed at this time is a step towards the realization of these requirements. In this section we first briefly overview these requirements and then describe how the current standard is being developed.

According to [1], two main requirements are: (1) the language must have formal syntax and (2) the language must have formal semantics. Formal syntax means that the language definition includes rules that a computer can use for deciding whether a given expression is in the language or not, or in other words, whether a given expression is syntactically correct or not. Formal semantics means primarily that all the terms in the vocabulary of the language are mapped to a mathematical domain. Such a semantics is called model-theoretic semantics. Additionally, the standard requires a proof-theoretic semantics, i.e., rules for deriving true statements from other sentences. The model theoretic semantics take precedence over the proof theoretic semantics, which means that inference rules must be compatible with the model theoretic semantics.

The main purpose of having a language with formal, computer-processable semantics is to enable automatic inference by computers. In other words, a collection of sentences stated in such formal language can be processed by an *inference engine* (also referred to as *reasoner*) the result of which is more sentences that express other facts about the domain that were only implicit in the original set of sentences. The inference engine makes them explicit. For instance, an inference engine should be able to infer whether a given transmission request is compliant with a given policy or policies. Moreover, it would be desirable that an inference engine can infer what conditions should be satisfied in order for this transmission request to be compliant.

The P1900.5 standard specifies a number of more specific requirements for a policy language. (1) The language shall be declarative. As in contrast to imperative languages like C, C++ or Java, a declarative language does not specify how particular tasks can be accomplished, but rather what tasks need to be accomplished. An imperative language, on the other hand, specifies how operations should be sequenced (referred to as *control*); the task to be accomplished is implicit in the program. Some discussion of declarative vs. imperative languages in the context of cognitive radio was provided in [2]. (2) The language must provide means for associating human-readable descriptions along with the formal statements of the language. Essentially, this means that the language needs to provide ways of adding comments so that a human reader can be informed of the meaning of the formal descriptions. (3) The language should support the expression of both permissive and restrictive policies. This refers to policies that either allow or disallow some operations or behaviors of the policy based radio systems. (4) The language must be able to express inheritance. This means that some policy expressions can be reused by specifying that they are inherited by other policies. (5) The language should support the expression of dynamics, e.g., temporal aspects of PBRSs. (6) The language should provide mechanisms for defining new functions in terms of other functions. This is another way of reuse of policies. (7) The language should be able to express the various concepts of object orientation – classes, instances of classes, data types, binary relations, composition of relations and logical expressions. Moreover, it should provide means for describing states of systems. (8) Negation. The standard requires that the language supports two types of negation: logical negation (intuitively, a sentence needs to be proven that it is true or that it is false; if none can be proven, then its truth value is unknown) and negation as failure, or NAF (if a sentence cannot be proven true, then it is necessarily false). (9) The standard stipulates that the language must support a large variety of policy types, e.g., geospatial, time based, identity based, frequency based, and more. (10) The language should support meta-policies, i.e., policies about policies – which express relations among policies. An example is precedence – one policy takes precedence over another policy, i.e., when the condition for both policies are satisfied, on the one with the higher precedence is used to derive a decision. Moreover, policies should be constructible from other policies (policy composition). (11) The language should support the use of policy templates, (12). The standard also list a large number of concepts that the language should be able to express. Collections of such concepts are relationships among them constitute domain ontologies. (13) Language expressiveness. The standard states that the language should be able to express various policies developed by regulators, system operators and users. The scope of the policies is not explicitly defined.

The specification is very ambitious. A language that satisfies all of the requirements would have very high computational complexity. Consequently, the approach to its development needs to take this issue into consideration. One of the possible paths to the achievement of the goals of this specification is to use an approach that considers a number of realizations of gradually increasing complexity, as advocated in [2]. Another part of this philosophy is to take advantage of a languages that already exist. And finally, in order to decide on the scope of the expressiveness of the language, use cases may be used for verifying that the proposed language is sufficient to express the policies required by all the use cases considered.

Some of these aspects have already been addressed by the Wireless Innovation Forum. The Modeling Language for Mobility (MLM) Work Group of the Forum has been working on MLM for a number of years now. First, seven use case have been identified. The use case labels were as follows: (1) Network Extension for Coverage and Reach Back; (2) Dynamically Access Additional Spectrum (this use case is most direct relation with the P1900.5 standardization effort); (3) Temporarily Reconfigure First Responder Communication Device Priorities; (4) Urban Fire (where a cognitive radio mediates interactions between the various roles of first responders to this emergency situation); (5) Load Balancing (where one of the networks is overloaded and thus some of the load needs to be offset by using the resources of other networks: (6) Software Download (downloading new functionality of a communication device): (7) Software Certification. All these use cases are described in the Wireless Innovation Forum document [3], which is available on line.

