

From “Smart Objects” to “Social Objects”: The Next Evolutionary Step of the Internet of Things

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ABSTRACT

Social networking concepts have been applied to several communication network settings, which span from delay-tolerant to peer-to-peer networks. More recently, one can observe a flourish of proposals aimed at giving social-like capabilities to the objects in the Internet of Things. Such proposals address the design of conceptual (and software) platforms, which can be exploited to easily develop and implement complex applications that require direct interactions among objects. The major goal is to build techniques that allow the network to enhance the level of trust between objects that are “friends” with each other. Furthermore, a social paradigm could definitely guarantee network navigability even if the number of nodes becomes orders of magnitude higher than in the traditional Internet. Objectives of this article are to analyze the major opportunities arising from the integration of social networking concepts into the Internet of Things, present the major ongoing research activities, and point out the most critical technical challenges.

INTRODUCTION

The future Internet will embody a large number of objects that, through standard communication protocols and unique addressing schemes, provide information and services to the final users. Indeed, billions of objects are expected to take a major active role in the future network, bringing physical world data into the world of digital content and services. The resulting networking paradigm, referred to as the Internet of Things (IoT), will provide a paramount set of opportunities to users, manufacturers, and service providers with a wide applicability in many productive sectors. These include environmental monitoring, health care, inventory and product management, smart home and workplace, security and surveillance, and many others.

In the IoT, all that is real becomes virtual: each person and thing has a locatable, addressable, and readable counterpart in the Internet. In this scenario, objects can produce and con-

sume services and collaborate with other counterparts toward a common goal. This is possible thanks to intense interactions among objects, which collaborate to realize complex services. This has brought the design of new generations of “smart objects” able to discover new services, start new acquaintances, exchange information, connect to external services, exploit other objects’ capabilities, and collaborate toward a common goal. At the present stage of the IoT evolution, the questions are:

Are there new potentials that smart objects are still expected to manifest?

Can these potentials bring new (more effective) models of IoT systems and contribute toward the achievement of a fully networked human society?

To answer these questions, we observe that smart objects will need to operate in an extremely complex context full of opportunities as well as difficulties and threats. It is unlikely that single (even very smart) objects will ever have the capabilities to face such complexity by themselves.

In the natural world, several species of animals (humans are the most brilliant example) have been able to master complexity and the difficulties that characterize the environment in which they live by creating a dense network of social relationships.

Accordingly, one can envisage a new generation of social objects that: i) are able to interact with other objects in an autonomous way with respect to the owners; ii) can easily crawl the IoT made of billions of objects to discover services and information in a trust-oriented way; and iii) are able to advertise their presence to provide services to the rest of the network.

This is resulting in a new vision of an augmented IoT where the concepts and technologies typical of social networks are applied to the world of things to foster resource visibility, service discovery, object reputation assessment, source crowding, and service composition, similar to what has been partially done to address the routing issue in delay-tolerant networks [1].

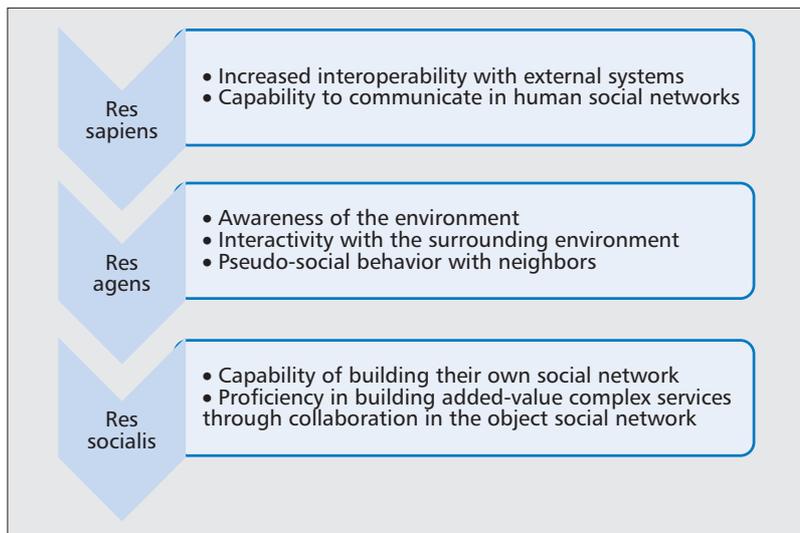


Figure 1. Main features of the identified three categories IoT objects.

