An Agent Model Based on Open Linked Data for Building Internet of Agents Ecosystems

JAAMAS Track

Pablo Pico-Valencia
Pontifical Catholic University of Ecuador
Esmeraldas, Ecuador
pablo.pico@pucese.edu.ec

Juan A. Holgado-Terriza
University of Granada
Granada, Spain
jholgado@ugr.es

José Senso
University of Granada
Granada, Spain
jsenso@ugr.es

ABSTRACT

This paper presents an smart, collaborative and self-adaptive reactive agent model aimed at managing the resources of objects connected to Internet of Things (IoT). This agent model, called Linked Open Agent (LOA), is described using both a semantic agent contract built from descriptors published as linked data, and a workflow for agent control that is completed at runtime by the agent itself to address its behavior. The accuracy for semantic discovering agents partners was evaluated and compared with generic models of discovery such as the Yellow Pages of Java Agent DEvelopment Framework (JADE) and the Java implementation of the Universal Description, Discovery, and Integration (jUDDI). The results demonstrated that our method had a better accuracy for recovering agents than the accuracy of JADE and JUDDI.

KEYWORDS

Internet of Agents; Internet of Things; Linked Open Data; contract

ACM Reference Format:
Pablo Pico-Valencia, Juan A. Holgado-Terriza, and José Senso. 2019. An Agent Model Based on Open Linked Data for Building Internet of Agents Ecosystems. In *Proc. of the 18th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2019), Montreal, Canada, May 13–17, 2019,* IFAAMAS, 3 pages.

1 INTRODUCTION

Nowadays, many devices compatible with the communication standards used by the Internet of Things (IoT) are interconnected to the Internet [1, 2]. However, most of these devices are merely passive and have still limitations to perform autonomous communication at an inter-network level [10]. In order to provide a solution to this issue and convert IoT devices into smart objects that have a higher level of proactivity, intelligence and collaboration, the process of modelling IoT with software agents has been proposed [7, 9, 15]. Thus a new approach called Internet of Agents (IoA) [16] and a novel method called agentification of the IoT [13] have emerged.

An IoA ecosystems must be able to communicate with heterogeneous Multiagent Systems (MASs). Therefore, a higher level of interoperability between agents running in heterogeneous MASs at different levels (e.g., technological, syntactical and semantic [15]) is crucial. Then, it is essential that the IoA defines new models of agents and mechanisms for the discovery of partner agents based on emerging semantic technologies [11] such as ontologies and linked data [4] . To do it, the concept of contract in the agent domain must be redefined similarly to the contract employed in services-oriented technologies [5] and thus improve the interoperability in MASs.

This paper presents a novel model of agent capable of controlling IoT objects. The proposed agent called Linked Open Agent (LOA) is described by using a semantic contract. This contract called Linked Agent Contract (LAC) is a descriptive unit similar to the web service contracts [5] but semantic, that is, it uses an ontology (IoA-OWL [12]) to be formalized. A brief description of the elements that compose a LOA are also detailed. Furthermore, the method employed for LOAs to discover partners in an IoA ecosystem constituted by 13, 100 and 1000 agents, and distributed in three MASs is also evaluated in terms of the accuracy of data recovery.

Proc. of the 18th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2019), N. Agmon, M. E. Taylor, E. Elkind, M. Veloso (eds.), May 13–17, 2019, Montreal, Canada.

2 LINKED OPEN AGENT MODEL

LOAs follow the baselines of the 'agent-of-thing' concept proposed in [10]. This concept establishes linking a software agent to specific IoT objects so that they can behave proactively, smartly and collaboratively. In order for the proposed agent to comply with these properties, as illustrated in Figure 1, a new agent architecture has been developed.

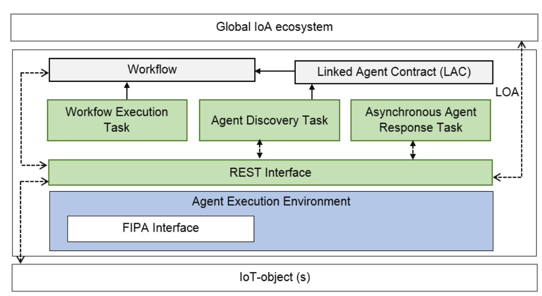

Figure 1: Architecture of a Linked Open Agent [14]

The proposed architecture integrates two elements, such as: a semantic description unit (linked agent contract LAC) described using linked data and a workflow for agent control (WAC) unit that directs the control actions that the agent must perform on the IoT ecosystem. Both units are stored with their corresponding agent and they are managed by three generic tasks including: workflow execution task, agent discovery task and asynchronous agent response task. Finally, the agent communication is realized by a REST interface that abstracts FIPA [6] communications via URIs.

In general terms, LOAs can execute semantic search and reasoning processes on the basis of the semantic information (descriptors) stored in their LAC. These descriptors follow the specifications of the IoA-OWL ontology which describes six elementary aspects that the IoA must model, that is, profile of agent, context-aware data, social context, service ecosystem, agent artifacts and IoT resources [14]. From these descriptors LOAs can explore an IoA ecosystem and retrieve data associated with external agents that can be used to complete their WAC. Thus, LOAs can select the suitable agent partners which help them to achieve their goals. Additionally, LOAs can request and support the collaboration with external LOAs running in heterogeneous IoA ecosystems. Therefore, LOAs develop features such as: autonomy, sociability and collaborative, semantic, context-aware, smart, SOA supporting and adaptable [14].

