CoordSS: An Ontology Framework for Heterogeneous Networks Experimentation

Valentina Nejkovic, Filip Jelenkovic, Milorad Tosic, Nenad Milosevic, and Zorica Nikolic

Abstract — **Experimenting with HetNets environments is of importance because of the role that such environments have in next-generation cellular networks. In this paper, the CoordSS ontology experimentation framework is proposed with an aim to support experimenting with HetNets environments on wireless networking testbeds. In the framework, domain and system ontologies are adopted for formal representation of the knowledge about the context of the problem. This paper outlines implementation details of ontologies in the CoordSS experimentation framework. The synergy between semantic and cognitive computing is introduced as the theoretical foundation of the paper.**

Keywords — **ontology, semantics, cognitive, computing, spectrum sensing, wireless, networking testbed, LTE-U, Wi-Fi**

I. INTRODUCTION

HETEROGENEOUS networks (HetNets) comprising different radio access technologies, such as GSM, WCDMA, LTE, and Wi-Fi, are viewed as a promising direction for next-generation cellular networks. In spite of intensive ongoing HetNets developments, there still exist open challenges regarding new practical deployments, such as coordination mechanism in LTE unlicensed (LTE-U) infrastructures, different technologies co-existence, etc.

Practical evaluation of new methods and mechanisms in HetNets environments is provided by networking testbeds. A promising environment that provides services and applications for experimental testing of LTE solutions to research community as well as industry is FIRE LTE testbeds for Open Experimentation (FLEX) [1]. As a part of FLEX, Coordination by Spectrum Sensing for LTE-U (CoordSS) provides a framework for experimentation with coordination mechanisms and co-existence within LTE-U based HetNets. The main aim is to provide support to experimentators working with HetNets based on spectrum sensing [2].

This paper proposes addressing the challenge of heterogeneity in Spectrum sensing (SS) experienced by experimentators working with radio devices that have different SS capabilities composing a self-organizing cognitive system by means of ontologies. The CoordSS ontologies experimentation framework (OEF) for management of semantics in such environment is proposed.

The OEF is evaluated in experiments that include automatic coordination protocols where LTE-U and WiFi users equipment share knowledge about available spectrum. A FLEX testbed, Network Implementation Testbed using Open Source platforms (NITOS) [3], is used as testing environment.

The CoordSS OEF consists of domain and system ontologies. They specify semantic descriptions of radio spectrum, coordination, frequency selection, dynamic spectrum access, command line, wireless, and spectrum sensing capabilities of supporting software. The framework facilitates a knowledge base of services and resources based on the set of developed ontologies [4], [5]. With a goal to provide more details about the role that ontologies have in HetNets, this paper first introduces fundamentals of semantic and cognitive computing aspects and then explains their role in providing a solution to the adoption of spectrum sensing for coordination in the HetNets domain.

Section II of this paper gives a background on networking testbeds and semantic technologies, because CoordSS OEF is evaluated on experiments with spectrum sensing and LTE-U using networking testbeds. This section gives a short introduction to OMF framework first, and then introduces OEF ontologies as the crucial constituent part of the framework. Semantic and cognitive computing aspects are given in Section III. Section IV is the main part of this paper where the CoordSS OEF hierarchy is introduced and discussed. Section V gives OEF practical implications. The last section is Section VI, which concludes the paper and gives some directions to the future work.

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II. BACKGROUND

A. Networking testbeds

Networking testbeds find their usage as platforms for conducting testing for algorithms, computational tools and new technologies. They are significant and popular due to application-like testing environment available to researchers which is more realistic than what is the case in simulation and emulation. Traditionally, testbeds were built for specific purposes of projects and specific research on new theories and technologies. Today their usage is much wider and open for testing by a global community on new platforms and environments.

There are a number of networking testbeds, such as: Nitos [3], Orbit [4], Fibre [7], PlanetLab [8], etc.. For example, Nitos testbed is deployed to have an interior and exterior component at the University of Thessaly's campus building. It has approximately one hundred nodes, consisting of three different hardware types with different performance characteristics. Control and management of the Nitos testbed is based on the OMF [9].

