A Cognitive Framework for Realizing and Exploiting the Internet of Things Concept

Gianmarco Baldini[1], Rao Venkatesha Prasad[2], Abdur Rahim Biswas[3], Klaus Moessner[4], Matti Etelapera[5], Juha Pekka Soininen[5], Nechifor Septimiu-Cosmin[6], Vera Stavroulaki[7], Panagiotis Vlacheas[7], Andreas Georgakopoulos[7], Panagiotis Demestichas[7]

[1]Joint Research Centre
Brussels, Belgium
gianmarco.baldini@jrc.ec.europa.eu

[2]Delft University of Technology
Delft, The Netherlands
R.R.VenkateshaPrasad@tudelft.nl

[3]CreateNet
Italy
abdur.rahim@create-net.org

[4]University of Surrey
Guildford, UK
K.Moessner@surrey.ac.uk

[5]VTT Research Centre
Finland
{Matti.Etelapera, Juha-Pekka.Soininen}@vtt.fi

[6]Siemens
Romania
septimiu.nechifor@siemens.com

[7]Department of Digital Systems
University of Piraeus, Greece
{veras, panvlah, andgeorg, pdemest}@unipi.gr

***Abstract*— This work proposes a cognitive management framework for realizing and exploiting the Internet of Things concept in the Future Internet (FI) era. Cognitive systems offer self-x and learning. A cognitive system has the ability to dynamically select its behavior through self-management/awareness functionality, taking into account information and knowledge on the context of the operations as well as policies and including the generation of the context itself. The framework is based on the principle that any real world object and any digital object that is available, accessible, observable or controllable can have a virtual representation in the Future Internet, which is called Virtual Object (VO). Basic VOs can be composed in a more sophisticated way by forming Composite VOs (CVOs), which provide services to high-level applications and end-users. The described paradigm is applied to various applications scenarios: smart home, smart office, smart city and smart business. This paper presents some background in IoT, identifies the requirements and challenges, and sets the directions that should be followed.**

Keywords- Cognitive Systems, Internet Of Things, Virtual Objects, Wireless Communications;

I. Introduction

The “7 trillion devices for 7 billion people” paradigm as described in [1], yields that the handling of the amount of objects that will be part of the Internet of Things (IoT) requires suitable architecture and technological foundations. The Internet-connected sensors, actuators and other types of smart devices and objects need a suitable communication infrastructure. At the same time, the lack in terms of management functionality and means to overcome the technological heterogeneity and complexity of the pervasive networks calls for the definition of mechanisms for enhanced context-awareness, to provide high reliability through the ability to use heterogeneous objects in a complementary manner for reliable service provision, for energy-efficiency through the selection of the most efficient and suitable objects from the set of heterogeneous ones and for security in these distributed networks of cooperating objects. The sheer numbers of objects and devices that have to be handled and the variety of networking and communication technologies, as well as administrative boundaries that have to be supported do require a different management approach. The idea is to enable seamless and interoperable connectivity amongst heterogeneous number of devices and systems, hide their complexity to the user while providing sophisticated services and applications [2].

In response to the requirement of overcoming technological heterogeneity this work proposes a cognitive management framework which aims to provide the means to realize the principle that any real world object and any digital object, which is available, accessible, observable or controllable, can have a virtual representation in the IoT. A cognitive system has the ability to dynamically select its behavior (managed system's configuration), through self-management/awareness functionality, taking into account information and knowledge (obtained through machine learning) on the context of operation (e.g., internal status and status of environment), as well as policies (designating objectives, constraints, rules, etc.).

The main purpose of this work is to propose a framework which will be based on the principle that any real world object and any digital object that is available, accessible, observable or controllable can have a virtual representation in the Future Internet, which is called Virtual Object (VO). Additionally, basic VOs can be composed in a more sophisticated way by forming Composite VOs (CVOs), which provide services to high-level applications and end-users.

The rest of the paper is structured as follows. Section II provides a description on the related work regarding virtual objects and composite virtual objects semantics. Section III elaborates on the proposal of a cognitive management framework for IoT and provides the basic definition for VOs and CVOs while Section IV discusses application scenarios and business benefits. Finally, concluding remarks are provided in section V.

