

# Semantic agent contracts for Internet of Agents

Pablo Pico-Valencia

Programming and Development of Software Department  
Pontificia Univ Católica del Ecuador, Esmeraldas  
Ecuador, Esmeraldas 080150  
Email: ppico@pucese.edu.ec

Juan A. Holgado-Terriza

Software Engineering Department  
Universidad de Granada  
Granada, 18071 Spain  
Email: jholgado@ugr.es

**Abstract**—The Internet of Things (IoT) is a current approach which aims to act on pervasive environments for connecting smart objects. These objects are capable to sense their own environment, interacting and cooperating with other devices. However, the IoT also requires to perform coordination actions that devices cannot carry out with the embedded electronic. In order to create smarter collaborative systems, the Internet of Agents (IoA) approach arises as an alternative for providing information and services to other objects, systems and people, and to initialize actions if necessary. In this paper, a semantic model of public agent contracts based on OWL ontologies enriched with Open Linked Data has been proposed as a fundamental way to describe standard collaborative units that can interact in a social context. The overarching ontology we have named IoA-OWL takes into account functional and non-functional aspects organized in six profiles such as agent, context, model, service, social, and object.

## I. INTRODUCTION

The era of cloud has originated that many existing model services are currently proposed based on the line “as a Service” [1]. This phenomenon called “anything as a service” (XaaS) is commonly used for supporting the delivery of Infrastructure (IaaS), Platform (PaaS), Software (SaaS), Data (DaaS), Social Network (SNaaS), among others, as an online service.

Last years the scientific community has proposed various approaches regarding the *Future Internet*. Some of them describe the Internet of Things (IoT) [2], Internet of Services (IoS) [3], Internet of People (IoP) [4], and the Internet of Agents (IoA) [5]. This last approach arises as an alternative to mitigate one of the deficiencies of the IoT regarding reasoning and social aspects. In this way, all connected objects on IoT scenarios will be able to act autonomously, collaboratively, and smartly [6] in a social context. Thus software agents will be the base for the creation of the future XaaS within the IoT paradigm.

The IoA approach is an accurate way to describe what is going on IoT. While a smart object in IoT refers to a connected device able to sense its own environment and report on it, that same object has to be able for performing reasoning actions. However, this kind of process cannot be performed by the current objects in a natural way. That is why, the IoA must deepen efforts to create smart system, but especially to build collaborative units that can interact in a social climate establishing communication with their current counterparts. The accomplishment of these actions will allow that the agents encompassing all connected things to provide information and services to other things, systems, and people.

This paper presents a semantic model for the standardization of agents for IoA based on public contracts that describe a social and collaborative unit by using an OWL ontology enriched with open vocabulary and open data structured in six profiles such as agent, context, model, service, social, and object. The rest of the paper is organized as follows: Section II presents a basic overview of the main issues related to the IoT and its necessity to evolve to IoA for encompassing all connected objects collaboratively, intelligent, and autonomously. Section III provides a semantic model of agent contracts for IoA. Finally, Section IV concludes the paper.

## II. FROM INTERNET OF THINGS TO INTERNET OF AGENTS

The IoT is one of the paradigm associated to the *Future Internet* [7] that is gaining ground with the evolution of devices and wireless technology. It proposes the pervasive presence of a variety of objects, and systems that interconnect the real world and cyberspace through the Internet [8].

The IoT approach is still under development. That is why there are not well defined standard. Nonetheless, a Reference Architecture have been proposed by WSO2. Whilst it is not a standard yet, it covers a number of systemic characteristics including interoperability, scalability, and security, privacy and integrity. Furthermore, at medium level this architecture accomplishes features such as device discovery and management, context-awareness, and management of large volumes of data. But, its main limitation is not able to build applications with capability for adapting dynamically [9].

In order to add reasoning capability to IoT systems, a layer of collaborative units capable to act intelligently and autonomously have to be included. That is why the IoA approach is lastly potentiating for helping smart objects to assistance in not predefined situations as a human would. For instance (i) an IoT application gets activated the machines in a gym based on individual profiles, while an IoA application even can recommend new extra activities to accomplish the normal routine, (ii) an IoT application for giving comfort at a home-automation controls the outdoor and indoor ambient light, while an IoA application can even pay the electricity bill or report fails in the electric system to the electricity company, (iii) if an IoT application can detect mechanical failures and notifies its owner about the problem, an IoA application even can book the nearest appointment at the garage to solve the fault, and so on.

