Now Radios Can Understand Each Other: Modeling Language for Mobility

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"If wireless devices are to communicate and interoperate autonomously, they first need to speak a common language." This was the main message of a paper [1] published in 2008. This paper described a need for a standardized language (MLM, or Modeling Language for Mobility) with formal syntax and computer-processable semantics in which radios could express various aspects of communications, like their hardware and software capabilities (frequency bands, modulations, MAC protocols, access authorizations, etiquettes, configurations), networks available to a user (parameters, restrictions, costs), security / privacy issues (constraints, policies), information types (QoS, priorities), local spectrum (spectrum activity, availability, propagation properties), manufacturer's concerns (hardware and software licensing policy, versions, compatibility), types of users (authority, priority), and other.

The main reason for developing MLM is to provide the flexibility necessary for future generation radios. One way to achieve this goal would be to develop communication protocols that would be capable of exchanging control messages related to many more aspects than the current protocols can provide. This would lead to an increase in the size of the headers of the PHY layer packets. But it would still be limited by the size of the header fields. Another way would be to define a large vocabulary of control messages and then include such messages into the payload. Such control messages could be expressed in XML and each message would need to be interpreted by the radio software. This would give a great flexibility, but it would also require that radios had procedural code for interpreting each kind of control message. And yet another way is to give radios a formal language with computer-processable semantics in which any control message could be encoded, provided that it can be expressed in terms of an ontology shared by the radios. This approach does not require the existence of a separate procedure of each type of control message, but instead, a generic interpreter (an *inference engine*, or *reasoner*). This is the approach advocated in this paper.

The main advantages of this approach are: (1) a great flexibility in terms of the number of possible message and query types (practically unlimited), (2) an increase in communications efficiency due to the ability of sending only parts of messages, while the rest of information can be inferred locally by the reasoner based on the generic knowledge encoded in the shared ontology, (3) the ease of the adaptability to changes in the message/policy vocabulary (only the ontology needs to be modified, while the procedural code remains unchanged).

It is expected that the MLM language will provide new opportunities for various stakeholders. In particular, it is expected that by using MLM vendors of the radio software will be able to develop next generation interoperable radios independently.

In this paper we report on the progress made since the publication of [1]. The main achievements during this period were: (1) Development of the first version of the Cognitive Radio Ontology (CRO); (2) Implementation of the Link Optimization demonstration in which two radios collaborate on establishing communication parameters of transmissions. The most important aspect of this demonstration is that the radios do not use any special signaling protocol, but instead exchange messages (in the payload) expressed in terms of the ontology. A reasoner on each radio infers then how to act, depending on the information (or request) received from the other node and on its own configuration (self-awareness).

CRO: Cognitive Radio Ontology

An ontology provides a shared vocabulary, which then can be used to model the knowledge about a specific domain. An ontology captures the type of objects/classes (or concepts) that exist, their properties (attributes) and relations among concepts.

The MLM Working Group (MLM WG) of the Wireless Innovation Forum developed a Cognitive Radio Ontology (CRO). The ontology has been approved by the Wireless Innovation Forum and thus it is a public document [2]. CRO covers (1) the basic terms of wireless communications from the PHY and MAC layers; (2) the concepts needed to express the use cases developed earlier by the MLM WG; (3) partial expressions of the FM3TR waveform (structure and Finite State Machines) and the Transceivers Facilities APIs. The CRO is formalized in the Web Ontology Language (OWL). It includes 230 classes, 188 properties and various constraints. Here we show only the top-level classes of this ontology (**Error! Reference source not found.**). The rationale behind some design decisions of this ontology is partially described in [3].

