Intelligent Environments 2016
P. Novais and S. Konomi (Eds.)

doi:10.3233/978-1-61499-690-3-76

A Framework for the Development of Smart Ubiquitous Real-Time Systems Based on the Internet of Agents and Internet of Services Approaches

Pablo PICO-VALENCIA [a, 1] and Juan A. HOLGADO-TERRIZA [b]
[a] *Programming and Development of Software Department, Pontificia Univ Católica del Ecuador, Esmeraldas, Ecuador*
[b] *Software Engineering Department, Universidad de Granada, Granada, Spain*

Abstract. The current proliferation of electronic things and smart devices are the main cause of arising of the Internet of Things, Internet of Services, and Internet of Agents approaches. This paper presents a framework for the development of soft real-time applications based on the Service Oriented Computing and Computer-Based Agents currently known as Internet of Services and Internet of Agents, respectively. The framework includes six dimensions —agent, interaction, environment, planning, organization, and normative— which are organized in order to accomplish the new current challenges of the Internet of Things. In addition, the framework also allows designing real-time agents through the inclusion of real-time restrictions in agent goals and plans in order to build real-time applications of Internet of Things.

Keywords. Internet of Services, Internet of Agents, Internet of Things, real-time, framework, Multi-Agent System.

1. Introduction

Recently, some approaches have been proposed regarding the “Future Internet”. The most important proposals are mainly related to the Internet of Things (IoT) [1], Internet of Services (IoS) [2], Internet of People (IoP) [3], and the Internet of Agent (IoA) [4] approaches.

The IoA approach arises as an alternative to mitigate one of the deficiencies of IoT regarding reasoning and intelligence [5]. In order to solve this problem in IoT platforms some approaches have been proposed focused mainly on the fusion between Multi-agent Systems (MAS) and Service Oriented Architecture (SOA) [6][7][8][9]; and also based on the concept of Agent of Things [5][10][11]. The majority of MAS frameworks are based on JADE framework. However, there are not prepared yet to handle the new challenges of IoT [12][13] neither to define real-time constraints nor to monitor their timely fulfilments.

[1] Corresponding Author: Programming and Development of Software Department, Pontificia Univ Católica del Ecuador, C/ Espejo y Santa Cruz, 08-01-0065 Esmeraldas (Ecuador); Email: ppico@pucese.edu.ec

Table 1. Main challenges associated to the Internet of Things.

Challenge	Description
Addressing and Networking	Connected devices have a unique address by which it can be identified.
Security and Privacy	Privacy policies and security mechanisms are adopted to protect data from potential attacks.
Standardization	Global standards compatible with heterogeneous devices are used.
Energy	Energy efficient regarding algorithms and hardware is required.
Real time solutions	Definition of soft real-time restrictions, feasibility scheduling analysis and fulfilment of soft real-time restrictions.
Intelligence	M2M communication has to be minimized in order to decrease the message traffic.
Semantic	The service discovery and communication process are implemented by using semantic techniques.
Scalability	New services in both small-scale and large scale environments have to be included over time.
Discovery	Dynamic and automatic search of services are discovered automatically.
Performance	Supported objects operate with minimal computational resources.
Data volume	Storing, fusion and generation of knowledge is performed from data acquired by devices.
Arrive and Operate	Establishment of spontaneous connections and auto configuration of new devices should be supported.
Mobility	Services are delivered to mobile users or devices.
Availability	Hardware and services are provided anywhere and anytime.
Fault tolerance	Redundancy levels are implemented to operate even if errors are presented.

The literature review about the proposed agent-based middleware [14][15] and frameworks useful for building IoT applications show that the current main tools generally do not cover challenges of the IoT approach such as real-time and fault tolerance. The majority of the proposals only cover some specific challenges, such as semantic, intelligence, discovering or mobility.

