

Smart Spaces and Smart Objects interoperability Architecture (S³OiA)

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Abstract—The presented work aims to contribute towards the standardization and the interoperability off the Future Internet through an open and scalable architecture design. We present S³OiA as a syntactic/semantic Service-Oriented Architecture that allows the integration of any type of object or device, not mattering their nature, on the Internet of Things. Moreover, the architecture makes possible the use of underlying heterogeneous resources as a substrate for the automatic composition of complex applications through a semantic Triple Space paradigm. Created applications are dynamic and adaptive since they are able to evolve depending on the context where they are executed. The validation scenario of this architecture encompasses areas which are prone to involve human-beings in order to promote personal autonomy, such as home-care automation environments and Ambient Assisted Living.

I. INTRODUCTION

The Internet of Things (IoT) presents a novel scenario where the processing capacity and the information processing are greatly increased by the inclusion of a large number of computational actors [1]. This new communication model aims to provide a common communication channel, the Internet, through which the aforementioned actors can interact and provide resources in a transparent and uniform way. For this reason the IoT is now conceived as the enabler interface between the physical and the virtual world [2]. This innovating ecosystem offers to world's inhabitants new and unimaginable interaction models and inspiring opportunities which should make their daily tasks more bearable than they currently are.

One of the main obstacles to hurdle in order to make reality the dream of the Internet of Things, lies into the interoperability issues among such a large number of heterogeneous actors (with regard to their capabilities and offered resources). This heterogeneity must be understood from the computational point of view of each object, the communication protocols they perform, the differences in resource's exposition, and in the mechanisms applied for

the interpretation of information related with consumed services. In this pervasive scenario semantic models are great candidates to describe them and the context where they are involved in a very expressive manner.

To such extend, this paper presents S³OiA, a three layer architecture that allows integration and interoperability among objects, people and applications over the IoT ecosystem being fully-aligned with *RestFul* Web standards. The architecture is designed to cope with the dynamic nature of available resources enabling the evolution and adaptation of already already created applications. Finally S³OiA devises mechanisms to manage and resolve the application dependencies among remote domains or distant smart spaces in a highly distributed, decoupled and resource-oriented manner, following the semantic Triple Space paradigm.

This contribution claims to demonstrate how such a novel design may be deployed in distributed smart environments to offer a more accessible “Human-Intelligent System” interaction and therefore, promoting the eInclusion¹ and the personal autonomy.

The rest of this paper is organized as follows: Section II presents a first glance on concepts such as smart everyday object and smart space. It also provides a review of similar middlewares for interoperability purposes. Section III describes the main challenges that IoT architectures should face up to offer true interoperability in such a big Internet world and we devote a subsection to explain a novel HCI interaction model. Section IV defines the proposed architecture. The user and scenario validation is explained in Section V. Finally, in Section VI the conclusions of this work and the areas that the authors consider relevant to future are presented.

II. RELATED WORK

Previously created context-aware enabling frameworks and architectures have used different approaches in order to promote personal autonomy [3]–[6]. Their analysis allows

¹http://ec.europa.eu/information_society/activities/einclusion

to highlight features like resource discovery, capability to reason over context, or the context model used in different scenarios.

From the point of view of reasoning and application maintenance, most of these features are crucial in environmental intelligence settings. The problem behind current solutions is that they have been conceived to work in physically delimited contexts, and they do not take into account the new models and possibilities that the IoT offers. In context-aware environments, a lot of devices communicate with each other and share continuously changes of their state in order to trigger actions within the environment. Following the IoT paradigm, this context should be extended to the whole world, then devising new solutions are paramount keep growing the dream.

The platforms and architectures closer to our proposal are the abstraction middlewares which facilitates the integration and the information exchange within distributed and ubiquitous environments. Nevertheless those solutions present scalability and acceptance issues since they are oriented to be leveraged in programmable devices (that use to be prone to rich resources [7]), or are only deployable in specific Operating Systems [8] or even worse they are proprietary solutions^{2,3}. Another limitation found in the majority of approaches reviewed is their specific purpose regarding the context where they are used, here we cite Jini and OSGi [9], [10] in home environments and SOAP-WS [11] for industrial application. Thus, the new IoT architectures have to be created with a general purpose-centric design.

