OWL and Rules for Cognitive Radio

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RF Spectrum Shortage

- RF spectrum is a valued resource
- Shortage
- But at the same time inefficient utilization (next slide)

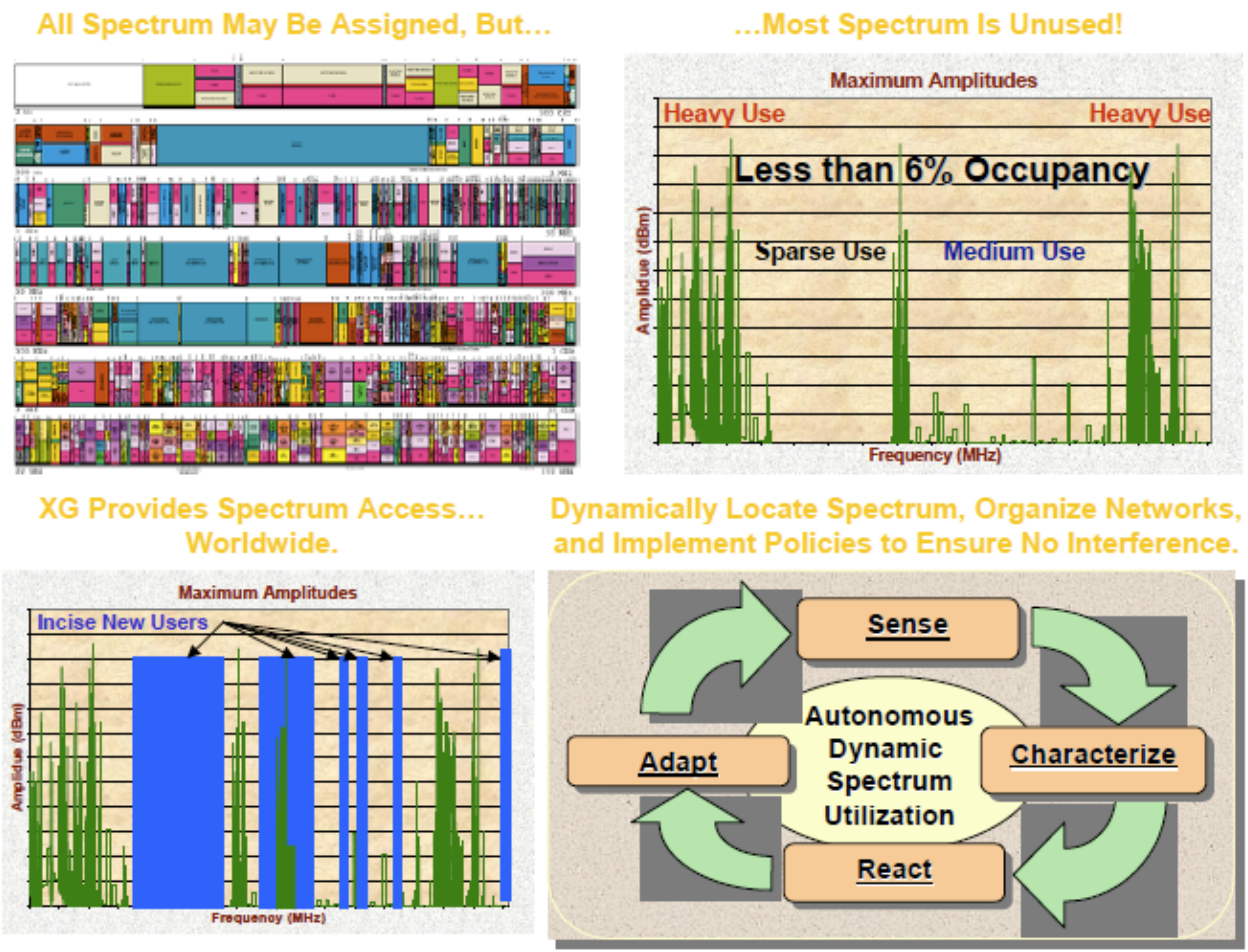


Figure 1: Spectrum is wasted. Opportunistic spectrum access can provide 10x improvement by reusing wasted spectrum.

Cognitive Radio: Not just Dynamic Spectrum Access

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.

Definition started by Mitola, then adopted by Cognitive Radio WG at the Wireless Innovation Forum and IEEE P1900.1 standardization work

