DESCRIBING RADIO HARDWARE AND SOFTWARE USING OWL-DL FOR OVER-THE-AIR SOFTWARE DOWNLOAD AND CERTIFICATION

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ABSTRACT

Recently, several researchers have discovered the need for radios to use description techniques. Previous research shows how information such as the current frequency band and waveform can be specified. However, these techniques fall short of describing waveforms at a level sufficient to determine software/hardware compatibility for over-the-air software download. For example, a device should not attempt to download a wideband waveform if its radio frontend is only narrowband. We use OWL-DL to describe the capabilities of the hardware and the requirements of the software. As a result, the problem of testing the compatibility of a radio device with specific software is reduced to the problem of checking for satisfiability is an OWL-DL knowledgebase, which can be performed using automated theorem provers.

1. INTRODUCTION

Consider the scenario where a user wants to download a communication program on a software defined radio (SDR) device ([10]). This software may or may not be compatible with the device. For example, if the device supports only the Bluetooth air interface standard (AIS), then it will not be able to operate software that requires Wi-Fi capabilities. The general problem is that of determining whether the communication capabilities of a SDR device are compatible with the communication requirements of software that can be potentially downloaded on the device.

Solving the compatibility problem will allow the user to automatically test whether the software they want to download can be used on their SDR device. It may be the case that the user has access to numerous software products and knowing which ones are compatible with their device is crucial.

The problem of deciding whether the capabilities of the software that is a candidate for download match with those of a SDR devise is not trivial. The reason is that the capabilities of different SDR devices and the requirements of different communication software are very diverse. Different vendors provide products with distinct characteristics and capabilities and therefore it is difficult to describe all products in a standardize way. For example, it is not enough to denote that a SDR device has two antennas; we also need to describe the type of the antennas and the properties of the antennas. For example, relational database technology is not rich enough to capture such unstructured knowledge.

Existing solutions list the minimal requirements for the software that is available for download. The user needs to manually check whether their SDR device meets these requirements before downloading it. However, if the number of potential software products to download is big, then doing this check manually will be unfeasible. Moreover, a list of the minimal requirements presents a very coarse-grained picture of the software. It is very possible that a SDR that does not meet these minimal requirements can still utilize the software to its full potential.

We propose that both the SDR devices and the communication software for them be described as OWL-DL knowledgebases ([7]) over the same ontology. Then the problem of deciding whether the communication capabilities of a software product are compatible with those of a SDR device will be reduced to checking for satisfiability in an OWL-DL knowledgebase. Although the later problem has exponential complexity, there exist commercial implantations (e.g., Racer ([8]) and FaCT++([9])) that perform the satisfiability check in reasonable time.

One limitation of our approach is that both the capabilities of the SDR device and the requirements of the communication software need to be described by a domain expert. Although this task is time-consuming, it needs to be performed only once. This work is significantly less than manually checking for the compatibility of every possible SDR device – communication software pair. Another limitation of our approach is that both the capabilities of the SDR device and requirements of the communication software need to be described in a formal language over the same ontology. In other words, in order for the compatibility test to be reliable, it must be the case that all SDR devices and communication software reference the same standardized ontology that describes the domain of SDR devices and software. The design of such a modeling language must fully meet the goals and objectives of all roles in the wireless value chain across the entire life cycle, including Network Operators, Equipment Vendors, Software

Vendors, Semiconductor Vendors, Component Vendors, Regulators and End Users.

2. RELATED RESEARCH

The idea of standardizing the language that describes the components and characteristics of a SDR device is not new (see for example [4]). This language has variously been called a Metalanguage [1-6], a policy language [7], a Functional Description Language, a Network Description Language [8], etc. [9-10]. This language allows radios and networks to autonomously negotiate with each other to specify and configure themselves in an optimal fashion given their capabilities, environment and the objectives of their users. The novelty of the paper is that this language is fixed as OWL-DL and we show how the language can be used to test for compatibility between hardware and software.

2. THE NEED FOR NDL

An ontology is a data model that represents a domain, describes the individuals in the domain, the constraints on the individuals, and the relationships between the individuals. In the radio world these in will include handsets and their subcomponents such as RF sections, DSPs, and application processors and the capabilities of the components. Constraints will include the antenna capabilities, DSP capabilities, and power amp limits. Beyond handsets we expect the network capabilities technical specifications and service capabilities to described via ontologies.

A system that can make full use of the flexibility of modern wireless systems must be able to identify the specific applicable objects in its domain description when confronted with a particular request for service, handset. For example, it must be able to match a request for bandwidth against service providers and handset capabilities. Candidates for supporting this feature of the Metalanguage include Description Logics, subsets of first order logic that efficiently model classes of objects. An example of description logic from the Semantic Web community is the Web Ontology Language OWL-DL. Depending on the degree of exactitude needed in the representation, larger subsets of first order logic may be needed, but at the possible cost of computational tractability.