The lack of standards in previous solutions have led to find some works oriented to translate information between middlewares by using bridges [12] which is, from the authors point of view, a backward step against the interoperability. Recently, some proposals that use the general purpose and open Web technologies for integration and intercommunication purposes are arising: Device Profile Web Services (DPWS) is centered on the interoperability of resource constrained devices, but it is not lightweight at all since it follows a SOAP approach and it is aligned with enterprise services. OBIX [13] have been considered as the new generation middleware for home and building automation, but it not features any kind of mechanism of interoperability and cooperation among distant and isolated domains. OPC UA [14] is Obix competitor offering a more lightweight approach for raw data transport, nevertheless both approaches are XML-oriented and their major drawback is their constrained scalability being Client/Server solutions. ETHZ-Web of Things Smart Gateway [15] and IETF-CoAP [16] are the most similar approaches to authors' IoT vision. Finally it appears the Semantic Web which aims to offer machine-understandable persistent data

forming a knowledge network for machines rather than the current World Wide Web which is more human-centered and require user intervention (Web services offer remote functionality to machines, but they are not really Web-based since they are driven by message exchange). S³OiA complies with Triple Space (TS) computing that performs a *tuplespace* based communication using RDF triples, in which the information unit has three dimensions: "subject predicate object", to express this semantic data [17]. Triple Space computing is a coordination paradigm based on tuplespace-based computing, which comes from the parallel computing language Linda [18].

Personal autonomy expects that a user working in a ubiquitous computing environment should be able to access, both the individual services provided by every device, and the complex services resulted from the dynamic combination of basic services. In the latter case, the underlying system should automate or assist the user in such composition process. It is well known that the different available techniques for service composition [19] require interoperability, and lots of them are centered in the creation of ontologies and semantics [20]. The main problematic that they present is again that such ontologies are specially created for enclosed environments and are difficult to extend to further domains, and more important the service and application composition is always conceived by the usage of an editor (in screens or table-top) by expert people. These approaches leave non-technical people out of the future IoT ecosystem and they run against the e-inclusion, e-accessibility and e-participation.

III. MAIN CHALLENGES OF IoT ARCHITECTURES

As have been largely stated in literature, the Future Internet and the IoT offer innovative communications and interaction models. Unfortunately, these future outcomes are today accompanied with a large number of issues and challenges that should be nearly solved if we want to make real the IoT assertions [21], [22]. The following bullets summarize these still unresolved needs:

- The integration of heterogeneous objects (legacy and future created) from a technological standpoint.
- Unify the countless device discovery protocols that are currently used. One of the ideas issued to overcome it aims to create a standardized new IoT common protocol or interoperable architectures that abstract these inconsistencies.
- Mechanisms aiming to ease and enable the device's cooperation and service discovery among distant/remote domains and spaces, both at semantic and at syntactic levels.
- Reducing the number of gateways should be rapidly take into account if we do not want to shift from the IoT to the Internet of Gateways and Proxies. This is possible with light architectures which should fit into any device, regardless of memory capacity and computing.

²<http://www.bacnet.org/>

³<http://www.echelon.com/technology/lonworks>

- The adaptation to the current and future market needs is mandatory. The authors state that personalization from an user-centric perspective is the key. In this regard, it is important to promote an architecture's design that can provide applications and services to any entity needing them. The SOA-standardized and the contextualized-Resource Oriented Architecture (ROA) offer a decentralized, flexible, economical and scalable way to do so.
- Intelligence at every architectural layer. That means adaptability to people involved in the interaction and the ability to reason in real-time about the resources available at any time.

