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Using trust and local reputation for group formation in the Cloud of Things

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HIGHLIGHTS

- Cloud of Things provides powerful tools to face the complex tasks of IoT.
- Exploiting the social attitude of software agents in the Cloud of Things can provide several benefits.
- Organizing the agents into groups will enable operations in a reliable social environment.
- An algorithm named CoTAG (CoT Agent Grouping algorithm) is proposed to form groups in the Cloud of Things.
- A trust metric is proposed to measure mutual trust among software agents in a Cloud of Things environment.
- Experimental results prove that the proposed approach leads to form groups with high values of mutual trust.

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ABSTRACT

Nowadays, a challenge for the "Internet of Things" (IoT) world is represented by the necessity of facing very complex and interactive tasks, such that IoT devices have to be equipped with hardware having very powerful capabilities. All this becomes particularly critical in presence of small and low-cost IoT devices. A way to deal with such problems is represented by the possible virtualization of the IoT environments over the cloud, the so called Cloud-of-Things (CoT), and then to associate each device with one or more software agents working in the Cloud environment. Moreover, the convergence of these technologies allows IoT devices to take significant benefits also by the social attitude of software agents to interact and cooperate. In this context, based on Machine-to-Machine (M2M) interactions, the choice of the partner for cooperating is a sensitive question, particularly in open and heterogeneous environments. If an agent does not hold suitable information to carry out a reliable choice then, similarly to real communities, it can ask information to other agents it considers as trustworthy. In this context, agents cooperation must be supported by a proper trust model which helps to select potential partners. This process can be further improved by partitioning the agents in different groups based on trust relationships. This way, each agent has the possibility to prefer the interactions with the agents belonging to its group that are, from its viewpoint, the most reliable for avoiding malicious behaviors and threats of different nature. To this purpose, we designed an algorithm, named CoTAG (CoT Agent Grouping algorithm), to form agent groups on the basis of information about reliability and reputation collected by the agents. To verify the efficiency and effectiveness of this algorithm, we carried out some experimentations in a simulated scenario. The results confirm the potential advantages deriving by the adoption of our proposal.

1. Introduction

In 1999 Kevin Ashton prophetically foresaw the "Internet of Things" age [1] that is connecting people and physical objects over

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Internet, on a massive scale[1] in an interactive manner. Internet of Things (IoT) realizes multi-dimensional and context-aware smart environments[2] for every aspect of our everyday-life [4]. In general, IoT can be assumed as a global network infrastructure composed by heterogeneous cooperating smart objects able to sense, reason, collaborate and act in real time upon the environment by using a wide range of different sensory, communication, networking and information technologies [5,6] and capable of social interactions [7,8].

Nowadays, a challenge for the IoT world is represented by the necessity of facing complex interactive tasks and, consequently, increasing hardware and power capabilities are required to IoT devices. This issue becomes particularly critical in presence of small and low-cost IoT devices. Therefore, given IoT potentialities, Information and Communications Technology (ICT) industries and important standard organizations are supporting IoT technical, social, and economical challenges by developing both new technologies and standards [9] to manage the complexity placed by the IoT world at best.

At the same time, Cloud Computing (CC) has emerged as a successful Internet information technology addressed to share ubiquitous, reliable, configurable and highly scalable services [10,11], a mainstream in processing and storing data to form knowledge ubiquitously accessible in distributed environments and in an interoperable fashion [12]. In this scenario IoT and CC converged to realize the so called Cloud-of-Things [13,14] (CoT). Such a tighter integration is strategically motived from the necessity to support, in a scalable way, the computational and storing requirements [15] coming by an overwhelming number of ubiquitous, heterogeneous and often small and low-cost IoT devices for discovering, composing or making available new services. Moreover, the virtualization of more IoT environments over a unique CC also makes easier to support mobile devices in their nomadic activities [16].