The use cases listed above supported the process of developing a Cognitive Radio Ontology (CRO) [3]. This ontology was developed with the input from many cognitive radio domain experts and representatives of the member companies of the Wireless Innovation Forum.

The CRO ontology includes the Core Ontology (covering basic terms of wireless communications from the PHY and MAC layers) and concepts needed to express the use cases developed by the MLM WG. Only the use cases that relate to the PHY and MAC layers are included. Partial expression of the FM3TR waveform (structure and subcomponents, FSM) is provided as an example. Partial expression of the Transceiver Facility APIs is also provided.

The CRO uses DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering) [5] upper-level (foundational) ontology as a reference model. DOLCE defines general concepts that are the same across different domains and is based on the fundamental distinction between *Endurant*, *Perdurant*, and *Quality*, which in the CRO correspond to the *Object* and *Process* classes as well as the *objectQuantity* and *processQuantity* object properties. The Object class refers to entities that are wholly presented at any given snapshot of time. The Process class refers to entities that can be represented only partially at any snapshot of time. The top-level design of CRO makes the ontology suitable for merging with other ontologies, especially with those that follow the same or similar reference model (See Figure 2).

The CRO has been utilized in a SDR'10 demonstration of a collaborative link optimization [6]. The goal of link optimization was attained by collaboratively fine-tuning the parameters (knobs) in the transmitter and the receiver, rather than locally by a single node. The CRO and the policies of each node provided a means to exchange control messages between the transmitter and the receiver. A complete description of this exercise can be found in [7].

In summary, the CRO has 230 classes and 188 properties, covering the basic terms 305 of wireless communications from the PHY layer, MAC layer and network layer. The CRO has been submitted by the Wireless Innovation Forum to the P1900.5 effort to be used as a base for the ontology in support of the standard.

The CRO was formalized in OWL (Web Ontology Language) [8]. The use case implementations used rules, in addition to OWL. The rules were expressed in terms of terms from the CRO. In some cases, the rules invoked procedural attachments written in Java.

One of the current tasks of P1900.5.1 is to determine whether OWL supplemented by rules is sufficient or not. It is an empirical question the answer to which needs domain expertise. While it is clear that OWL and rules are not sufficient to express the various aspects of communications, especially some of the behavioral features (see [2] for more discussion of the expressiveness of a formal language), the real issue is whether such a language can cover a significant amount of problems. To answer this question, P1900.5 is seeking more use cases that could be used for the verification of such a statement. The Model Based Spectrum Management effort described in the next section will serve as a use case for this verification task.

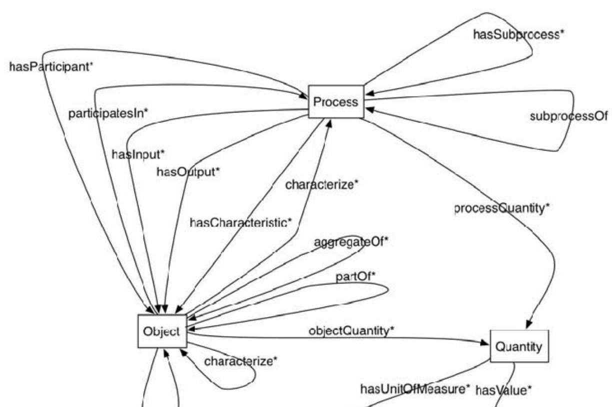

Figure 2. Top-Level Classes of CRO from the MLM WG

IV. 1900.5.2 SPECIFICATION

In addition to the 1900.5.1 project, the IEEE 1900.5 WG also launched an effort to standardize a method for modeling spectrum consumption called 1900.5.2. The 1900.5.2 project authorization was granted in March 2013 with expected completion of December 2014.

This project seeks to write a standard that defines a vendor-independent generalized method for modeling spectrum consumption of any type of use of RF spectrum and the attendant computations for arbitrating the compatibility among models. The goal for these products is that they become a loose coupler for spectrum management as the Internet Protocol (IP) is a loose coupler for networking.

