

IEEE Standard for Policy Language Requirements and System Architectures for Dynamic Spectrum Access Systems

IEEE Communications Society

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IEEE Standard for Policy Language Requirements and System Architectures for Dynamic Spectrum Access Systems

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Abstract: This standard defines a vendor-independent set of policy-based control architectures and corresponding policy language requirements for managing the functionality and behavior of dynamic spectrum access networks.

Keywords: DSA, DSA architecture, DySPAN, IEEE 1900.5, policy language, policy-based DSA radio systems

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Introduction

This introduction is not part of IEEE Std 1900.5-2011, IEEE Standard for Policy Language Requirements and System Architectures for Dynamic Spectrum Access Systems.

Industry is increasingly utilizing Cognitive Radio, Software Defined Radio, and similar technologies for creating adaptive, reconfigurable devices and networks. This has prompted the emergence of multiple technical and business models by various user communities, such as military and public safety, most with conflicting goals and operating procedures. Devices, networks, and applications that can use Cognitive Radio for Dynamic Spectrum Access applications require an interoperable means of specifying rules to govern the functionality and behavior of Cognitive Radio in a scalable manner. Policy-based management has this general capability since it enables these entities to be re-purposed to solve different application-specific needs and to serve in different scenarios where interoperability among devices from multiple vendors is required. This standard focuses on the policy language requirements and system architectures for dynamic spectrum access systems. It is expected that there will be follow-on standards to further define the policy language as well as the interface specification identified in the IEEE 1900.5 policy-based DSA radio system (PBDRS) architecture.

The IEEE 1900™ Standards Committee was established in the first quarter 2005 jointly by the IEEE Communications Society and the IEEE Electromagnetic Compatibility Society. The objective of this effort is to develop supporting standards dealing with new technologies and techniques being developed for next generation radio and advanced spectrum management. On March 22, 2007, the IEEE Standards Board approved the reorganization of the IEEE 1900 effort as Standards Coordinating Committee 41 (SCC41) on Dynamic Spectrum Access Networks (DySPAN). In February 2008, the IEEE 1900.5 working group was launched. In December 2010, SCC41 was dissolved and responsibility for managing the DySPAN Standards projects was transferred to the Communications Society Standards Board.

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1. Overview

1.1 Scope

This standard defines a vendor-independent set of policy-based control architectures and corresponding policy language requirements for managing the functionality and behavior of Dynamic Spectrum Access networks.

1.2 Purpose

The purpose of this standard is to define policy language requirements and associated architecture requirements for interoperable, vendor-independent control of Dynamic Spectrum Access functionality and behavior in radio systems and wireless networks. This standard will also define the relationship of policy language and architecture to the needs of at least the following constituencies: the regulator, the operator, the user, and the network equipment manufacturer.

1.3 Document overview

This standard specifies policy language (PL) requirements and policy architecture(s) for policy-based Dynamic Spectrum Access (DSA) radio systems.

In this standard, 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 provision of 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.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 1900.1™, IEEE Standard Definitions and Concepts for Dynamic Spectrum Access Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management.^{1,2}

3. Definitions, acronyms, and abbreviations

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary: Glossary of Terms & Definitions*³ should be referenced for terms not defined in this clause.

3.1 Definitions

awareness: The ability of a radio to gain (or acquire) the knowledge of the state of itself and of its environment for the purpose of assessing the implications of such state on its current and future operating behavior.

binding: Associating a value with a variable. A variable may be bound or unbound. The value of a variable may be unbound (unknown) when the policy is written, for example, values that must be provided by a policy-based DSA radio system (PBDRS) when the policy is processed.

coexistence policy: Policy specifying coexistence constraints and parameters.

coexistence: The ability of two or more spectrum-dependent devices or networks to operate without harmful interference.⁴

NOTE 1—Coexistence policy may be specified by the regulator as a subset of the regulatory policy, or may be specified by the spectrum manager/planner or the system administrator.⁵

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³ *IEEE Standards Dictionary: Glossary of Terms and Definitions* is available at <http://shop.ieee.org>.

⁴ From IEEE Std 1900.1™.

