A Semantic Framework for Enabling Radio Spectrum Policy Management and Evaluation*

Henrique Santos, Alice Mulvehill, John S. Erickson, James P. McCusker, Minor Gordon, Owen Xie, Samuel Stouffer, Gerard Capraro, Alex Pidwerbetsky, John Burgess, Allan Berlinsky, Kurt Turck, Jonathan Ashdown, Deborah L. McGuinness
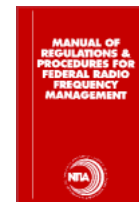
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Request
- Requester (device, service, system …)
- Start and end time
- Location
- Requested frequency (range)

Spectrum manager

Permit / Deny / Obligations

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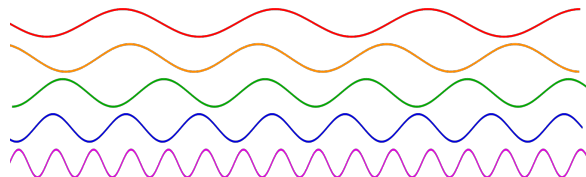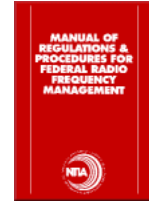19th International Semantic Web Conference – ISWC 2020 In-use track
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Request
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US91 In the band 1755-1780 MHz, the following provisions shall apply:
(a) Non-Federal use of the band 1755-1780 MHz by the fixed and mobile services is restricted to stations in the Advanced Wireless Service (AWS). Base stations that enable AWS mobile and portable stations to operate in the band 1755-1780 MHz must be successfully coordinated on a nationwide basis prior to operation, unless otherwise specified by Commission rule, order, or notice.
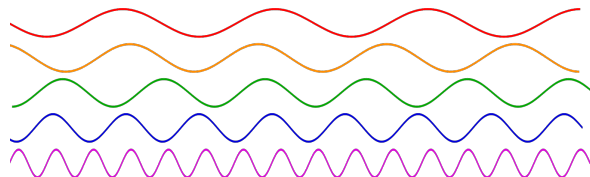
Spectrum manager

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Request
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DSA Policy Framework

Spectrum manager

Permit / Deny / Obligations

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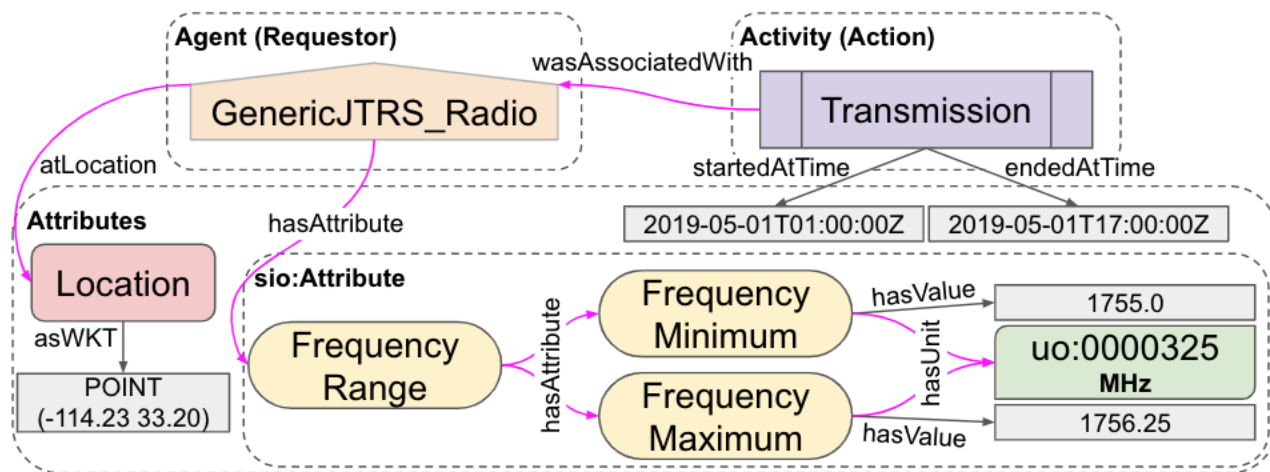
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- Policies for spectrum management are **published in natural language** in authoritative documents