Due to promising experiences with experimenting on testbeds, federations of multiple testbeds, such as Future Internet and Distributed Cloud (FIDC) testbeds, have attracted attention of the research community. FIDC testbeds provide different options and features to experimenters. They represent heterogeneous federations of collaborating resource providers. They support different networking and computing experiments, and storage resources, as well as programmability of resources from low level hardware to virtualized components [15].

The most popular testbeds federations on national level are, for example: The Federation for Future Internet Research and Experimentation (Fed4FIRE) [10], Global Environment for Network Innovations (GENI) [11], Future Internet Testbeds Experimentation Between Brasil and Europe (FIBRE) [12], National ICT Australia (NICTA) [13], Network Virtualization Testbed (VNOde) [14]. This trend is continued with an intercontinental join of several different national testbed federations, such as federation of Fed4FIRE, GENI, FIBRE, NICTA and VNode, started 2013. with a goal addressed to development of federated infrastructure that facilitates intercontinental research [15].

B. Ontologies

In order to formalize knowledge and organize information, different scientific domains use ontologies [14]. Value of data and information is improved by using ontologies due to support for proven highly effective meta-data management, among other things. They represent a formalized way of representation of human knowledge. The knowledge represented by ontologies can be processed by computers. It is scalable, distributed, agile, code-independent, understandable by machines, open, supported by communities and enterprises, standardized and manageable.

By using ontologies, knowledge can be organized as: 1) a set of concepts and properties for these concepts; 2) a set of facts associated with the concepts. According to how we organize knowledge, different ontologies types may exist. Further, different dimensions in how ontologies organize knowledge can be identified [16][18]. For example, authors of [18] identify two dimensions: a) expressivity and formality of the languages and b) scope of the objects described by the ontology. For the purpose of this paper, we use two dimensions to organize ontologies in the CoordSS OEF, which will be given later.

C. Networking testbeds and semantic technologies

By joining different testbeds into a global federation one can expect greater scale, flexibility and many functionalities. FIDC testbeds willing emerge as a highly heterogeneous infrastructure, which is continually in development and changing. New technologies are constantly added to existing networks being themselves very complex. Thus, we need a solution which will help in experimenting and easily adapt to new changes.

Semantic technologies and ontologies are good candidates. Semantic technologies usage can bring benefits to testbeds federations such as: 1) semantic search over a repository; 2) automatic experiment code generation. Semantic search over a repository can be two-fold: 1) searching existing similar experiments, based on semantical description of experiment, 2) searching experiments with similar results, and giving explanations of obtained experiment results. Automatic experiment code generation can be obtained by using semantic technologies for descriptions of experiments.

Testbeds can be used for conducting experiments on the latest 5G mobile networks demands and challenges. For example, coexistence of Long-Term Evolution in unlicensed spectrum (LTE-U) wireless network technology and Wi-Fi is today an actual challenge. Please note that LTE-U is a very promising technology, which offers better efficiency and robust mobility in comparison with other previously used technologies, constituents of 4G networks, such as Wi-Fi, LTE, LTE-A, etc. To the best of our knowledge, research community has already offered some solutions for LTE-U and Wi-Fi coexistence. One solution which used semantic technologies for spectrum usage coordination is given in [19]. It models the coordination as an interactive process among different agents which communicate and share specific information with a common goal of a high spectrum usage effectiveness. The knowledge in such a heterogeneous communicating network is represented by ontologies whose representation and usage is specified in a standardized way.

D. OMF

Testbeds need software tools and a set of software components for its managements. OMF is one of the control frameworks in use in two major research environments/testbed federations: FIRE and GENI [20].

OMF operates on several testbed deployments world wide with many different types of resources and technologies. It provides: a set of tools for describing and executing experiments; a set of tools for collecting experiment's results; and set of services for managing and operating testbed resources.

OMF is accompanied with a domain-specific language used to describe experiments that would run on the platform. This language is reffered to as OEDL (The OMF Experiment Description Language) [21], which is based on the Ruby language extended with a set of OMF specific commands.