Several approaches have been presented for the development of IoT applications, and some of them are aligned with the idea of IoA. We have analyzed various papers where the concept of agent is fused with IoT to contrast the main ideas. Mzahn proposes the *Agent of Thing* concept to everything of IoT. Each thing has an internal reasoning capability which allows to interact directly with other things in the same or in a different system type [6]. Similarly, Katasonov proposes that each resource is connected to an autonomous software agent for monitoring the state of the resource and for discovering and using external help if needed [10], while Jarvenpaa proposes the definition of mobile agents based on web technologies in the context of IoT which can move or clone between different devices [11]. Finally, Yu proposes the IoA approach as an alternative that allows end-users to actively participate in the developing or adapting of agents at various stages of the agents lifecycle [5].

### III. SEMANTIC CONTRACT MODEL FOR AGENTS OF IOA

Many proposals regarding software oriented agents have been proposed. Unfortunately as Yu asserts there are not many MASSs deployed in practical and real applications at present [5]. The main contributions done by the scientific community in this field are related to methodologies, software tools, notations for modeling, ontologies, languages for the communication between agents, among others. However, the FIPA Foundation has only standardized the FIPA-ACL language which is currently employed by software tools such as Jade, JACK and Zeus.

After investigating the website of Linked Data Project, we did not find a technical ontology to describe software agents neither social agents in the IoA domain. Therefore, we think that a formal public ontology must be created in order to help developers for describing their agents using a standard contract model similar to WSDL contract in SOAP or WADL in RESTful. In this way, the employment of the same vocabulary allows to get a higher interoperability level between IoA systems.

#### A. Upper ontology for agents of IoA

Regarding the agent approach some ontologies for describing the agent components have been proposed. Commonly, these ontologies are mainly focused to accomplish only a specific issue, e.g., modeling reactive agents (AgentOWL [12]), modeling BDI agents (SOUPA [13], ontology for agents ADL [14], CoDaMo [15], BDI workflow agents[16]), modeling mobile agents [17], modeling agent context (context [18], context-aware [19]), modeling web services (WSs) within agents (OWL-S [21], Ontia iJADE[20]), among others.

It is important to highlight that none of the proposed ontologies have been published as open data in the Linked Data Project. The unique description included in DBpedia only includes a superfluous and not technical description of software agents and intelligent agents.

Based on the best practices of WSs regarding to standard contracts, we recommend a standard ontology capable to de-

scribe agents that belonging to the IoA world employing open data. Thus, we propose the IoA-OWL ontology shown in Fig. 1 that allows creating public agent contracts for reusing the same vocabulary and for providing access to this data to agent developers. Currently, it does not exist a complete ontology like the WS area. That is why, each modeled application that includes agents is completely different to other ones without to be interoperable. We propose an upper ontology in order to be developed in any semantic language. However, we have oriented its development to OWL because it is the most extended semantic language to represent and verify rich and complex knowledge with a high and formal expressiveness that can be exploited by software agents in the web. Furthermore, we propose the adoption of OWL because many ontologies are published in this format and we can reuse the vocabularies already existing.

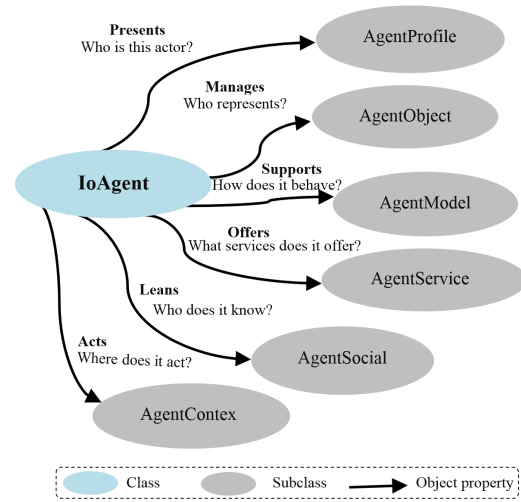


Fig. 1. Upper ontology for agents of IoA.

The IoA-OWL ontology shown in Fig. 1 provides a complete organizational point of reference to formalize collaborative units for IoA. Some concepts are previously included in some works, but none accomplishes the complete requirements of IoA to provide a description including all concepts without to be oriented to a specific issue. Six are the main object properties that compose the IoA upper ontology. The *presents property* introduces the profile of the agent, and the *manages property* links the agent with an object of IoT. On the other hand, the *supports property* specifies the components of the agent architecture, the *offers property* describes the WSs offered by the agent, the *leans property* depicts the relationships between the agents, and finally, the *acts property* represents the context where the agent operates.

