1 Introduction

According to IDC (www.idc.com) – a global provider of market intelligence, advisory services, and events for the information technology, telecommunications and consumer technology markets – the worldwide shipment of smart connected devices will surpass 2.5 billion units in 2017. As the cost, size, and power requirements keep decreasing, computing will be embedded in all kinds of products and everything that can benefit from the Internet will be connected. Not only stations, computers or laptops, but also tablets, smartphones, cars, game consoles, TV sets, cameras, machines, lights, locks, and home appliances.

People and data are already online and an increasing number of, things with sensors, actuators and places are also online. Thus, various sectors of activities will benefit from applications that leverage the interconnection of embedded systems with IT systems. But few examples: (1) Intelligent transport solutions can speed up traffic flows, reduce fuel consumption, and safe lives. (2) Smart farming solutions will improve the production and delivery of safe and healthy food. (3) Remote health monitoring will provide convenient access to healthcare, raises it quality, and save money. Utilities management, education, government services, retail sectors etc. all will also benefit from such couplings between embedded systems and IT having operational lives across different systems. One of the enabling next steps is to formalize the notion of meta-systems i.e., interconnecting individual systems into system of systems and here we are confronted to a scale and heterogeneity reaching the limits in networking and software engineering.

In this project, we aim to investigate issues related to the design and development of a secure physical and computational networked environment, consisting of billions of connected smart objects (things), which allows interoperability and facilitates efficient collection and processing of data and analytics. These smart objects may come from diverse environments such as smart appliances at homes, smart mobile surveillance system such as fire trucks and police cars, smart transportation entities (e.g., cabs or buses), etc. By establishing a dynamic instantiations of Internet of Things (IoT) structures, we aim to provide an automatic resource optimization and other intelligence into these evolving collections of smart connected objects. However, rather than endowing them with autonomously cognitive chips, we ask for manufacturers, retailers and users/owners, through an established social network of things, to elaborate finely tuned dispatches to be distributed toward the smart objects through middleware fogs located in the individual homes.

Nowadays, existing start of the art related to the design of IoT systems is highly compartmentalized, the data collection and analytics processing across a variety of heterogeneous IoTs has limited support, and the interoperability of objects across domains has not been addressed at a level that would provide the kinds of optimizations that this project aims..
In this project, we introduce the concept of collaborative Social Network of Things that would enable data and analytics sharing across objects that exhibit similar operating characteristics and/or have similar profiles in terms of usage and user/manufacturer parameters. In addition, we propose to develop a hierarchical middleware implemented as fogs to allow interoperability with context-aware security properties associated with different nodes. These middleware fogs, mainly implemented in smart boxes/gateways within local networks, will manage the communication between the associated smart objects and the network in an optimized way that takes into account both the characteristics of the smart objects and the preferences of the users. The massive generated data by all these connected smart objects and stored in the system will enable the cognitive network, through deep learning algorithms, to raise dynamic procedures that will enable a multi-criteria optimizations of the behavior of these smart objects.

A typical scenario could be as follows. During his coffee break at the office, Jack decides to lower by 5 degrees the set point temperature of his home heating system which must go into action when he is less than 1 mile from his home and in any case no later than 6PM. However, if the outside temperature drops below certain threshold, the temperature must go up by 5 degrees. At lunchtime, a colleague of his gives Jack a list of instructions corresponding to a new method for washing wool sweaters; he sends the file directly to his home through the social network where a service will adapt the instructions to that washing machines particular technical features and his personal preferences for extra soft cloths. Back at home, Jack launches my angry day profile through smartphone, which automatically dims the light and has the Hi-Fi play his favorite relaxing music. Meanwhile, a tip from the network tells Jack to turn off all TVs to avoid getting further depressed. During the night the washing machine starts the cycle at the time the electric company informs it to be the most favorable.

While the above describes a single user, what we aim to investigate in this project is how to incorporate multiple users and smart devices into multiple instances of Social Network of Things, that can be generated/organized and dissolved on-the-fly; where different criteria can be used to orchestrate the behavior of (groups of) instances subject to multiple constraints; and certain security and privacy concerns are ensured. In the context of Jack scenario, this would mean collaboratively regulating the temperature with other units in Jacks building; collaboratively deciding about the cycle of the washing machine in terms of optimizing the grid-demand within a city-block; adjusting the Hi-Fi themes based on the fact that Jack decided to join his co-workers for a happy-hour; etc Moreover, we plan to provide novel data analytics methodologies that will: (a) incorporate the fact that some users may not be cooperative in terms of suggested regime of use for certain devices/task; (b) provide a specific behavioral insights to be used by various manufacturers when planning the design of certain devices so that they can be better adapted to changing conditions of use. The architecture we target to support such scenarios is depicted in Figure 1. We aim at providing methodologies and tools for two basic modes:

(1) The first setup consists of a set of middleware fogs, located in each smart box/gateway of a smart home or public area, grouped together in a social network along with profiles of manufacturers, retailers and users/owners. The lower layer is formed by all the real devices/objects (things), such as a fridge, a washing machine, a heater, a TV, a Hi-Fi, etc., where each one is abstracted by what we refer to as WiThing (WiT) for Wireless Thing. The WiT is the first level of the device abstraction and its role is to (1) uniquely identify an object/device worldwide, (2) represent the object in terms of its properties/functionalities through an MIB (Management Information Base), and (3) constitute a bidirectional interface for all communications between the object and the middleware fog located in the smart box/gateway. The intermediate layer contains the smart box/gateway where the middleware fog is implemented. The latter is composed of an ensemble of interconnected modules that will govern all the requests issued by the user through a proper front-end application. To this end, this smart box must interface with any object/device it meets in the surroundings, i.e., any virtual device communicated by the real objects/devices. The upper layer contains the social networks of manufacturers, retailers and users/owners with the generic representations (avatars) of their objects/devices. It consists of a large database with an enquiry system based on sophisticated algorithms. Throughout this complex environment, and in order to fully automate the deployment and control of such Internet of Things, gathering of important data, identification of correlations in this chain of complex events, and triggering the required responses, a plethora of issues in data collection and processing (storage/retrieval, querying and information fusion), knowledge discovery, and security and privacy need to be investigated in unified framework. We assert that such integrated large scale effort, involving researchers from diverse backgrounds, is necessary to enable exploiting the full potential of the Internet of Things technology and make it ubiquitous of use.

(2) The second setup complements the previous one in terms of inter-contexts couplings and dynamic formations (and dissolution) of corresponding Avatars. In terms of notation in Figure 1. it is best explained by the following scenarios: (a) If we have a collection of Avatars corresponding to a particular device (e.g., a washer) in a collection of residential units, depending on the geographical context we may want to form different instances of (meta)Avatars corresponding a group of same devices but operating in: (i) a group of houses in a suburban residential area; and/or (ii) a group of buildings in a near-downtown area. (b) Complementary to this, the Avatars corresponding to washers in different units in an apartment complex, may be tied with the Avatars corresponding to entertainment devices in the same and/or neighboring buildings. (c) The collection of Avatars representing the traffic-density in different geographical regions may be tied with the crime-rate in those and/or near-by regions and with the ones corresponding to activities of electronic devices in the police cars. However, after a certain time of the day/night, such (meta)Avatars may cease to exist.

The situational awareness that we aim to capture by dynamically creating Meta-Avatars is illustrated in Figure 2. We note that, in addition to the scenario-oriented discussion above, the Meta-Avatars may be created based on: - Particular cyber-properties: e.g., status of network infrastructure, privacy constraints, etc. Logical or semantical properties which may entail dynamically forming (and dissolving) hierarchies of such avatars. The main Intellectual Merits of the proposed project are: —-Repeat the Intellectual Merits here

2 State of the art

We now present an overview of the state of the art, both from the perspective of the current properties of devices and networking technology features, as well as from the perspective of related works in several fields that, in one way or another, may be used to achieve our objectives however, the fall short of several important aspects.

2.1 Whatever Proper title of this sub-section

The vast majority of devices are endowed with electronic interfaces, made of buttons and the like, inviting users to operate selections from among a limited set of options pre-featured by the manufacturers. They may concern options, such as, ventilation on/off button in an oven, a selection of delicate option in a washing machine, air-condition on/off button in a car, and so on. While these older devices are considered somehow efficient and simple, the trend is towards more technological and ubiquitous devices. The operational innovation of our approach is to make a move of the interface a step ahead and a step farther so as to realize a deep, remote and smart control. In this case, the manufacturer makes all/most of the operational parameters, such as spin speed and duration, totally manageable and configurable by the user. In turn, the user drives these parameters via software, hence makes them obeying to automatic procedures/instructions that have been elaborated and optimized in advance, with the help of the manufacturer, other contributors, and/or the networked intelligence. Thus, we need to have this new hardware/software interface managing signals/data back and forth between actuators/sensors and a logic unit with the result of detaching the user from any physical contact with the device (thing). To this end, in the project we will use open source electronic boards, such as Arduino boards (https://www.arduino.cc/), Parallella boards (https://www.parallella.org/) and/or Raspberry-Pi boards (https://www.raspberrypi.org/). They are powerful prototyping boards based on flexible, open and easy-to-use hardware and software. These devices are wirily and/or wirelessly connected to the Internet from which they can be easily visible and accessible. We foresee that their exploitation will lead microelectronic companies to develop specific chips for a massive diffusion of this new technology in a near future. In order to realize the vision of an Ambient Intelligence in a future network and service environment, heterogeneous wireless sensor and actuator networks have to be integrated into a common framework of global scale and made available to services and applications via universal service interfaces [20]. The goal is to reach a distributed open architecture with interoperability of heterogeneous systems, neutral and easy access, clear layering and resilience. It should provide the necessary network and information management services to enable reliable, secure and accurate interactions with the physical environment. The idea is to provide an integrated platform that offers unified data access, processing and services on top of existing ubiquitous services of the Internet of Things to integrate heterogeneous sensors/actuators in a uniform way. From an application perspective, a set of basic services encapsulates sensor/actuator network infrastructures hiding the underlying layers with the network communication details and heterogeneous sensor hardware and lower level protocols.