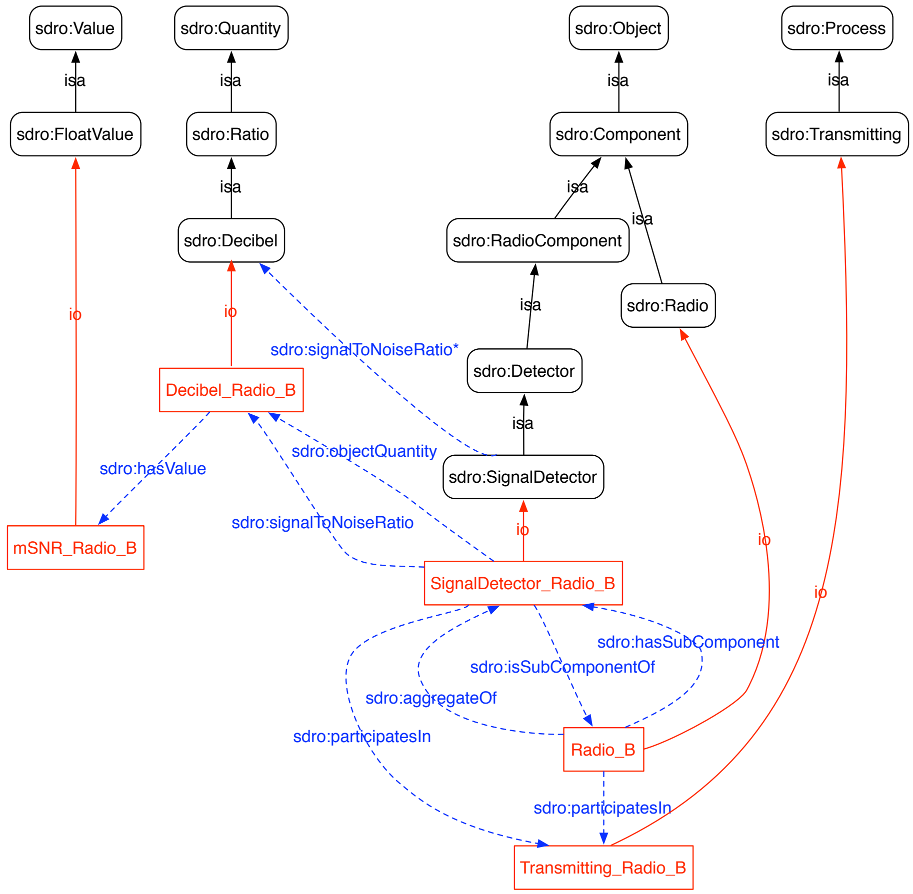

Figure 1. A small part of the CRO ontology

According to this ontology, concepts are classified as either *objects* or *processes*. Both objects and processes can have associated *quantities* (parameters) expressed as *values* in a given *unit of measure*. Concepts are related via various relations; here only a few are shown. For instance, *Decibel_Radio_B* is the *signalToNoiseRatio* of *SignalDetector_Radio_B*, which *hasValue mSNR_Ratio_B*.

The most basic relation that links objects and processes is *participatesIn*, i.e., an object can participate in a process. In the example shown in Figure 1, objects *Radio_B* and *SignalDetector_Radio_B* both *participateIn* a process called *Transmitting_Radio_B*. Another basic relation is the relation of aggregation. For objects it is the *partOf* (or *aggregateOf*). For processes, it is *subProcessOf* (or *hasSubprocess*). In Figure 1, *Radio_B* is an aggregation of *SignalDector_Radio_B*. Note that *hasSubComponent* is a sub-property of *aggregateOf*; its inverse property is *isSubComponentOf.*

Qualities are the basic attributes or properties that can be perceived or measured. Qualities cannot exist on their own; they must be associated with either an object or a process. All the qualities have values and some qualities have unit. The qualities without units are represented as data-type properties. The qualities with units are associated with a type of quantity.

Quantity is a representation of a property of an object. In other words, quantity is a representation of quality. For instance, a physical quantity represents a property of a physical object. Quantity carries three types of information: the type of the quantity (e.g., mass, length), the magnitude of the property (typically a real or integer number) and the unit of measurement associated with the given magnitude (e.g., [*kg*], [*m*]). In this ontology, quantity is a top-level class; it is further divided (sub-classified) into different types, such as length, frequency, time, etc. Each *quantity* is associated with a unit and a value.

Note that there is no explicit *Quality* class in our ontology. Instead, we use *objectQuantity* and *processQuantity* to represent the quality of an object or a process, as shown in **Error! Reference source not found.**.

MLM Based Link Optimization

We use a link optimization use case to demonstrate how MLM can be used to achieve automatic adaptation in cognitive radio. This demonstration has been implemented on the GNU Radio USRP1 platform and exhibited at the 2010 Software Defined Radio Forum Technical Conference in Washington, D.C. [4]

The general goal for this link optimization use case is to maximize the power efficiency (i.e., the information bit rate per transmitted watt of power), subject to a set of constraints. This is attained by fine-tuning the parameters in the transmitter and the receiver. Here, MLM provides a means to exchange the control messages between the transmitter and the receiver.

In short, the goal is to minimize the following objective function:

$$objFunc = 10^{\frac{PowdB}{10}} \left[\frac{528 \cdot (1 + \frac{m}{2^m - m - 1})}{v} + trainPeriod \right]$$

In this objective function, there are four tunable variables (*knobs*): (1) *PowdB* - the transmitter power, (2) *m* - the hamming code index, (3) *v* - the QAM modulation index, and (4) *trainPeriod* - the length of the training sequence.