- They specify which **services/systems/devices are allowed or prohibited** to transmit in **some frequency range**

- They **can be location-specific**

- Our team worked with documents from the NTIA, FCC and IEEE

Action	Requester	Affiliation	Frequency	Location	Effect	Obligations

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*NTIA: National Telecommunications and Information Administration | FCC: Federal Communications Commission | IEEE: Institute of Electrical and Electronics Engineers

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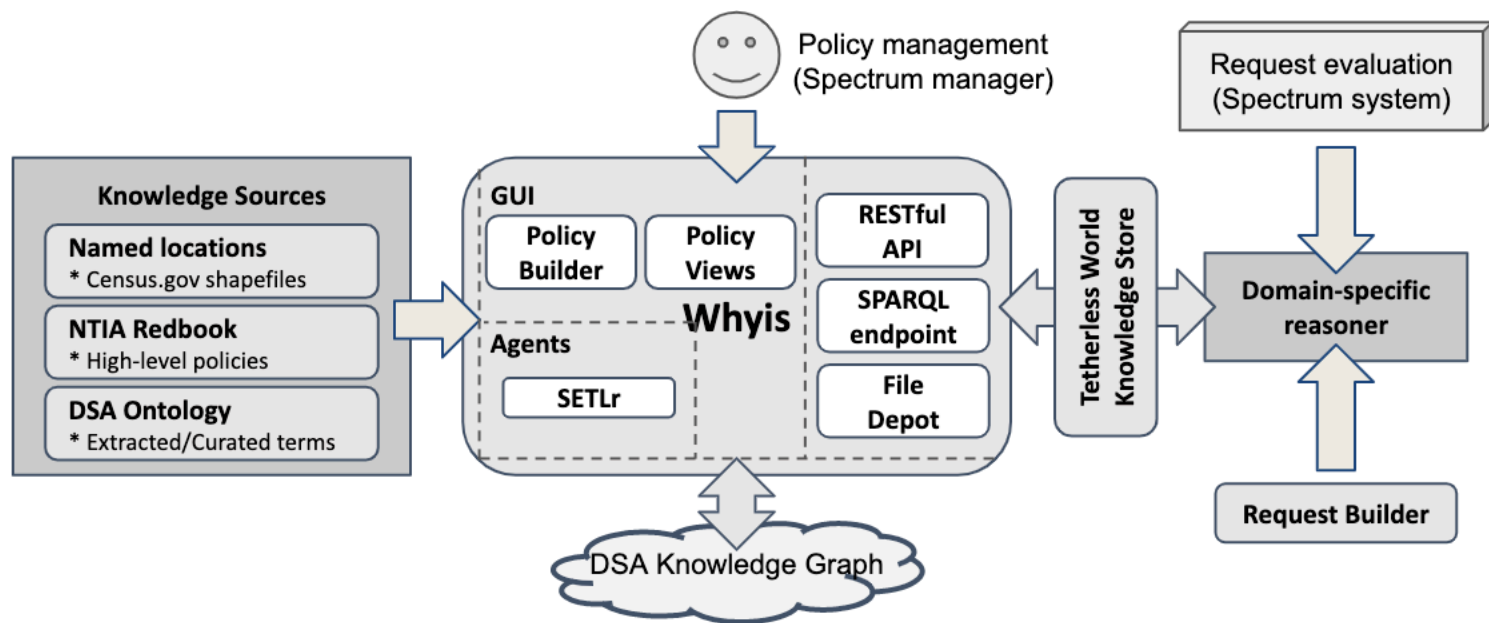5
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- Policy rules were converted to a more structured logical form
  - **IF** (some device/system/service) **AND** (some frequency) **AND** (at a location) **AND** (…), **THEN** it is either **PERMITTED** or **DENIED**

- Identified terms and their relationships were collected and incorporated into a domain ontology (DSA Ontology)

- Named locations were represented using the GeoSPARQL vocabulary and integrated with high-definition shapes (polygons) from Census.gov public datasets