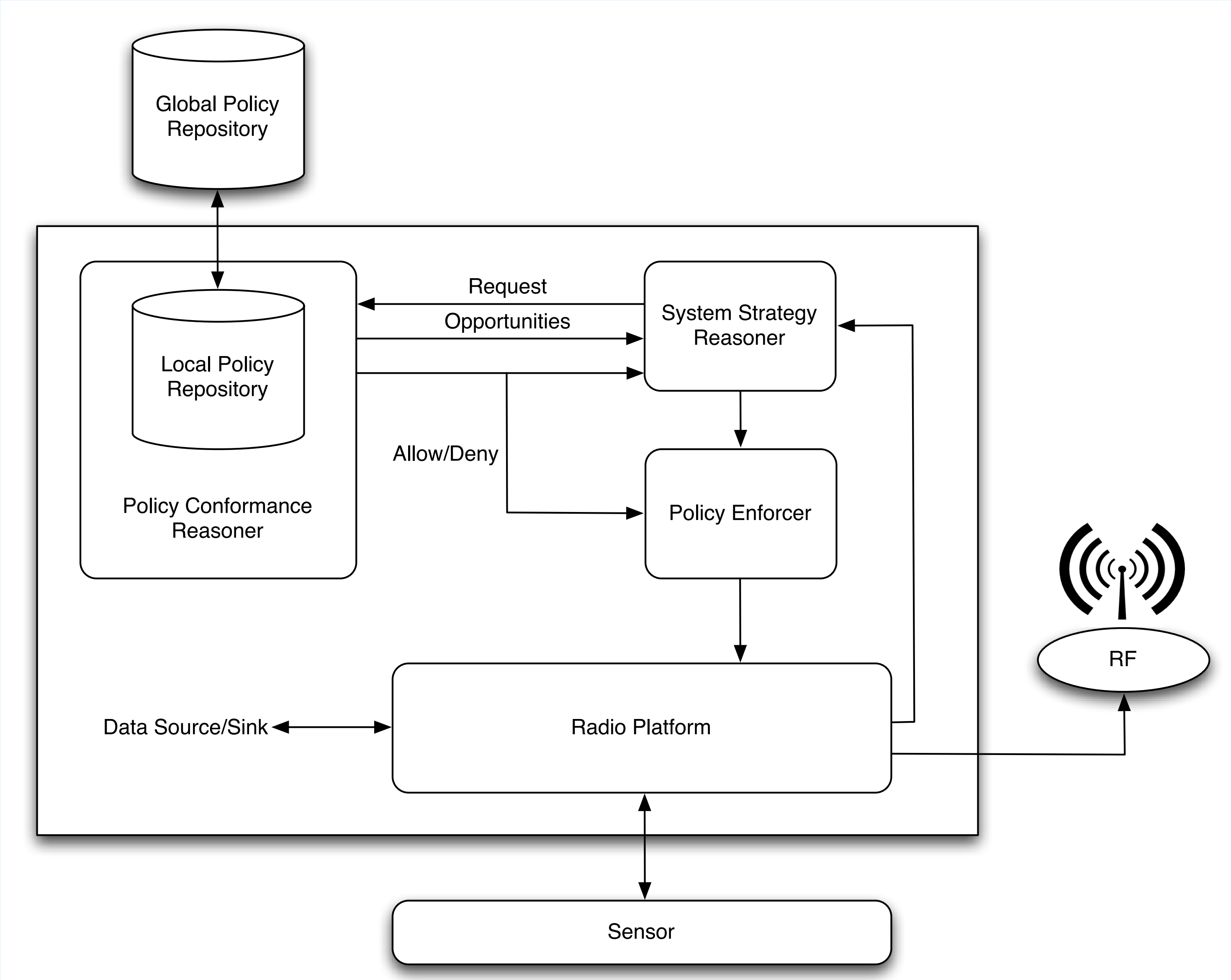
Other Cognitive Radio Capabilities

- Sensing and information collection
- Query by user or other radios
- Situational and self-awareness
- Autonomous decision making
- Query execution
- Command execution

Approaches to DSA

- Centralized spectrum management
  - Policy at the controller
  - Database of assignments
- Decentralized spectrum management; aka Dynamic Spectrum Selection (DSS)
  - Sensing and selection
  - Policy interpretation is needed
- Should assignments be “fair”?
  - Tactical Battlefield DSA
  - Public safety
  - Role based, attribute based assignments
- Should policies be fixed over time, space, roles, attributes?

Architecture of PBDRS



Policy: An Example

- Policy: “A node can transmit in the frequency range 350.00 MHz - 370.00 MHz in locations between latitude 37.123456 and 38.123456 and between longitude 68.123456 and 79.123456.”
- SSR must provide:
  - Operation ID: e.g., T002
  - Operation type: transmit
  - Frequency range: e.g., 375.00-380Mhz
  - Transmit location:
    - e.g., latitude=37.234567, longitude=70.123456
- PR returns
  - <type T002 disallowed>

How should policies be represented?

- Procedural code (C/C+/Java)
  - Problems with interoperability and modifiability – would require multiple versions of policies for different platforms
  - Rewrite, recompile, reload, re-deploy with any change in policies
  - Possibly would require re-certification of the platform code when policies change
- A language with formal syntax (XML)
  - Requires procedural code to interpret XML tags for each platform
  - Expand the code library for the modified or additional policies
  - Re-certify the code
- A language with formal semantics (OWL, ++?)
  - Requires a generic interpreter running on different platforms
  - Load new sets of policies into local policy base
  - The interpreter does not need to be changed because it is specific to the language and not to the policies
  - No need to re-certify the interpreter when policies change

