A Multi-agent approach for devices management and control in IoT environments

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Abstract. *The Internet of Things (IoT) envisions millions of heterogeneous smart devices in an open, distributed and dynamic environment. IoT addresses the complexity involved in connecting, discovering and accessing all these devices, and also integrate and analyze the amount of data produced by them. In this paper is presented a proposal for the development of an architecture based on Multi-agent systems, Service-Oriented Architecture and Semantic Web technologies. The architecture aims to support the design and development of robust, flexible and scalable application to automate devices management and coordination in IoT based environments.*

1. Introduction

The Internet of Things (IoT) envisions a network of heterogeneous devices communicating with each other in an open and dynamic environment. These devices, also called smart devices, represent sensors and actuators connected in the Internet, providing data and other resources from their environment for other systems. The advances in hardware and network infrastructure have contributed more and more to the development of cheaper, smaller and more powerful devices, endowed with more processing capabilities, and also wireless network interfaces. These network interfaces provide the devices with the communication capabilities, necessary to connect to the network, publish and provide their resources, and interact with each other and with their surrounding environment [Karnouskos and Tariq 2009].

Smart devices have been used in a wide range of environments, also called smart environments, such as home, industry and also open and urban areas, for a variety domain of application [Ruta, M. et al., 2013]. Most often such applications aim to provide users with information to monitor and control the environment. However, just integrate and provide users with data measured from the environment may not be enough to address user intends. It means that in a smart environment the application can integrate and coordinate devices, providing high level information and resources in order to support users in the achievement of complex tasks and automate the execution of related processes.

The complexity inherent in smart environments arises primarily by the distribution and amount of heterogeneous components (devices and systems), as well as the large volume of produced data and high communication among components. This problem arises from the different communication technologies and data models used by these components. In this sense, service-oriented architectures (SOA) are a promising technology to support the interoperability among different components [Ruta et al.

2013]. In the last years, service-oriented technologies have been adopted in order to handle these problems, creating standardized interfaces and mechanisms for publishing and discovering new devices connected to the network. Examples of such technologies are OPC-UA and DPWS (Devices Profile for Web Services) [Izaguirre, Lobov and Lastra 2011].

In this context, new approaches for devices management and control must arise in order to ensure the cooperation and coordination of the connected devices. The Multi-Agent System (MAS) approach provides a set of appropriate abstractions for dealing with the design and development of distributed, open, dynamic and complex heterogeneous systems [Jennings and Wooldridge 1998], such as IoT environments. In a MAS approach a set of agents is designed as independent and autonomous components responsible to create organizations and cooperate in order to achieve the required task.

In addition, Semantic Web technologies such as ontologies have been used to overcome the semantic heterogeneity inherent from the variety of data models used by the smart devices. Such technologies are employed in order to increase the data models interoperability and the systems tasks automation, by defining common vocabularies for representing the application knowledge. Thus providing better data integration and processing [Aloulou et al. 2013].

In this work we present a proposal of a reference model architecture that integrates MAS approach, SOA and Semantic Web technologies. The architecture organization and components were defined and specified in order to be used as a reference model to design and develop applications for automating the monitoring and controlling tasks in IoT based environments.

2. Related work

The IoT is a research field that has emerged with the increasing usage of smart devices in many different domains. So, this research field aims to investigate and propose solutions to address the new challenges posed by the IoT environments. Such challenges are mainly related to the connection, discovery, access, and integration of heterogeneous smart devices and also to retrieve, integrate and process the large amount of data produced [Alberti and Singh 2013].

In this context, many approaches can be found in the literature proposing a variety of solutions in order to support IoT features, such as network protocols and frameworks [Presser et. al. 2009].

In the IoT SOA approaches, based on Web Services and RESTful, have been widely adopted to ensure the connectivity and interoperability necessary for accessing and integrating several heterogeneous devices [Stirbu 2008]. Also others light-weight implementations are adopted, such as DPWS and OPC-UA [Izaguirre, Lobov and Lastra 2011], which comprises a collection of standards that empowers embedded devices allowing them to run web services natively [Sucic; Bony and Guise 2012].