III. Semantic and Cognitive computing

We believe that semantic and cognitive computing could be used to improve coordination in HetNets. In HetNets SS and coordination can be represented as an interactive process consisting of communication between distributed agents and information sharing about specific spectrum usage effectiveness [1]. Semantic computing (SC) can be used to represent conceptual agreement on vocabulary among agents in the HetNets, while cognitive computing (CC) could enable humans and agents to share and exchange descriptions of their communication capabilities and harmonize the communication.

For conceptual clarity and general understanding of SC and CC, we exemplify them using a possible scenario in HetNets. Let us consider, for example, a heterogeneous network composed of LTE-U and Wi-Fi user equipment upon the unlicensed spectrum. Situation when LTE-U user coverage overlaps with other technologies such as Wi-Fi currently operating in unlicensed bands sometimes may totally disable Wi-Fi user transmission, because LTE-U fully occupied a channel that was previously used by a Wi-Fi. LTE-U network observes the spectrum, selects the channel with the least interference, and dynamically adjusts the operating frequency.

For such a case the knowledge about SS, the capabilities of users in HetNets, etc. could significantly help.

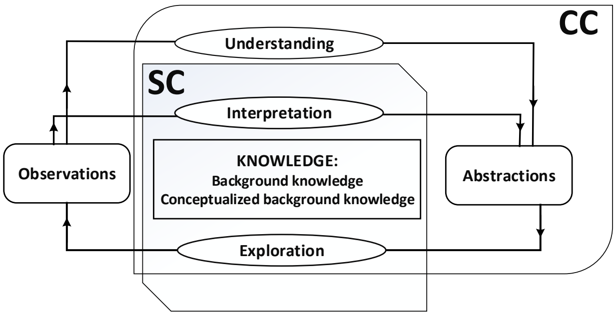

Fig. 1. Cognitive and semantic computing.

SC encompasses the understanding of users intentions, meanings of computational contents and mapping these intentions with contents [22]. SC deals with representing concepts and their relations in an integrated semantic network. The conceptual knowledge can be represented formally with ontology. Such knowledge can be used for data annotation and new knowledge production from interpreted data.

The semantic network of general HetNets domain knowledge related to SS defines the possible features and capabilities of participants in HetNets. HetNets general knowledge may be integrated with knowledge of HetNets coordination such as specific case of Wi-Fi and LTE-U co-existence.

The parameters such as band, transmission, and frequency of participants in HetNets may be observed by server. These annotated observations are in connection with general domain knowledge and context-specific knowledge (specific case of Wi-Fi and LTE-U co-existence), which lead to challenge for its interpretation. The interpretation of observations needs background knowledge, which can be presented using domain knowledge.

CC represents the use of represented knowledge, knowledge accumulation, reasoning, learning from experience, and a capability to respond to surprises in heterogeneous situations. Simply, it represents the simulation of human thought processes in a computerized [22]. Cognitive algorithms interpret data by learning and matching patterns in a similar way of cognition process from human mind. CC systems acquire knowledge from the observed data and by mining data for getting information.

Fig. 1 gives the general overview of cyclical process which utilizes and refines background knowledge to include contextualization, and which involves interpretation and exploration. The interpretation of observations leads to abstractions, which are concepts in the background knowledge. Exploration leads to actuation to seek the most relevant next observation and to disambiguate between possible abstractions.

We will examine the role of CC in the LTE-U and Wi-Fi co-existence scenario. In order to make a decision about how to avoid interference in the network where access, new network equipment contact a server for help. Let's assume that a server has information on broadband, possible interference and on different parameters of connected users in HetNets. Server has contextualized knowledge about environment as well as cognitive algorithm which can solve and give recommendation to new user equipment how to avoid possible interference. For example, which channel and frequency to take.

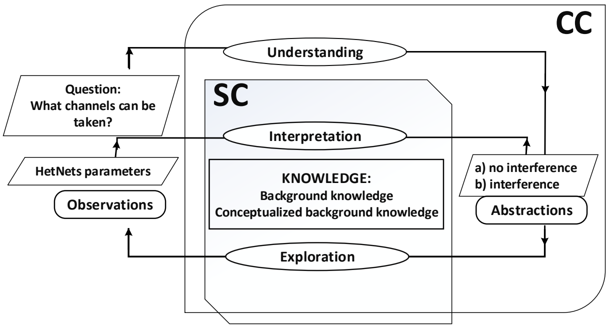

Fig. 2. LTE-U/Wi-Fi co-existence scenario to demonstrate the role of SC and CC for providing actionable information.