In order to accomplish one of the requirements of the Linked Data we have identified some vocabularies published as open data such as *FOAF* for describing aspects of identifying agents, *Time* for describing time concepts, *location-ont* for describing location context, *computer* for describing computational resources, *m3-lite* for describing objects in IoT, *Relationship* for describing relationships between agents,

*OntoSNA* for describing the social components associated to Social Network Analysis, and *OWL-S* for describing services offered by agents. All of them are published in the website of Linked Data Project. In addition, we employed some concepts of the ontologies for agents previously cited, but we have not reused them because these ontologies are not widespread and they are not published as open data.

### B. Agent Context

The AgentContext ontology shown in Fig. 2 describes the basic information that allows characterizing the current situation of the agent entity [18]. This ontology reuses five contextual classes of the ontology included in [19], which are related to time-context, location-context, resource-context, and computational-context.

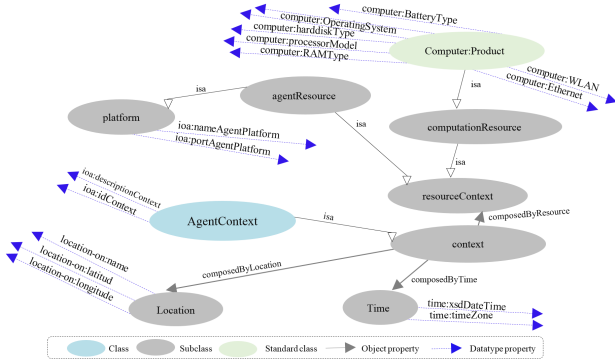


Fig. 2. AgentContext ontology for agents of IoA.

### C. Agent Profile

The AgentProfile ontology illustrated in Fig. 3 describes an IoA entity which includes four basic types of information such as the organization that provides the agent, real-time restrictions satisfied by the agents, data required for the agent, and finally agent information that certifies and validates the agent in order to avoid the code modification and to guarantee the signer is who he or she claims to be really.

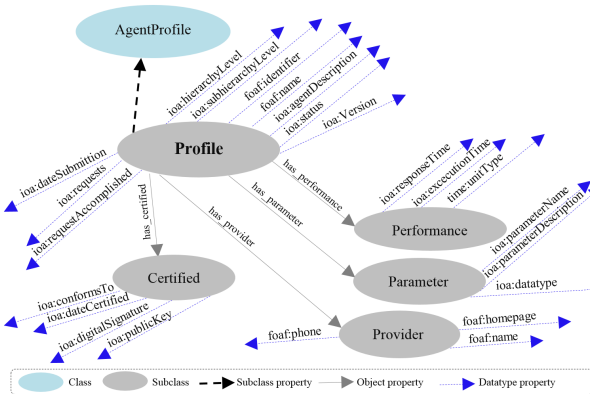


Fig. 3. AgentProfile ontology for agents of IoA.

### D. Agent Service

The AgentService ontology of the Fig. 4 describes the services offered by agents. We have employed the ServiceProfile for describing the WSs and ServiceProcess for specifying how to use those WSs. Both profiles belongs to the OWL-S ontology [21] which is widely used for describing WSs.

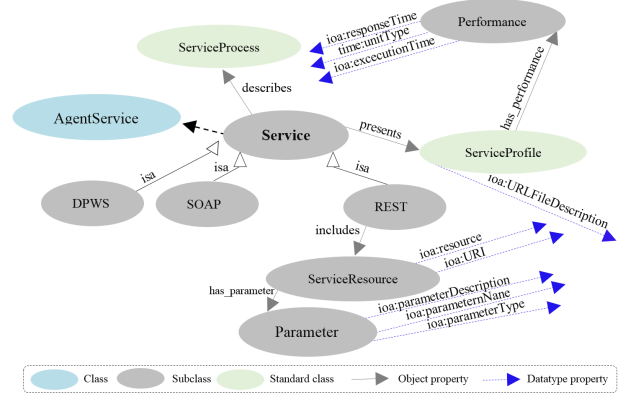


Fig. 4. AgentService ontology for agents of IoA.

### E. Agent Architecture

The AgentArchitecture illustrated in Fig. 5 is based on the AgentOWL [12] that includes concepts of reactive agents. Furthermore, we have also employed some BDI concepts included in SOUPA [13] and BDI workflows [16] ontologies. However, these ontologies are not published as open data and are not enough widespread.