Razzaque et al. [14] provide a list of middleware solutions that includes —Impala, Smart messages, AFME, MAPS, MASPOT, and TinyMAPS— which have been designed for Wireless Sensor Networks (WSN). However, these solutions do not address issues such as real-time guarantees, security and privacy. Other popular middleware is ACOSO (Agent-Based Cooperating Smart Objects) [15]. But, it is only focused on the cooperation between smart objects. Similarly, Razzaque et al. [14] include other most popular agent-based middleware for IoT —ActorNet, Ubiware, and UbiROAD— that support security, agent mobility, and automatic resource discovery. Nevertheless, these solutions neither support the real-time issue.

Regarding agent-based frameworks for IoT, we have studied five proposals which they are also focused on covering a specific issue. For instance, Hirankitti [16] proposes an agent-based framework oriented specifically for home energy management systems employing four well-defined agents, such as generic, logic, smart-home, and home-resident agent. In this way the energy saving is achieved by an efficient energy management based on a smart reasoning technique. Otherwise, DIVAs is another framework proposed by Al-Zinati et al. [17], but it is only for simulating virtual scenarios (e.g., virtual city). Besides, other agent-based frameworks more specific for IoT real scenarios are the proposed. Angulo-Lopez and Jimenez-Perez propose a collaborative agent framework for IoT that stores data of the context for enabling interactions and collaboration among agents [18]. This tool also considers the identification of devices, the execution of tasks modelled by means of goals, the support for security mechanisms, and the application of data processing techniques in order to include decision support processes. Likewise, Godfrey et al. present an agent-based framework for IoT, but specifically targeted to support mobile agents in collaborative environments [19]. Finally, Chih-Hao et al. [20] propose a semantic model capable to support —location, time, device, and activity— context to encourage social cooperation.

The idea behind our proposed framework is to facilitate the design and development of IoT monitoring and meta-monitoring applications. We have based on the basis founded by Boissier et al. [21] regarding the use of dimensions as the unit for mapping high-level concepts originated from the perspective of a smart IoT platform. Specifically, we have adopted the —environment, agent and organization— dimensions already employed by the JaCaMo platform [21]. Moreover, we have added three new dimensions, such as interaction, normative, and planning. These dimensions allow to design and develop real-time agents capable to adjust their behavior in order to adapt the behavior of the global system.

It is important to note that the creation of a general agent-based framework for IoT is not an easy task. The IoT includes several applications useful in different domains, e.g., transportation, home-automation, patient monitoring, among others. However, our proposal is focused to support monitoring processes. That is why we have included new dimensions to support real-time tasks and dynamic adaptation based on norms. Also, we have proposed an agent hierarchy with different levels and sub-levels, and an agent structure to facilitate the design and development of IoT monitoring applications with well-defined components.

This paper is structured as follows. Section II introduces the six dimensions intended by the framework. The main concepts originated from the interaction between the dimensions, and their organization in layers. Section III describes each one of the dimensions, their components and their interrelations. Finally, Section IV draws the conclusions and specifies the possible future works.

2. Dimensions of the Framework

Unlike previously presented frameworks, we propose in this paper an agent-based framework for designing IoT applications describing agent actions with real-time constraints. The proposed framework has to assure that execution times of agent actions will be below the deadline specified in real-time constraints. That is a key issue in transport or health care systems, among others. Thus, we accomplish the real-time challenge in IoT that it has not been considered by the current tools.

In addition, the agents in our framework are able to manage data and information which can be retrieved from the consumption of services based on a SOA architecture as IoS approach proposes. Unlike other proposals, our framework can invoke operations on heterogeneous service ecosystems based on SOAP or Restful paradigms whenever we can access to WSDL or WADL service contracts respectively [22]. Therefore, the IoT challenge related to availability can be overcome because, if a SOA infrastructure is operative, services are available 24/7 and the candidate data sources are expanded.