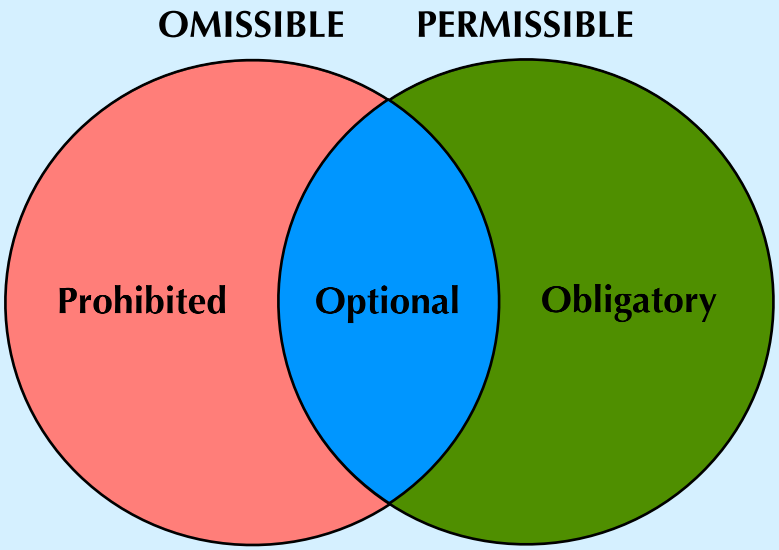
CRO: Cognitive Radio Ontology

- Document: "*Description of the Cognitive Radio Ontology*"
- Approved at the WIF 67th Working Meeting, Schaumburg, Sep. 2010
- Available here: http://groups.winnforum.org/d/do/3370)
  - Core ontology (covering basic terms of wireless communications from the PHY and MAC layers)
  - Concepts needed to express the MLM use cases developed earlier
  - Partial expression of the FM3TR waveform (structure and subcomponents, FSM)
  - Partial expression of the Transceiver Facility APIs
  - 230 classes and 188 properties
- Work is underway to extend CRO in order to express concepts of Model Based Spectrum Management (MBSM) – see MITRE Technical Report number 110131, May 10, 2011.

Deontic Action Ontology

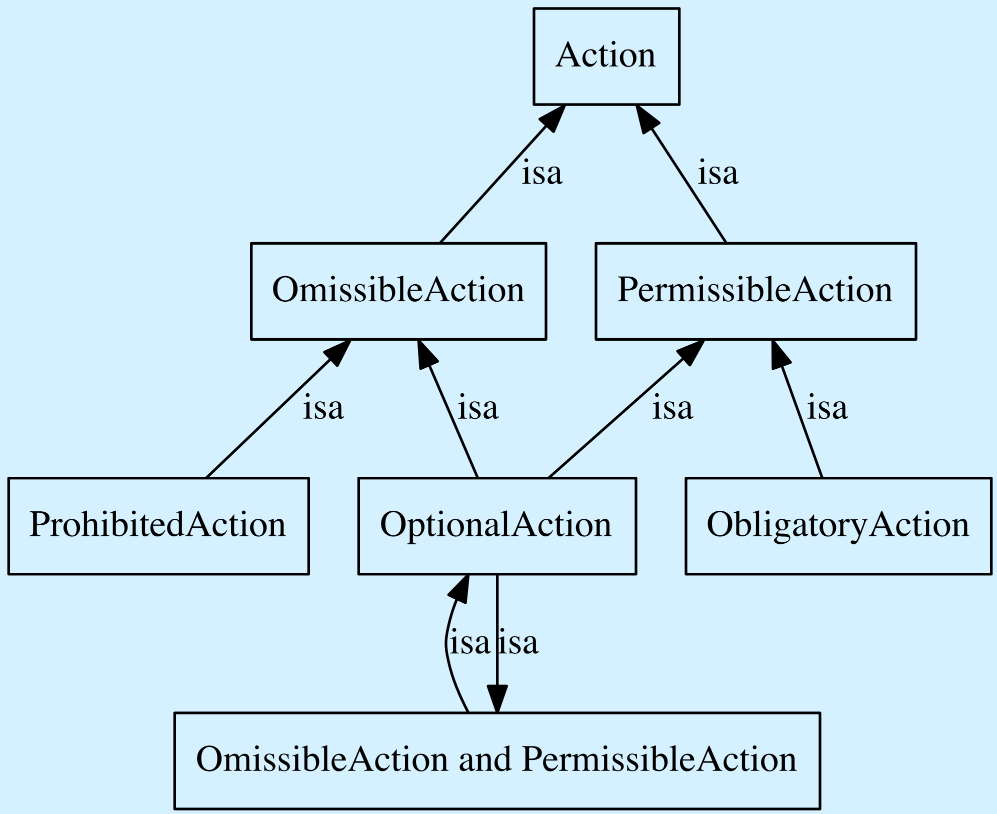
PEp ↔ ~OB~p
PRp ↔ OB~p
OMp ↔ ~Obp
OPp ↔ (~OBp & ~OB~p).