A heterogeneous networking environment indeed calls for means to hide the complexity from the end-user, as well as applications, by providing intelligent and adaptable connectivity services, thus providing an efficient application development framework. To face the coexistence of many heterogeneous set of things, a common trend in Internet of Things applications is the adoption of an abstraction layer capable of harmonizing the access to different devices with a common language and procedures [11]. Standard interfaces and data models ensure a high degree of interoperability among multiple systems. However, typical drawbacks of misconfigurations and traffic congestions are normally exasperated by the node heterogeneity. These drawbacks will be overcome in the project through the adoption of islands architecture. On the one hand, smart gateways in their locations will hide all the complexities of the underlying standards. Hence, wireless connections of the devices/machines to the web/Internet, using communication technologies like Zigbee [3], Z-wave [31], Wi-Fi [32], plus the mapping of every device to a unique ID, will provide full, intelligent and secure control over it. With these smart boxes/gateways, technological limitations will completely disappear and the devices will become identifiable only through their functionalities with clear and consistent APIs. On the other hand, the middleware fog constitutes an abstraction level where all the devices, viewed as entities sharing their functionalities (avatars), are transparently managed and used. The goal is to manage the collaboration between heterogeneous devices through a simple API level in conjunction with the mentioned communication protocol able to reach the peer within the location singularly. Most existing solutions for middleware adopt in general a service-oriented design tailored mainly to support a network topology of sensors that is both unknown and dynamic. But while some projects focus on abstracting the sensors in the network as services (such as in HYDRA [19, 33, 34], SENSEI [26], SOCRADES [12], and COBIS [27]), other projects devote more attention to data/information abstractions and their integrations with services (among which are SOFIA [15], SATware [21], and Global Sensor Networks GSN [1]). A common thread throughout all of these solutions, however, is that they handle the challenge of an unknown topology through the use of discovery methods that are largely based on the well-known traditional service/resource discovery approaches of the existing Internet, ubiquitous environments and wireless sensor and actuator networks [2,22,35]. For instance, SOCRADES provides discovery on two levels, the sensor level and the service level, which can employ either standard web-service discovery or a RESTful discovery mechanism (for RESTful services). COBIS, on the other hand, uses its own service description language COBIL 2 (Collaborative Business Item Language), where service functions and keywords are annotated with a verbal description. Another point of agreement in the state-of-the-art of middleware solutions is in the widespread use of semantics and metadata to overcome heterogeneity challenges. Indeed, it is standard practice to use ontologies to model sensors, their domains, and sensor data repositories [10, 18, 19]. Some projects even go a step further and also include context information [26], or service descriptions [19, 33, 34]. And as a type of service composition, many projects support the concept of virtual/semantic sensors (for instance, in HYDRA, GSN and SATware), i.e. entities that abstract several aggregated physical devices under a single service. A different implementation of a similar idea, though, is provided in the SATware project, where virtual sensors actually correspond to transformations applied to a set of raw sensor streams to produce another semantically meaningful stream. Regarding scalability, most projects address this challenge by pursuing modifications in the underlying sensor/actuator network topology. Sometimes, this is done by adopting fully-distributed infrastructures (such as in COBIS and SOFIA), and sometimes through an architecture of peer-to-peer clusters (e.g., GSN). In our view, however, while these approaches work well for the existing Internet, where traffic is made up of a relatively small amount of service interactions, they will not fit for the complex weave of interactions that will be commonplace in the Internet of Things. In the Internet of Things, a large number of requests will involve intricate coordination among millions of things and services, whereas on today's Internet most requests are largely point-to-point. Therefore, the number of packets transmitted in the network will grow strongly and nonlinearly as the number of available services increases. In such an environment, performing even a simple service discovery may exceed acceptable time, processing, and memory constraints. //NOTE: the last paragraph needs to be tied (cf. (2)/Fig.2 in the intro with the problems related to "Possible Worlds Semantics" and the efficient pruning the needs to be performed