In addition to modeling the objects in the radio world, the metalanguage must provide a protocol for exchanging information about the supported objects and for resolving conflicts when capabilities and requests do not match. The negotiation language allows parties to state their requirements and capabilities and find shared operating regions. The messages associated with the protocol exchanges can be modeled using OWL-DL.

As a radio moves between air interface standards, services, networks and operators, it may change its configuration. The configuration and capability of a radio can change also as a result of software downloads. Since the number of possible configurations even of a single device is very large, networks cannot store all possible configurations of all devices in a database.

These developments require description techniques for identifying the various objects in the wireless universe, their configurations and capabilities, and the services that the users are requesting. What needs to be described is the current configuration of a radio, its potential configuration / functionality, the characteristics of current and potential waveforms and Air Interface Standards (AIS's), the type of information being handled, the environment (spectral, physical/geographic, and in some cases situational such as whether special emergency conditions exist) and the type of end users involved. In a world with low levels of volatility, small numbers of radio types, modes of operation, end-user services, and simple, fixed economic relationships between carriers the construction of formal descriptions is not required. Then all the necessary information can be stored in centralized databases. In real world networks, the high level of volatility, and the very large number of possible configurations, combined with heterogeneity make it impossible for a centralized database to keep an accurate and current representation of "the" configuration.

A system that can make full use of the flexibility of modern wireless systems must be able to identify the specific applicable objects in its domain description when confronted with a particular request for service. For example, it must be able to match a request for bandwidth against service providers and handset capabilities. In addition to modeling the objects in the radio world it is necessary to have a protocol for exchanging information about the supported objects and for resolving conflicts when capabilities and requests do not match. The negotiation language allows parties to state their requirements and capabilities and find shared operating regions.

3. THE RDF AND THE SEMANTIC WEB

In scale, the Web is analogous to a ubiquitous wireless network. It has billions of devices and a huge amount of information. However searching by keywords yields mostly irrelevant information. The search capabilities are limited, because web-browsers do not understand the meaning of the data that is exchanged. The idea of the Semantic Web is to solve this problem; it tries to make it easier for computers to understand the meaning of data, so that they can navigate autonomously through the information. In 2000 the Semantic Web initiative was started by the World Wide Web Consortium (W3C).

The concept of ontology is important. Ontology is a data model that represents a domain, describes the objects in the domain, the constraints on the objects, and the relationships between the objects. In the radio world, these objects will include handsets and their subcomponents such as RF sections, DSPs, and application processors and the capabilities of the components. Constraints will include the antenna capabilities, DSP capabilities, and power amplifier limits, etc. In addition to devices and handsets, we expect the network capabilities, technical specifications, and service capabilities, etc. to be described via ontologies.

The Resource Description Framework is a W3C recommendation and is a lightweight implementation of semantic web capabilities. The Resource Description Framework (RDF) was created to define terms using URIs (URIs is a superset of URLs) in an XML syntax. It allows for the creation of schemas.

The Resource Description Framework is a method for representing information about resources, i.e. metadata. It allows the metadata to be exchanged without loss of meaning. It is a lightweight ontology system describing things using triplets, e.g. subject, predicate, object. The subject is the resource being described. The predicate is a property of the subject, and the object field contains the value of this property. For example, device, frequency band, 700 MHz, is an RDF triplet. Using these triplets a graph can be obtained, with subjects and objects as vertices, and properties as edges. This graph form is the underlying format of RDF descriptions, meaning that sequence or syntax does not matter. Another feature of RDF is to point to other descriptions.

The use of RDF has several advantages. One reason for choosing RDF is that it can support multiple ontologies, which may even overlap. Another reason for choosing RDF over XML is extendibility. RDF applications do not have to understand the complete description. They look for parts they can understand and ignore the rest. This allows the ontology to be extended, while maintaining complete backward compatibility. The available tools and parsers provided by the Semantic Web community are another reason for choosing RDF. Yet other advantages are the numerous libraries available for all major programming languages, making it very easy to develop new applications for it. All implemented libraries make simple data access straightforward. For more complicated operations on the data, there is SPARQL, an SQL-like query language for RDF, which is also implemented in most RDF libraries.

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4. SOFTWARE DOWNLOAD USE CASE

In this scenario shown in Figure 3-3, a user requests a service from the handset (Service requests can come from the infrastructure or from the radio in response to environmental conditions. For simplicity these are not considered in this use case.). If the requested service is within the handset's currently configured capabilities, the service is initiated. If not, the MLM reasoner[1] searches its local Repository for software code modules (Software) that will allow satisfaction of the request. If such Software is found, the MLM reasoner installs it. If not, the MLM reasoner asks the infrastructure if it can provide the Software for the requested service. If yes, the reasoner obtains a description of the software. The MLM reasoner then checks the Software to determine that the Software is from a Trusted Source (indicated by the appearance of a cryptographically protected certificate, then checks the Software's Message Authentication Code (MAC) to determine that the Software and its attached MLM description has not been changed in transit, and finally using the Software's MLM description and the radio's MLM description determines that there is no conflict and that the software can actually be run on the hardware. If all of these "tests" are satisfied, the Software is installed and the requested service is established.