3 EXPLORATION OF THE IOA VIA LOAS

An IoA ecosystem can integrate both non-collaborative and collaborative LOAs. A non collaborative LOA uses the descriptors stored in its LAC to complete its WAC and start its operation with its own described resources. Conversely, a collaborative LOA uses the same elements; but in this particular case, LOAs have to publish their LAC content into a central repository in RDF triplets format. These triplets are the knowledge that empower LOAs for exploring the IoA ecosystem in order to recover partners which can help them achieve their goals. This exploration is done through a semantic discovery process implemented by Algorithm 1.

Algorithm 1 : LOA discovery algorithm [14]

```
Require: LOA_name (α);
Ensure: partnership_list (ρ);
 1: ω ← get_workflow(α) ;
 2: if (has_all_metadata(ω) = true) then
 3:     ρ ← null ;
 4: else
 5:     ϕ ← get_lac(α) ;
 6:     μ ← reasoning_over_ioa(ϕ, semantic_arguments) ;
 7:     if (μ ≠ null) then
 8:         ρ ← apply_selection_method(μ, selection_operator) ;
 9:         for (individual_partner ∈ {1, . . . , ρ.size()}) do
10:             ϕ′ ← get_parther_lac(ρ[individual_partner]) ;
11:             ω ← update_workflow_channel(ϕ′) ;
12:             ϕ ← update_lac_social_circle(ϕ′) ;
13:         end for
14:     end if
15: end if
16: return ρ
```

Algorithm 1 is executed by the agent discovery task according to a time constraint that the LOA must define. This constraint determines how often the LOA has to explore the IoA ecosystem. In general, the IoA infrastructure requests a single argument to perform the process. This input argument is the name of the agent (α) that launches the semantic discovery process. As result algorithm 1 returns a list of partners that satisfy the request (ρ).

The first block of actions of the algorithm checks if the WAC of the LOA is complete (lines 1-3). If this, the process is aborted; otherwise the exploration of the IoA ecosystem is initiated. Next, the algorithm loads the LAC descriptors (ϕ) of the LOA who made the request (line 5) and then, it executes the reasoning process sending both ϕ and the values of semantic descriptors on which the discovery works (line 6). Then, it is verified if the discovery process recovered something (line 7). Depending on this, the process is finished or continued. In case of recovering at least one partner, the algorithm applies a selection process that discards the worst LOAs retrieved (line 8). After that, the algorithm analyses each recovered partner and according to the descriptors of the recovered LOAs, updates the LAC and the WAC of α.

4 RESULTS

A collaborative community scenario was implemented through an IoA ecosystem composed of three MASs, one for each of the communities. Based on this scenario, three similar ones composed of 13, 100 and 1000 agents were created to evaluate the LOA model. Then, three experiments where the semantic discovery process addressed by Algorithm 1 were conducted. The results using 1, 2 and 6 descriptors (D) and their descriptor-values (V) for a LOA called $loa\_shutter\_c_2\_f_3$ are shown in Table 1. This agent controls shutters in the floor 3 of community 2 in the modelled scenario.

Table 1: Accuracy of the discovery process

	D	V	C	F^+	F'^+	T^+	T'^+	P	T^-	ACC
JADE	1	2	100	6	**6**	20	**14**	0.70	60	0.74
jUDDI	1	2	100	6	**6**	20	**14**	0.70	60	0.74
IoA	1	2	100	6	**5**	20	**15**	0.75	60	0.75
IoA	2	4	100	6	**3**	20	**15**	0.88	63	0.77
IoA	6	9	100	6	**1**	20	**15**	0.94	63	0.79

Using one D ($magnitudeofinterest$) with two V ("$temperature$", "$illumination$") the semantic discovery process recovered 14 true positive agents (T^+) and 6 false negative agents (F^-). Hence data recovery was obtained with an accuracy (ACC) of 74% for both JADE and jUDDI, and 75% for IoA —using the relationship "same as" allowed the agent to discover data that was not possible for JADE and jUDDI due to the fact of performing purely syntactic operations. ACC in this context is the degree to which the result of a discovery conforms to the correct values and is calculated from the equation: $ACC = (\Sigma T'^+ + \Sigma T'^-)/(TotalPopulation)$, where T'^+ is a true positive recovered and T'^- is a true negative recovered. On the other hand, adding one more D ($insideOf$) with two additional V ("$community\_c1$", "$community\_c2$") the discovery process was not supported by JADE and jUDDI. However, the ACC for IoA was better, this is 77%. Finally, in the latter case, Algorithm 1 could discriminate F^+ previously retrieved. This time, ACC was 79% because two more D ($meximunexecutiontime$, $bandwitdh$) with two extra V ("$54Mbit/s$", "$11Mbit/s$") were used. Therefore, using the suitable rules, D and V ensures decreasing T^- and increasing T^+.