Other important contribution of our framework is the adaptability to new requirements. The inclusion of norm concept allow us to regulate the agent behaviors that compose the system, providing a mechanism to modify the agent behavior without stopping the execution of agents

Finally, some contributions have been performed to solve IoT challenges such as semantic, interoperability, fault tolerance, and intelligence. In fact, we have include concepts such as ontological communications, semantic description of agents, definition of mechanisms for looking up new strategies for the accomplishment of agent-goals, and the employing of a hybrid agent architecture (reactive and belief-desire-intentions model) capable of reasoning semantically taking into account real-time constraints.

Figure 1 illustrates the six dimensions supported by the proposed framework. The integration of each dimension provides a smart level that neither web services, nor electronic things support [5]. The first four dimensions —agent, interaction, environment, and organization— are dimensions intrinsically belonging to agents [21], while the complementary dimensions —planning, and normative— have been included in this model in order to provide support to soft real-time tasks and adaptation to the system based on norms.

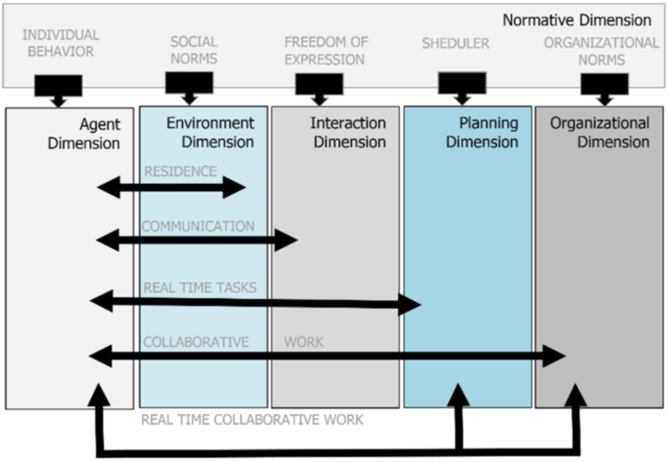

Figure 1. Dimensions of the proposal framework.

The "*agent dimension*" is an abstraction level where we define the entities and reasoning mechanisms, the way how agents deduce conclusions to internal situations, and further the constraints that have to respect to act correctly. This dimension includes issues related to Agent Oriented Programming (AOP) in order to encapsulate the behavior and mental state of an agent entity. Then, the agents have the capability to react to fired events and take decisions based on the semantic knowledge that they hold associated with these events.

The "agent dimension" supports completely the "interaction dimension" as it is accomplished by FIPA communication mechanisms. This allows agents to interact between them even covering agents of different distributed platforms.

The third dimension of our framework corresponds to the "*environmental dimension*". This dimension is an abstraction level which provides to agents the conditions to live, giving access to available resources and changing their behavior depending of the raised events. It allows the creation of scenarios based on artifacts (resources) which can be employed by agents or groups for accomplishing agent goals.

Formed groups require a new dimension, that we named "*organizational dimension*". This dimension is an abstraction level that establishes the elements, protocols, communication languages and groups to be used by the interaction process at inter-agent and intra-agent level to accomplish the goals collaboratively. Its main responsibility is the coordination of the collaborative work among agents of a group. This is, the creation of groups, roles, cooperative agents, and workflows composed by web services where more than one agent needs to collaborate to accomplish a common goal in a formed group.

Complementary to previously described dimensions included in the JaCaMo platform [21], we have added two additional dimensions. The first one is the "*planning dimension*" that is an abstract level that establishes processes related to the coordination and the execution of tasks required by the system to accomplish the proposed goals linked to real-time restrictions. Therefore, it allows planning the agent goals as real-time workflows composed by web services by using a real-time scheduler. The second one named "*normative dimension*" is an abstraction level that adds a set of rules and constraints which influence significantly the behavior of agents that operate in a specific environment and the interactions to be carried out among the components that form them. The normative dimension monitors the possible changes in norms and business rules that govern agents and the global system.