⁵ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

NOTE 2—As an example, a coexistence policy might specify a listen-before-talk coexistence mechanism and might specify the sensor detection threshold (e.g., -90 dBm in a 10 kHz bandwidth).

cognitive radio: A) A type of radio in which communication systems are aware of their environment and internal state and can make decisions about their radio operating behavior based on that information and predefined objectives. B) Cognitive radio [as defined in item a)] that uses software-defined radio, adaptive radio, and other technologies to adjust automatically its behavior or operations to achieve desired objectives.^{6,7,8}

NOTE—The environmental information may or may not include location information related to communication systems.

domain: An area of knowledge or activity characterized by a set of concepts and terminology understood by practitioners in that area.

dynamic spectrum access (DSA) policy language: A formal system for representing information that includes both grammar (syntax) and meaning (semantics) that has been created for the purpose of communicating DSA policy primarily between machines (computers). There are two types of languages, declarative and imperative. Declarative language may be implemented with imperative extensions to address language pragmatics.

dynamic spectrum access (DSA): The real-time adjustment of spectrum utilization in response to changing circumstances and objectives.⁹

NOTE—Changing circumstances and objectives include (and are not limited to) energy-conservation, changes of the radio's state (operational mode, battery life, location, etc.), interference-avoidance (either suffered or inflicted), changes in environmental/external constraints (spectrum, propagation, operational policies, etc.), spectrum-usage efficiency targets, quality of service (QoS), graceful degradation guidelines, and maximization of radio lifetime.

fact: A formula that is either asserted or proved to be true under a given interpretation.

formal policy: A set of formulas in the logic associated with the policy language that specify how a resource (e.g., radio spectrum) may be used.

formal semantics: The interpretation or mapping from the vocabulary of the language to a mathematical domain.

machine learning: The capability to use experience and reasoning to adapt the decision-making process to improve subsequent performance relative to predefined objectives.¹⁰

NOTE—This notion of learning corresponds most closely to the subdiscipline of machine learning known as reinforcement learning. Learning in the intelligent radio context is meant to exclude learning “by being told”—e.g., acquiring information, messages received from other systems, configuration files, and initialization parameters. Rather learning implies the adaptation of decision making based on direct experience resulting from previous actions.

⁶ See Footnote 4.

⁷ IEEE recognizes that the terminology commonly used is “cognitive radio.” However, generally the cognitive functionality may be outside the boundary normally associated with a radio (e.g., environment sensing is a cognitive function that is not normally part of a radio).

⁸ IEEE notes that the terms “dumb radio,” “aware radio,” and “smart radio” are used in the technical literature, but IEEE does not define these terms at this time. They are additional descriptive terms that are sometimes applied to radios.

⁹ See Footnote 4.

¹⁰ See Footnote 4.

machine-understandable policies: Policies expressed in a form that allows for a policy-based radio to read and "interpret" them automatically (without requiring human intervention). That is, an automated procedure exists by which the implications of the constraints expressed by the policies are reflected in the actions of the radio.¹¹

meta-policy: One or more assertions in the policy language that state relationships between policies.

model-theoretic computational semantics: Defines logical consequents by relating statements in the language to entities in a given structure, the so-called model.

NOTE—The importance of the model-theoretic semantics lies in its simplicity that allows us to understand the meaning of a policy without the need to understand the reasoning process.

ontology: Definitions that associate the names of entities and concepts in a problem domain (e.g., objects, classes, relations, functions, objects) with text describing what the names mean, and axioms (expressed in a formal language) that constrain the interpretation of these entities and concepts.

NOTE—Modified from IEEE Std 1900.1™.

policy: A) A set of rules governing the behavior of a system.¹²

NOTE 1—Policies may originate from regulators, manufacturers, developers, network and system operators, and system users. A policy may define, for example, allowed frequency bands, waveforms, power levels, and secondary user protocols.

B) A machine-understandable instantiation of policy such as defined in Definition A).

NOTE 2—Policies are normally applied post manufacturing of the radio as a configuration to a specific service application.

NOTE 3—Definition B) recognizes that in some contexts the term "policy" is assumed to refer to machine-understandable policies.

NOTE 4—See also: **formal policy**, **meta-policy**, **machine-understandable policies**, and **coexistence policy**.

policy authority: An entity that has jurisdiction over spectrum usage and is authorized to create policy for that jurisdiction.

NOTE—An authority may be, for example, a regulatory agency or a primary user who is authorized to lease their spectrum to other users.

policy-based radio (PBR): A type of radio in which the behavior of communications systems is governed by a policy-based control mechanism.¹³ See also: **policy-based control mechanism**.

NOTE 1—Policies may restrict behaviors (e.g., policies constraining time, power, or frequency use) associated with a specific set of radio functions, but they do not necessarily change the functional capability of a radio. Because policies often do not change basic radio functionality, a policy-based radio need not also be a reconfigurable radio.

NOTE 2—Because the definition for the term policy-based control mechanism considers radio policy to be a type of radio control software, the policy-based radio is considered a subset of software-controlled radio.

¹¹ See Footnote 4.

¹² See Footnote 4.