In addition, the IoT designers must not forget people. The aim at such a new communicated world is to integrate novel ways of information processing in order to achieve the maximum benefit in the daily people lives [23]. It is therefore paramount to determine what role should be played by users to not leave them as mere IoT-consumers. This presents a major challenge from the point of view of the Human-Computer Interaction on ubiquitous and interactive environments. The authors state that a right IoT architecture have to be designed with the people involvement in the IoT computational loop.

A. Intentions: a novel interaction paradigm

In a future IoT world it will be virtually impossible for users to build a mental map of the available resources, and therefore rather more complicated their whole perception and suitable interactions [24].

This paper defines a novel interaction model which is non-intrusive from the point of view of the "user-intelligent system" relationship. This model will permit a user to accomplish IoT-tasks without the need of a composition environment, i.e. screen editors. The intentions, the name we have given to this new model, are the metaphor used to perform a interaction between IoT-actors, and are defined as the minimum information given by human beings to perform a IoT-task but without defining how to accomplish them.

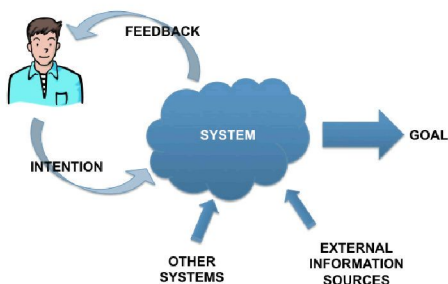


Figure 1. Interaction diagram based on intentions.

This novel interaction expresses what a user want to do and a set of requirements which have to be accomplished.

Like a black-box, the user doesn't define how the process should be done, the system decides the best way to do a specific task or action. However, we argue that intelligent systems must inform to the user about the global execution by feed-backing them.

The Figure 1 shows a diagram that summarize the intention's idea. The smart spaces adapt the information that will be shown to the user (feedback action) and then, the user can supervise the whole process.

IV. S³OIA DESIGN

The challenges and open issues which have been analyzed in the previous section have guided the design of the proposed architecture. Thus, it comprises the mechanisms for the inclusion of every device, irrespective to their nature, in the IoT ecosystem, as well as it covers the requirements aroused about the interoperation among them. Also, this design covers the needs obtained from the new role, that from the authors point of view will be performed by the users into the innovate IoT world.

S³OiA follows the Web services and resources as the basis for IoT standardization. Moreover it has been extended from the syntactical, at Web resource level interoperation, to a more semantic approach by applying the Triple Space computing paradigm.

Due to the constrained capabilities and the heterogeneity presented by new IoT actors, it is still necessary the presence of powerful nodes, gateways, which help towards the transition of a complete standardization and uniformity in such complex systems. S³OiA is designed with this issue in mind: the more standardized the IoT ecosystem will be, the less the number of such powerful nodes needed. The actual role of these nodes is to hide the underlying heterogeneity and to push forward the Web resource interoperation. Authors envision three abstraction levels for the IoT scenarios as the Figure 2 shows. A physical layer where devices are placed, a service exposition layer where those may be discovered, and a virtual overlay which permits the services cooperation not mattering the smart space where they are located. This representation may be extended to a decentralized, but networked, space where each of the super-nodes manages one or more spaces and enable to communicate with others. In a previous work the authors have advocated for a network-federated approach by applying the eXtensible Messaging and Presence Protocol as an interlinking substrate to connect distant OSGi platforms (powerful nodes) [25] that enabled the event's triggering and the asynchronous message passing among distant domains.

The S³OiA has been devised with a modular design in mind as it is appreciated in Figure 2. Such a modular design allows the architectural evolution through a parallel development and code implementation. The architecture is based in dynamic SOA principles (loose coupling, late