Operations/Actions



Expressed in OWL using disjointClass, subClassOf, complementOf, intersectionOf…

Deontic Action Ontology



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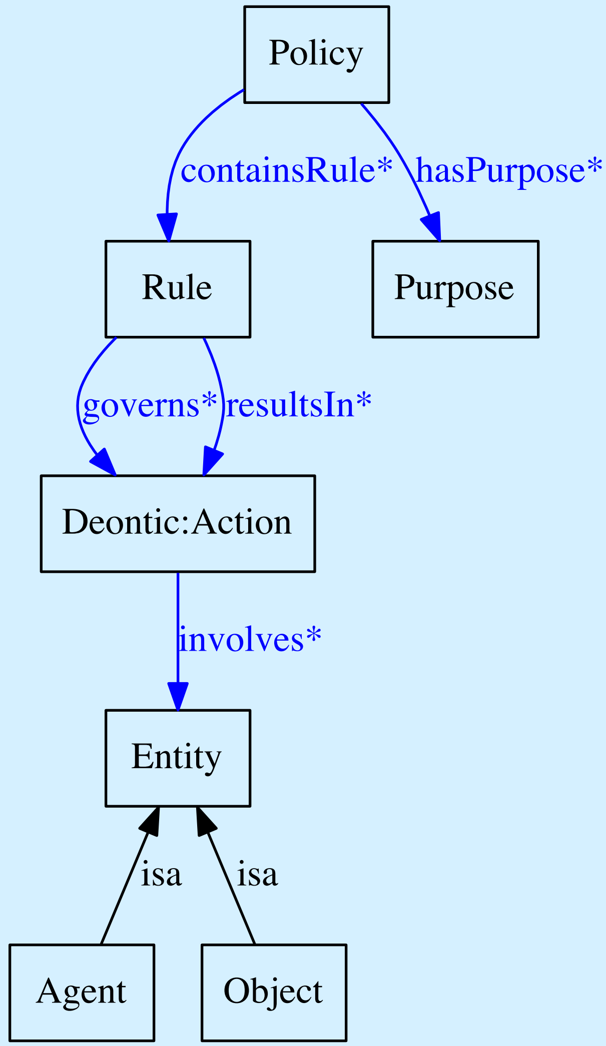
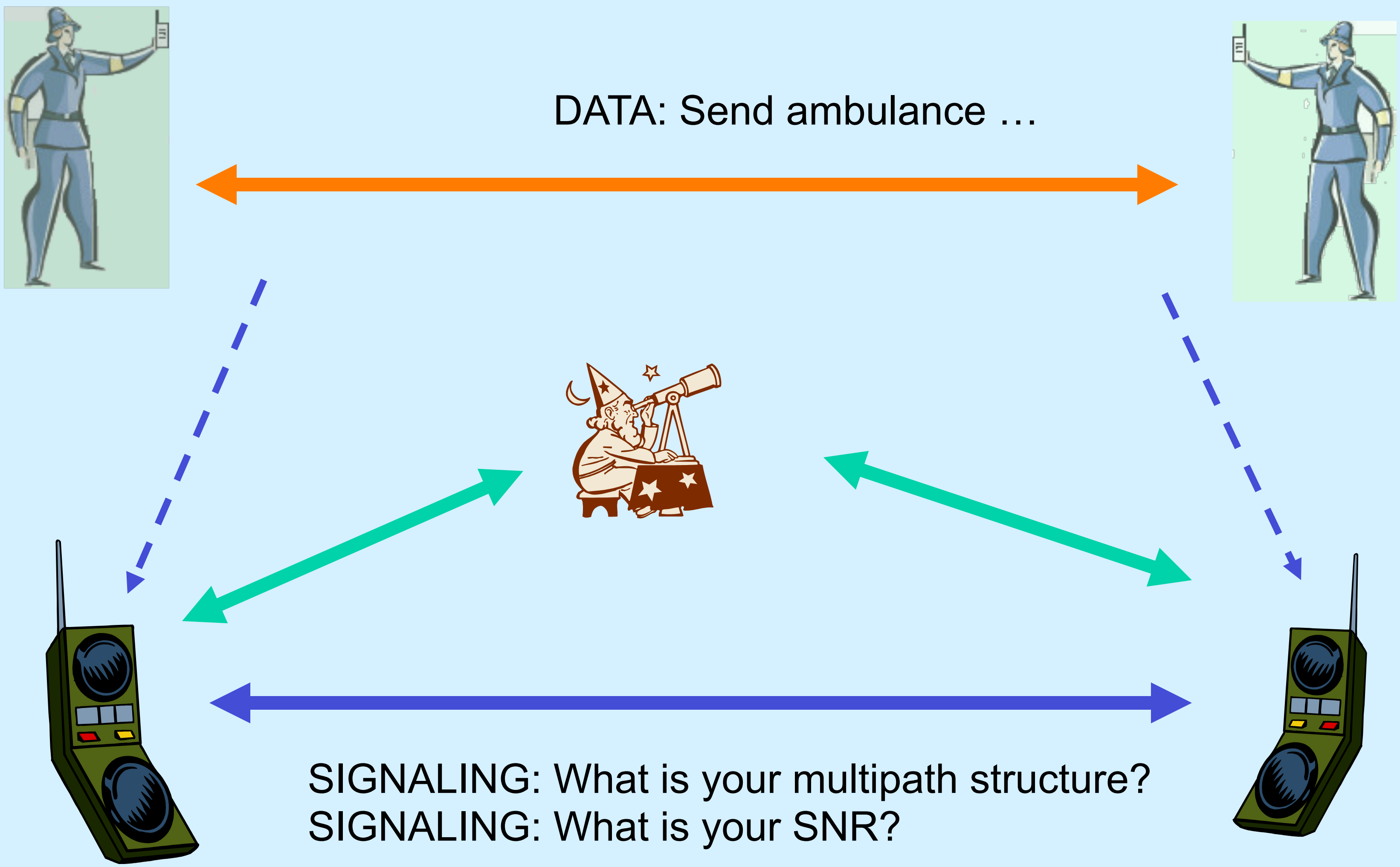
Policy Ontology



Two Conversations



Limits of Current Software Radios

- **Reason 1**: Local information is stored in a data model that does NOT have high expressivity and machine processable semantics.

?

What control information can be exchanged

Scalar variables	Structure of a component	FSM of a component	More complicated information …
✓	✗	✗	✗

XML might help?

But XML does NOT have machine processable semantics

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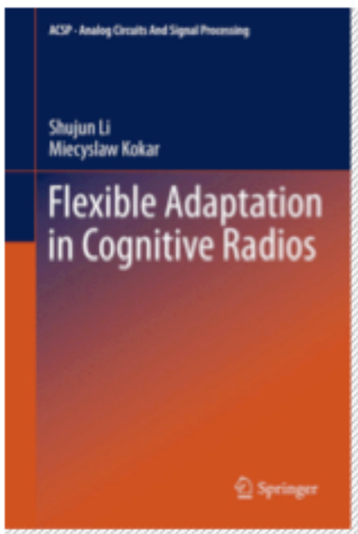

Flexible Adaptation in Cognitive Radios

Series: » Analog Circuits and Signal Processing

Li, Shujun, **Kokar**, Miecyslaw

2013, 2013, XIX, 155 p. 84 illus.

