Activity Report 2015

Team TACOMA

TAngible COMputing Architectures

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Rennes - Bretagne-Atlantique

THEME
Distributed programming and Software engineering

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2. Overall Objectives

2.1. Overall Objectives

Pervasive computing is based on the assumption of an integration of objects from our environment in the digital world. Such integration requires an understanding of the status of the real environment by computer systems to automatically be able to react to changes in that status. This is called context-awareness. Today, the necessary technology for the development of pervasive computing in the pioneering work of researcher Mark Weiser [1] are available: a ubiquitous Internet, short-range and low-energy communications, inexpensive sensors and actuators, and the expected democratization of the Internet of Things (IoT).

The objective of the TACOMA team is to build pervasive and context sensitive applications targeting Smart Spaces and considering all or some of the following five properties:

1. Data sovereignty and residency. The pervasive applications are backed by the capture of data in the environment. Most current solutions are sending the bulk of information collected on remote servers without the possibility for the user to control its spread and nature. Examples are smartwatches that transmit physiological user data to remote information systems to provide an overview of an individuals' physical activity. The collected data can also be used by insurance companies to customize their contracts according to the physical health of their customers. The final component of this scenario is nothing futuristic and illustrates the need to control the mass transfer of data generated by pervasive applications. Data sovereignty covers different aspects: strategic issues for the company that delivers the service using this data, strategic issues for companies wanting to use this service, legal constraints and the respect of user privacy.

The TACOMA research team considers four questions: What is the nature of the stored data? Where is it stored? Who holds it? Who can access it?

2. Acceptability. Perceptible pervasive applications rely on an instrumentation of the environment, particularly via sensors. This type of deployment is often hampered by two factors in the systems shown in the state of the art. First, a complex environmental instrumentation (e.g., an active ground to locate a user) results in unrealistic costs for pervasive systems. And the use of technologies considered too invasive by users (such as cameras or microphones) poses significant problems of acceptability.

The TACOMA research team considers that the instrumentation of the environment must be guided by a criteria of acceptability (operating somewhat intrusive sensors) and costs (using basic sensors that are very low cost, both economically and in regards to energy use).

[1] https://en.wikipedia.org/wiki/Mark_Weiser

3. Dynamism. The pervasive applications are deployed in environments subject to high variability. The resources accessible by the system depends on many factors: the mobility of the user, the presence of network connectivity, the surrounding objects, etc.

The TACOMA team apprehends this variability through two questions: How should a pervasive system react to the appearance/disappearance of resources (services/objects)? How can a pervasive system opportunistically exploit the available resources in the environment (for example, based on radio waves to power a sensor)?

4. Autonomy. The operation of connected objects is often based on access to a remote service through a centralized infrastructure or the cloud. We find this approach in the field of automation, for example, where smart thermostats capture data of the presence/absence or change in temperature. On this basis, a remote information system learns the habits of users and sends commands via the thermostat for heating the home. This strong dependence of a remote service poses problems in cost (the need to have access to infrastructure can undermine the economic model of a service), data sovereignty and acceptability .

The TACOMA team considers original and alternative approaches: autonomous systems that are integrated with the physical environment. Specifically, this autonomy is understood as a sort of strong independence of the application in relation to external infrastructure and remote information systems. This principle differs from more common approaches in the field of pervasive applications that use data to support processing only in a remote system.

5. Resilience. A pervasive application must deal with the volatility of the resources on which it is based. First, despite the ubiquity of the Internet, connectivity is extremely variable. For example, buildings have irregular radio coverage at the floor which could be problematic for the operation of a swarm of cleaning robots. Furthermore, objects may experience failures or breakdowns by giving false readings. It is necessary then to propose services that are equivalent or degraded to the user (more costly or with less functions, etc.).

The TACOMA research team believes in approaches that allow opportunistic resilience in using local resources. These approaches are based both on autonomous systems/structures (low infrastructure dependency) and the management of dynamism (elasticity of applications depending on available resources).

3. Research Program

3.1. Construction of context information

The term *context* here is understood in a very broad sense: it is any information to characterize the situation of an entity (a person, an object, a location etc.). A context is built using data captured in the environment. In pervasive systems, a typical approach is to build and maintain a logical representation of the real world (or model) from a mass of data captured in the environment, then analyze it to "find" the underlying context, for example the flow of traffic on a city scale, or human activities within a building, etc.

This approach poses different problems:

- The data is carried in a way that is relying on the infrastructure, which must be sized accordingly and can be subject to latencies.
- The mass of data collected is based on technical analysis, which is costly in time and computing power.
- Data is collected without filter, which can pose user confidentiality problems.

Considering these aspects, the TACOMA team focuses on two issues.