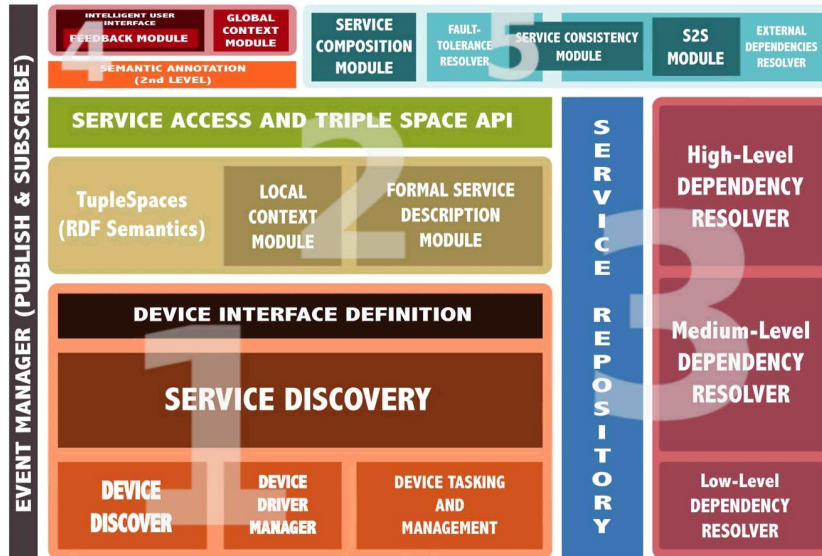


Figure 2. S³OiA: IoT architecture for interoperability.

binding and promote the services reuse) and is separated in five main functional groups:

- 1) **Device and Service Discovery.** Group of modules in charge of integrating and abstracting every device offering whatever communication protocol. For instance, it will be possible to communicate a DPWS device with no matter what UPnP consumer appliance with also a simple sensor. To such extent the gateways will abstract their heterogeneity by offering a common communication bus since the gateways features the appropriate proxies for such protocols.
- 2) **Semantic Triple Spaces and Web Service Exposition** These set of modules make possible bringing a semantic *tuplespace-based* distributed computing to ubiquitous systems, where many heterogeneous devices share knowledge asynchronously and in a resource-oriented manner. Triple Space computing performs a *tuplespace* based communication using RDF triples, in which the information unit has three dimensions: "subject predicate object", to express this semantic data. TS offers reference autonomy, time autonomy and space autonomy which ables to expose a Web compliant API that aimed to share knowledge among groups of similar and context-aware nodes.
- 3) **Service Repository and Dependencies Resolution** This modules' group manages the services available within a Smart Space and solves the dependencies extracted from the application composition in the local context (see Figure 3—a)). Furthermore, it features a event manager module that follows the publish/subscribe paradigm. In this way, when a new service is available or not longer exists it will be

advertised to the appropriate software modules. This repository has to be conceived as a storage instance in the whole distributed IoT space.

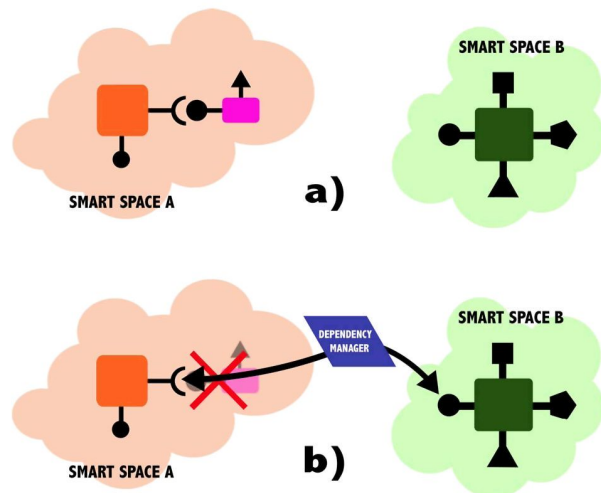


Figure 3. a)Local and b)remote dependencies resolution.

- 4) **Interaction Interface** These group of modules manage the interaction with the human beings within the Smart Space boundaries. The main idea behind such group is to retrieve information from the users interaction, the intentions, which can be converted in a sort of order aiming to compose complex applications, or to adequate the already deployed ones to the user's needs.
- 5) **Composition, Fault Tolerance and Distant Dependencies** Finally at the same level that the afore-

mentioned interaction framework, there appear the modules that deal with the composition and orchestration. Further, these modules manage the access to Smart Space resources when two or more super nodes required them at the same time. As we have stated before we propose a decentralized architecture, i.e. when inconsistencies or dependencies are not resolved locally they have to be triggered to upper layers reaching distant contexts in the virtual overlay (see Figure 3–b)). At the same level there appear the modules that manage the appropriate methods for resilience purpose and fault tolerance.