The major contribution of this article is to provide the reader with a comprehensive analysis of the key aspects of this new phenomenon, with particular attention to the different visions, technical solutions, ongoing projects, and open research challenges that the research community is called to address. In the following section we analyze the evolution of the objects' behavior as key components of the IoT; we then introduce the major developments that are ongoing in this area and the most relevant products already available on the market. Exemplary use cases that exploit the major benefits of the convergence between IoT and social networks are then analyzed. The last section draws important directions for future studies.

FROM SMART THINGS TO THINGS THAT SOCIALIZE

The scientific literature provides a wide range of examples of how modern technology has been able to accomplish the definition of devices that, thanks to their abilities, we might call "smart objects" and consider, without a doubt, the constituent elements of the IoT [2]. Besides, software frameworks to build user-centric extensible smart object systems are the subject of very interesting research activities like the one in [3].

Nonetheless, smart objects are only the first step of an evolutionary process that is affecting modern communication devices and has been triggered by the advent of IoT in the telecommunication scenario.

We are currently observing a generational leap from objects with a certain degree of *smartness* to objects with an actual *social consciousness*.

In analogy with the human evolution from *homo sapiens* to *homo agens* used in economic and sociological studies, we may talk of a similar evolutionary path from a *res sapiens* (smart object) to what we call a *res agens* (an acting object), which is able to translate the awareness of causal relationships — the basis of knowledge of change and evolution of its environment — into actions.

In our opinion, the time is ripe to take even a further important step in the evolution of the objects, without which the fully development of an IoT populated by trillions of objects cannot be achieved. What we intend is a further evolution toward a new type of object that can be considered a *res socialis* (i.e., social object, again in analogy with the socio-economic term *homo socialis*). The term refers to an object that is part of and acts in a social community of objects and devices (which, in our case, is a social IoT).

The features of the three identified categories of IoT objects are illustrated in Fig. 1 and described in the following subsections, highlighting the advantages these provide (or will provide) to advances in the IoT.

THE STATUS QUO: RES SAPIENS IN THE IOT

Most IoT solutions have been initially devised and built in isolation, resulting in limited and fragmented small islands of heterogeneous smart objects (*res sapiens*) disconnected from each other. This is the natural consequence of isolated studies and developments conducted without a widely recognized and interoperable reference architecture in mind. This has prevented and still prevents implementing an actual IoT ecosystem on top of which composite applications can easily be developed. An obvious, yet effective, countermeasure to IoT fragmentation consists of enabling the *res sapiens* to directly communicate with the external world by relying on web protocols and communication paradigms universally recognized by the current Internet of services. This made the *res sapiens* objects evolve through different stages as sketched in Fig. 2 and described in the following.

The first innovation has been the introduction of what is today commonly referred to as the Web of Things (WoT) [4], which relies on the implementation of web protocols into either the objects themselves or specific objects' proxies/gateways. Mostly, the current implementations make use of either the Device Profile for Web Services (DPWS) or Representational State Transfer (RESTful) application programming interfaces (APIs) (also in thing-specific versions, such as Thing-REST [5]). Accordingly, the services and information provided by the things can be incorporated in the open ecosystem of the Internet of services. On top of this, applications can be created by using standard web languages and tools.

Still, the WoT paradigm by itself has some limits, caused by the difficulties in advertising, discovering, accessing, and exploiting the objects and their services.

An additional desirable feature is the capability that allows Internet users and services to sense the physical world and act on it. One approach in this direction is to create a platform where the objects can easily be found, searched for, exploited, and composed. This is the case of some solutions that have recently appeared on the web, such as SenseWeb (<http://www.sensormap.org>) and Xively (formerly called Pachube — <http://xively.com>), which provide people with a central platform to share their sensor data and deploy relevant applications. The people's inter-

est in making their objects available to the rest of the community allowed these platforms to quickly gain great popularity.