Localized aggregation and performance information from heterogeneous, unobtrusive, low-cost and unreliable sensors. The reactivity required in IoT systems and the aggregation of large amounts of data (and its processing) are antagonists. We study how to relocate the building of contexts near objects. The techniques covered use the principles of data fusion and are guided by different criteria: relevance of abstractions produced for pervasive applications (e.g., detecting user activity), anonymization of exploited raw data, processing time, and computing power required for processing.

The spatial layout of physical objects. The term *layout* can be understood in several ways: the co-location of multiple objects in the same space, the physical arrangement of two objects relative to each other (e.g., two objects arranged at right angles), or even the passage of an object of a physical area to another, etc. The context here is based on the physical layout of objects in space and their movements. In our approach, the use of "spatial" properties allows building pervasive applications in accordance with the principles set out in section 2.1. These properties can be obtained in different ways: via electronic tags (RFID) for annotating the most common objects, by using specific properties for light waves or short-range radio, or even by using specialized sensors.

3.2. Organization of context

Building a context results in the creation of contextual information. The TACOMA research team is focused on placing this information in the pervasive systems, and in mechanisms to allow applications to access and develop it.

Placement. Our approach seeks to promote local placement while allowing the recovery of data in the cloud whenever relevant. We explore two possibilities. The first is to store information (or semantics) directly on objects (a physical object, embedded computer, sensor, etc.). This involves addressing complex issues for the objects and storing some information with very limited computing power. The other approach is to rely on one or more local coordinators (a node placed in the vicinity of objects). These coordinators can be organized into a network or hierarchical system, in order to provide sufficient processing capacity to build and store a context.

Access control. The system should provide access control mechanisms for information collected in the environment and for the various actuators available. This is an essential aspect for context-aware applications, such as medical applications that can use or build patient information. We study mechanisms to restrict access only to authorized applications. For example, we address the problem of access priority for the actuators during the interaction with the environment. Critical applications such as fire detection applications must be able to preempt the actuators, even when these are normally operated by other applications.

Context enrichment. The construction of the context may be carried out permanently for all applications. In fact, each application has specific needs and a vision of the particular context. It is impossible to predict all the data that will be necessary for the proper operation of applications *a priori*. Each application must therefore build a set of relevant contextual information independently. We seek to provide software mechanisms that enable those applications to enrich the context and share it with other applications if necessary. For example, a set of services created by a public building operator can calculate contextual information related to the use of energy in the building and share it. The storing and organizing of this information (on objects, coordinators, or in the cloud) is supported by the pervasive system, thus alleviating the burden of building applications for developers.

3.3. Designing pervasive applications

The TACOMA team is focused on building pervasive applications and implementing proven concepts according to all the attributes put forward in section 2.1. Our goal is to identify the hardware and software requirements for the development of pervasive applications through various tests. This approach is inherited from the former ACES research project [2], which two TACOMA members come from. Our past experience has shown that in the field of pervasive applications, the solutions were given credibility when they were faced with real scenarios and real environments. We have experimented in the recent past through applications such as "Ubi-Board" [5] or even as part of a shared platform of a bilateral project conducted with an energy producer [3]. We continue to do so as part of the TACOMA project.

[2] http://raweb.inria.fr/rapportsactivite/RA2013/aces/uid0.html
[3] http://raweb.inria.fr/rapportsactivite/RA2013/aces/uid34.html

Some of our experiments are based on the principle of composite objects. These are hybrid digital objects combining virtual and physical aspects in their structures. For example, opening a door by an RFID device is a simple case where the badge, carrying digital information, is placed in a physical area in order to trigger the opening. We are working on more complex scenarios, particularly in the field of smart cities and waste treatment. In this context, an object can be denied access to a recycling container when its deposit could cause dangerous interactions with waste already present. The focus on composite objects is to benefit from implicit treatments that accompany the actual activities in the form of movements and the spatial arrangement of the objects presented in section 3.1. Implementation of the principle presupposes the massive "annotation" of everyday objects (and their components) with information and the ability to read/write these annotations by surrounding systems.

TACOMA is also focused on different applications for Smart Spaces. We currently pay special attention to developments in the context sensitive services in the field of Smart Buildings. For economic reasons, one of the challenges is to install the instrumentation (sensors, actuators) in the building, without disrupting existing spaces. From this point of view, the lighting of a building offers great potential. Existing light fixtures are being replaced by LEDs. Instrumented via a radio interface, the light fixture becomes an unobtrusive connected object that is easy to equip and fits naturally into the building. Equipped with sensors, it can collect data characterizing the local environment and the attached context. In addition, part of the ongoing experiments within the team focuses on the metamorphic house (see section 4.2 for more details).

3.4. Programming models for pervasive applications

The pervasive applications can be designed in an ad hoc manner depending on the target area of application. In contrast, the goal of our experiments presented in section 3.3 is to get away from technical aspects, clearing common and reusable mechanisms for all applications studied, and identifying activities redundant in creating the code for these applications. Based on this analysis, the TACOMA research team seeks to build pervasive programming models taking into account the properties of Section 2.1 and incorporating all or part of the work based on the context in sections 3.1 and 3.2.