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Limits of Current Software Radios

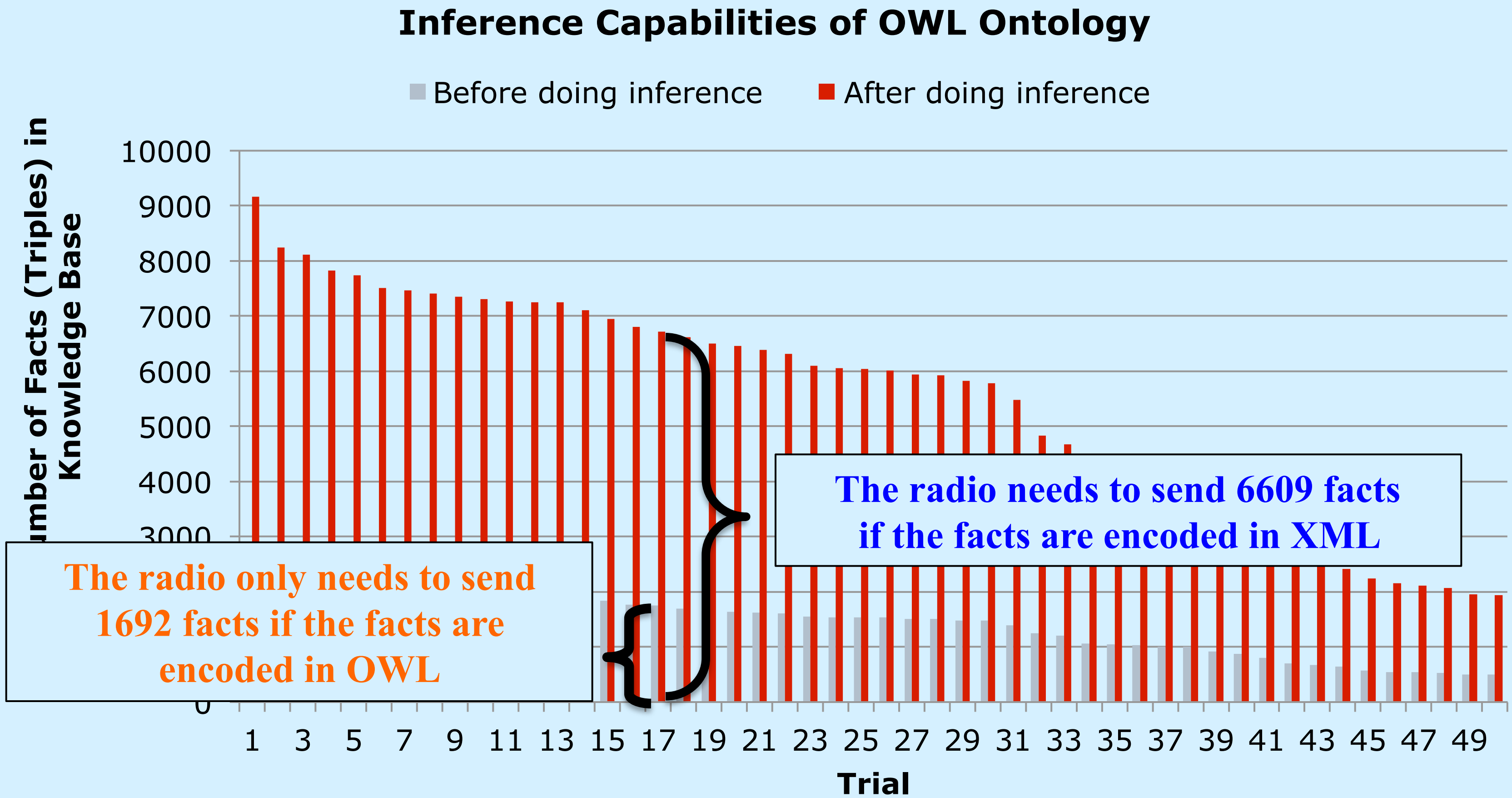
- **Reason 2**: Signaling messages are limited in the frame structure defined by the protocol

Frame format of 802.11

Frame Control	Duration ID	Address1 (source)	Address2 (destination)	Address3 (rx node)	Sequence Control	Address4 (tx node)	Data	FCS
2	2	6	6	6	2	6	0 - 2,312	4

It is **NOT** possible to exchange some signaling messages that are **NOT** defined in the protocol