The natural evolution of this idea is improving the attitude of users about sharing their smart objects with people they know and trust (e.g., relatives, friends, colleagues, and fellow researchers), without the need to recreate from scratch any additional social network or user database on a new online service.

This has nothing to do with the IoT object's evolution toward the social consciousness we are addressing in this article, but it is worth mentioning as evidence that the IoT and social networks are two worlds not that far apart from each other.

One of the first proposals along this line is in [6]. The main idea proposed in that article is that a user who wishes to share data sensed by her own objects can do this by posting such data on Facebook and allowing selected people to view them. A similar approach is proposed in the CenceMe application (<http://metrosense.cs.dartmouth.edu/projects.html>), which focuses on combining information on the presence of individuals obtained through off-the-shelf sensor-enabled mobile phones, with the user profile in social networking platforms such as Facebook and MySpace.

Another interesting example is given by the MemPhone memory augmentation system, which enables users to associate their memory/experience data with various physical objects through mobile tagging [7]. The interesting results of this study is that by embedding physical contexts into human social networks, object-based social networks can be formed that are augmented by new connections among people with shared memories.

Not only are experimental platforms available, but commercial products can also be found on the market. A popular product is the Nike+, which combines individual statistics and visualizations of sensed data and promotes competition between users. The collected data can be shared in social networks with the intent of forming communities around a sensing application. Other applications have emerged that are considerably more sophisticated in the type of inference made, but have had limited uptake, and it is still too early to predict which of them will become the most compelling for the IoT user communities.

A further step ahead in this direction is the definition of an interaction model that does not rely on tight coupling with a single external service whose contract (API and allowed accesses) is subject to change over time. In this sense, the best solution would be to define an interaction paradigm that allows supporting different social networks and enabling users to control which ones to use for each device. This is presented in [8], where a system is described to share IoT smart objects and facilitate access to real-world services offering a RESTful web API. A web platform called Social Access Controller is proposed, which acts as an authentication and sharing proxy for smart things. This helps users to fine-tune the nature of interactions they want to allow for their smart things (e.g., read-only,

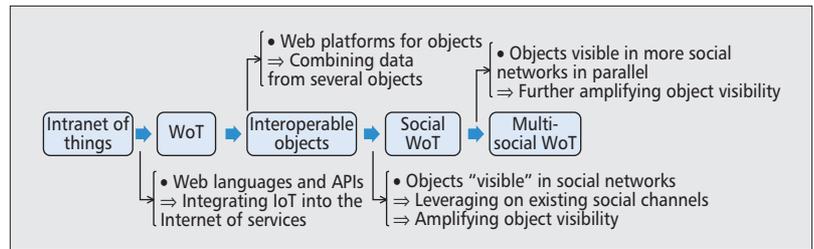


Figure 2. Increasing interoperability and visibility of smart things in the IoT.

read-write) and manages the access control based on the existing social structure of several social networks.

THE ONGOING EVOLUTIONARY STEP: RES AGENS IN THE IOT

Actually, the evolutionary path toward the notion of objects that *are not simply included and made available in a social network of humans but manifest their own social behavior* began years ago. Some of the founding ideas date back to early 2000 and were developed in areas distant from both social networks (at that time still in their infancy) and the IoT (whose concept began to emerge through the work of the Auto-ID Labs some years later).

Indeed, one of the first ideas of pseudo-socialization between objects belonging to the *res agens* category can be found in an interesting paper by Holmquist *et al.* [9]. Through the so called Smart-Its Friends procedure, users had a very easy-to-use interface to impose temporary relationships of friendship on Smart-Its (smart wireless devices, which in general integrate sensing, processing, and communication functions) based on the devices' context.

More recent research has been carried out addressing the issue of a *res agens* that exhibits pseudo-social behavior. The result is that several papers have appeared in the literature and in project reports demonstrating intense experimental activity involving objects of everyday life augmented in their capabilities to interact in modes that were inconceivable in the past.