To explain part of our approach, consider the example of pervasive games, which is one of our focuses. These games allow users to interact in space with other players or objects in their environment. This is an example of using the composite objects discussed in the previous section. Game development is based on a set of abstractions that allow the structuring of interactions between game objects, for example to treat a collision. We want to be able to rely on this type of abstraction in a pervasive environment. In prior years, the team worked on models for processing object interactions in the physical world to automatically deduct processing. This is the case in particular of the spatial programming: physical space is treated as a tuple-space in which objects are automatically synchronized according to their spatial arrangement. We continue this approach by considering more rich and expressive than the synchronization models using tuples.

This approach, turned toward low-level programming models, does not allow us to process all the applications we study. We are also focused on recent software engineering work in pervasive systems, especially that of service-oriented architectures exploiting IoT resources. Service-orientation is not new: this is to enable the development and evolution of the separate components of an application by reducing their dependence. With loosely-coupled components, the potential to change the application in a dynamic way are extended. The challenge here is to exploit these properties through the framework defined in section 2.1.

4. Application Domains

4.1. Pervasive applications in Smart Home

A smart home is a residence equipped with information-and-communication-technology (ICT) devices conceived to collaborate in order to anticipate and respond to the needs of the occupants, working to promote their comfort, convenience, security and entertainment while preserving their natural interaction with the environment.

The idea of using the Ubiquitous Computing paradigm in the smart home domain is not new. However, the state-of-the-art solutions only partially adhere to its principles. Often the adopted approach consists in a heavy deployment of sensor nodes, which continuously send a lot of data to a central elaboration unit, in charge of the difficult task of extrapolating meaningful information using complex techniques. This is a *logical approach*. TACOMA proposed instead the adoption of a *physical approach*, in which the information is spread in the environment, carried by the entities themselves, and the elaboration is directly executed by these entities "inside" the physical space. This allows performing meaningful exchanges of data that will thereafter need a less complicate processing compared to the current solutions. The result is a smart home that can, in an easier and better way, integrate the context in its functioning and thus seamlessly deliver more useful and effective user services. Our contribution aims at implementing the physical approach in a domestic environment, showing a solution for improving both comfort and energy savings.

4.2. Metamorphic House

The motivation for metamorphic houses is that many countries, including France, are going through socio-demographic evolutions, like growth of life expectancy and consequent increase in the number of elderly people, urbanization and resource scarcity. Households experience financial restrictions, while housing costs increase with the raise of real estate and energy prices [4].

Important questions arise concerning the future of housing policies and ways of living. We observe novel initiatives like participative housing and developing behaviors, including house-sharing, teleworking and longer stay of children in parents' homes.

To tackle the challenges raised by these emerging phenomena, future homes will have to be modular, upgradeable, comfortable, sparing of resources. They should be integrated in the urban context and exchange information with other homes, contribute to reducing the distances to be covered daily and respect the characteristics of the territory where they are located.

To reach these goals, metamorphic domestic environments will modify their shape and behavior to support activities and changes in life cycle of occupants, increase comfort and optimize the use of resources. Thanks to Information and Communication Technologies (ICT) and adaptive building elements, the same physical spaces will be transformed for different uses, giving inhabitants the illusion of living in bigger, more adapted and more comfortable places.

4.3. Pervasive applications in uncontrolled environnements

Some limitations of existing RFID technology become challenging: unlike standard RFID application scenarios, pervasive computing often involves uncontrolled environment for RFID, where tags and reader have to operate in much more difficult situations that those usually encountered or expected for classical RFID systems.

RFID technology is to avoid missing tags when reading multiple objects, as reading reliability is affected by various effects such shadowing or wave power absorption by some materials. The usual applications of RFID operate in a controlled environment in order to reduce the risk of missing tags while scanning objects.

In pervasive computing applications, a controlled reading environment is extremely difficult to achieve, as one of the principle is to enhance existing processes "in situ", unlike the controlled conditions that can be found in industrial processes. Consider for example a logistic application, where RFID tags could be used on items inside a package in order to check for its integrity along the shipping process. Tags would likely be placed randomly on items inside the package, and reading conditions would be variable depending on where the package is checked.

RFID operation in uncontrolled environments is challenging because RFID performance is affected by multiple parameters, in particular:

- Objects materials (on which tags are attached to),
- Materials in the surrounding environment,

- RFID frequency spectrum,
- Antenna nature and placement with respect to the tags.

In controlled environment, the difficulty to read tags can be limited by using the appropriate parameters to maximize the RFID performance for the application. But in many cases, it is needed to read large number of objects of various nature, arranged randomly in a given area or container. **Most pervasive computing applications fall in this context**.