Loose coupling refers to a thing that exists at the intersection of a large set of systems that allows them to interoperate and to be integrated. When identified and placed between the layers of complex systems then something nearly magical occurs where the larger system becomes boundless in its ability to support innovation. A well-known system that revolves around a loose coupler is the Internet. The IP serves as a loose coupler between two layers with those layers being the "means of transport" and the "applications / services" on the internet. There can be innovation in the means to enable transport so long as the systems can accept and route IP packets and there can be innovation in the services and applications that ride the network and use the transport so long as they conform their communications to the standards of IP.

Loose coupling also works within the layers. In the Internet, the IP enables multiple transport technologies to interoperate to support the larger transport function and allows multiple services and applications to be integrated within the same network.

The spectrum consumption modeling (SCM) sought by this standard will serve as a loose coupler among spectrum management systems and RF systems since it provides a means to share the data that is necessary at their intersection. The shared data are models of spectrum consumption and the attendant computations that are used with these models to arbitrate compatibility. Figure 3 is a bowtie diagram that illustrates the loose coupler role of the spectrum consumption model. At the top layer it provides a means for systems that collectively perform spectrum management to convey to spectrum users and each other their vision of spectrum consumption. At the bottom layer, it allows RF systems that use the spectrum to coexist and improve their usage of spectrum. Spectrum consumption models provide a means for spectrum management systems to convey to RF systems what spectrum they can use. It also allows RF systems to express their spectrum needs. The SCM will include means to convey machine readable protocols and policies to DSA systems and a means for RF systems to convey the actual spectrum they are using to spectrum management systems. By standardizing the loose coupler, in this case spectrum consumption modeling, we create opportunities for innovation in the adjacent layers, in this case (policy based) spectrum management, and RF systems and devices that can access spectrum dynamically.

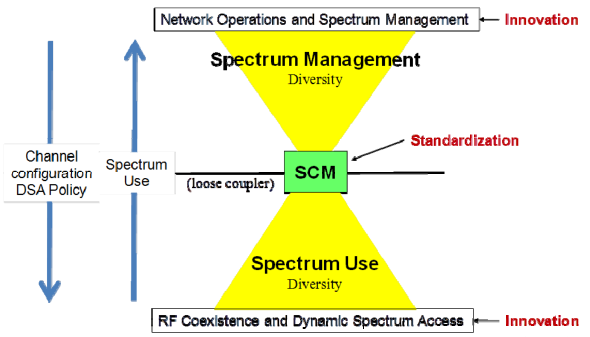

Figure 3 - Bowtie diagram with SCM as the loose coupler revealing the regions of innovation and the use of models for DSA

IEEE 1900.5.2 seeks to define an analytical framework of necessary modeling constructs which can be used to express the boundaries of spectrum consumption by any transmitting or receiving device. The methods of modeling will be selected to support the development of tractable algorithms for determining the compatibility between SCM and for performing various spectrum management tasks that operate on a plurality of models. The modeling methods will be exclusively focused on capturing spectrum use but will be defined in a schema that can be joined with other schemata related to spectrum management and related policies. An initial definition of constructs, a schema, and methods for arbitrating compatibility can be found in [9]. This initial work can serve as a foundation for the standard.

The timeliest applications of the products of this standard will be in dynamic spectrum management. SCM provides a means for specifying spectrum consumption without requiring the revelation of system details. Combining these models with a common tractable means for computing compatibility allows multiple spectrum managers to collaborate in managing coexistence by simply sharing models. It is well suited to support Electromagnetic Battle Management (EMBM) in the military domain where different military communities need to collaborate in the use of spectrum (i.e. the signal community concerned with accessing and protecting spectrum use, the operations community concerned with attacking and denying enemy use of spectrum, and the intelligence community interested in sensing and exploiting spectrum use) but need to hold close operational and technical details of their systems. It is equally well suited for the current spectrum sharing proposed between federal and commercial spectrum users [10] where there are similar security and proprietary reasons to hold operational and system performance details close. Spectrum consumption models provide a means to commoditize spectrum.

Further, Cognitive Radio, Software Defined Radio, and similar technologies are increasingly being adopted by both military and commercial industries. These radios increase the ability to dynamically access spectrum by moving the reasoning into the end device. Spectrum Managers would then use policies to control the activities of these devices.