II. RELATED WORK AND CONTRIBUTION

The concept of virtual representations of devices/ objects in the scope of the IoT is a key issue in most of the Future Internet, IoT projects and research initiatives. Indicatively, the CONVERGENCE project [3] focuses on the enhancement of the Internet with a content-centric, publish-subscribe model, based on a common container for any kind of digital data, including representations of people and real world objects. Authors in [4] introduce the concept of the Versatile Digital Item (VDI), which is a package of information about services, people and physical objects, independently of the structure or geographical location of the context . Also work in [5] aims at creating an open, business driven architecture that would addresses the scalability problems for a large number of globally distributed wireless sensor and actuator networks (WS&A) devices [6]. Additionally, a platform, which among others aims to transform every device into a web service with semantic resolution, is described in [7]. The platform features a Service oriented Architecture (SoA) based on open protocols and middleware, with the aim of transforming every subsystem or device into a web service with semantic resolution [8].

Virtual representations of real world objects are also addressed in [9] with the target to make physical world "information" available for smart services - connecting the physical world with the information world. A core component of its Open Innovation Platform is Smart-M3 [10], which aims at providing the baseline for a solution to cross-domain and cross-platform interoperability platform and information exchange. Smart-M3 makes it possible to mash up and integrate information among all applications and domains ranging from different embedded domains to the Web.

The concept of the "ucode", an identification number assigned to tangible "physical objects" and "places" is one of the work topics of the Japanese Ubiquitous ID Center [11]. This concept of "ucodes" can also be applied for content and information which do not exist in the real world and for more abstract concepts. One of the most recent works relevant to virtual representations of devices/objects is the concept of the "Web of Things" discussed in [12], where the aim is to integrate real world objects, data and functionality into the Web, instead of exposing these through vertical system designs. More specifically it is suggested that the exploitation of Web technologies is a suitable solution for building applications on top of services offered by smart things.

Regarding research on virtual objects and composite virtual objects semantics various activities also address the issue as a means for interoperability. An example work is [13] which aims to investigate unified concepts, methods, and software infrastructures that facilitate the efficient development of applications that span and integrate the Internet and the embedded world [14].

The main aim of this work is to contribute to the definition of VOs & CVOs, the specification of VOs and CVOs semantics and to propose a cognitive management framework for IoT. The registration and discovery of VOs and CVOs in the cognitive management framework for IoT will be linked to user and context information (pertinent to application requirements, real world objects and functionality, business domain, geographic domain, etc). Fig.1 illustrates the overall concept for providing cognitive management and control for VOs and CVOs.

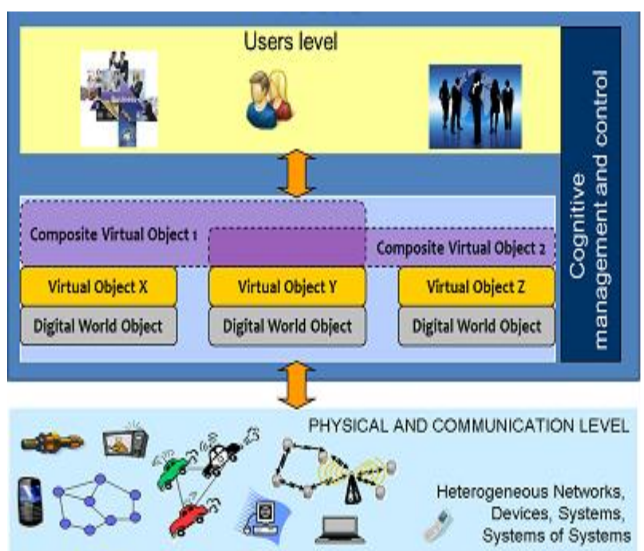

Fig. 1: Overall concept comprising VOs and CVOs

III. Cognitive Management Framework for IoT

The virtual objects are primarily targeted to the abstraction of technological heterogeneity. VOs accomplish their role through the cognitive management and handling of real-world or digital objects (e.g., sensors, actuators, devices, etc.). VOs are cognitive virtual representations of real-world objects and/or digital objects. The concept of VOs is based also on distributed objects which are used in object-oriented middleware applications in the Web as described in [15].

User/ stakeholder related objects will convey the respective requirements. The entities will be capable of detecting human intentions and behavior, inferring, and eventually acting on behalf of the users. In this respect, there is seamless support to users, which is in full alignment with their requirements (the learning capabilities of the cognitive entities of this layer will be applied for acquiring knowledge on user/stakeholder preferences, etc.). Capabilities for governing the entities will also be included (through any type of interaction - multi-modal interactions)

Composite virtual objects will be using the services of virtual objects. A CVO is a cognitive mash-up of semantically interoperable VOs that renders services in accordance with the user/stakeholder perspectives and the application requirements. Fig. 2 illustrates the transition from legacy to cognitive IoT by using simple objects as examples. In addition, Fig. 3 depicts the aforementioned layers of the proposed cognitive management framework.