5 CONCLUSIONS

The use of LACs allows LOAs to use a common vocabulary. This enables LOAs to achieve a level of interoperability similar to the one achieved by web services. However, introducing a semantic contract to LOAs allows them also to explore heterogeneous MASs and retrieve partner agents more accurately than traditional syntax-based methods such as the JADE Yellow Pages [3] and the JUDDI [8] repository. The accuracy depends on the number of descriptors-values are employed. On the other hand, the use of LACs enables LOAs to cooperate with agents running at IoA intra-platform and inter-platform level. Additionally, LOAs can take advantage of recovered partners at any time to self-recover at runtime from failures that their current collaborators may present.

REFERENCES

[1] Ala Al-Fuqaha, Mohsen Guizani, Mehdi Mohammadi, Mohammed Aledhari, and Moussa Ayyash. 2015. Internet of things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials* 17, 4 (2015), 2347–2376.

[2] Luigi Atzori, Antonio Iera, and Giacomo Morabito. 2010. The internet of things: A survey. *Computer networks* 54, 15 (2010), 2787–2805.

[3] Fabio Bellifemine, Giovanni Caire, Agostino Poggi, and Giovanni Rimassa. 2008. JADE: A software framework for developing multi-agent applications. Lessons learned. *Information and Software Technology* 50, 1-2 (2008), 10–21.

[4] Christian Bizer, Tom Heath, and Tim Berners-Lee. 2009. Linked Data-The Story So Far. *International Journal on Semantic Web and Information System* 5, 3 (2009), 1–22. https://doi.org/doi:10.4018/jswis.2009081901)

[5] Thomas Erl, Anish Karmarkar, Priscilla Walmsley, Hugo Haas, L Umit Yalcinalp, Kevin Liu, David Orchard, Andre Tost, and James Pasley. 2009. *Web service contract design and versioning for SOA.* Prentice Hall.

[6] FIPA. 2002. FIPA ACL Message Structure Specification. (2002). URI: http://www.fipa.org/specs/fipa00061/SC00061G.html. Accessed on November 3, 2016.

[7] Giancarlo Fortino. 2016. Agents meet the IoT: toward ecosystems of networked smart objects. *IEEE Systems, Man, and Cybernetics Magazine* 2, 2 (2016), 43–47.

[8] The Apache Software Foundation. 2014. jUDDI Project, An open source implementation of OASIS's UDDI v3 specification. (2014). https://juddi.apache.org/ Accessed on December 20, 2017.

[9] Nicholas J Kaminski, Maria Murphy, and Nicola Marchetti. 2016. Agent-based modeling of an IoT network. In *2016 IEEE International Symposium on Systems Engineering (ISSE)*. IEEE, Edinburgh, UK, 1–7. https://doi.org/10.1109/SysEng.2016.7753151

[10] Anas M Mzahm, Mohd Sharifuddin Ahmad, and Alicia YC Tang. 2013. Agents of Things (AoT): An intelligent operational concept of the Internet of Things (IoT). In *2013 13th International Conference on Intelligent Systems Design and Applications (ISDA)*. IEEE, 159–164. https://doi.org/10.1109/ISDA.2013.6920728

[11] Fang-Ping Pai, I-Ching Hsu, and Yeh-Ching Chung. 2016. Semantic web technology for agent interoperability: a proposed infrastructure. *Applied Intelligence* 44, 1 (01 Jan 2016), 1–16. https://doi.org/10.1007/s10489-015-0690-x

[12] Pablo Pico-Valencia and Juan A Holgado-Terriza. 2016. Semantic agent contracts for internet of agents. In *IEEE/WIC/ACM International Conference on Web Intelligence Workshops (WIW)*. IEEE, 76–79. https://doi.org/10.1109/WIW.2016.033

[13] Pablo Pico-Valencia and Juan A Holgado-Terriza. 2018. Agentification of the Internet of Things: A systematic literature review. *International Journal of Distributed Sensor Networks* 14, 10 (2018). https://doi.org/10.1177/1550147718805945

[14] Pablo Pico-Valencia, Juan A Holgado-Terriza, and JA Senso. 2018. Towards an Internet of Agents model based on Linked Open Data approach. *Autonomous Agents and Multi-Agent Systems* (2018), 1–48. https://doi.org/10.1007/s10458-018-9399-7

[15] Claudio Savaglio, Giancarlo Fortino, Maria Ganzha, Marcin Paprzycki, Costin Bădică, and Mirjana Ivanović. 2017. Agent-based computing in the internet of things: a survey. In *International Symposium on Intelligent and Distributed Computing*. Springer, 307–320. https://doi.org/10.1007/978-3-319-66379-1_27

[16] Han Yu, Zhiqi Shen, and Cyril Leung. 2013. From internet of things to internet of agents. In *2013 IEEE and Internet of Things (iThings/CPSCom), IEEE International Conference on and IEEE Cyber, Physical and Social Computing Green Computing and Communications (GreenCom),*. IEEE, 1054–1057. https://doi.org/10.1109/GreenCom-iThings-CPSCom.2013.179