2.1. Associated Concepts

The interaction among the "*norm dimension*" and the remaining dimensions are detailed in Figure 1. These interrelations arise some new concepts of the real world generally employed in Sociology area, as described below:

- *Individual behavior (Norm ∩ Agent):* Self-imposed norms are far away to equate with a human behavior. However, agents can act based on the behavior norms that govern the system.
- *Social norm (Norm ∩ Environment):* The norms imposed by the environment imply that agents have to respect social norms in order to use correctly the resources available in the environment where agents are living. The accomplishment of these norms is very important because the resources are shared with other agents and groups.
- *Freedom of expression (Norm ∩ Interaction):* Agents can exploit their capacity of communication to express to other ones the actions related to requests, response delivering, negotiation, or any other actions where a speech act is required.
- *Scheduler (Norm ∩ Planning):* In general in the real world the processes have to be performed serving a time-bounded scheduling. It implies that agents have to schedule its workflows in order to satisfy the real-time constraints defined on applications.
- *Organizational norm (Norm ∩ Organization):* At an organizational level there are hierarchies that categorize the norms according to the size or nature of the organization. These norms affects only to some specific agent groups.
- *Agent's residence (Agent ∩ Environment):* Analogously to the human need to develop its activities on a specific space room or an environment, the agents also require an environment where they live. Thereby, agents will consume the nearest resources in order to accomplish their goals.

- *Agent communication (Agent ∩ Interaction):* The use of a standard communication and a language such as FIPA, allows the agents to have access to a semantic agent communication through ontologies between agents of a same or external multi-agent systems.
- *Real-time work (Agent ∩ Planning):* The use of a scheduler requires that agents have to accomplish execution times before their corresponding deadlines.
- *Collaborative work (Agent ∩ Organization):* Some tasks need the collaboration of several entities because some agents do not have the enough resources to execute a process. Therefore, the collaborative workflows must be composed by agent goals in order to accomplish a more complex common objective.
- *Real-time collaborative work (Agent ∩ Organization ∩ Planning*): Similarly, as a real-time agent task, the collaborative work can be time bounded.

3. Integration of the Dimensions

Previously described concepts have been organized in layers as it is schematized in Figure 2.a. The layers related to devices and services have not been considered as dimensions of the framework. We assume that the physical infrastructure already exists. Therefore, the first step to follow is to identify the main available resources (ecosystems of services, web services, URIs, servers, agent platforms existing, among others) linked with devices, or to implement them if the required resources do not exist. Then, each resource is needed to be described by using the AgentContext ontology belonging of the IoA-OWL ontology [23].

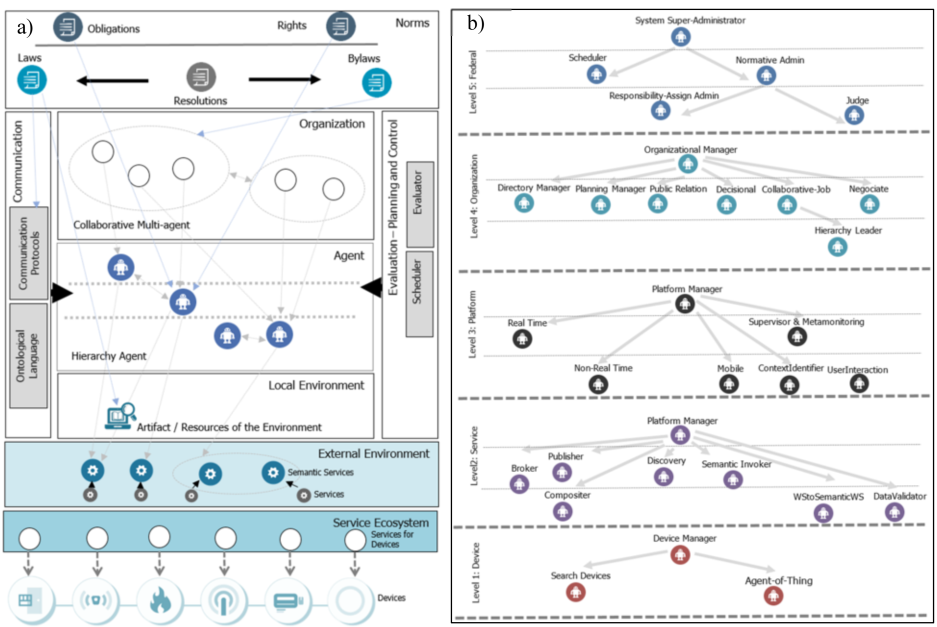

Figure 2. a) Integration of the dimensions and b) hierarchy levels of the framework.