5. New Software and Platforms

5.1. THEGAME: data fusion for Smart Home and Smart Building

KEYWORDS: Smart home - Smart building

- Participants: Aurélien Richez
- Partner: Université de Rennes 1
- Contact: Frédéric Weis
- URL: https://github.com/bpietropaoli/THEGAME/

DESCRIPTION

Context-aware applications have to sense the environment in order to adapt themselves and provide with contextual services. This is the case of Smart Homes equipped with sensors and augmented appliances. However, sensors can be numerous, heterogeneous and unreliable. Thus the data fusion is complex and requires a solid theory to handle those problems. The aim of the data fusion, in our case, is to compute small pieces of context we call context attributes. Those context attributes are diverse and could be for example the presence in a room, the number of people in a room or even that someone may be sleeping in a room. For this purpose, we developed an implementation of the belief functions theory (BFT). THE GAME (THeory of Evidence in a lanGuage Adapted for Many Embedded systems) is made of a set of C-Libraries. It provides the basics of belief functions theory, computations are optimized for an embedded environment (binary representation of sets, conditional compilation and diverse algorithmic optimizations).

THE GAME is published under apache licence. It is maintained and experimented within a sensor network platform developed by TACOMA since June 2013.

5.2. Platforms

5.2.1. Platform Pervasive_RFID

KEYWORDS: Composite objects - RFID

- Participants: Paul Couderc and Nebil Ben Mabrouck
- Partner: Université de Rennes 1 (IETR)
- Contact: Paul Couderc

SCIENTIFIC DESCRIPTION

In 2015 we completed the RFID experiment testbed realized in 2014 in collaboration with IETR (see Figure 1).

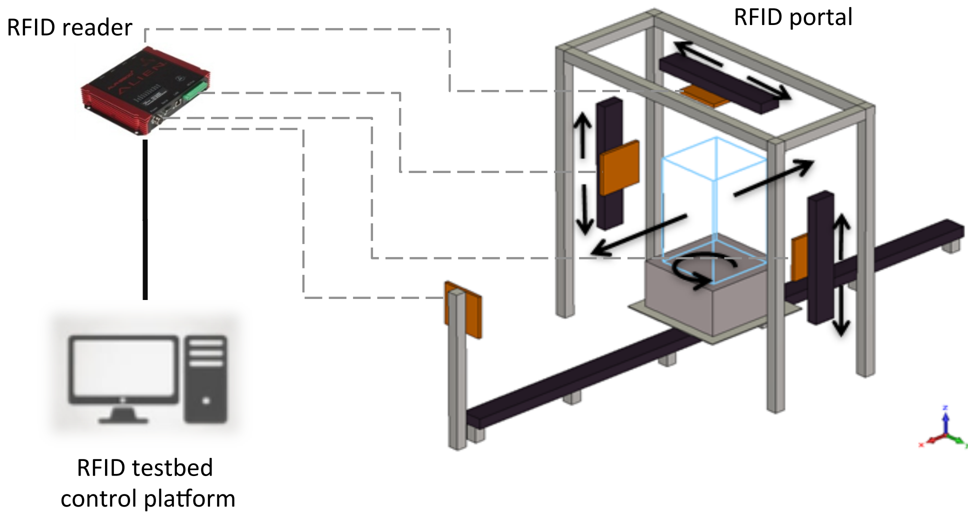

Figure 1. RFID testbed

This system allows both interactive testing as well as long running experiments of RFID reading protocols. It comprises a software platform (see Figure 2) allowing fine control over all dynamic aspects influencing RFID readings: movements for target and antenna, RFID reader configuration, and smart antenna configuration (diversity and power control). This testbed supports the reproduction of most situations found in real applications. We achieved the following improvements on the testbed in 2015:

- The implementation of a software controllable smart antenna, with dynamic radiating pattern, was completed along with its the hardware interface. This is an important feature when experimenting pervasive application, in particular to determine the radio performance improvements expectable from antenna diversity.
- A particular effort was put on improving the operational performance and robustness of the system: the initial implementation was completed in 2014 in a context tightly coupled with our on-going RFID research, and with an important dependency on the technical expertise of short term positions staff-member. In order to widen the testbed?s perspectives as a research tool, two aspects were improved:
  1. a high-level scripting interface was added to offer easy automatized experimentation campaign. Iterative RFID experiments with fine-tuning parameters can be specified using a variety of script languages, and further executed in a remote fashion via the added interface.
  2. A virtualization of RFID readers and motion drives was also developed to simulate the behavior of critical experiments or new software updates before executing them on the real testbed.
  3. Functional tests were developed to ascertain that crucial functions of the testbed would work correctly after future software updates, thus ensuring the maintainability and sustainability of the system.