The so-called Blog-jects, a synonym for "objects that blog" introduced in [10], are examples of this new attitude to *tight interaction with the world*, which is felt necessary to be instilled in traditional devices. The leap forward from the past is represented here by the clear distinction between a "thing" that is simply connected to the Internet and a "thing" that has an active role in the social network.

From this definition, it can be seen that a significant evolution in the concept of "spime" (neologism for a currently theoretical object introduced by Sterling) is already in place. In practice, besides the typical properties of a spime, which can be tracked through space and time throughout its lifetime, a further property is envisaged by Bleecker, that is, the ability to "foment action and participate; ... have an assertive voice within the social web."

An interesting example of the attempt to go *well beyond the current vision of an IoT as a mere opportunity of having objects connected and easily*

In the scientific arena there have been, and still are, extensive discussions on what an object really has to say to another object for which you really need an IoT and how these “conversations” between objects may promote the development of human society.

accessible over the web is represented by the theoretical concept of embodied microblogging (EM) introduced in [11]. It does not focus on thing-to-thing or human-to-thing interactions, but proposes a novel role for augmented everyday objects, which are called to:

- Mediate human-to-human communication
 - Support additional ways for making noticeable and noticing activities in everyday life
- Specifically, the authors of [10] implement some EMs that facilitate the social contacts among elderly people living in the same neighborhood.

The work in [12] is an example. In fact, the authors’ vision presented in that position paper is a user-centric network in which augmented objects are connected to facilitate the interactions between human beings and their physical and social environments. This is achieved thanks to embedded software solutions and sensorial capabilities, which made the involved objects able to develop a spontaneous networking infrastructure based on the information to be disseminated other than information on the objects themselves. The participative market solution proposed in [13] is also an example of how objects can share key marketing information with external systems for the benefit of customers, who are then able to retrieve and share knowledge among the different products.

Very similar to this approach is the one in [14, 15] in which the basics of the novel concept of “opportunistic IoT” are addressed. The main objective of the authors is “bringing awareness and enhancing intelligence to the IoT system by analyzing the interactions between humans and smart objects.” In this view the objects within the IoT *actively contribute* to provide the IoT with user, ambient, and social awareness by sensing and monitoring human behavior.

THE FUTURE EVOLUTIONARY STEP: RES SOCIALIS IN THE IOT

In the scientific arena there have been, and still are, extensive discussions on what an object really has to say to another object for which you really need an IoT and how these “conversations” between objects may promote the development of human society. Well, here we are discussing a concept that goes even beyond: *why objects should have their own social network, separate from that of humans, if they are not supposed to call each other to agree to go clubbing by themselves (at least for the next years)?*

Indeed, there are a thousand reasons that could inspire a director of science fiction films to create her new masterpiece centered around robots having their own social network, which may even host some elected humans. But these reasons are not enough for pragmatic computer scientists and engineers, who prefer to focus on use cases that are already possible to implement. Some interesting examples, which allow understanding the advantages of applications based on social networks of objects *separate* from those of human beings but *subservient* to their needs, are given in [16].

This attractive idea, which starts from Bleecker’s vision but goes beyond it, is supported by recent studies, of which there is evidence in the

literature, aiming to address the real convergence of social networks and IoT.

An example is the work in [17], where the authors envision the future of the Internet as being characterized by what they name ubiquitous IoT architecture. This resembles the social organization framework (SOF) model. Reference [18] provides an insightful overview of the expected IoT network structure, but does not indicate which characteristics the social network structure of an IoT should have.

An important contribution toward the definition of a social IoT is given in [18]. This article investigates the possibility of integrating IoT and social networks, and gives interesting examples of applications; unfortunately, it addresses neither possible procedures to establish social relationships among objects and indications nor possible architectural solutions for a social IoT. Similarly, within the objectives of several strategic research agendas, the concept of social IoT is appearing, but just in the form of a mere declaration of interest (e.g., the Finnish Strategic Agenda for Science).

Major attention to the exploration of social potentialities of the IoT building blocks is given in [19]. In this paper, an architecture is described in which objects are clearly identified as potentially able to participate in communities of objects, creating groups of interest and taking collaborative actions. Notwithstanding, this article again lacks a description of how to build the envisioned social network of objects and how to implement the needed architecture and protocols. Differently, in [20] social attributes, which reflect the social relations of nodes, are analyzed, and the results of an initial investigation of the system characteristics are presented in terms of some key parameters. Also, the mobile node behavior is studied by applying the typical theory of social networks.