In particular, associating IoT devices with software agents, working on their behalf in the Cloud [17,18], can provide several different benefits: first of all, software agents are able to manage complex tasks independently from the IoT hardware and power capabilities; secondly, the convergence of these technologies allows IoT devices to take significant benefits also by the social attitude of software agents to interact and cooperate, very useful in engaging IoT challenges. In other words, the level of "satisfaction" in the M2M (Machine-to-Machine) interactions occurring among devices in the composition of CoT services is highly influenced by the choice of the "partner" for cooperating [19], particularly in open and heterogeneous environments. Therefore, when an agent has not suitable information to choose a reliable partner then, similarly to real communities, it can ask information to other agents it considers as trustworthy. As a result, agent cooperation can be promoted by supporting agents with reliable recommendations about their potential partners [20]. To this purpose, the intuition underlying our proposal is that of supporting this process by encouraging agents to form groups of reliable recommenders.

In fact, software agents (in the interest of their associated devices) can form complex social structures, as agent groups, on the basis of some type of social relationships among the group members [21,22]. Given their relevance in real and virtual communities, the dynamics underlying formation, evolution and roles of social groups have been widely investigated in the literature [23–26]. In this context, a common viewpoint considers that groups should be formed on the basis of both structural and semantic similarities (representing commonalities of relations, interests and preferences) [27]. Due to the high heterogeneity of devices, a similarity approach could be not applicable at all the devices and, therefore, different criteria have to be adopted. We observe that an important property considered in forming groups within a community is a high level of mutual trustworthiness among the group members. This is particularly important in promoting agents mutual collaboration based on their mutual trust [28]. Therefore, we consider the trust-based processes devoted to form agent groups of reliable recommenders over a CoT context as worthy of investigation because, potentially, such groups can significantly improve the devices activities.

1.1. The scenario

Basing on the premise above introduced, we consider a CoT environment where devices, heterogeneous for characteristics and/or goals, consume/produce services and/or extract/exchange knowledge by exploiting the assistance, over the cloud, of personal software agents. More formally, let us denote with A the set of software agents, associated to IoT devices; these agents, as already discussed, live in the Cloud. For sake of simplicity, the set of agents and their relationships are represented by means of a graph $G = \langle N, L \rangle$, where N represents the set of nodes belonging to G and each node $n \in N$ is associated with a unique agent $a \in A$, while L is the set of oriented links where each link $l \in L$ represents a relationship occurring between two agents. Since each IoT device and its associated agent are identified in an univocal manner, from this point we assume that the single device and its associated agent $a \in A$ are the same entity.

With respect to the agent group membership, we consider that the agents are free of belonging to one or more groups, as well as to leave a group on the basis of their convenience. At the same time, we assume that each group is coordinated by an agent group administrator that, to maximize the effectiveness of the group itself, can contact other devices (i.e., agents) to join with or to remove from the group those agents resulted ineffective.

To reach their goals, the consumer agents can exploit some data services (s) made available by other agents only for payment. Note that each agent can be a consumer or a provider of services.[3] In requiring a service to a provider, an agent might take benefit from its past experiences, but if they are not sufficient to perform a good choice it can also require the opinions of other agents [29].

More formally, we assume that the generic agent a_i has not a suitable direct past experience about a provider agent a_j, it can ask a recommendation $rec \in [0, 1] \subseteq \mathbb{R}$, where $\mathbb{R}$ is the set of real numbers, to another agent a_r. If a_r belongs to the same group of a_i this recommendation is provided for free, otherwise a fee has to be paid from a_j to a_r after the recommendation was provided.[4] This mechanism implies that, on the basis of trust measures, groups are interested in accepting those agents having a high reliability and helpfulness; at the same time agents are interested to be affiliated with those groups formed by agents with a high reliability and helpfulness. However, remember that all the services are provided only for payment, differently from the recommendations that could be provided also for free; in this way, the proposed scenario has a competitive nature.

In this context, to evaluate the helpfulness of an agent we consider the effectiveness of its recommendations, while trivially that of a group is the average of the helpfulness of its members.

[1] In our context, an *object* (i.e., a thing) is a physical (or virtual) entity that throughout its lifetime is precisely traceable in space and time, sustainable, enhanceable and uniquely identifiable [2].

[2] A smart environment is characterized by the capability of acquiring knowledge about itself and its inhabitants so as to adapt itself to their needs and behaviors [3].

[3] In presence of an agent performing both the roles (i.e., a prosumer) by acting as provider for some services and consumers for other services, we consider these activities as disjointed.

[4] To assure the competitiveness, each agent can satisfy at most Y requests of recommendation for payment.