5.2.2. On-demand room

KEYWORDS: Smart Home - Metamorphic House

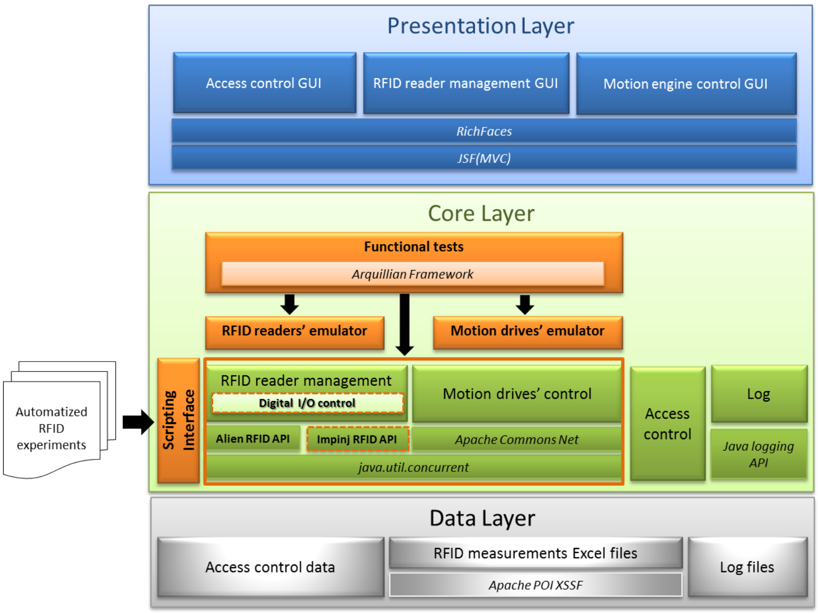

Figure 2. Software architecture of the RFID testbed

- Partner: Université de Rennes 1
- Partner: Université de Rennes 1 (Fondation Rennes 1)
- Contact: Michele Dominici and Frédéric Weis

DESCRIPTION

As part of the demonstration activities, we realized a prototype of the on-demand room as an immersive interactive virtual-reality application, leveraging the Immersia platform. Two iterations were achieved so far.

For the first iteration of the demonstrator, we realized a three-dimensional model of the on-demand room and two adjacent apartments, using the software SketchUp. This model was then imported in Unity3D and MiddleVR, which allow to display and navigate inside the model using the virtual reality platform Immersia [4]. We then implemented the application logic of the on-demand room using Unity scripting facilities. By wearing 3D glasses and a marker on their hand, users can literally walk inside the apartments, open doors and observe how the configuration of the room changes to become a part of one dwelling or another, as shown in Figure 3.

The second (and current) iteration of the demonstrator introduced a major feature: the real/virtual integration. Actual domestic appliances can now be connected to Immersia and participate to the on-demand room demonstration. In this phase we showed that a real light switch, located in the virtual on-demand room, can change its behavior and alternatively control one of the two real lamps, each located in one of the aparments, as shown in Figure 4.

To develop the real/virtual integration feature, we used home automation controllers and devices implementing the KNX standard. After wiring and programming the domotic network, we developed an application that leverages the Falcon library, provided by the KNX association, to dynamically change the behavior of the real light switch.

[4] http://www.irisa.fr/immersia/

Figure 3. 3D model in the Immersia platform

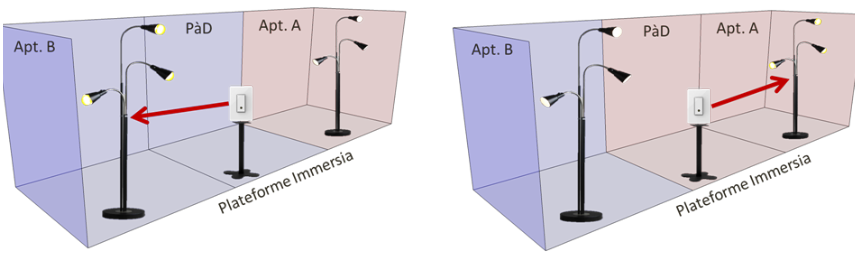

Figure 4. Integration of real devices

6. New Results

6.1. Self-describing objects and tangible data structures

Participants: Nebil Ben Mabrouk, Paul Couderc [contact].

A development in the line of the composite objects (see section 3.3) are self-describing objects. While previous works enabled integrity checking over a set of physical objects, these mechanisms were limited in two aspects: expressiveness and autonomy. More precisely, objects support the detection of special conditions (such as a missing element), but not the characterization of these conditions (such as describing the problem, identifying the missing element). Moreover, this compromises the autonomous feature of coupled objects, which would depend on external systems for analysing these special conditions. Self-describing objects are an attempt to overcome these limitations, and to broaden the application perspectives of autonomous RFID systems.

The principle is to implement distributed data structure over a set of RFID tags, enabling a complex object (made of various parts) or a set of objects belonging to a given logical group to "self-describe" itself and the relation between the various physical elements. Some applications examples includes waste management, assembling and repair assistance, prevention of hazards in situations where various products / materials are combined etc. The key property of self-describing objects is, like for coupled objects, that the vital data are self-hosted by the physical element themselves (typically in RFID chips), not an external infrastructure like most RFID systems. This property provides the same advantages as in coupled objects, namely high scalability, easy deployment (no interoperability dependence/interference), and limited risk for privacy.