Summing up, we can say that the novelty of the idea of *res socialis* lies in the fact that the social networks of objects, which we are addressing, are established between objects that are owned by humans who may have no connection with each other. These are not human social networks in which the members share objects (as in the cases described for *res sapiens*) or the social networks of human enhanced by the presence of objects (as in the cases described for *res agens*). Differently, they are networks based on relationships among objects, which may offer services to humans efficiently by exchanging information through the social relationships they have established. The resulting objects’ social network is expected to enhance the performance of IoT systems with particular reference to the functionalities of object discovery, service composition toward the deployment of added-value services, and evaluation of trustworthiness of objects and provided information. Exemplary use cases highlighting these potential improvements are described later.

PLATFORMS AND IMPLEMENTATIONS

In recent years several projects have aimed at the integration of the IoT into a social networking framework.

Project/ company	Website or Twitter	Interaction between things	Autonomous establishment of social relationships	Open to the development of new applications	Clear application/ business case
Toyota Friend	https://twitter.com/#!/toyotafriend	Minimal	No	No	Yes
Nike+	http://nikeplus.nike.com	Minimal	No	No	Yes
Xively	http://www.xively.com	Yes	No	Yes	Unspecified
Paraimpu	http://www.crs4.it/paraimpu	Yes	No	Yes	Unspecified
Social Web of Things	http://labs.ericsson.com/	Yes	Unspecified	Yes	Yes
Evrythng	http://www.evrythng.com	Yes	Yes	Yes	Unspecified
Platform in [21]	N.A.	Yes	Unspecified	Yes	No

Table 1. Major characteristics of platforms and implementations on a social web of things.

The **Toyota Friend Network** is certainly one of the earliest platforms in which data generated by objects, in this case *automobiles*, is made available in a social network. Developed within the context of a partnership between Toyota and Salesforce, Toyota Friend is a private social network aimed at networking all actors involved in the Toyota car ecosystem, including the cars that become part of the social network as well. Major objectives of the Toyota Friend network are to improve customer service and build a virtual community among the owners in order to increase customer loyalty to the brand. The Toyota Friend Network focuses on a clear application/business case; therefore, it is not planned to provide APIs to allow for the development of third-party applications. Furthermore, in the scenario of interest, objects do not interact with each other (cars just send data about their status to a server).

Nike+, as already mentioned, is another commercial platform in which objects (in this case sensors deployed in basketball shoes) post data in a social network. Nike built around this concept/platform an ecosystem of devices that are sold to customers and services to increase the fidelity of customers to the Nike brand. The Nike+ platform is proprietary, and no APIs are available to third parties to implement new applications.

Third party applications are supported by **Xively** and **Paraimpu**, which are two platforms with similar characteristics realized by LogMeIn and CRS4, respectively. The objective of both platforms is to support the connection, use, sharing, and composition of *things*, services, and devices to provide a framework to create new Web of Things applications. Through the above platforms things can be linked to each other (in a mesh-up manner) or to existing social networks, and thus can react to explicit requests by their owner. This latter can share the data produced by her objects with her friends. In this sense note that interactions between objects are programmed by the application (i.e., objects do not have autonomy).

Higher degrees of autonomy and thus interaction between objects are enabled by the **Social Web of Things**, which is being developed by scientists at Ericsson Research. The objective is to provide things with more autonomy to help people master the complexity involved in the IoT networking paradigm. Often, the major difficulties for users have arisen from the inability to achieve even a small glimpse of the rationale governing the interactions between the IoT elements. Scientists at Ericsson have observed that people are able to achieve more familiarity with IoT technologies if the interactions between objects of the IoT are presented in analogy to the interactions they usually experience on Facebook, Twitter, or other social networks.

Public documentation available to date does not specify whether the establishment of relationships between things is automatic or triggered by humans. Also, it is not mentioned whether APIs will be provided to support the development of third party applications.

