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## An agent middleware for supporting ecosystems of heterogeneous web services

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### Abstract

The integration of a Multi-agent technology with a service oriented architecture provides a convenient way to build smarter applications that satisfy the demand of the current ubiquitous web systems. This paper provides a software tool to develop ubiquitous applications adopting the philosophy of agents and services as data sources. ADELE (Agent Dynamic Evolutionary at runtime) is a middleware that allows developers to create reactive agents with the capability to evolve through the injection of external behaviors at runtime. An ADELE external behavior is a software component that allows agents to accomplish their goals. To facilitate the programming of these behaviors, agents can obtain the information consuming local and public web services (WSs) previously published on different services ecosystems. This paper shows how a Multi-agent System can consume heterogeneous WSs to satisfy the agent goals using a normative model. We have created three add-ons compatible with SOAP, RESTful, and DOHA (Dynamic Open Home-Automation) WS model. The integration of these add-ons within the ADELE tool is helpful to facilitate the invocation of heterogeneous WSs with a high abstraction level. In addition, we describe as an example, an Internet of Thing (IoT) scenario where the approach presented in this paper is very helpful. Finally, we also evaluate an ADELE application for giving home comfort employing heterogeneous WSs.

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## 1. Introduction

New trends emerging around the Internet technologies are changing the way about how web and mobile applications can offer new-value services to users in order to satisfy their needs. The use of semantic models to achieve interoperability<sup>1</sup>, the inclusion of agents to add intelligence and mobility<sup>2</sup> or the application of Cloud Computing to share resources and trying everything as a service<sup>3</sup>, are some trends in the development of current web and ubiquitous applications. However, one of the most promising technologies in these fields is undoubtedly related to Web Services (WSs), since they are able to create interoperable communications between machines over the Internet<sup>4</sup> managing also the requests of billions of web and devices that are interconnected at any time everywhere. This is the origin of the current Internet of Service (IoS).

The IoS describes an infrastructure through a logical collection of WSs which uses the Internet as a medium to offer, change, adapt, sell and operate WSs for any consumer using one or more WS ecosystems<sup>5</sup>. Considering that a WS ecosystem can flood Internet with many atomic and composite services, it is required to apply a discovery stage for finding services and an execution stage for describing how the realization of a service is carried out<sup>5</sup>. In this line, several research works have proposed the fusion between Service Oriented Architecture (SOA) and Multi-agent Systems (MASs)<sup>6,7,8</sup>. However, we have considered to use the approach defined by Paz<sup>9</sup> that exposes agent behaviors as WS (SOAP services) without using a discovery process; but, in our approach, this idea is extended in order to support the integration of heterogeneous WSs in agent behaviors. In fact, we can access to SOAP (Simple Object Access Protocol)<sup>10</sup>, RESTful (Representational State Transfer)<sup>11</sup>, and DOHA (Dynamic Open Home Automation)<sup>12</sup> WSs to compose basic and complex functionalities from these ones, and indirectly helps agents to meet their goals.

Though WSs have important implicit features for the development of scalable distributed systems such as the autonomy, the simplicity, and the interoperability, they do not have the ability to act intelligently. However, the fact that atomic and composite WSs can be encapsulated within the behavior of agents at compile time or at runtime, we can achieve a higher level of interoperability at MASs level. This is the main reason why we propose a middleware able to build agents that satisfying their goals by using data obtained from heterogeneous WSs. We have also considered the use of several WS technologies, such as SOAP, RESTful and DOHA. SOAP and RESTful were selected because they are currently the most widespread WS technologies for the development of this type of software components<sup>13</sup>. In addition, we have also included a specific WS technology, DOHA<sup>14</sup> based on DPWS<sup>15</sup> (Device Profile Web Service), because in ubiquitous scenarios, it may require lightweight WSs which act on scenarios with limited resources<sup>15</sup>.

The future of the Internet and even the future of the web are mainly focused on building smarter applications with the capacity to satisfy the requirements of the future ubiquitous web<sup>16</sup>. In applications of this nature the mobility and adaptation are two elementary aspects<sup>17</sup> that they are still under investigation. Respect to the adaptation we have used the ADELE (Agent Dynamic EvoLutionary at runtimeE) middleware<sup>18</sup> which offers the adjustment of agents by means of the injection of external behaviors at runtime for giving to developers the capacity to build these external behaviors by using Dynamic Clients (DC) or add-ons that allow invoking directly heterogeneous WSs that belong to distinct service ecosystems. Thereby, ADELE becomes a useful software tool for creating agent platforms that can operate intelligently on ubiquitous scenarios thanks to its mechanisms of evolutions at runtime and the capability to work with WSs independently of their location and technology.

The content of this paper is structured in five sections. In Section 2 we discuss some of the related works. Section 3 introduces the main concepts associated with the basic unit of the IoS. Section 4 presents the architectural model of ADELE to support agent actions as a composition of heterogeneous WSs. In addition, a description of the add-ons SOAPDC, RESTDC and DOHADC are described. In Section 5, we discuss the obtained results of the evaluation of an ADELE application for giving comfort to a smart home that includes agent goals which are accomplished using the composition of heterogeneous WSs, and we compared with other similar application that solves the same agent goals, but by using each service model individually. Finally, conclusions are commented.

## 2. Related works

Some years ago the approaches related to services and agents have been worked as independent self-contained technologies without any interaction. However, in the last decade, the integration of both approaches has widely been accepted by their complementary features for building distributed, open and flexible applications, which have led to smarter applications that satisfy the demand of the current ubiquitous web. As a result of the integration of the MAS

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