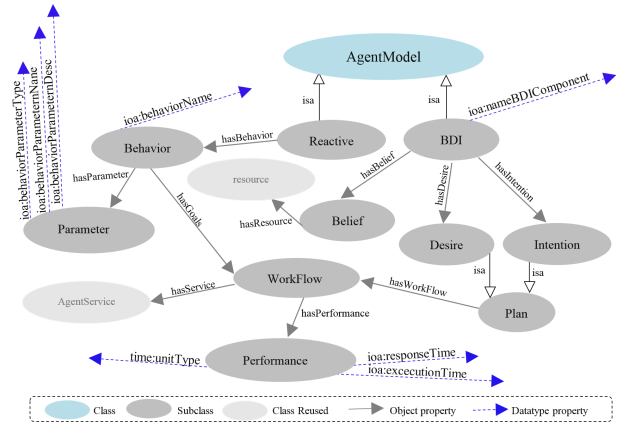


Fig. 5. AgentModel ontology for agents of IoA.

### F. Agent Social

A SocialUnit defines the features of the agents as a collaborative or not collaborative unit in IoA. When an agent is collaborative it specifies its centrality measures and relationships with other ones. Furthermore, the social ontology illustrated in Fig. 6 stores information such as density and adjacency matrix of formed social networks based on the *ioa:relationshipName* attribute.

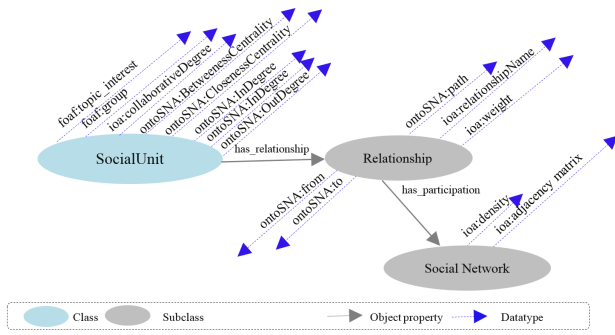


Fig. 6. AgentSocial ontology for agents of IoA.

### G. Agent Object

The AgentSmartObject ontology shown in Fig. 7 is a context ontology that describes each object connected to an IoT network. Every object is linked to an agent in order to improve the performing of actions employing reasoning mechanisms.

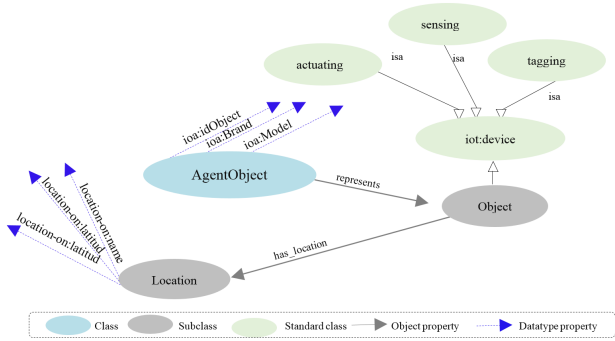


Fig. 7. AgentObject ontology for agents of IoA.

## IV. DISCUSSION AND CONCLUSIONS

The addition of an intelligence level to IoT applications in order to perform actions according to not-predefined events is a demanding need for IoT applications. In this line, the IoA approach is a good alternative that allows modeling and building semantic collaborative units capable to act in a social context.

The proposed ontological model named IoA-OWL is a semantic model of agent contracts based on OWL profiles. These contracts published as open data in the Linked Data Project pretend to be a public contract of agents in order to help developers of IoA systems the description of agents with a high and formal expressiveness level reusing the same vocabulary. In this way, a high level of interoperability can be achieved to agents of different platforms facilitating the communication and interaction between them.

### ACKNOWLEDGMENT

This work was funded by the Ecuadorian Ministry of Higher Education, Science, Technology and Innovation (SENESCYT) through the Program of PHD for university professors.