Along the same line, the vision pursued by **Evrythng** is to give each individual object a unique active digital identity (ADI), which provides a permanent presence online. Any ADI corresponds to a *Thng* and can be accessed by means of a URI on the web. Evrythng makes available the environment and engines that are required to manage such ADIs. The basic business idea is that manufacturers may want to provide ADIs along with the assets they produce. ADIs can be linked by relationships which may resemble social relationships; nevertheless, most of the envisioned interactions still occur between objects and humans (through a smartphone). Also, public documentation does not provide specific business cases where the Evrythng paradigm will be employed in the beginning.

Note that in all the above cases establishment and maintenance of the relationships between objects is governed by the application; objects cannot be considered as *res socialis* (some of them act as *res agens*; others can be considered

Feature	Description
Find service providers	The network of friends is crawled to find another object capable of providing the needed service.
Publish information	The object publishes new information along friendship paths to optimize its consumption while limiting message exchanges.
Evaluate trustworthiness	The community is exploited to rate the trustworthiness of potential providers of information and services.
Get filtered information	To improve the accuracy of information, communities of objects collaborate to provide a common view.

Table 2. Main features of a possible social network of objects to be exploited toward the development of complex IoT applications.

mere *res sapiens*). An interesting initiative in this direction is represented by the prototypical platform described in [21], in which robots establish social-like relationships between each other as well as with humans in accordance to the paradigm envisioned in [16] to achieve awareness of context. More specifically, robots try to recognize objects and ask for help from their *friend* for such a purpose. Most of the focus in [21] is on the recognition procedure. No details are available about the procedures run to establish relationships and for the diffusion of information.

The major characteristics of the reviewed platforms are summarized in Table 1. We conclude this analysis by observing that even if several platforms exist in which objects are included in social networks of humans and envision interactions between objects, the *res socialis* concept has not been realized yet. In fact, although the enabling technologies are available in our opinion, the identification of clear business cases that may foster the development of this concept is still missing.

EXPLOITING FEATURES OF SOCIAL OBJECTS AT THE APPLICATION LAYER

Applications with the highest level of interaction among objects are the most powerful and fascinating as well as the most difficult to implement of IoT applications. This is the case, for instance, for applications where several sensors, RFID tags and readers, and communication devices have to collaborate to accurately track the position and status of goods and persons to offer contextualized and personalized services. These issues can easily be tackled by objects belonging to the *res socialis* category by exploiting the main features of the social network of objects, as listed in Table 2. Some of these features are similar to those that push humans to participate in social networks.

In the following, four sample use cases are described by highlighting the advantages derived from the employment of social objects organized into social networks.

THE TECHNOLOGICAL ASSISTANT

Storyboard: The use of our personal and domestic electronic devices is making our lives a hassle due to the complexity in their configuration. The technological assistant installed in our devices may help us if it drives the social objects toward the exchange of best practices. This is the case of Pavla, who has just bought a new smartphone with a flat rate Internet connection that she wishes to use in an always-tethering modality with her other devices. She has moved from the Android to the iOS world, and at the beginning, this new world is a jumble for her because of the difficulties in finding the right configuration. Exploiting *parental* (objects of the same brand) relationships with other smartphones, Pavla's smartphone can autonomously find a *mate* (through such key features as class of object, brand, and typology), which has already addressed the same configuration issues, and fix the problem.

The development of this use case requires the objects to store experiences that could be of interest (e.g., setup of a new printer, configuring the wireless connection) for the community in a semantically meaningful way to drive the setting of queries and implement matching operations during the search.

Advantages of the *res socialis* feature: This use case could be implemented without the social network among objects as well, but the following limitations would apply:

- The objects would need to register their experiences in a centralized server, which would drive the search operations. The entire search process would be conducted in a centralized way, making the system less dynamic.
- The search will not benefit from the information about the links among objects that help in driving the search and speeding up the process.