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A PROV-based transmission request

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Representing policies in OWL

First
LevelRule —— owl:equivalentClass

```
prov:wasAssociatedWith some
    (sio:hasAttribute some
        (<Attribute> and
            (sio:hasValue some xsd:float[<= some_value])
        )
        ...
    )
```
Frequency range

Second
LevelRule —— owl:equivalentClass

```
FirstLevelRule and
(prov:wasAssociatedWith some <Agent>)
```
Requester

Third
LevelRule —— owl:equivalentClass

```
SecondLevelRule and
(prov:wasAssociatedWith some
    (prov:atLocation some <Location>)
)
```
Location

Fourth
LevelRule —— owl:equivalentClass

```
ThirdLevelRule and
(prov:endedAtTime some xsd:dateTime[>= "2019-10-01T15:00:00Z"]) and
(prov:startedAtTime some xsd:dateTime[<= "2019-10-01T21:00:00Z"])
```
Time

...

n-th
LevelRule —— owl:equivalentClass

```
(n-th - 1)LevelRule and
(...)
```
(More attributes…)

Permit / Deny

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```
EquivalentTo:
Transmission and
(wasAssociatedWith some CommercialRadio) and
(wasAssociatedWith some (hasAttribute some
   (FrequencyRange
     and (hasAttribute some
           (FrequencyMaximum and
             (hasValue some xsd:float[<= 1800.0f])))
     and (hasAttribute some
           (FrequencyMinimum and
             (hasValue some xsd:float[>= 2000.0f]))))))
SubClassOf:
Deny, Priority_1
```

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RDF individuals
- Proposed transmission (**prov:Activity**)
- Associated requester (**prov:Agent**)
- Time frame (**prov:startedAtTime**/ **prov:endedAtTime**)
- Location (**prov:Location**)
- Requested frequency (**sio:Attribute**)

Description Logics
- Classification
- Realization
- DL query
`:request rdf:type <policy>`

Traverses the policy hierarchy (**rdfs:subClassOf**) to identify unsatisfied rules that would turn the DENY effect into a PERMIT

Requests

Request evaluation engine

GeoSPARQL

OWL reasoner (HermiT)

Precedence evaluation

Evaluation explanation

- Request ID
- Policy ID
- Effect
- Obligations
- Explanations

`:location geo:sfWithin <named_location>`

Resolves conflicts when multiple policies are applicable

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The DSA Policy Framework in use

Exercise duration	~20 minutes
Number of high-level policies (NTIA policies)	85 policies
Number of local policies	11 policies
Number of involved physical radios	4 radios
DSA radios' rate of frequency change	Every minute
Number of transmission requests	450 requests
Number of calls to the evaluation API	~23 calls
Number of transmission requests per API call	~20 requests
Evaluation API response time	< 10 seconds

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Advantages of Semantic approach

- Creation of machine-readable **policies in a vocabulary closer to the original textual policy**
  - **Background knowledge is represented as a Knowledge Graph**, created and curated by domain experts, encapsulating valuable domain knowledge
  - Semantic Web standards are used to enable the **creation of policies using recognized domain concepts**

- **Reuse of existing policies and rules** to quickly create derivatives
  - Enabled by the use of OWL subclasses

- Policy evaluation as a **classification problem**
  - **Domain knowledge is used in conjunction with policies**
  - It is able to **handle conflicting policies** and evaluate precedence
  - **Explanation of results is possible** by identifying rules that were not satisfied

- **Open ended**, accommodating the evolution of the domain and policies

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To conclude…

- The DSA Policy Framework stores policies in a **novel policy representation paradigm using OWL and PROV**

- It allows users to interact with the DSA Knowledge Graph to **create spectrum policies in a user-friendly way**

- It enables the evaluation of policies with the use of a **reasoning pipeline that mixes GeoSPARQL, OWL reasoning, and graph traversal**

- For more information on the framework's UI and user features, check our <u>Poster</u> "**The Dynamic Spectrum Access Policy Framework in Action**"

- Released assets: <u>https://github.com/tetherless-world/dsa-open</u>

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Thank you!

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