Once the resources have been described semantically, the "*environment layer*" can be described in a formal way. As time passes, the environment can be enriched with the inclusion of new elements that agents can employ. This layer also describes the location and time context, and save information about the actions and perceptions performed by agents.

The "*agent layer*" includes the modelling of agents based on the BOID (Belief-Desire-Obligation-Intention) architecture [24] illustrated in Figure 3 composed by —beliefs, desires, intentions, obligations, rights, prohibitions, penalties, plans, and real-time restrictions— in order to operate more autonomous and intelligently. It is important to note that we have proposed a hierarchical structure of agents (Figure 2.b) useful to perform monitoring process by using an IoT infrastructure. The hierarchy proposed is formed by five levels—device, service, platform, organization, and federal— with their respective sub-levels.

The device level formed by —device manager, search device, and agent-thing— agents allow for looking-up the devices presents in the IoT infrastructure and also to create an agent by every electronics or smart thing. The service level of the hierarchy is composed by —platform manager, broker, publisher, discovery, semantic invoker, compositor, WStoSemanticWS, and DataValidator— agent that helps to create, compose, discover or validate contracts and data used by the semantic web services offered by agents. These web services can belong to heterogeneous services ecosystems [22]. On the other hand, the platform level is composed by —platform manager, real-time, no real-time, supervisor & meta-monitoring, mobile, context identity, and user interaction— agent that allow performing any kind of monitoring task in an IoT scenario. This level also includes agents that interact with users and agents that allow monitoring the agents belonging to these hierarchical levels. The organizational level, composed by—organizational manager, directory manager, planning manager, public relation, decisional, leader, and negotiator—agent that allow to coordinate the tasks in the formed groups and to establish relationships with external agents in order to negotiate with them.

Every agent in the hierarchy shown in Figure 2.b has a well-defined description including the actions, the list of behaviors, beliefs, desires, intentions, plans, obligations, rights, prohibitions, and finally the set of agent types on which it can interact at the same hierarchical level and sub-level. This allows building agent-based IoT applications with a same structure, avoiding possible disorder in the agent communications between created agents.

The agents can organize in groups in order to perform collaborative tasks that agents cannot perform individually. This dimension we have named "*organizational layer*" interacts with the "*agent layer*" directly. The main responsibility of this layer is the creation of groups to perform organizational plans in a collaborative way. A collaborative plan is a set of agent goals where different agents collaborate to get a more complex common goal. The groups can be organized in alliance or a hierarchy of agents. Both cases include collaborative agents with a specific role. However, in the case of a hierarchical structure there will be also present a leader that coordinate the collaborative work performed by the subordinated agents. As "*agent layer*" and "*organizational layer*" have to use the "interaction layer" to establish communication processes. This layer proposes the use of FIPA-ACL language and the communication protocols (FIPA Request, Query, Propose, Subscribe, and FIPA Contract Net) in order to accomplish with the current agent standards.

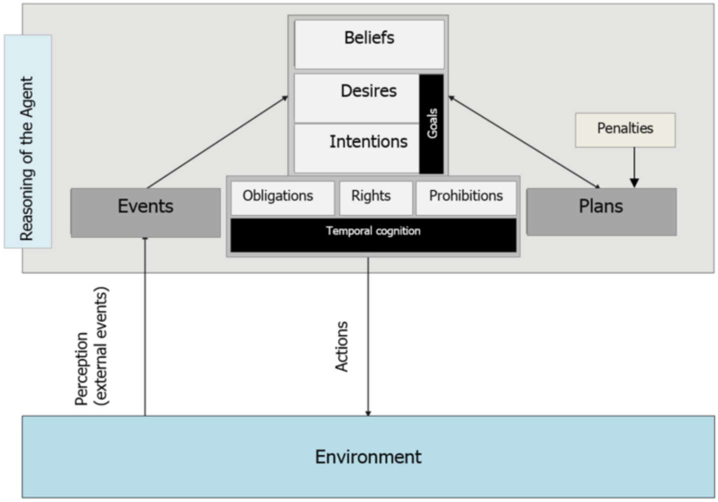

Figure 3. Agent model of agents of the proposed framework.