THE HEALTHCARE MANAGER

Storyboard: The use of drugs in Mario's family is always cumbersome as there is the need to monitor the deadline of the medicines, go to the doctor in time to get new prescriptions, and keep drugs in a safe place. A healthcare manager installed in his smartphone may assist him in these activities. Mario keeps his medicines for his and other family members' needs at home. Once purchased, the social pill bottles are automatically recorded as "his" objects by the RFID reader located at the drug storage place, so his smartphone automatically establishes a *co-ownership* (object of the same owner) friendship with them. In this way, the smartphone will be automatically notified when the drugs are about to either expire or finish. His smartphone will also receive information about the drug availability from pharmacies he has entered in since it has established other *co-location* (object located in the same place for a while) friendships with the pharmacy management system and the available drugs. Depending on the privacy policies set by Mario, the availability of such products may be made public even to other smartphones with a *social* (link with an object owned by people encountered during frequent human social activ-

ities) friendship so that this information can reach the members of his family. Also, thanks to these relationships, Mario's smartphone will alert the doctor's system about the need for a new drug prescription, so Mario does not have to do anything but pick it up.

Advantages of the *res socialis* feature: These features can be supported only if the mentioned object-to-object links are established in a dynamic way and without human intervention. Alternatively, this use case would require the establishment of static links with direct intervention of humans, which would make all the application deployment and management quite complex.

LOGISTICS MANAGEMENT

Storyboard: Chests of perishable goods know the quality and quantity of their contents (set by the producer), are able to continuously monitor the status of the environment, and know their current position. They make this information available to the rest of the objects' community according to specific rules defined by the owner (the carrier):

- Without any restriction, all the information is shared with *co-ownership* devices, such as the management system that has to deal with scheduling the next transport according to the status of the goods (how much of the sent goods are adequate for selling).
- The position is shared with all the co-work objects (which share the same working location) they encounter. This is helpful to allow external systems to better plan the transport and store the goods needed to reach the final destination.
- The quantity of the foods, origins, quality (predefined and set by the owner), and location are made available to all friends without any restrictions as soon as a collocation friendship is established with a vending booth. This information is spread for marketing purposes.
- Whenever the vending machine registers the selling of a chest, this information is shared with the chest itself, which then makes this information available to the management system. This information is useful to collect key market information.

Advantages of the *res socialis* feature: An alternative solution would be to program the mentioned devices so that they share information with other specific devices. This requires to define in advance the complete list of objects that will take part in the application. As a consequence of such static setting, two drawbacks will occur:

- Configuration will be more complex.
- Flexibility will be reduced.

URBAN TRAFFIC

Storyboard: Effective "traffic efficiency" applications are highly demanded as people hate spending time stuck in traffic due to unexpected congestion caused by incidents, strikes, or natural events. This is the case of Angela, who is always driving as she is a sales representative. However, recently, her car has become *res socialis*, so it exchanges information about the status of traffic with the cars it frequently meets.

This information includes the path travelled during the last ten minutes and the time spent. Collecting this information from several reliable sources allows computing the best path to get to the next meeting and avoiding unexpected congestion points.

Advantages of the *res socialis* feature: The same use case could be implemented if each car sent the information to a central server that could process the data and provide the required information on the time needed to run along each path. However, if the car has "social" behavior, as depicted, it would significantly improve the system scalability.

OPEN RESEARCH ISSUES

Many research issues linked to the topic of social behavior of smart objects need investigation. In the following, we describe what we believe are the most major such issues.

DEFINITION OF INTER-OBJECT RELATIONSHIPS

Enabling smart objects to establish heterogeneous social relationships is the first prerequisite to implement the illustrated vision. This demands great research effort toward the study of the interactions among objects. Major issues on which to focus are:

- Proper digital representations of social smart objects
- Novel types of social relationships between objects accounting for the possible interactions in the virtual and physical worlds
- Methodologies to crawl the Internet and effectively and efficiently discover other objects and socially interact with them
- Semantic representational models for the social relationships with the view of forming the social structure
- Technological solutions to autonomously sense other (heterogeneous) objects, exchange profile information, and interact

ANALYSIS OF THE GRAPH OF RELATIONSHIP STRUCTURE

Following the establishment of social relationships, social graphs among smart objects will be generated (also uncorrelated to those of human social networks). Strong research effort is needed to model this network of objects and introduce proper network analysis algorithms. These may be derived from previous research activities in the field of human social networks. Nevertheless, the suitability of traditional analytic procedures and metrics to study social networks of objects needs to be assessed. Concepts such as node "centrality" and "prestige" based on traditional scoring methods have to be confirmed in the new scenario and likely adapted to it.