¹³ See Footnote 4.

policy-based control mechanism: A mechanism that governs radio behavior by sets of rules, expressed in a machine-understandable format, that is independent of the radio implementation regardless of whether the radio implementation is in hardware or software.¹⁴

NOTE 1—The definition of rules and associated modification of radio functionality can occur:

- during manufacture or reconfiguration
- during configuration of a device by the user or service provider
- during over-the-air provisioning
- by over-the-air or other real-time control

NOTE 2—As implied by the scope of this standard, the control of radio dynamic spectrum access behavior is expected to be a typical application of a policy-based control mechanism. However, the concepts of policy-based control could be applied to network management policies as well. Policy sources include spectrum regulators, manufacturers, and network operators.

policy conformance reasoner (PCR): The IEEE 1900.5 system component that evaluates the policy compliance of transmission requests.

NOTE—The PCR is software capable of making logical inferences from a set of asserted facts and rules (i.e., policies). It is able to formally prove or disprove a hypothesis (e.g., that a transmission request is policy compliant), and is capable of inferring additional knowledge (e.g., identifying transmission opportunities for unbound transmission requests).

policy enforcer (PE): The Policy Enforcer is the realization of the Policy Enforcement Point in an IEEE 1900.5 system. It examines transmission control commands received from the System Strategy Reasoning Capability (SSRC) to ensure the Policy Conformance Reasoner (PCR) has found them to be policy compliant and only outputs policy-compliant commands to the transmitter for execution.

NOTE—The Policy Enforcer may maintain a record of previous SSRC transmission decision requests, PCR transmission decision replies, and validity periods to support its policy enforcement function.

policy rule: A policy rule is a formula in the policy language that has the form of an implication (e.g., A logically implies B).

policy traceability: The ability to provide evidence of the source of a policy that cannot be repudiated.¹⁵

NOTE—Policy includes machine-understandable policy.

procedural attachments: An executable procedure (code) written in an imperative language and invoked from within a reasoner.

proof-theoretic semantics (PTS): In proof-theoretic semantics (PTS), proofs are entities in terms of which meaning and logical consequences can be explained. PTS are the axioms and inference rules.

NOTE—Proof-theoretic semantics is an alternative to model-theoretic semantics. In PTS, meanings are assigned to expressions of the languages as proofs rather than as truth. In this sense, PTS is inferential rather than denotational in spirit.

¹⁴ See Footnote 4.

¹⁵ See Footnote 4.

reasoner: The decision making entity which uses a logical system to infer formal conclusions from logical assertions. It is able to formally prove or disprove a hypothesis and is capable of inferring additional knowledge.

regulatory policy: A policy that is specified by a regulatory authority [such as the Federal Communications Commission (FCC) or the National Telecommunications and Information Administration (NTIA) in the U.S.A.]. Typically, these describe what constitutes valid use of spectrum without having specific knowledge of the environment.

semantics: Defines the meaning of expressions (formulas) in the language.

NOTE—There are various types of semantics including model-theoretic computational semantics and proof-theoretic semantics.

system policy: A policy, specified by a system administrator, which typically specifies inputs beyond those available in regulatory policy. It can provide specific strategies or instructions to the radio. System policy depends on the knowledge of the operational environment.

system strategy reasoning capability (SSRC): The functional capability in an IEEE 1900.5 system that generates transmission requests and proposes the parameters of each transmission.

NOTE 1—The system strategy reasoning capability gathers data to optimize radio operation, formulates communications strategies, and coordinates these strategies with the policy conformance reasoner to evaluate compliance with the active policy set.

NOTE 2—The system strategy reasoning capability may maintain a record of previous SSRC transmission decision requests, PCR transmission decision replies, and validity periods.

transmission request: A query expressed in the policy language about the validity of a specific transmission with respect to the policies currently in use. A transmission request may include parameters of a transmission that are necessary for the PCR to establish whether the proposed transmission satisfies the conditions defined by the current policies.

NOTE—A transmission request may regard a specific transmission, or a strategy for transmissions (unbounded requests).

transmission opportunity reply: A set of transmission parameters (e.g., tuned frequency, power, bandwidth, coexistence protocol, etc.), evidence (e.g., sensor data and other awareness knowledge), and the validity period associated with a Transmission Opportunity Request or Transmission Decision Refresh Request that the PCR has found to be policy compliant.

transmission opportunity request: A set of transmission parameters (e.g., tuned frequency, power, bandwidth, coexistence protocol, etc.) and evidence (e.g., sensor data and other awareness knowledge) that is sent as a request from the SSRC to the PCR.

variable: A variable is a symbol in the policy language that may be associated with (bound to) a value. The value may change over time.

3.2 Acronyms and abbreviations

AGC	Automatic Gain Control
API	Application Programming Interface
ARQ	Automatic Repeat reQuest