However, given the extreme storage limitation of RFID chips, designing such systems is difficult:

- Data structures must be very frugal in terms of space requirements, both for the structure and for the coding.
- Data structures must be robust and able to survive missing or corrupted elements if we want to ensure the self-describing property for a damaged or incorrect object.

In the context of RFID system, the resiliency property of such data structures enables new information architecture and autonomous (offline) operation, which is very important for some RFID applications. We previously applied the self-describing objects approach to the waste management domain [1], which has shown to be a specially challenging situation for RFID. This challenge is found more generally in pervasive computing scenarios involving RFID reading in uncontrolled environments (see section 4.3).

Pervasive support for RFIDs.

We propose to apply our approach to improve the robustness of RFID inventories / batch checking: when many objects are read at once by an RFID reader, miss read are common and raise reliability and operational issues for applications. An innovative solution to this problem is to take advantage of the multiplicity of tags by leveraging them as a distributed memory shared by a logical group. In this way, it is possible to support error detection as well as information recovery. We proposed a flexible protocol to support robust EPC retrieval in adverse reading conditions. The proposed protocol uses erasure correcting techniques to enable error-free recovery of misread EPCs [2]. It is further customizable with respect to the rate of misread tags and application requirements. This work was the object of an Inria patent [5]. Fine-tuning the protocol parameters is still the object of on going experimentation in the context of the Pervasive_RFID project (see section 7.1.1).

At the software level, RFID inventory reliability issue is usually addressed by anti-collisions mechanisms and redundancy mechanisms. Anti-collisions protocols limit the risk of data corruption when multiples tags have to reply to an inventory request. Redundancy is often implemented in RFID readers by aggregating the results of multiple inventory requests over a time frame, to give the tags multiple opportunities to reply. While useful, these strategies cannot ensure that a given inventory is valid or not (in other words, one or more tags may be missing without being noticed). In situations where we have to read large collection of objects of various types, the performance is difficult to predict but may still be adequate for a given application. For example,

[5] Patent filed in April 2015 - Inria 179

some application can tolerate missing some tags, provided that miss read probability could be characterized. In some cases, read reliability could be improved using mechanical approaches, such as introducing movements in objects or antenna to introduce *radio diversity* during read. Finally, distributed data structure can be used over a set of tags to be used to mitigate the impact of misread (by using data redundancy) and to help the reading protocol by integrating hints about the tag set collection being read.

We studied extensively by experimentation the behaviour of existing RFID solutions in the context of uncontrolled environment (meaning, random placement of tags on objects mixing various materials) in order to characterize their real-world performance regarding the parameters of such as tags numbers, density, frequencies, reader antenna design, dynamicity of objects (movements), etc. From these experimentations, we would like to identify the conditions that are favorable to acceptable performance, and the way where there are hopes of improvement with specific design for these difficult environments. These results should also allow improving the performance: high level integrity checks can guide low level operations by determining whether inventories are complete or not. This cross layer strategy enables faster and more efficient inventory protocols.

6.2. Interactions between connected objects in a Smart Building

Participants: Adrien Capaine, Yoann Maurel, Frédéric Weis [contact].

Tacoma group is focussed on the conception and implementation of innovative services for the Smart Home/Building. The range of considered services is broad: from "optimizing the energy consumption" to "helping users to find their way in a building". One of our goals is to build a pervasive platform with constrained performance and cost [7], without disrupting existing spaces. Within this idea, we explored in 2015 the services provided by different modes of interaction in a physical space between neighboring objects, and also between an object and a nearby user.

More precisely, we conducted some experiments with LEDs. Instrumented via a short distance radio interface, a lighting device becomes an unobtrusive connected object that is easy to integrate to a mesh network. A relevant aspect of this platform is the consideration of potential conflicts in data access offered by the connected objects. One of the first scenarios we considered is to operate an LED-based light path to guide the evacuation of a building in the case of a fire alarm. When our objective is to multiply the uses of LED devices ("go beyond lighting", see section 7.1.2), the question is then the priority of access to resources offered by the platform distributed in the environment. Specifically, we addressed the following issues (similar to some of the issues presented in section 3.2):

- How to prioritize the lighting functions (classic) and occasional (but priority) uses of the LED to help in the care of a fire alarm?
- How do you prioritize access to the objects and/or resources that carry these items?

6.3. Context computing for Smart Home

Participants: Yoann Maurel, Frédéric Weis [contact].

To provide services for smart Homes, automation based on pre-set scenarios is ineffective: human behavior is hardly predictable and application should be able to adapt their behavior at runtime depending on the context. We focused on recognizing user's activities to adapt applications behaviours. Our aim is to compute small pieces of context we called *context attributes*. Those context attributes are diverse, for example a presence in a room, the number of people in a room etc.

