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Cognitive friendship and goal management for the social IoT☆

Panagiotis Kasnesis [a,*], Charalampos Z. Patrikakis [b], Dimitris Kogias [b], Lazaros Toumanidis [b], Iakovos S. Venieris [a]

[a] School of Electrical and Computer Engineering, National Technical University of Athens, Iroon Politechniou 9, 15773 Athens, Greece
[b] Department of Electronics Engineering, Piraeus University of Applied Sciences, Petrou Ralli & Thivon 250, 12244 Aegaleo, Greece

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The concept of an Internet of Things is already mature, enough to start evolving towards an Internet of Everything, over which humans, objects and virtual items can be interconnected. For this to be feasible though, there is the need for a framework which not only supports the interconnection between the entities of this Internet, but also allows the meaningful interaction between them. In this paper, we present an idea on how this can be materialized, based on the use of semantic web technologies and smart software agents. These middleware technologies, combined with machine learning techniques, can lead to cognitive friendship and goal management. The paper includes a presentation of the theoretical framework, a use case scenario, and results over the use of a simulation tool.

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1. Introduction

With Internet counting more than 45 years of existence, in which it has changed the way people communicate, get informed and entertain, the next step in its evolution is to expand beyond human-to-human communication. In this course, machines which up to recently have been used for enabling communication over the Internet, are now taking actively part in this communication, extending the traditional Internet, to the Internet of Things (IoT), over which humans, machines and even (connected) objects are able to communicate. If we take into account the proliferation of Online Social Networks, and the power they hold for linking people based on preferences and personal profiles, it is only natural that this communication between things over IoT will adopt and benefit from the potential of socialization between Things. But before we get into a deeper analysis of this potential, let us take a closer look into the term: Socialization [soh-shuh-luh-zey-shuh n]: "*A continuing process whereby an individual acquires a personal identity and learns the norms, values, behavior, and social skills appropriate to his or her social position*" [1]. From this definition, one can easily understand the benefits socialization of connected objects can introduce to the IoT. The idea is not new. It was firstly introduced in [2] and provides the basis on which interaction between things (and humans) can happen in a meaningful way. In this paper, starting from the definition of a Social Internet of Things (SIoT), as this has been presented in the global bibliography; a proposal is presented on the support of cognitive interaction through the establishment of "friendship" between peers, and supported by the necessary ontological framework.

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* Corresponding author.
E-mail address: pkasnesis@icbnet.ece.ntua.gr (P. Kasnesis).

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The presented proposal extends the concept of smart interconnected systems, as this is defined in IoT, by enabling the connection and the collaboration between the *cyber* (agents and applications) and the *physical* (humans and things) worlds. This leads to the establishment of a *cyber-physical ecosystem*, in which humans and things connect and interact based on the use of ontologies and specific rules. The reason behind the creation of new relationships between the entities, is to satisfy the large number of needs that these entities declare. As the number of connected devices and their relationships is increasing, the probability that a certain need can be served by a "friend" of any device in the network is increasing proportionally, leading to a co-operative world of entities that constitute the cyber-physical ecosystem populated by multi-agent instances.

Our Multi-Agent System (MAS) is an environment comprising multiple interacting cognitive agents, namely the *Device Agents*, the *Human Agents* and the *Task Agents*. *Device Agents* represent smart objects, while *Human Agents* represent humans, and *Task Agents* represent applications. All of these entities *produce services* and *have needs*. For example, a *Human Agent* needs to have its house cleaned.[1] If a *Task Agent* responsible for cleaning exists, then it will communicate with its co-work friends that produce cleaning services (e.g. smart vacuum cleaner) in order to complete this task. However, *Human Agents* can produce services by acting as sensors. If a human is annoyed by the noise the vacuum cleaner produces, (s)he can act (through the corresponding human agent) as a noise sensor and inform the cleaning agent about this annoying situation. In this case, the cleaning agent can communicate with local sensors in an attempt to clean the rooms where the resident is not present. The communication between humans, devices and agents should be enabled through smart interfaces and light IoT protocols, such as MQTT (Message Queuing Telemetry Transport).

Since the main objective of our work is the creation of a cognitive middleware capable of managing the social relationships of smart Internet of Everything (IoE) entities, it is important to discuss how we address interoperability issues concerning service discovery in order to support the collaboration of smart entities for achieving common goals. In this course, the main contributions of our study are as follows:

- Firstly, we propose the use of smart software agents for representing IoE entities in the SIoT paradigm.
- Secondly, we designed two ontologies for handling cognitively the social relationships of the smart entities.
- Then, based on the designed ontologies, we propose the introduction of an embedded descriptive file in smart objects, which will define the profile of the smart object and as a result its Life Cycle.
- Subsequently, we present candidate machine learning methods which could be used for Cognitive Friendship and Goal Management and the features that should be taken into account in this process.
- Finally, on the basis of the proposed cognitive middleware, we investigate an IoT use case scenario, where the social links are built using a set of semantic rules and run it on our SIoT simulator.

The rest of the paper is organized as follows: In Section 2, an overview of the state of the art in IoT is presented. In the next section, two ontologies empowering the ecosystem are described. Section 4 introduces the Life Cycle of a smart object, and Section 5 discusses possible issues on cognitive friendship management and goal management. Section 6 describes a SIoT simulation tool and analyzes its performance based on a given scenario. Finally, Section 7 concludes the paper and proposes future work.

2. State of the art in IoT

2.1. Social Internet of Things

The SIoT, is a "social network of intelligent objects". Similarly to the way humans participate in Social Networks (SNs), there can be a network built upon social relationships between smart objects. The SIoT paradigm offers: a) network navigability for scalable and effective service and object discovery, b) exploitation of models of Social Networks to address IoT related issues, and c) creation of a level of trustworthiness among things which are "friends". The first concept is what makes the SIoT such a powerful paradigm. Every object searches the network for a desired service by querying its friends, the friends of its friends and so on, in a highly distributed way. This idea is what made the human SNs so useful and was firstly introduced in a Stanley Milgram's experiment, where in an attempt to measure the average path length for social networks of people, he realized that everyone is separated from another with at most six degrees (links), leading him to the theory of small worlds [3].

In [4] Atzori et al. propose a possible architecture for the SIoT, and by analyzing several types of possible services and applications, they divide the social relationships of a smart object into five types ("*Parental object relationship*", "*Co-location object relationship*", "*Co-work object relationship*", "*Ownership object relationship*" and the "*Social object relationship*"). In [5], Nitti et al. present five possible strategies for friendship selection. It is a well investigated approach which leads to the conclusion that having more random friends is preferable than having a "clique" of friends. In the SIoT ecosystem this means that occasional friends and sometimes co-work friends are more valuable than the other types of friends. However, the above conclusion leads to another one: ownership friends (i.e., smart entities that belong to the same owner) are less important. In many cases this is true, but in others, the object will not be able to satisfy the personalized needs of their

[1] Since by the term agents we will refer to software components, the term in the paper will be used with no gender.

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