	Domain		Explanation	Examples
IoT with cognitive functionalities	Cognitive		Context-aware, event-based virtual service composition	Smart World (iCore)
	Virtual object		Interoperable service domains, information sharing	Smart Environments (Smart-M3)
IoT	Digital world object	Digital services	Services in digital domains	UPnP, DLNA, Web services
		Digital connectivity	Communication between digital objects	Bluetooth
		Digital interface	Digital expressions of physical objects	Digital thermometer
	Real world		Physical objects	Analog thermometer

Fig. 2: Legacy and cognitive IoT

The cognitive management framework for the IoT, will enable the handling of diverse objects and the functions and services these objects provide. Thus, it will generate or support, a wider IoT eco-system which can and will be used by many different parties and types of users and stakeholders (across different application and usage domains). While (real world or digital) objects may be owned (controlled) by a particular stakeholder, the virtual objects (i.e. the abstractions of real world or digital objects) can be owned (controlled) by particular service providers. And in turn, composite virtual objects may be owned (controlled) by yet another provider who adds value by combining different virtual objects and providing these combinations to users.

This hierarchical structure leads to a rather complex eco-system, but it opens new opportunities for all stakeholders. Furthermore, the cognitive management system will ensure that the complexity of this eco-system will be well hidden from the different players and stakeholders. The life-cycle depicted in Fig. 4 illustrates the main stages and features of the approach.

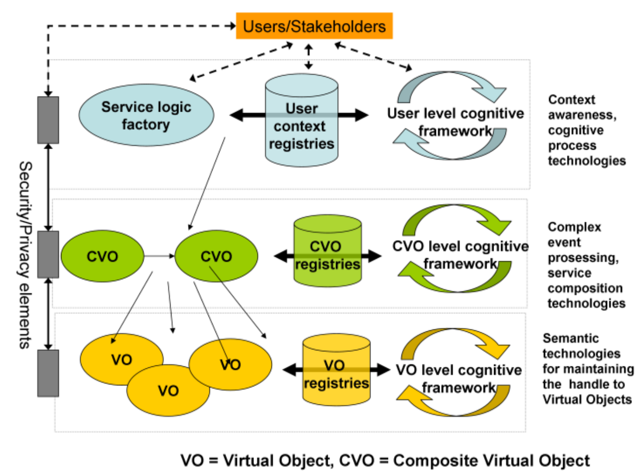

Fig. 3: Layers of the Cognitive Management framework [16]

IV. Application Scenarios and Business Benefits

The proposed paradigm is applied to various applications scenarios such as smart home (ambient assisted living), smart office (easy meeting), smart city (smart transportation) or smart business (supply chain management). Cognitive technologies constitute an efficient approach for addressing the technological heterogeneity and obtaining context awareness, reliability and energy efficiency. Cognitive technologies have been applied to the management of diverse heterogeneous technologies (e.g., wireless access, backhaul/ core segments). Therefore, new IoT-oriented cognitive functionality will be provided, which will be part of the service layer of the Future Internet.