DEFINITION OF APPLICABLE ARCHITECTURAL MODELS

Several architectural models for the IoT are already available in the literature; many more are currently under investigation. The same is

Following the establishment of social relationships, social graphs among smart objects will be generated (also uncorrelated to those of human social networks). Strong research effort is needed to model this network of objects and introduce proper network analysis algorithms.

While the technical advantages of integrating IoT and social networking concepts have been largely analyzed, the identification of the killer application and the definition of the underlying business model are still missing.

not true for architectural models that account for the social relationships between smart objects to facilitate faster service discovery and retrieval. The proposed approaches should go beyond the state of the art in many aspects:

- The architecture should allow for the establishment and exploitation of social relationships among smart things, not among their owners.
- Through social relationships things should be enabled to crawl the IoT, and discover services and resources.
- The envisioned architecture shall not be a mere IoT service platform centered on the concept of a web of things, but a real multi-technology platform with suitable components that cope with the presence of smart objects.

DEFINITION AND SUPPORT OF NEW COMMUNICATION PRIMITIVES SPECIALIZED FOR THE NETWORK OF SOCIAL OBJECTS

The configurations of the communication supported by traditional networks are unicast, broadcast, multicast, and anycast. A social network of smart objects requires the definition of new configurations of the communication in which the destinations of a given piece of information are characterized by their role/position in the social network. Such functionality can be realized as services at the application layer, but it would be much more effective to embed them as networking primitives. The new primitives should allow distinguishing whether a node is to be included among the destinations of a given piece of information based on its distance from the source, the types of relationships linking it to the source, and the policies set by both the source and the node itself.

DEFINITION OF THE KILLER APPLICATIONS AND BUSINESS MODELS

While the technical advantages of integrating IoT and social networking concepts have been largely analyzed, the identification of the *killer application* and the definition of the underlying business model are still missing.

Several activities carried out in this domain focus on smart environment applications, but it is not clear who should pay and why. Should the user pay for a service that enriches existing objects, or should the cost of the social instances of an object be part of the price of the object itself? Why should the user pay when applications are not available yet that justify additional cost?

We believe that research effort should be devoted to the definition of the killer application and underlying business model for a social IoT.

SECURITY AND PRIVACY ISSUES

The development of social networks of smart objects will surely raise some serious concerns on the security and privacy of sensitive data and information associated with some smart objects (similar to what is happening with another key technology for IoT: RFID). This is why research effort must be finalized to handle the security of the communications and evaluate the objects'

trustworthiness. The proposed models should account for the way the resources interact with each other over time and promote a shift toward trust-centric communication models in which it shall be possible to infer the degrees of trustworthiness from computation of the degree of the shaped relationships.

CONCLUSIONS

In this article, we have identified three stages that involve increasing levels of social involvement of the objects composing the Internet of Things. In the first stage, objects can post information about their state in the social networks of humans. In the second stage, objects can interact at the application layer in social networks with humans and other objects. At the third stage, objects socially interact with each other to build a communication network. We have described some possible advantages of the latter vision in terms of network navigability and support of novel communication primitives. Furthermore, we have described two use cases in which social relationships between objects can be fruitfully exploited. At the same time, we have highlighted the main research issues linked to the topic of an *independent* "social behavior of smart objects," which still needs investigation. Logically, this apparent independence (which must be carefully controlled by setting the behavioral profiles of any future *res socialis* in the SIoT) could be scary; thus, much research must be pursued in the direction. However, in our opinion, it is enough to remember to always apply Asimov's Three Laws of Robotics to the social communities of the *res socialis*, and what scares humans will turn into an advantage for humans themselves.

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In our opinion, what will be enough is to remember to always apply Asimov's Three Laws of Robotics also to the social communities of the res socialis, and what scares humans will turn into an advantage for humans themselves.