Semantic Web technologies, such as ontologies, have been used for knowledge representation and sharing, improving system interoperability and data integration. Ontologies can also be used to semantically annotate services provided by devices in order to improve and automate their discovery, access and composition. In this sense, domain and application ontologies should be specified to define a common vocabulary that describes the domain concepts such as devices, data models, events, monitoring and control tasks [Song, Cardenas and Masuoka 2010]. There are already several ontologies developed for different domains that can be used and adapted for this purpose. Through the use of ontologies, application data become machine readable and interpretable, enabling agents to use it to automate their tasks.

In [Aloulou et al. 2013], ontology and rules are used to represent the knowledge about entities in a collaborating nursing home environment. This collaborating environment involves patients, caregivers, assistive services, sensors and interaction devices. The system behavior is determined by reasoning through the semantic model and defined rules. The semantic model keeps the knowledge about patient conditions and needs.

Ontologies are also used to describe the application context in order to perform the execution of most adequate services in a given scenario. The context-awareness enables the automatic modification of the system behavior according to the current situation with minimal human intervention. In [Han, Lee, and Crespi 2014] is presented an architecture for treating data acquired by devices and coordinate them according to the user environment context and the context rules.

MAS approach is a paradigm suitable for designing and developing distributed and heterogeneous systems that involve complex interaction between entities, e.g. humans, industrial robots, and smart devices. Therefore MAS approaches have been applied to ensure organization and cooperation between devices in IoT applications [Angulo-Lopez and Jimenez-Perez 2012]. In [Karnouskos and Tariq 2009], a MAS approach is used for simulating a dynamic environment containing distributed devices in IoT. In this MAS a set of agents with different roles is in charge to handle various tasks along the system.

3. Proposed architecture

In the architecture proposed, presented in Figure 1, it is defined a set of components to support the development of IoT applications for environment monitor and control, which integrates MAS, SOA and Semantic Web features. The architecture is composed of different layers responsible for a set of different tasks:

Devices Layer: corresponds to the physical devices (sensors and actuators) connected to the network, responsible for sensing and modifying the physical environment.

Service Layer: comprises a service middleware, responsible for wrapping devices resources and creating an interoperability layer for publishing and discovering their services on the network. The Service Layer provides an infrastructure that allows the agents of MAS to easily and seamlessly search, discover and access the resources. This layer is proposed to be developed using DPWS technology.

Multi-agent Layer: presents set of agents responsible for the integration and management of the resources. This layer is composed by Reactive and Cognitive Components.

- Reactive Component: It is composed by the Resources agents responsible to directly handle the physical devices provided by Service Layer.
- Cognitive Component : comprises the agents responsible to perform reasoning and inferences along the application knowledge in order to delegate tasks and

coordinate other agents in the execution of the application tasks. These agents are responsible for decision-making and plan coordination to ensure system self -adaptation.