2.2 Data and Process Integration

Heterogeneous data integration is a topic which, in addition to the database community broadly [8, 13], has also been investigated by more specialized research foci: – bioinformatics [16, 23]; information management and text retrieval [9, 14, 30]; sensing/actuation and tracking [4, 7, 28] (to name but a few). While the role and the impact of the semantics have been recognized and addressed [5, 6], the existing results still have limited cross-contextual support. For instance, the works investigating the benefits of semantics for resource discovery (cf. [6]) do not take into consideration the role of different devices that may enter and/or leave a particular "geo-social" network dynamically, as well as their impact on real-time adjustments (as well as the impact of their cessation). To-Do – Goce: Overview of:

a. Data integration + distributed query processing; workflows [17, 24, 25]; Wireless Actuator Networks

b. Analytics and platforms in-context (Cloud/Hadoop; NoSQL; Warehousing) [29]

3 Proposed research overview

We now proceed with identifying the main challenges that the proposed project will address, with a brief overview of the proposed research tasks (research challenges), followed by an introduction of the team and their expertise.

Research Challenge 1 (RC-1): Data collection and processing

Research Challenge 2 (RC-2): Knowledge discovery

Research Challenge 3 (RC-3): Security, privacy (anonymity) and trust

The Internet of Things is foreseen to bring a multitude of services with a vision of creating a smart self-configuring and interconnected world for the benefit of end users. With the extensive research and development of computer, communication and control technologies, it is possible to connect all things to the Internet such that the so-called Internet of Things (IoT) can be formed. These things may be equipped with devices such as sensors, actuators, and tags, in order to allow people and things to be connected anytime and anywhere, with anything and anyone. IoT will enable collaborations and communications among people and things, and among things themselves, which expand the current Internet and will radically change our personal, corporate, and community environments. However, a plethora of security, privacy, and trust challenges need to be addressed in order to fully realize this vision [20, 21, 22, 23]. When more and more things connect to the Internet, security and privacy issues become more serious, especially in the case that these things are equipped with actuators and can support control. For better protection of secure communication and user privacy, including location, identity and behavior habits, it is necessary to develop anonymous communication theories, methods and key technologies of anonymous communication systems in all varieties of application environments. Anonymous communication is used to hide communication participants or communication relations to achieve effective protection for network nodes and user identities. Anonymous communication can address potential network security issues, and becomes one of the hot topics in the field of network and information security. With reference to security, data anonymity, confidentiality, and integrity need to be guaranteed, along with providing authentication and authorization mechanisms in order to prevent unauthorized users (i.e., humans and devices) to access any system. Concerning privacy requirement, both data and user personal information have to be confidentially manipulated since devices may manage sensitive information (e.g., user habits, locations, etc). Finally, trust is also a fundamental issue since the IoT environment is characterized by multiple devices that have to process and handle the data in compliance with user needs and rights. To realize a trusted, secure, and privacy preserving social network of things, we plan to address in this proposal the following security, privacy, and trust management related tasks:

T-3.1: Define a new scheme of anonymizing things and representing them as avatars in the social network of things.

T-3.2: Authentication of data collected in fogs in the presence of malicious attackers, despite the attack surface being very broad, ranging from PHY layer to application layer.

T-3.3: Achieving end-to-end secure and privacy-preserving information flow monitoring between users and things, covering all sort of things and access networks using physiological and physical layer properties.

T-4.3: Design of secure, fast and friendly authentication schemes to allow users of the social network of things to access the data of interest through diverse mobile devices such as smartphones and tablets.

4 Research tasks

We now proceed with a detailed presentation of the main research of the proposed project.

4.1 Data collection and processing

(Goce + Mubbasir) Data cleaning, data collection, sharing, processing, analytics How can we secure the collected data and how to make it available? APIs and libraries for building applications

4.2 Knowledge discovery: social network of avatars (virtual world)

(Ashfaq + Vladamir) . .

4.3 Security, privacy and anonymity

(Farid + Alex) Data security System level security Privacy, anonymity
Greedy behavior (?) Key sharing problem Privacy, trust and anonymity

4.4 Implementation and validation

(All)
Letters of Collaboration) Campus wide implementation Letters of Commitment Shall we rely on KAA? APIs: flexibility of formats/schemas

5 Broader Impact

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6 Results from current and recent prior NSF support

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7 Data management plan

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8 Project management plan including timeline

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