We adapt Fig. 1 which presents conceptual distinctions between SC and CC to the LTE-U/Wi-Fi co-existence scenario, to further exemplify the role of each paradigm. Fig. 2 provides the observations and abstractions specific to the scenario. Background knowledge contains generic knowledge of SS and HetNets, such as the fact that Wi-Fi and LTE-U may interfere in certain circumstances, etc.. This information can be obtained from a CC system which analyzes for example experiments results from this domain as well as current situation in the environment to answer a question such as: What channels can be taken? A CC system helps in understanding the environment specific situation. There are some specific questions, such as: What channel and frequencies are free in the environment? Which steps should be taken by new environment user? Does existing user which interference should change channel? Personalization of HetNets and SS knowledge on specific situation has to be done before answering these questions. Personalization of generic background knowledge can be achieved through the iterative cycle of interpretation and exploration. The abstractions indicating the coordination in the environment are much more intelligible for recommending corrective actions.

For example, in our example possible abstractions are no interference and interference, where if interference exists there are two scenarios: a) user A channel recommendation and user B replace channel, and b) only user A channel recommendation. In the first scenario a newly coming user A will obtain a proposition from the server which channel to take but the user B which may interfere with user A should replace channel at which it currently operates. The reasons why the best to user B is to change channel are out of the scope of this paper. The second scenario will offer only user A to take a free channel, without any changes reflected to user B. SC represents explicit modeling of the domain. CC generates possible solutions for a question explicitly asked by a user by utilizing unstructured data. A CC system facilitates cyclical interaction between system participants and the server for constant learning and improvement of the generated solutions to questions.

In the rest of this section, we provide an end-to-end example starting from the collected data and demonstrate the capabilities of SC and CC as shown in Fig. 3. SC makes raw data more meaningful by annotating data with semantic concepts defined in an ontology.

SC adds meaning to data for enhanced consumption, reasoning, and sharing. The framework ontology defines concepts and relationships for modeling environment observations. In Fig. 3, there are several observation types: frequency, channel and throughput of different user equipment in the environment. These raw data points represent concrete values. These raw data can be enriched by linking them through annotation to concepts defined in an ontology; in this case, frequency, channel and throughput, respectively. Annotated data is amenable to knowledge-aware interpretation, which is a valuable feature. SC provides a language to represent such concepts and allows for the linking of raw data points to concepts in the ontology as shown in the annotation step of Fig. 3. The annotated data does not have a sufficient direct value to be used for generating recommendations.

A CC with access to knowledge base and unstructured data and data on SS can provide recommendations for further actions. A CC can reveal valuable information that is otherwise hidden in massive amounts of data. Personalization involves the data on SS for deriving information of interest in relation to the given scenario. The system now has personalized data and the interpretation of current observations. Personalization for a current HetNets scenario would categorize the annotated data of frequency, channel and throughput. Interpreting frequency, channel and throughput of network users depends on the interference level of certain co-existence. Abstractions are provided by contextual interpretation. These abstractions are used to provide a recommendation to a new coming user to the HetNets.

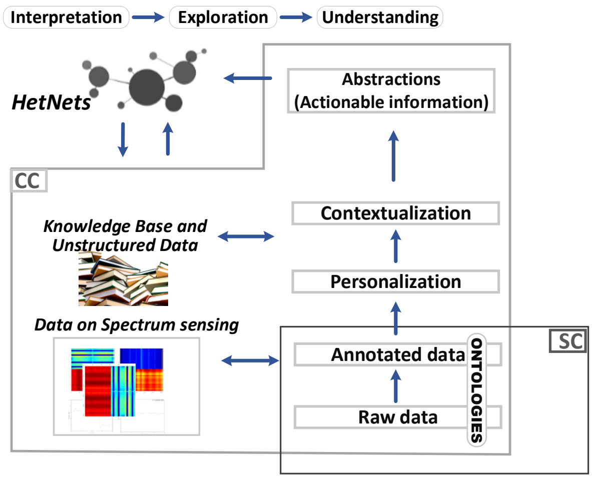

Fig. 3. Operations performed over raw data by SC and CC for the LTE-U/Wi-Fi co-existence scenario.