The "*planning layer*" is supported by the components of the "*agent layer*" The planning of agent workflows is carried out by means a dynamic real-time scheduler based in resources that allows performing real-time tasks optimizing the resources available in the environment and the computational resource where agent platforms are running. Moreover, the evaluation component assesses the real-time agent goals in order to control and verify the performed actions carried out by each real time agent to ensure the quality of service (QoS) offered by the agents.

Finally, at the highest level the "*normative layer*" defines the norms [25] to control the "*agent layer*" and "*organizational layer*" through laws, bylaws, and resolutions. Laws and Bylaws allow controlling the behavior of agents and organizations respectively. The employment of resolutions is used to change the state of laws and bylaws. Further, we have considered to include agent norms (right-obligation-prohibition-penalties), social norms, interaction norms, and organization norms to control all the other components belonging to the rest of layers previously defined.

4. Conclusions

The agent approach is becoming an important paradigm to add intelligence to IoS and IoT. The reasoning capacity of agents allows performing actions in not predefined or modelled situations. This work presents an agent-based framework for developing IoT applications modelling devices as smart agents and agent-goals with real-time restrictions in order to build soft real-time applications.

A complex stage of any smart agent-based application is the design stage. It is difficult to provide a framework compatible with the description of applications in any domain. We have proposed an agent architecture and a structural hierarchy of agents organized to design monitoring applications. Then, the definition of these components, such as agent classes, well defined functionalities, specification of hierarchy levels and sub-level, and the definition of the adequate FIPA communication protocols used by each type of agent are very helpful to reduce the effort when it is required to create an IoT monitoring application.