A limitation of this approach to reusing spectrum is the difficulty of arbitrating the efficacy of policy with existing spectrum assignments. The models to be defined in this standard are an alternative means for specifying spectrum use policy to RF systems resolving the efficacy problem as it is easy to assess the compatibility of policy defined by models with the database of models of assignments used in spectrum management. It is anticipated that regulators would ultimately move to an SCM based approach to assigning usage of spectrum. In this context, this standard provides a critical component of other standards work that is being completed by WG 1900.5 and potentially to regulatory approaches.

V. Future Plans

The demand for spectrum and need to be efficient in its use is ever increasing. DSA is seen as a key component to achieving spectral efficiency and there is near term interest in policy controlled DSA solutions within both the defense and commercial industries. As such the work of 1900.5 has near term criticality, and efforts are being made to accelerate the pace of progress without sacrificing the quality of the standards.

As written, the scope in the 1900.5.1 project authorization request (PAR) is very broad, and when coupled with the requirements of IEEE 1900.5 it will take many man hours to satisfy all those requirements in a single standard. On the other hand 1900.5.2 has a much more restrictive scope. It is expected that 1900.5.2 will complete its work first, and feed back into the work of 1900.5.1. Tentatively, a goal is to approve a 1900.5.2 draft standard within the WG by the end of 2014. The standard could then achieve Sponsor and IEEE Standards Board approval by the end of 2015.

For 1900.5.1 the group is actively considering a more incremental approach to development of the standard. Existing capabilities such as OWL and CRO can provide a solid starting point but may not meet all the requirements identified in 1900.5. However a useful standard that is partially responsive to the requirements should be possible if it can provide a basis for a clear path to meeting the full requirements. If so, it seems that having a 1900.5.1 draft for 2014Q2 that has full standards board approval in 2015Q2 is possible. The group could potentially take a 3GPP Long Term Evolution (LTE) approach where yearly amendments and revisions are conducted each with bounded scope.

Ultimately it is expected that revisions to the existing IEEE 1900.5 standard will be necessary. An initial PAR for 1900.5a has already been drafted, but is not yet approved. IEEE 1900.5a would amend the existing 1900.5 standard to add additional interface information, but also to feedback lessons learned from the WG's other activities.

In addition to standards development, members of the IEEE 1900.5 WG also monitor various regulatory activities. For instance, the WG submitted comments on the recent US FCC Notice of Proposed Rules Making (NPRM) on "Enabling Innovative Small Cell Use [11]. These comments were conveyed via the DySPAN-SC to the FCC [12]. It is anticipated that 1900.5 will continue to monitor and comment on regulatory matters.

Finally, the original scope of 1900.5 was restricted to DSA for communications systems. It has become clearer over time that many different types of systems, including for example radar and navigation systems, must share the electromagnetic spectrum with communications devices. The current efforts of 1900.5 are tailored to sharing with communications systems. It is anticipated that additional standards work (e.g. 1900.5.3, 1900.5.4, etc.) will be required to facilitate sharing with other users for the Electromagnetic Spectrum. A possible schedule for the activities in IEEE 1900.5 is given in Figure 4.

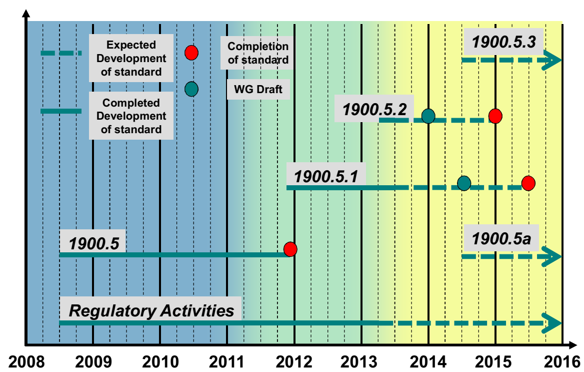

Figure 4 – Possible development schedule for 1900.5

VI. Summary

Dynamic Spectrum Access (DSA) will play a critical role in achieving efficient use of spectrum. Policy controlled RF devices will enable flexible application of DSA technology and the ability to control cognitive features within these devices. A common language to express policies and control these devices is needed. IEEE 1900.5 is actively developing DSA policy language standards. A base standard defining requirements and architecture already exists. Development of spectrum usage modeling methods and the language itself is ongoing. The WG would welcome contributions in these areas and looks forward to additional engagement with radio developers in the exciting area of endeavor.

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