IV. THE COORDSS OEF

The knowledge in HetNets can be represented in a form of ontologies. We use a standardized way for this representation [4], [5].

Different knowledge dimensions of the problem in the CoordSS framework are implemented by using ontologies. Different knowledge dimensions depending on the specific application context are identified. It is possible to identify different architectures that correspond to different knowledge contexts. The Coordss framework architecture builds upon the approach originally proposed in [23]. Figs 4 and 3 show the proposed architecture.

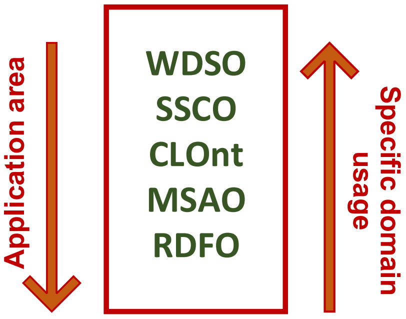

Fig. 4. CoordSS ontologies hierarchy.

A layered overview of CoordSS ontologies and its hierarchy in the framework based on the generality of the application on one side and focus of the domain, on the other side, is given in Fig. 4. CoordSS framework has layers corresponding to the following ontologies: General Wireless Ontology (GWO), Wireless Domain Connector ontology (WDSO), Spectrum Sensing Capability ontology (SSCO), Command Line ontology (CLOnt), Meta System

Architecture ontology (MSAO), Resource Description Framework ontology (RDFO). Framework has two dimensions of ontologies: a) application area, and b) specific domain usage. Ontologies closest to the bottom of the hierarchy have more general application areas represented by more wide blocks. Ontology RDFO that is at the bottom of the hierarchy represents a very general ontology. RDFO can be used to describe any concept. Moving to the top of the hierarchy, more specific domain of usage is reached. For example, WDCO is used for very close concepts descriptions in wireless radio area and important for the CoordSS framework.

The second dimension of the CoordSS ontology architecture in the manner of conceptualization and implementation is given in Fig. 5. From the top of hierarchy, WDCO gives very narrow wireless domain concepts descriptions. WDSO is in connection with GWO [14]. WDCO has a loose connection with SSCO, which is enough to connect concrete components from SS to a more theoretical view of spectrum sensing and wireless networking.

	Conceptualization	Implemenation
WDSO	Wireless domain concepts	
SSCO	Radio spectrum foundational definitions	Wiserd implementation of spectrum sensing capabilities
CLOnt	Argument and command concepts are given	Wiserd software module commands
MSAO	Entity, element and attribute descriptions	
RDFO	Value and property concepts	

Fig. 5. Coordss Framework Ontologies Overview.

The fundamental concepts for SS domain are specified in Spectrum Sensing Ontology (SSO) [23]. SSO provides foundational definitions related to radio spectrum and the basic characteristics of SS. SSO defines basic concepts related to radio spectrum, which can be used for descriptions of different aspects of spectrum sensing. The CoordSS framework covers SSCO, which provides descriptions for some resource capabilities in the SS context. The SSCO is used as a core semantic extension for the WDSO.

SS capabilities are practically considered in the context of one possible implementation represented by the Wideband Software Extensible Radio Platform (WiSER) [24]. For spectrum sensing and signal generation WiSER uses USRP. The WiSER has implementation in a form of a software demon named Wiserd [24]. Wiserd receives arguments via a command line, configures USRP for the needed task, receives data from USRP and writes results to the database. We developed Wiserd ontology, which semantically describes Wiserd software module that implements spectrum sensing capabilities.

CLOnt gives a semantic description of concepts used in a command line. Since Wiserd receives arguments via a command line, Wiserd ontology as well as SSCO is in close connection with CLOnt. MSAO represents ontology for describing in computational systems. MSAO gives descriptions of entity, element and attribute concepts. Finally, the last ontology is RDFO, which is the most generic ontology in the framework. RDFO describes value and property concepts.