4. SOFTWARE CERTIFICATION USE CASE

Consider the case where a software vendor (SW Vendor) creates a new Software module and then presents its Software and its MLM description to an Approved Certification Lab. The Certification Lab checks the software to determine if the MLM description is accurate and adequate. The Certification Lab may install the module on a selected set of radios and/or simulate its operation on a selected set of MLM descriptions of radios. If the Lab finds that the SW Vendor's MLM description is accurate and adequate, it approves release of the Software with the approved MLM. The SW Vendor releases the Software with its attached MLM description all MAC protected.

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[1] In earlier literature, the SDR Forum has called this function the MLM reasoner (see SDR Forum TR2.1 for the basic MLM reasoner architecture. *The internal structure of the MLM reasoner to support MLM was presented at the 2006 SDR Technical Conference, but it did not appear in the Proceedings In that presentation the role of the MLM Reasoner is shown.*). Current cognitive radio literature call it the MLM reasoner [ref fette], and it monitors functional requests and manages the air interface standard.

4. HARDWARE DESCRIPTION

Most wireless communication systems employ a Transceiver (Transmitter/Receiver), sometimes called a Radio Frequency Front End (RF FE) located between the antenna (and associated front end switches, filters, etc.) and the baseband subsystem (see Illustration 6.1). The requirement for more cost-effective and reconfigurable SDR Transceivers grew out of the appearance of reconfigurable Baseband subsystems and, therefore, to some extent has lagged the development of Baseband SDR approaches.

The basic functions of the Transceiver are:

- Down/Up Conversion,
- Channel Selection,
- Interference Rejection,
- Amplification.

Down Conversion is required for receivers. A receiver subsystem takes the weak signal from the antenna, converts [*Down Conversion*] the signal from the transmission radio frequency (high - RF) to baseband frequency (low – typically low end of the desired signal will approach zero Hertz), filters [*Interference Rejection*] out the noise (from external sources out of band / in band, and internally generated sources) and unwanted channels [*Channel Selection*], amplifies [*Amplification*] the signal to a level that can be used efficiently by the rest of the system and delivers the signal to the baseband subsystems.
Up Conversion is required for transmitters. A transmitter subsystem takes the signal (much stronger than the received signal at the antenna, but much lower power than the signal to be transmitted) from the Baseband subsystem, converts the signal up from baseband frequency [*Up Conversion*] to the desired transmission radio frequency, amplifies the signal to the desired transmission level [*Amplification*], filters out any noise (sometime referred to as spurious emissions) introduced in the process [*Interference Rejection*] and delivers the signal to the antenna.
Additionally, some implementations may require the Transceiver to generate control information generally relating to signal strength (such as Automatic Gain Control-AGC) and noise environments.

- 1 or more antennas. Every antenna has the following parameters
  - Center frequency – specify the range in which it can be tuned
  - Bandwidth - the range over which it can be tuned
  - The antenna(s) may be connected to a switch or an analog front-end block
- There may be 0 or more switches
- 1 or more receiver analog downconversion blocks
  - Bandwidth – again, the range over which it can be tuned
  - Receiver sensitivity – could be constant, or could be range
- 1 or more transmit analog front-end blocks
  - Bandwidth
  - Center frequency
  - Third-order intercept point
- 1 or more ADC
  - SNR – range
  - Sampling frequency – range
  - Placed at IF or placed at baseband level
- If the ADC is placed at the IF level, there will be a digital downconversion block
- 1 or more DAC
  - SFDR - generally 50 – 80 dB
- 1 or more baseband DSP module
  - MIPS – this is upper limit
  - Memory – this is upper limit

5. CONCLUSIONS

802.11a description

- Requires 1 antenna, the antenna can be connected to a switch because it is TDD

- 20 MHz bandwidth
- Center frequency greater than 5.25 GHz and smaller than 5.825 GHz
- Receiver sensitivity smaller than -82 dBm
- MIPS greater than 9000

802.11n description

- Requires 4 antennas
- 40 MHz bandwidth
- Center frequency greater than 5.25 GHz and smaller than 5.825 GHz
- MIPS greater than 50000

Examples:

1) A device wants to download 802.11n. Does the device support MIMO?

Example of an architecture that does not support MIMO. There are multiple RF chains, but only one can be connected to the antenna at one time.

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