Comparison: XML vs. OWL

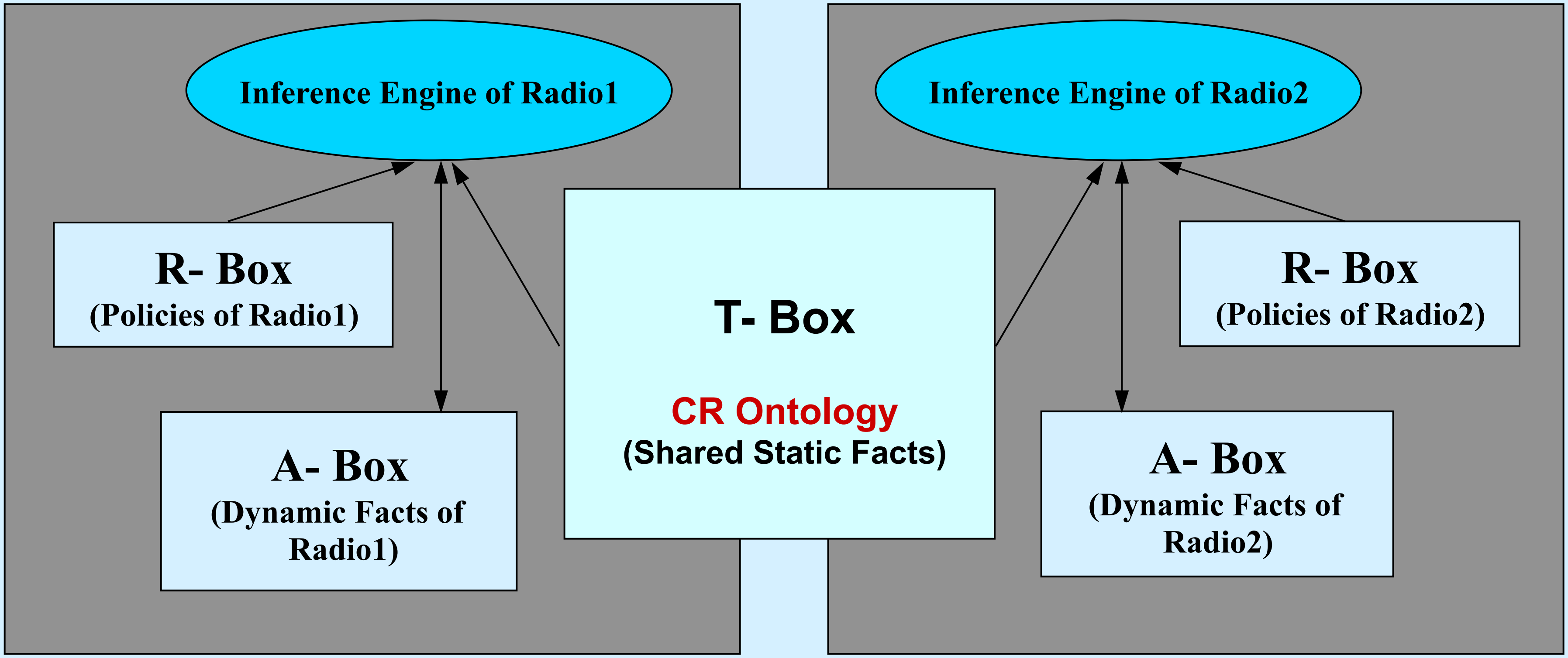


- **XML**: the radio must send all the information explicitly
- **OWL**: the radio only needs to send parts of the message, while the rest of the information can be inferred locally by the inference engine based on the generic knowledge encoded in the shared ontology
  - ➔ Less communication overhead imposed to the network

Example Inferences

- Infer whether particular frequency bands are contiguous, overlapping, covering
- Whether requested frequencies, bands, times of transmission, locations, power levels satisfy particular policies
- From description of responsibilities a user’s node has, infer the user’s *role* and then derive decision on whether allow transmission (e.g., fireman in an emergency situation)
- Whether security requirements of a specific request are satisfied
- Whether the content of a message can be sent (provided meta-information about the content is provided)
- Execution of rules (condition-action) to determine which knob should be adjusted and by how much
- Radio A sends a description of a component to Radio B; infer whether a specific component it has satisfies the description
- Whether a specific transmission is within the constraints of a given model (refer to MITRE Model Based Spectrum Management)

Policy-based radio control – real time demo



- The inputs to Inference Engine contain:
  - Static facts (T Box): Basic terms in communication domain, usually including classes and properties expressed by the Ontology
  - Dynamic facts (A Box): Facts that are only available as the radio is operating, usually instances in the Ontology generated by the system at run-time
  - Policies (R Box): Rules specified in a declarative form, describing how to react to particular situations.

Generation of Waveforms from Descriptions (L. Lechowicz, Ph.D. thesis)

- Objective: Verify that dynamic Ontology-based SDR reconfigurability is feasible
- Transfer of knowledge (description of BPSK31, QPSK31, RTTY waveforms)
- Transferred knowledge integrated in the local knowledge base
- A waveform described in OWL/Rules constructed from its description
- FSM built from the ontological description
- A complex software module composed from simpler software modules dynamically
- Determine the boundaries of the applicability of the method

It all works! Publications forthcoming.

MLM: Modeling Language for Mobility

- *Development of use cases for wireless communication in which the MLM language can facilitate flexible communication,*
- *Development of Cognitive Radio Ontology (CRO) that is capable of expressing structural, functional and behavioral aspects of models for wireless communication,*
- *Corresponding signaling plan, requirements and technical analysis of the information exchanges that enable these next generation features,*
- *Policies and rules for policy based radio control,*
- *Ontology extensions needed to support policy based radio control.*

MLM Work Group of the Wireless Innovation Forum

What is the Wireless Innovation Forum?