V. PRACTICAL IMPLICATIONS

The CoordSS OEF is evaluated and used for: a) experimenting over testbeds federation, b) coordination in heterogeneous communication networks.

Experimenting over multiple testbeds is challenging and can be extremely useful in the following situations: a) an experiment requires different types of nodes, and none of the existing testbeds have them all; b) an experiment requires more nodes than a single testbed can provide. The Coordss OEF enables easier experimenting over multiple testbeds.

Another problem considered through the CoordSS OEF lenses is coordination in heterogeneous communication networks with no constraints in the band to operate whether licensed or unlicensed. In such environments interference among multiple wireless networks may be produced, which is a consequence of an overlapping in the usage of the same set of resources. Typically, such a case happens when the same radio frequencies are used for multiple communication channels that use different radio technologies. A coordination protocol defined by the technology standards is usually used to solve the problem when networks use the same technology.

In order to achieve efficient coexistence between different systems in an unlicensed spectrum, new coordination mechanisms should be defined. Essential coexistence is satisfied by using Spectrum Sensing, which enables detection of free parts of the considered spectrum, and listen-before-talk protocol, which supports sensing the target channel of the user before transmission. A newly added user to a heterogeneous network is able to sense free frequencies, to detect spectrum holes and occupy them without causing harmful interference to other users operating in the same spectrum. Although SS and listen-before-talk protocol have been proved effective, some problems still exist.

The main challenge is how to manage the resources in space, frequency, and device dimensions to improve the spectrum efficiency for the affected networks. The CoordSS OEF represents a base for a solution of coordination protocol based on semantic technologies and ontologies. Such a coordination protocol is practically evaluated in a series of experiments based on the CoordSS OEF on two networking testbeds [1] [19]. In such experiments, the role of the CoordSS OEF is shown in Fig. 6.

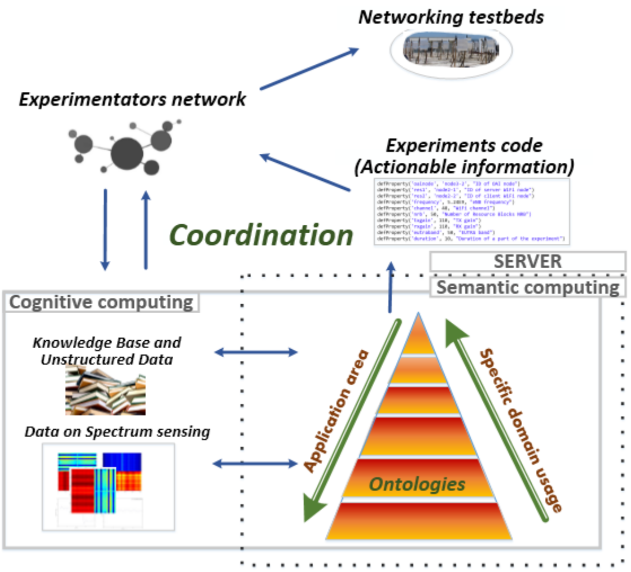

Fig. 6. Semantic coordination in HetNets: Experimenting over networking testbeds.

VI. CONCLUSION

In this paper a CoordSS OEF overview is given. In spite of the clarity, this paper also outlines and exemplifies synergy between two computing paradigms: SC and CC, from the HetNets lenses. Conceptual distinctions between SC and CC to the LTE-U/Wi-Fi co-existence scenario is presented. Based on presented clarifications, CoordSS OEF has a clear role in HetNets.

The CoordSS OEF presents a precondition for automatic code generation for experiments in the SS domain. The OMF framework and OEDL language could be used as the target platform for practical implementation of the automatic code generator. Some of the benefits of the automatic code generation approach are: 1) OEDL code can be generated based on a user's specification given at a higher level of abstraction (for example, by means of a natural language) where existing knowledge (ontologies) can be reused; 2) It will be possible to do a semantic search over a repository of existing experiments and easily find needed examples.

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