V. USER AND SCENARIO VALIDATION

Due to the increasing demand of applying the IoT advantages to contexts that promote personal autonomy (such as Ambient Assisted Living), the authors have decided to test an initial system based on S³OiA design in this kind of scenarios. Currently, the research project Suggestive Autonomy for Elderly People⁴, founded by CAPTA⁵, is backing this validation process. An early result has been achieved by carrying out a survey in order to determine the elderly people real needs for their daily routine, and how a new IoT world may push for them. This studio has entailed to a complete rethink of the S³OiA architecture, claiming for a more human-centered design for next revision. This evaluation has been possible due to a first prototype that is being assessed by the subjects under study, i.e. a group of elderly people in a Madrid's day residence.

A. Elderly people needs

The main objective of the survey has been to define a use case which would be useful to promote their personal autonomy. The survey was done to 20 elderly people from Madrid, Spain.

One of the most significant result was to realize that more than four in five elderly people use a kind of diary or notepad to control dates, medicine taking, checkups and others ordinary activities. Also, every respondents admit to have some memory problem. Other result extracted from the survey were that the elderly people do not feel comfortable with the use or inclusion of new technology in their settings. These findings demonstrate the authors initial assumption about the relevance of using augmented everyday objects as an interaction interfaces with people rather than intrusive technology.

B. The Smart Diary Prototype

Several S³OiA concepts and modules have been applied in the design and implementation of a Smart Diary intended to improve the personal autonomy of elders. This Smart Diary prototype collects and recognizes the house-inhabitant

activities, it is able to annotate them and finally transmit such information to an intelligent system (reasoner) which will use the available context-services to send suggestive advises (by any of the three perceptive channels: sight, touch or hearing) to the diary owner. Thus, the system doesn't send explicit messages about what the user have to do, but using ambient colors, lights and sounds that can encourage the receivers to think and remember some date, meeting or medicine taking.

The Smart Diary is an augmented object working in three different context and able to adapt within each of them: where elderly people program several physical and memory activities to be accomplished at home (The Day Care Center), where elders acquire medicines (The chemist) and which suggest activities (physical and mental) to elderly people (The Smart Home-Care).

The prototype has used RFID cards enabling to annotate of regular recurrence of a specific medical taking. This information is taken by the Smart Diary and it is merged with other inputs. For instance if the person doesn't remember the taking, the system will switch on red-color and ambient lights to suggest this activity (the survey revealed that a red light is associate with a problem by users). Each device have a semantic description which the system uses to compose the suggestion and to select the appropriate communication channels.

VI. CONCLUSIONS

This work have presented a novel IoT architecture design which tackle several of the IoT challenges defined in Section III. The most important characteristic is its general-purpose platform design that may be deployed in any kind of scenario which is prone to involve human beings in order to promote personal autonomy. This paper also contributes to standardize the concepts of smart everyday object and smart space from the point of view of the user interaction by defining: how the communication should take place within such smart spaces, how the coordination is performed among remote areas, and how it can ultimately support all the interoperability levels.

S³OiA as a syntactic/semantic Service-Oriented Architecture that allows the integration of any type of object or device, not mattering their nature, on the Internet of Things. It allows an ad-hoc dynamic application composition in cooperating and distributed environments which are uniformly described. To such extend it has been defined within the architecture design a set of semantic dependency management modules which track services and resources (available and used) allowing the already created applications to continue running despite changes of the context. The resulting applications can be created either by the users, or either on user's behalf by a series of intelligent devices with more computing power, named gateways, which enable

⁴<http://www.autonomiasuggestiva.es>

⁵<http://www.capta.org.es>

integration, uniform exposure and use of any object type regardless its resources from any distant domain.

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