Building efficient and accurate context information using inexpensive and non-invasive sensors was and is still a great challenge 3.1. We proved, through the use of dedicated algorithms and a layered architecture that it is achievable when the targeted Home is known - due to the specific and non automated calibration process we used. Among all the available theories, we used the Belief Function Theory (BFT) [8] [9] as it allows to express **uncertainty** and **imprecision**.

Context is computed by a chain a tasks as illustrated in figure 5:

- The transition between a raw sensor value and a belief function is made through the use of a belief model which maps a sensor value to a belief function. A belief function represents the degree of belief associated to each possible value of the context attribute.
- Then a set of belief functions (corresponding to a set of sensors) can be combined (fused).
- Finally the system can decide what is the "best" value for the context attribute.

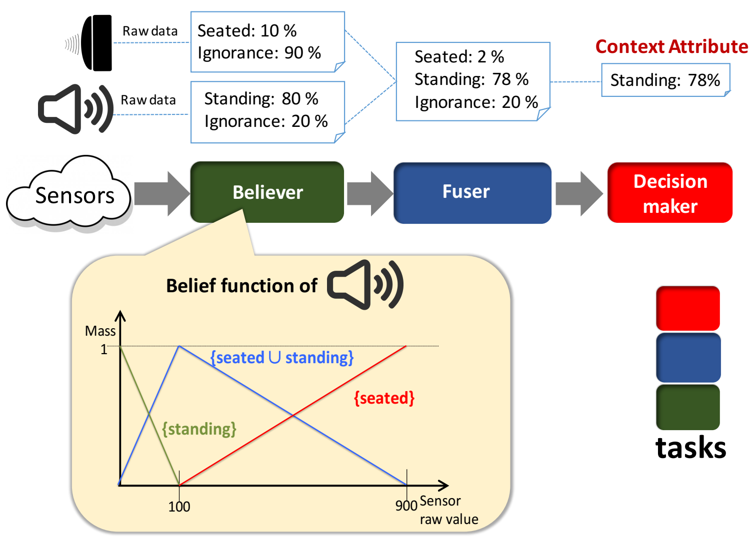

Figure 5. Context attribute computation

Alleviating the complexity of the platform configuration and maintenance is a prerequisite for the adoption of Smart-Home environments by consumers. Currently the BFT theories requires a huge calibration process. We focussed our efforts on the semi-automated building of belief functions, required by the theory, that have to be provided by each sensor.

Automated configuration of sensors.
The belief model is provided to the platform by us and a component is in charge of transforming a sensor value in a *belief function*. The fine tuning of a belief function can be a tedious task. It must be done by a specialist who understands the belief function theory and knows the behavior of the sensors. The model is often built iteratively by experimenting. This may take several hours or days. Moreover, this method is directly connected to the output of each sensor. Biased and noisy measures can cause major modifications on the resulting beliefs.

Ideally, the calibration of the model should be as automatic as possible (few interaction with the user during calibration). The person setting up the sensors should not have to understand the belief function theory. We proposed to generate our belief model from a training set of sensor data. We mainly focused on k-nearest neighbors (KNN) algorithm [6]. We used a training data set to compute the presence belief model. We acquired a set of data with someone present in the experimentation room and a second data set with nobody in the room, which gives us a labelled data set. This principle is illustrated in figure 6.

6.4. Design of a framework for distributed pervasive environments

Participants: Adrien Capaine, Yoann Maurel [contact], Frédéric Weis.

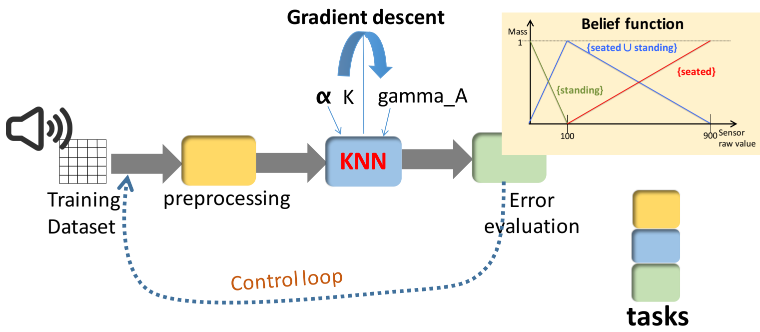

Figure 6. Sensor autocalibration

Pervasive environment brings into play complex interactions between a large number of heterogeneous entities: computing units executing third-party applications delivering multiple services to users, with various (sometimes conflicting) requirements, based on the information provided by dynamically (un)available smart object or sensors. The development of pervasive application is consequently hard and must be supported by architectures and frameworks that propose solution to manage the heterogeneity, to organize the interaction of distributed entities, to support the dynamic discovery of the entities, to ensure the privacy of collected data and inferred context, to organize and structure information sharing, and to enforce access control over data and entities.