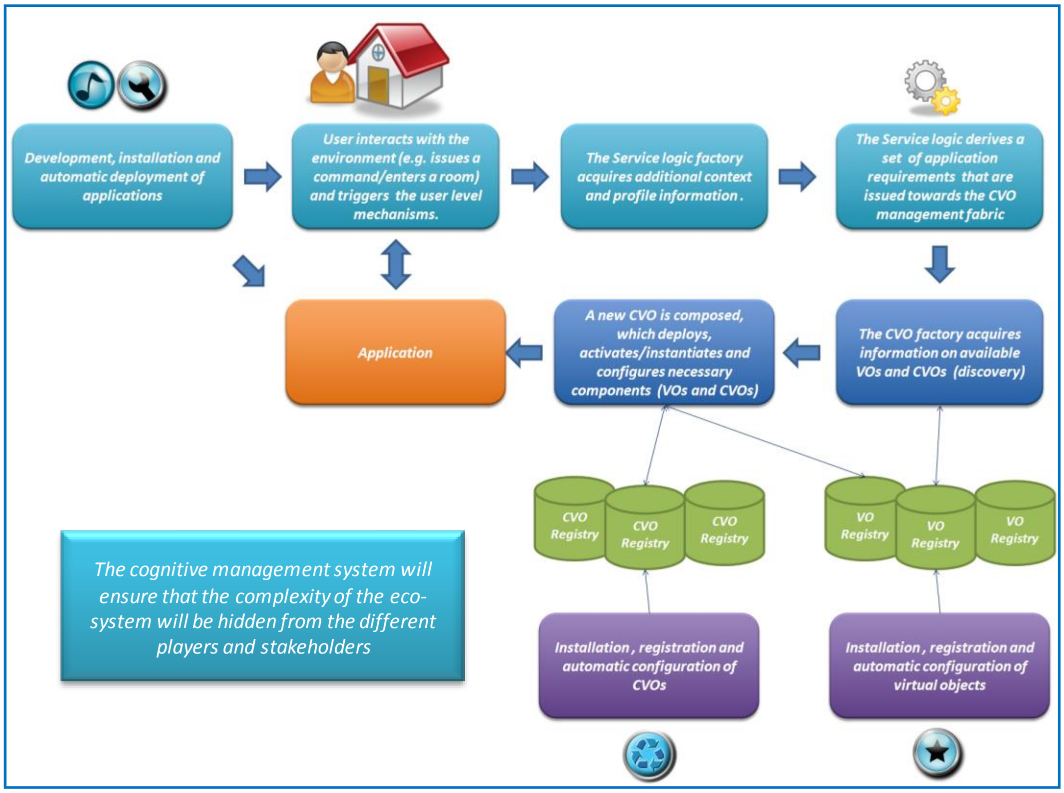

Fig. 4: Virtual Object lifecycle

A cognitive system consists of the "cognitive engine" (offering intelligence and service capabilities) and the "reconfigurable/managed part", which is technology specific. The engine interacts with the managed part and with other engines. Each managed part is directly controllable by one engine (i.e., other engines have to interact with the managing cognitive engine in order to affect a specific managed resource). Through this approach there is the accomplishment of the abstraction of the technological heterogeneity, which leads to the removal of the sector specific boundaries.

Self-management (self-x) features are essential for addressing the existence of a sheer number of objects and devices. Context awareness is inherent in the model, while policies and decision-making (part of self-x features) can be oriented to address the targets of enhanced reliability and energy-efficiency.

From the users/ applications perspective, three concepts IoT, ubiquitous computing, and ambient intelligence aim at delivering smart services to users [17]. A part of the smartness relies on context awareness, e.g., service provision according to the needs that exist at the place, time and overall situation. Also, at a societal level, smartness also requires that the needs of diverse users and stakeholders are taken into account. Stakeholders can be the owners of the objects and of the communication means. Different stakeholders that are part of the current Internet environment and they will be part of Future Internet, have interests that may be adverse to each other and their very own criteria on how objects could be used and should be accessed. So, a key challenge that needs to be tackled includes the handling of the diversity of information while respecting the business integrity, the needs and rights of users and of the various stakeholders. The following table provides information on the use case validation activities.

Table I. Use case validation activities

Use Case	*How*	*Before*	*After*
Smart home (ambient assisted living)	Virtual objects to interact with each other in a cognitive way. Reusability of virtual objects will enable collaboration across sectors, which will reduce the costs of services.	The patient lifestyle is not that good. Will be measured.	Better monitoring of patients

Smart office (meeting support/ easy meeting)	Seamless and faster configuration of user's wireless devices allowing them to connect to network they are "visiting"	Unproductive schedules, worst productivity will be measured	Increased productivity
Smart city (transportation)	Personalization of car feature based on user preferences and recorded profile	Low performance and time consuming transportation will be measured	Better and increased performance in the itineraries
Smart business (supply chain management)	Through the reusability of virtual object, various stakeholders collaborate with each other and reduce the costs of the services and increase efficiency of the entire supply chain	Effectiveness of the supply chain was not good enough. Will be measured	Improved supply chain management and performance

V. CONCLUSION

This work described a new cognitive management approach to manage the huge amount of data, systems and services which the Future Internet will be comprised of. The approach is based on the concept of CVO and VO to simplify the management of heterogeneous systems and data. Specific features of digital and physical objects can be represented as VO attributes. Future developments will investigate how to address scalability of the proposed approach: the cognitive management architecture must be able to support millions of CVO/VOs and make them accessible from various instances of the management framework for IoT deployed in various domains.

ACKNOWLEDGMENT

This work will be funded from FP7 Integrated Project iCore (**I**nternet **C**onnected **O**bjects for **R**econfigurable **E**co-systems). Also, it is supported by the Wireless World Research Forum. A. Georgakopoulos, P. Demestichas and V. Stavroulaki have performed this work in the framework of the E3 project National Participation, funded by the General Secretariat of Research and Technology (GSRT) of the Greek Ministry of Development.

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