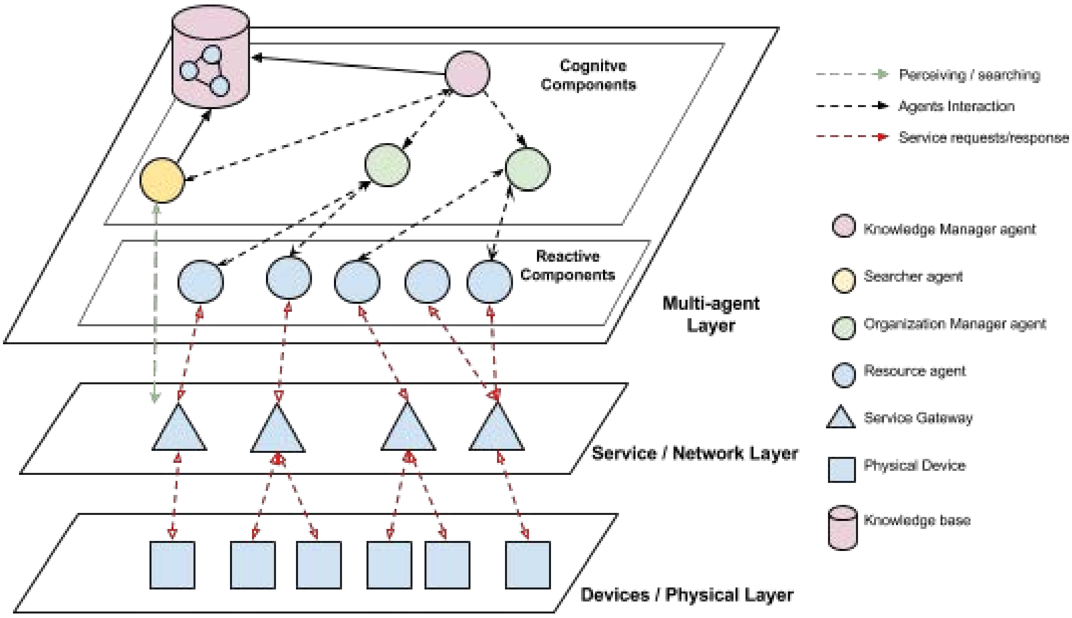

Figure 1: Proposed MAS architecture overview.

3.1. Multi-agent layer

The Multi-agent Layer is composed by one or more agents that can perform a set of different roles, described in the following:

- Searching Agent: responsible for monitoring and searching for devices in the Service Layer and initialize a Resource Agent for handling their resources. Thus, when a new device is found or connected, the agents performing this role is responsible to search for the semantic description of this device and their resources. The device semantic description need to be defined previously and stored in the application knowledge base. The knowledge retrieved through the Knowledge Manager Agent will be used to initialize a new specialized Resource agent for handling the device's resources.
- Resource Agent: are specialized for every different class of devices and have the capabilities for data processing according to the devices requirements and specifications. For example, if the device is a camera, the related agent must have all knowledge and data analysis functions necessary for image processing.
- Knowledge Manager Agent: are responsible to manage all the application knowledge that includes the semantic description of data models, devices and process. The knowledge is stored in the application knowledge base and structured according to application ontologies. This agent must monitor the Resource agents and their resources, in order to try to identify the application context. Then determining the tasks that can be executed with the resources connected and available to the system. If in a given context a complex task can be executed, it must instantiate an Organization Manager Agent and defines the tasks to be performed by each Resource agent.

- Organization Manager Agent: manages and creates the organization for a given task realization. This agent can create organizations in a dynamic way, assigning a set of goals to be achieved for each agent in the system. Another function performed by this agent is the task of management of each Resource Agent, according to their roles in the organization. This agent is also responsible for destroying or aborting organization's global goals. In the application, there can be several different organizations created according to the user needs, context and resources availability.

4. The architecture implementation

For the architecture implementation is proposed the use of a set of frameworks to achieve each of the architecture requirements. Thus, the Service Layer is implemented using a DPWS framework with a Java API called JMEDS (http://ws4d.e-technik.uni-rostock.de/jmeds/). JMEDS implements the DPWS stack protocol and will be responsible for connecting the device along the network and provide an interface between the physical devices and MAS.

The MAS will be implemented using the framework JaCaMo (Jason, CArtAgo e Moise) (http://jacamo.sourceforge.net/), which provides the infrastructure necessary for developing the agents and the communication between them. The Jason framework will be used to implement the agents. The framework CArtAgo will be used to develop the environment of the agents, where artifacts will provide an interface between the agents and Service Layer. The Moise framework will be used for the creation, management and maintaining of the agents organizations, where the structural, functional, and normative specifications of the organizations will be described.

The ontologies, coded in OWL, will be reused or created and managed using the Protégé and Jena frameworks.

Conclusion

An architecture has been proposed based on MAS, SOA and Semantic Web technologies, for application to automate the monitoring and controlling tasks in IoT based environments. Together these technologies can be used to create a robust, flexible and scalable software infrastructure for monitor and control IoT environments, managing and coordinating the smart devices in the execution of tasks according to the application context or user needs.

The work in progress, has already implemented the lower level layer of the architecture. The implementation is achieved by integrating the technologies provided by the frameworks JaCaMo and JMEDS. The MAS can already automatically detect and access any DPWS device connected on the network.

The next step is the creation of the knowledge base and the goals for the Knowledge Manager agent annotate automatically the services and identify the semantic context, through the devices and services metadata. Also with the knowledge base, the Organization Manager Agent will be able to assign roles and plans for each Resource Agent created, in order to achieve the tasks defined by the context.

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