## REFERENCES

- [1] Duan, Y.; Cao, Y. & Sun, X. Various aaS of everything as a service. Software Engineering, Artificial Intelligence. Networking and Parallel/Distributed Computing (SNPD), 2015 16th IEEE/ACIS International Conference on, 2015, 1-6.
- [2] Al-Fuqaha, A.; Guizani, M.; Mohammadi, M.; Aledhari, M. & Ayyash, M. Internet of things: A survey on enabling technologies, protocols, and applications. Communications Surveys & Tutorials, IEEE, IEEE, 2015, 17, 2347-2376.
- [3] Schroth, C. The internet of services: Global industrialization of information intensive services Digital Information Management, 2007. ICDIM'07. 2nd International Conference on, 2007, 2, 635-642.
- [4] Eloff, J.; Eloff, M.; Dlamini, M. & Zielinski, M. Internet of people, things and services-the convergence of security, trust and privacy 2009.
- [5] Yu, H.; Shen, Z. & Leung, C. From internet of things to internet of agents. 2013 IEEE and Internet of Things (iThings/CPSCOM), IEEE International Conference on and IEEE Cyber, Physical and Social Computing, 2013, 1054-1057.
- [6] Mzahm, A.; Ahmad, M.; & Tang, A. Agents of Things (AoT): An intelligent operational concept of the Internet of Things (IoT). 13th International Conference on Intelligent Systems Design and Applications, 2013, 159-164.
- [7] Krajjak, S. & Tuwanut, P. A survey on Internet of Things architecture, protocols, possible applications, security, privacy, real-world implementation and future trends. 2015 IEEE 16th International Conference on Communication Technology (ICCT), Hangzhou, 2015, 26-31.
- [8] Pande, P. & Padwalkar, A. R. Internet of Things. A Future of Internet: A Survey. International Journal, 2014, 2.
- [9] Cavalcante, E.; Alves, M. P.; Batista, T.; Delicato, F. C. & Pires, P. F. An Analysis of Reference Architectures for the Internet of Things. Proceedings of the 1st International Workshop on Exploring Component-based Techniques for Constructing Reference Architectures, 2015, 13-16
- [10] Katasonov, A.; Kaykova, O.; Khriyenko, O.; Nikitin, S. & Terziyan, V. Y. Smart Semantic Middleware for the Internet of Things. ICINCO-ICSO, 2008, 8, 169-178.
- [11] Jarvenpaa, L., Lintinen, M., Mattila, A.-L., Mikkonen, T., Systa, K., Voutilainen, J.-P. Mobile agents for the internet of things. 3rd Workshop on Applications of Software Agents, WASA2013, Sinaia, Romania, 2013.
- [12] Laclavik, M.; Balogh, Z.; Babik, M. & Hluch, L. Agentowl: Semantic knowledge model and agent architecture. Computing and Informatics, 2012, 25, 421-439.
- [13] Chen, H.; Perich, F.; Finin, T. & Joshi, A. Soupa: Standard ontology for ubiquitous and pervasive applications Mobile and Ubiquitous Systems: Networking and Services, 2004. MOBIQUITOUS 2004. The First Annual International Conference on, 2004, 258-267.
- [14] Faulkner, S. & Kolp, M. Ontological basis for agent ADL, International CAISE 03 Forum on Advanced Information Systems Engineering, 2003.
- [15] D. Preuvenciers, J. V. den Bergh, D. Wagelaar, A. Georges, P. Rigole, T. Clerckx, Y. Berbers, K. Coninx, V. Jonckers, and K. D. Bosschere. Towards an extensible context ontology for ambient intelligence. 2nd European Symp. Ambient Intelligence, LNCS 3295, pages 148-159, 2004.
- [16] Liu, C.-H. & Chen, J.-Y. Using ontology-based bdi agent to dynamically customize workflow and bind semantic web service. Journal of Software, 2012, 7, 884-894.
- [17] Price, R.; Krishnaswamy, S.; Loke, S. W. & Chhetri, M. B. Towards an ontology for agent mobility. International Conference on Conceptual Modeling, 2004, 484-495
- [18] Dey, A. Understanding and Using Context. Personal and Ubiquitous Computing, vol. 5, no. 1, 2001, pp. 4-7.
- [19] W. Qin, Y. Shi and Y. Suo, Ontology-Based Context-Aware Middleware for Smart Spaces. Tsinghua Science & Technology, vol. 12, no. 6, pp. 707-713, 2007.
- [20] Lam, T. H. & Lee, R. S. Ontia iADE: an intelligent ontology-based agent framework for semantic web service. International Conference on Knowledge-Based and Intelligent Information and Engineering Systems, 2006, 637-643
- [21] World Wide Web Consortium (W3C). OWL-S: Semantic Markup for Web Services, <http://www.daml.org/services/owl-s/>, 2004.