Acknowledgements

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

References

[1] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, Internet of Things: A Survey on Enabling Technologies, Protocols and Applications, *IEEE Commun. Surv. Tutorials* **17**(4) (2015).
[2] C. Schroth, The internet of services: Global industrialization of information intensive services, *2nd Int. Conf. Digit. Inf. Manag. ICDIM* **2** (2007), 635–642.
[3] J.H.P. Eloff, M.M. Eloff, M.T. Dlamini, and M.P. Zielinski, Internet of People, Things and Services - The Convergence of Security, Trust and Privacy, in *Third International Workshop IoPTS* (2009).
[4] H. Yu, Z. Shen, and C. Leung, From internet of things to internet of agents, in *Proceedings - 2013 IEEE International Conference on Green Computing and Communications and IEEE Internet of Things and IEEE Cyber, Physical and Social Computing, GreenCom-iThings-CPSCom 2013* (2013), 1054–1057.
[5] A.M. Mzahm, M.S. Ahmad, and Alicia Y.C.Tang, Agents of Things (AoT): An Intelligent Operational Concept of the Internet of Things (loT), in *13th International Conference on Intelligent Systems Design and Applications (ISDA13)* (2013), 159–164.
[6] D.I. Tapia, J. Bajo, and J.M. Corchado, Distributing Functionalities in a SOA-Based Multi-agent Architecture, in *7th International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS 2009)* (2009), 20–29.
[7] J.I. Fernández-Villamor, C.A. Iglesias, and M. Garijo, A framework for goal-oriented discovery of resources in the RESTful architecture, *IEEE Trans. Syst. Man, Cybern. Syst.* **44**(6) (2014), 796–803.
[8] D. Ryzko and W. Radziszewska, Integration between web services and multi-agent systems with applications for multi-commodity markets, *Adv. Intell. Soft Comput.* **121** (2012) 65–77.
[9] V. Herrera, A. Bepperling, A. Lobov, H. Smit, W. Colombo, and J.L.M. Lastra, Integration of Multi-Agent Systems and Service-Oriented Architecture for industrial automation, *IEEE Int. Conf. Ind. Informatics* (2008), 768–773.
[10] L. Jarvenpaa, M. Lintinen, A.L. Mattila, T. Mikkonen, K. Systa, and J.P. Voutilainen, Mobile agents for the Internet of Things, in *17th International Conference on System Theory, Control and Computing (ICSTCC)* (2013), 763–767.
[11] A. Katasonov, O. Kaykova, O. Khriyenko, S. Nikitin, and V. Terziyan, Smart Semantic Middleware for the Internet of Things, in *5th International Conference on Informatics in Control, Automation and Robotics* (2008), 169–178.
[12] R. Khan, S.U. Khan, R. Zaheer, and S. Khan, Future internet: The internet of things architecture, possible applications and key challenges, *Proc. - 10th Int. Conf. Front. Inf. Technol. FIT 2012* (2012), 257–260.
[13] P. Pande and A. Padwalkar, Internet of Things –A Future of Internet: A Survey, *Int. J. Adv. Res. Comput. Sci. Manag. Stud.* **2**(2) (2014), 354–361.
[14] M.A. Razzaque, M. Milojevic-Jevric, A. Palade, and S. Clarke, Middleware for Internet of Things: a Survey, *Internet Things Journal, IEEE* **3**(1) (2016), 70–95.
[15] G. Fortino, A. Guerrieri, W. Russo, and C. Savaglio, Middlewares for Smart Objects and Smart Environments: Overview and Comparison, in *Internet of Things Based on Smart Objects* (2014), 1–27.
[16] V. Hirankitti, An Agent Framework for Home Energy Management System, in *World Congress on Engineering* **1** (2015), 184–189.
[17] M. Al-Zinati, F. Araujo, D. Kuiper, J. Valente, and R. Z. Wenkstern, DIVAs 4.0: A Multi-Agent Based Simulation Framework, in *2013 IEEE/ACM 17th International Symposium on Distributed Simulation and Real Time Applications* (2013), 105–114.
[18] P. Angulo-Lopez and G. Jimenez-Perez, Collaborative Agents Framework for the Internet of Things,

Work. Proc. 8th Int. Conf. Intell. Environ. ***13*** (2012), 191–199.
[19] W.W. Godfrey, S.S. Jha, and S.B. Nair, On a mobile agent framework for an Internet of Things, *Proc. - 2013 Int. Conf. Commun. Syst. Netw. Technol. CSNT 2013* (2013), 345–350.
[20] C.H. Lin, P.H. Ho, and H.C. Lin, Framework for NFC-Based Intelligent Agents: A Context-Awareness Enabler for Social Internet of Things, *Int. J. Distrib. Sens. Networks* (2014).
[21] O. Boissier, R.H. Bordini, J.F. Hübner, A. Ricci, and A. Santi, Multi-agent oriented programming with JaCaMo, *Sci. Comput. Program.* **78**(6) (2013),747–761.
[22] P.A Pico-Valencia and J.A. Holgado-Terriza, An agent middleware for supporting ecosystems of heterogeneous web services, in *13th International Conference on Mobile Systems and Pervasive Computing*, 2016 (in press).
[23] P.A. Pico-Valencia and J.A. Holgado-Terriza, Semantic agent contracts for Internet of Agents, in *First International Workshop on the Internet of Agents (IoA)*, 2016 (in press).
[24] T. Balke, and N.T. Gilbert, How Do Agents Make Decisions? A Survey, *J. Artif. Soc. Soc. Simul.* **17**(4) (2014), 1–30.
[25] F.L. y Lopez, M. Luck, and M. d'Inverno, A Normative Framework for Agent-Based Systems, *Computational and Mathematical Organization Theory* **12** (2006), 1–26.