In this demonstration, each radio has an inference engine (System Strategy Reasoner, or SSR for short), as shown in Figure 2. The SSR has three types of inputs: (1) the T-Box, which is the CR ontology that defines the common static knowledge shared by the two radios; (2) the R-Box, which is the policies specified in MLM, describing how to react to particular situations; (3) the A-Box, which are the dynamic facts about some knobs and meters that are only available as the radio is operating. The two radios interoperate by exchanging control messages expressed in terms of CRO.

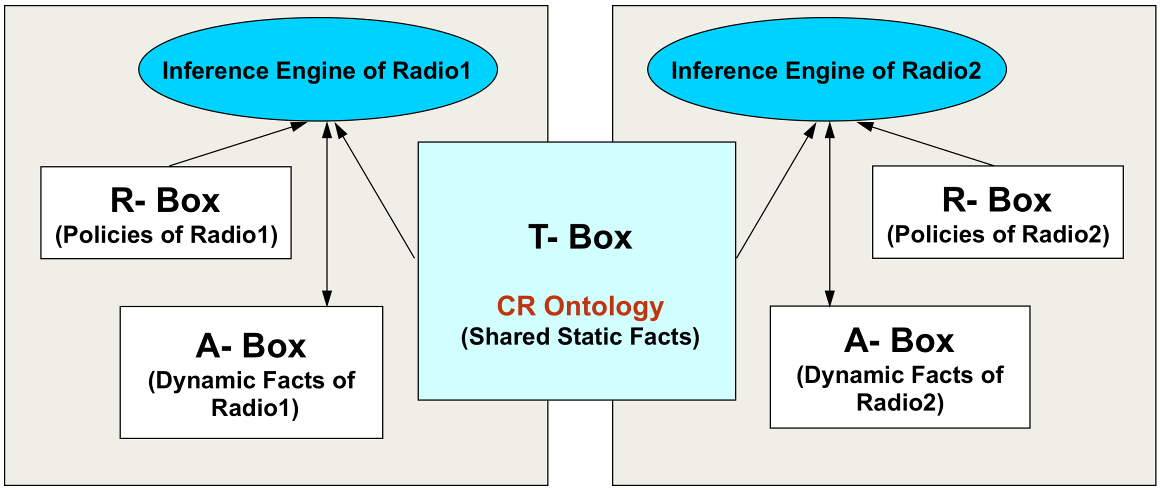

Figure 2 Inference Engine, Ontology and Policy

Figure 3 shows the architecture of this cognitive radio. All the incoming messages from the RF are first processed by the Radio Platform. Data messages are passed to the radio application (we call it Data Sink), whereas control messages are passed to the SSR. Similarly, all the outgoing control messages are generated by the SSR and then passed to a buffer. Data and control messages are then merged and passed to the Radio Platform. After being processed in the Radio Platform, the messages are sent out through the RF.

In addition to describing various parameters related to radio communications in terms of CRO, radios need to also implement *communication acts*. For instance, a node needs to understand whether a specific piece of information is a query, a request to perform a specific act (like set the value of a variable to a given value), or information about a variable's value of the transmitter. To achieve this level of interaction, we used the FIPA[1] Agent Communication Language (ACL) message structure, which provided the envelope for radio control messages. FIPA ACL is a specification that helps ensure interoperability between agents by providing a standard set of ACL message structures. The ACL part of the message indicates what kind of communication act it is. The inner part is the content of the control message described using MLM. The incoming control messages are first processed by the Monitor Service (MS), which unwraps messages, generates acknowledgments and other interactions with the MS of the other radio, and passes the MLM content to the SSR. The inference engine of the SSR interprets the content and makes decisions accordingly, passing replies to the MS for sending to the other nodes.