- A nonprofit “mutual benefit corporation” dedicated to:

“Driving the Future of Radio Communications and Systems World Wide”

WIRELESS INNOVATION FORUM™

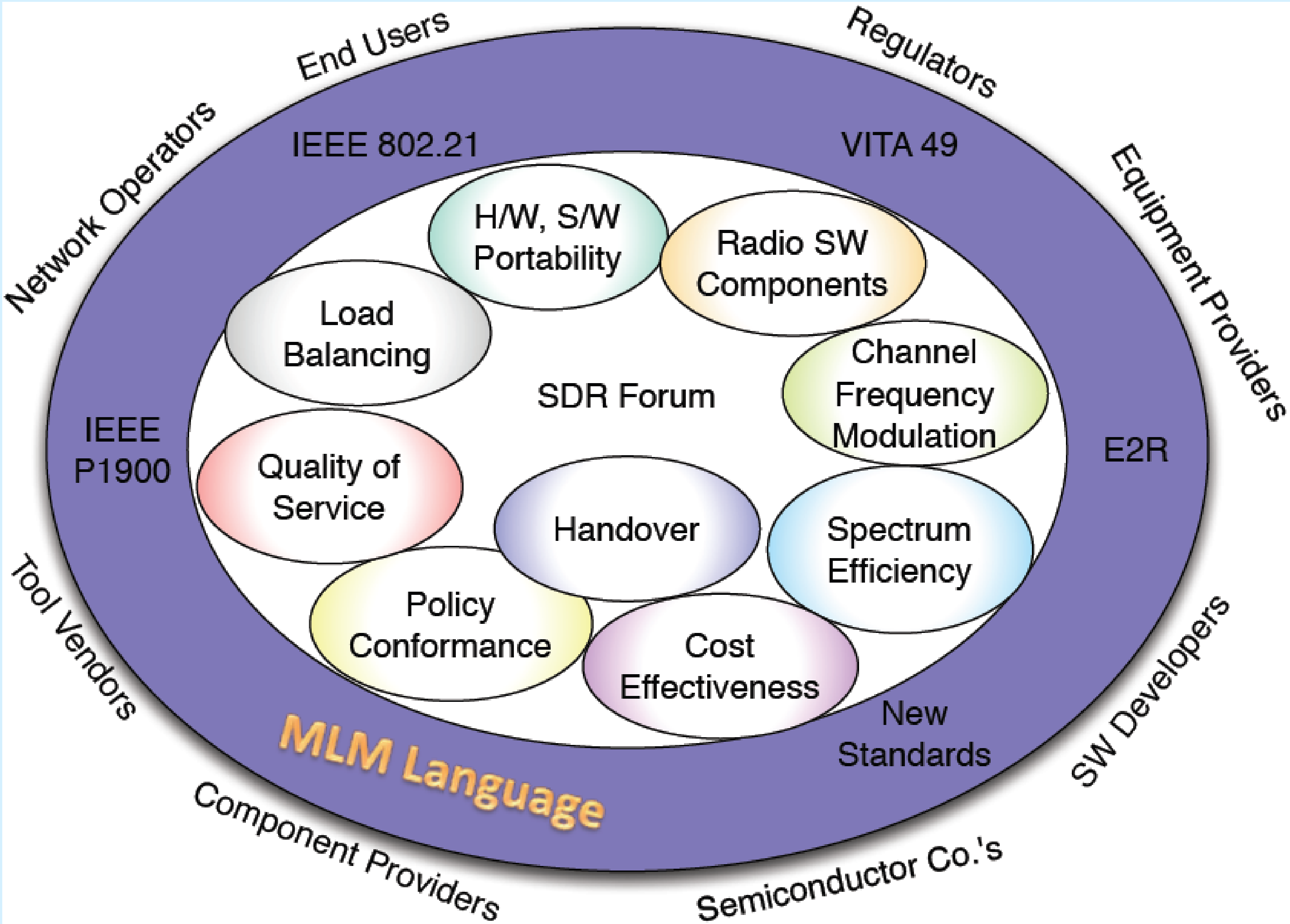
Through this collaboration, the Forum should help its members to:

- Expand opportunities
- Improve service
- Reduce cost (development, production, maintenance)
- Reduce time to market/time to deployment

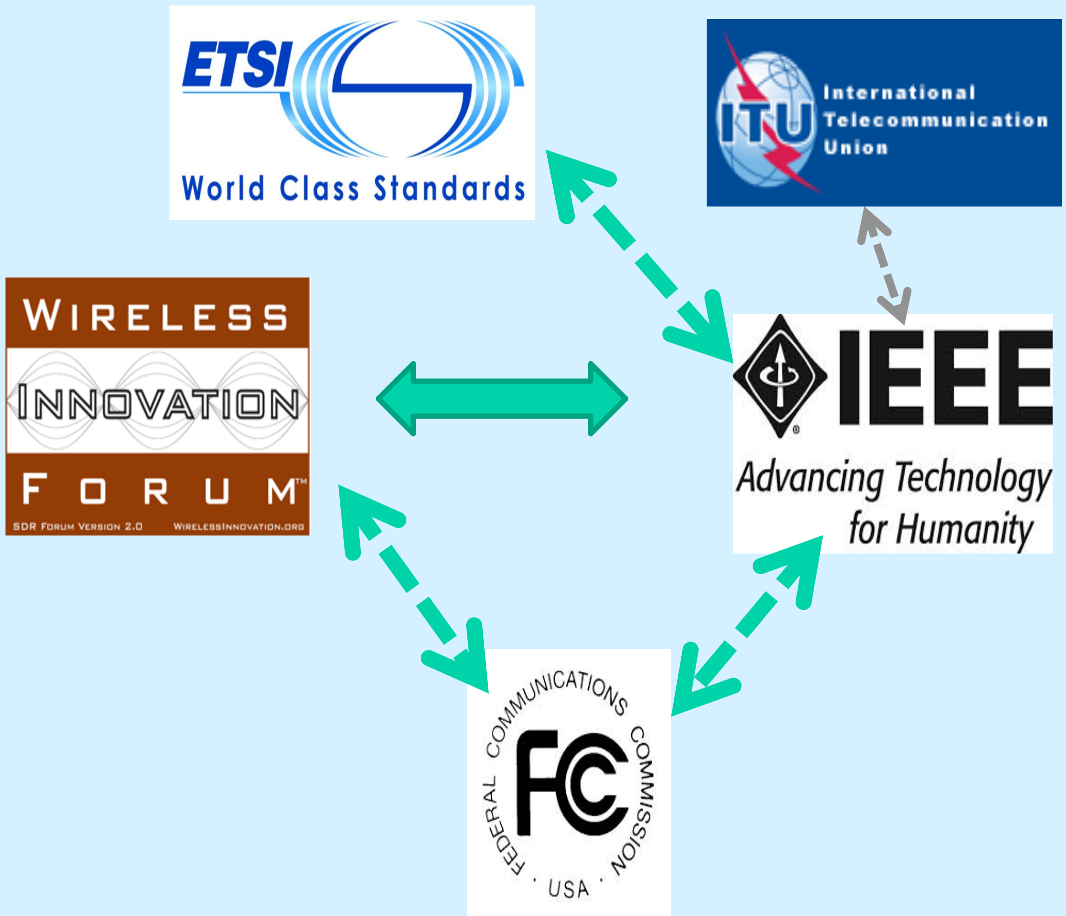
a “tool “to be used by its members’ representatives to achieve their objectives …

