

# COGMAN: A cognitive management framework to support exploitation of the Future Internet

Gianmarco Baldini, Ranga Rao Vencatesha Prasad, Abdur Rahim Biswas,  
Klaus Moessner, Matti Etelapera, Juha-Pekka Soinen,  
Septimiu-Cosmin Nechifor, Vera Stavroulaki, Panagiotis Vlacheas

**Abstract.** — In this article, a cognitive management framework is proposed for ensuring exploitation of the Future Internet (FI). 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

## 1 Introduction

The “7 trillion devices for 7 billion people” paradigm [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. While several research projects (e.g., IoT-A 2, CASAGRAS2 3) have set out to define architectures or reference models to ensure interactions and facilitate information exchange, there is a significant lack in terms of management functionality and means to overcome the technological heterogeneity and complexity of the pervasive networks. This is essential for the IoT, in order to enhance context-awareness (by being able to exploit more objects), provide high reliability (through the ability to use heterogeneous objects in a complementary manner for reliable service provision), energy-efficiency (through the selection of the most efficient and suitable objects from the set of heterogeneous ones, and, in general, through the

optimal management of a large population of resource constrained devices) and 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 [4].

In response to the requirement of overcoming technological heterogeneity this paper proposes a cognitive management framework called CogMan. The proposed framework 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. This means that the functionality or features offered by any kind of object can become part of more composite functionality/features, which will be reusable in the context of sophisticated application/service provision in the IoT.

Moreover, the aim of the CogMan framework is to provide the foundations, architecture and functionality for a cognitive management paradigm for the IoT. A cognitive system has the ability to dynamically select its behaviour (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.).

In the light of the above, 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). The CogMan framework applies this successful paradigm for solving problems that are particular to the IoT. Therefore, new IoT-oriented cognitive functionality will be provided, which will be part of the service layer of the Future Internet. 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.

Additionally, the CogMan framework addresses security, resilience and user privacy issues, which are vital for the Future Internet, through a policy management approach where access to data and resources is regulated by policies and access levels.

From the users/applications perspective, three concepts IoT, ubiquitous computing, and ambient intelligence aim at delivering smart services to users [5]. 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. This is not all. 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 milieu 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. Clark et al. 6, calls this process “the tussle” and any Future Internet framework should be able to accommodate such “tussle” to support a smooth evolution of Future Internet. 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 approach presented in this paper aims to overcome the issues above by bringing further intelligence in the Internet of Things. The remaining part of the paper is organized as follows: Section II describes the proposed approach to address such challenges through a cognitive management framework based on the concept of “virtual object”. Section III describes the Security and Privacy aspects. Section IV describes the application of the cognitive management framework to two scenarios: smart home and smart office. Section V concludes the paper and provides future directions in this research area.

## **2 CogMan: Cognitive Management Framework for Future Internet**

The CogMan framework is targeted to concealing technological heterogeneity and for satisfying the requirements of different users/stakeholders so as to meet the objectives for context awareness, reliability, and energy efficiency. Additionally, security will be a primary concern and an important property at all levels of the cognitive framework. The framework comprises three main levels of enablers, which are reusable to various-diverse applications.

In each layer there are scalable fabrics, which offer mechanisms for the registration, look-up and discovery of entities, and the composition of services.

Cognitive entities at all levels provide the means for self-management (configuration, healing, optimization, protection) and learning. In this respect, they are capable of perceiving and reasoning on their context (e.g., based on event filtering, pattern recognition, machine learning), and of conducting associated knowledge-based decision-making (through associated optimization algorithms and machine learning).

Through such features the CogMan framework constitutes an open networked architecture encompassing highly intelligent (i.e., adaptive, knowledge based, eventually proactive, etc.) software.

The virtual objects (VOs) 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.

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 (CVOs) 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.

The concept of VOs is not new. Object-oriented (OO) approaches have been used in computer programming for decades and distributed objects are used in Object-oriented middleware applications in the Web 7. The intention is not to create new digital representations/objects, but to combine previous concepts with cognitive management mechanisms to create and maintain dynamic, intelligent virtual representation of real world/digital objects that can enhance the Future Internet.

As already introduced, CogMan comprises three layers of cognitive components, which are depicted in Figure 1.

The first cognitive management layer (*VO level cognitive framework*) is responsible for managing the VOs and for the abstraction of the technological heterogeneity. Real-world or digital objects (e.g., sensors, actuators, devices, etc.) are represented in the first layer through VOs. The management layer is responsible for the VO lifecycle (i.e., creation, update, destruction) and to address the heterogeneity by defining the logical links among VOs. For example the container transported by a truck is a VO as the truck itself. A tracking device on the truck (with GPS and communication terminal) is also a VO.

The second cognitive management layer (*CVO level cognitive framework*) is responsible for composing the VOs in Composite VO (CVO). CVOs will be using the services of VO to compose more sophisticated 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. For example, the combination of the trucks, the transported goods and the tracking device is represented in the cognitive framework as a CVO.

The third level (*User level cognitive framework*) or Service Level, is responsible for interaction with User/stakeholders. The cognitive management frameworks will record the users needs and requirements (e.g., human intentions) by collecting and analyzing the user profiles, stakeholders contracts (e.g., Service Level Agreements) 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).

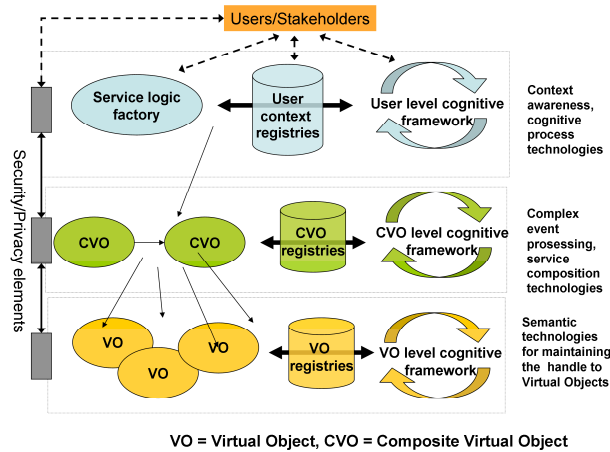


Figure 1 Layers of the Cognitive Management framework

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