[1] The Foundation for Intelligent Physical Agents

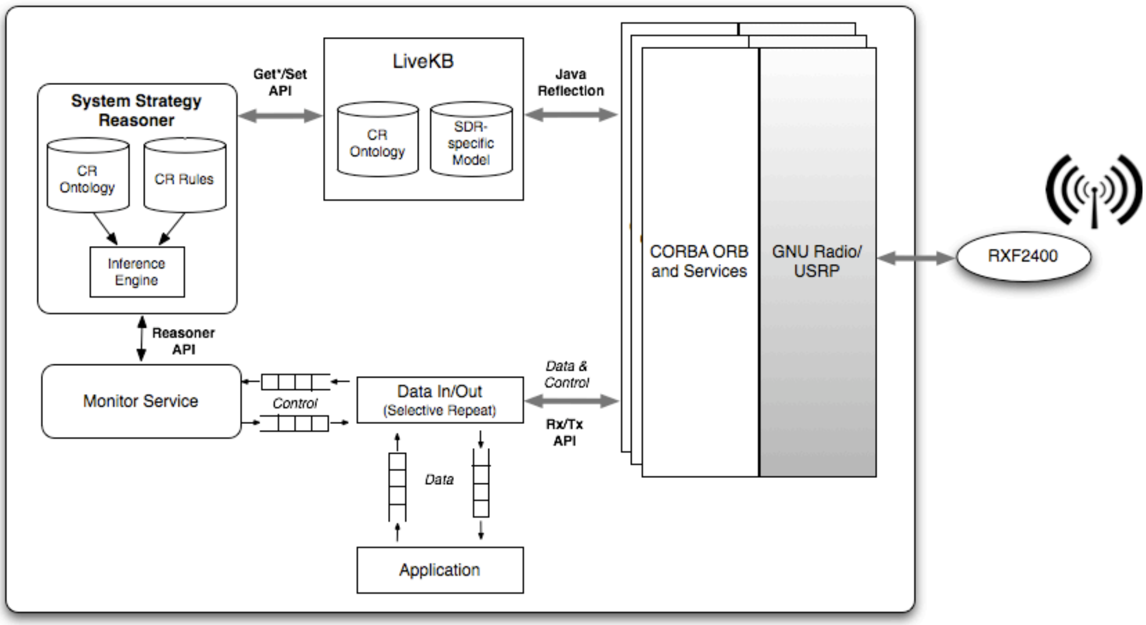

Figure 3 Architecture of Ontology-Based Radio

Figure 4 shows the demonstration results of the adaptation of the communications parameters of the two GNU radios. These plots show the mean SNR at the receiver and the power efficiency of the communications link. When the SNR falls out of the bounds of the predefined values, according to the policy of the transmitter, the transmitter power is adjusted in order to increase the overall power efficiency while keeping the mean SNR within the acceptable range. It can be seen that when the mean SNR at the receiver is too high, the two radios will exchange their parameters and a lower transmitter power is used at the transmitter, thus increasing the power efficiency. Conversely, when the mean SNR is too low, they will decrease the transmitter power and thus decrease the power efficiency.

Conclusion and Future Work

In summary, this paper has shown the main ideas behind the development of MLM – Modeling Language for Mobility. First, the main components of the rationale behind this development were discussed. Then the Cognitive Radio Ontology developed by the MLM WG of the Wireless Innovation Forum was briefly described. And finally, the results of a successful demonstration of the use of the ontology and of MLM for the purpose of link optimization was described.

While the link optimization implementation clearly demonstrated the feasibility of the ontology and MLM based approach to radio interoperability, more work is needed to make this capability fully operational. In particular, the CR ontology needs more work to provide more expressiveness in characterizing various radio configurations, waveforms and behaviors. Second, more use cases need to be developed to test the expressiveness of CRO and MLM. MLM Work Group will welcome contributions to this mission.

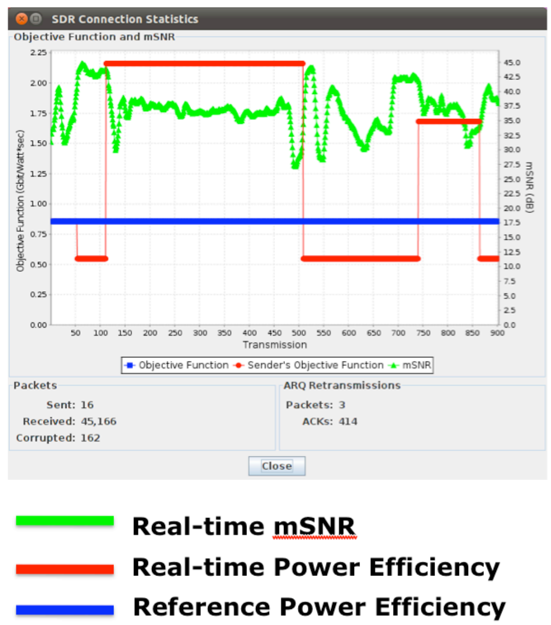

Figure 4 Implementation Results

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[1] B. Fette, M. M. Kokar, and M. Cummings. Next-Generation Design Issues in Communications. *Portable Design Magazine*, No. 3:20-24, 2008.

[2] WIF Forum MLM Working Group, "Description of Cognitive Radio Ontology v.1.0", 2010. Available at http://groups.winnforum.org/d/do/3370.

[3] S. Li, M. M. Kokar, D. Brady, "Developing an Ontology for the Cognitive Radio: Issues and Decisions", SDR Forum Technical Conference, Dec. 2009.

[4] S. Li, M. M. Kokar, D. Brady, and J. Moskal. Collaborative adaptation of cognitive radio parameters using ontology and policy approach. In *Software Defined Radio Technical Conference, SDR'10*. SDRF, 2010.