- **115 members**

MLM Addresses Interoperability



Introduction



The IEEE Dynamic Spectrum Access Networks Standard Committee (DySPAN-SC) is among several key standards bodies aims to develop and standardize radio and dynamic spectrum management solutions.

IEEE P1900.5

A formal language, with a computer-processable semantics, that could be used for describing various aspects of network devices, capabilities, operations and policies for component and network management.

Descriptions and policies to be interpreted by general purpose Inference Engines (Reasoners) rather than being hard coded into devices at the design time.

The IEEE P1900.5:standardization effort. Currently developing P1900.5.1. Chair: Matthew Sherman, BAE Systems, matthew.sherman@baesystems.com

P1900.5 developed requirements for a policy language

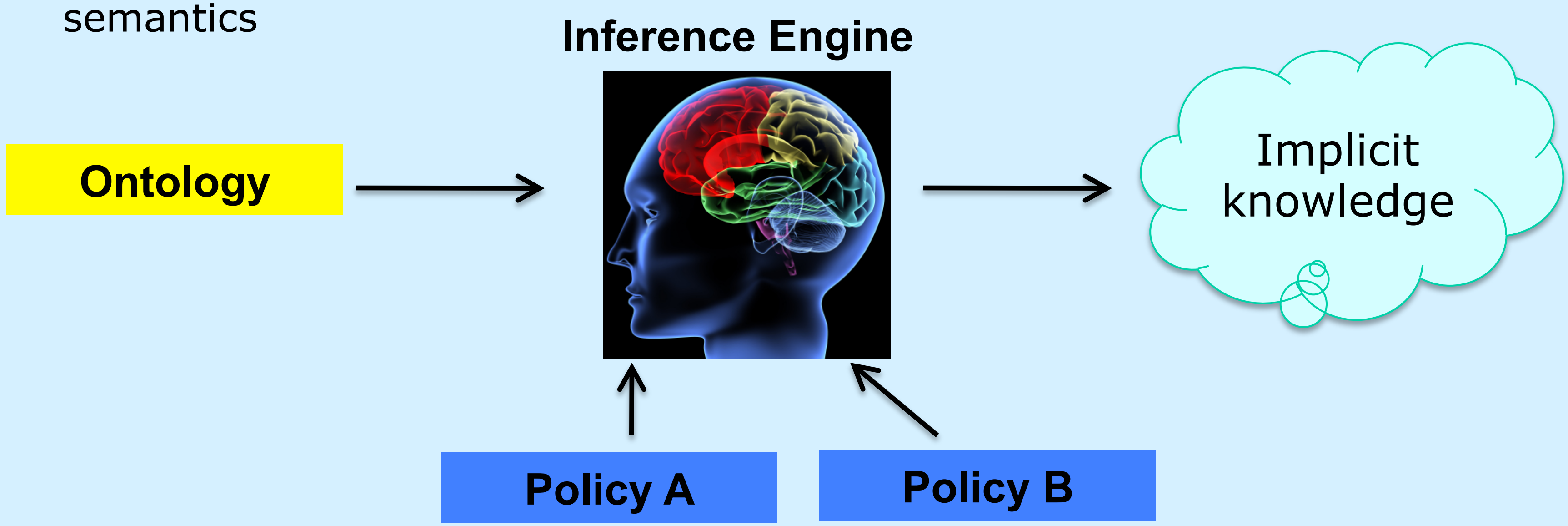
P1900.5.1 working on a language

Submission by MLM to P1900.5.1: Overview

- The proposed language to be based on:
  - OWL 2 RL (W3C) – both syntax and semantics
  - Cognitive Radio Ontology (CRO) (WinnForum)
  - RIF (Rule Interchange Format) (W3C)
    - Plus Procedural Attachments
  - Deontic Policy Ontology

Summary: Policy-based Radio Control

- Policy-based radio control
  - The behavior of the radio is controlled by (local) policies
  - Policies are expressed in declarative form with unambiguous semantics, e.g., OWL and rules
  - Standards Based Inference Engine: e.g., BaseVISor
- Policies are separated from implementation
  - Modification of radio behavior becomes flexible
  - Simpler certification process
  - Represent policies at a more abstract level and with easier understood semantics



Thank You!