To alleviate the development of such application (see section 3.4), we worked on a distributed pervasive environment made of several processing nodes (or gateway) managing interacting Smart Spaces (*i.e* a room, a corridor etc.). A Smart Space contains one or more nodes that coordinate to provide services to users. A node is a low cost computing unit with constrained performances. Each node is responsible for the management of entities and services available in their close proximity: they dynamically discover available devices and source of information, computes contextual information and offer services to nearby users. Nodes are organized hierarchically: in each space one *supervisor node* is responsible for coordination between nodes (*e.g.* managing conflicting requirements and enforcing global policies) and communication with neighboring Smart Spaces. The whole environment (a Smart Building or a Smart Home) is controlled by a master node that distributes policy between Smart Spaces to provide global services (*e.g.* global energy management). Data are stored and processed by nodes as close as possible to the users in order to enforce data privacy (see section 2.1).

Each node supports the execution of several services and application. To help the development of these services, applications are built on top of a framework (**Matriona**) running on each gateways.

Matriona proposes a unified representation of the concepts manipulated by applications in order to hide the heterogeneity of technologies to the application. We rely on the concept of *resource*. A Matriona's resource is quite similar to a REST resource but is not identical: HTTP protocol is only used for remote call; the structure of a resource is constrained; a resource can be dynamically discovered; it can provide notification (PUSH operation); it is uniquely identified in the environment; it is any object used or shared by applications, by bridges, or by the system itself: a device, a room, a platform, a user or a contextual information; it is implemented as a standard object and has a type specified by its interfaces (annotated Java interface). Types describe the data and the operations on resources. *CRUD* (**C**reate, **R**ead, **U**pdate, **D**elete) and *PUSH* operations are used to represent the semantic of operations. Specifying the semantic of operations allows to operate some generic processing (*e.g.* gathering all the information provided by a resource) on resources without knowing their types.

Matriona enables dynamic discovery between nodes and inter-platform communication between the applications and resources. The platforms automatically discovers other platforms using a discovery mechanism. Each platform enables the discovery and the use of its resources to other platforms' applications. Remote resources are using exactly the same API as their internal counterparts: using remote resources is completely transparent to the application. The data is serialized / deserialized automatically by the platform during the call. Calling remote resources induces a performance cost equivalent to the use of a traditional REST resource.

Matriona allows to dynamically add new properties and new behaviors to a resource using decorators. Resources are built using multiple layers in the same way as "Russian dolls". Each layer is responsible for implementing a specific behavior such as retrieving, conversion operation or adding new properties (*e.g.* localization). For instance, the implementation of a thermometer resource will consist of 1) a core layer providing standard information (id, date of creation, the groups to which it belongs); 2) a protocol layer able to communicate with the real devices; 3) a conversion layer (Kelvin to Celsius). The application interacts with the top layer that exposes all or part of information and treatments offered by lower layers. While some layers are static (part of the resource declaration) and cannot be removed, most can be added afterward by the applications. It creates a virtual resource composed of the original resource and the new layers. This virtual resource can be used and discovered as any other resources.

Matriona allows to organize the information. Resource may reference other resources, for example the localization of a "thermometer resource" refers to the resource representing the room in which it is located. The value of the property is the *id* of the referenced resource. This allows applications to easily find resources and their interactions. It is also possible to create composite resources using aggregation mechanisms provided by the framework. The virtual resource can be used directly by applications as any other resources.

Matriona provides a basic language queries. Applications use resources directly or send queries to the platform registry. The query language allows to apply filters and to aggregate data on available resources. A request is represented by a specific URL. For instance, the mean temperature of thermometers in the whole meeting rooms of a building can be obtained using the URL `/*/*/$ location/meeting_room/temperature!mean`. The query language can be extended by providing new decorators and new filters.

Matriona provides access management: each resources belongs to one or many groups. The groups are defined when the resource is created or during its lifecycle by the owner of the resource. Groups gather applications that share the same permissions on access resources. Groups are managed by a "group owner" that can limit members permissions. Permissions describe the ability of an application to read, write, update, delete, manage or lock a resource. Resource locking avoids conflicting requests to be performed by different applications. Locks are given to applications for a fixed period of time. A resource can always be unlocked by the platform itself or by "critical" applications (*e.g.* emergency fire alarm, see section 6.2).

Matriona allows applications to extend resource properties and to share these meta-information with others. Each application can add new information to a given resource. Tagged information are available only for the application and its group. Meta-information are stored by the platform and associated to the resource until the latter is destroyed. This mechanism allows application to easily share information on the resource they used. For instance, this can be used to retrieve previously used resources or to rate the quality of service provided by a given resource. For the application, meta-information are part of the resource. It is then possible for an application to only use resources that have been approved by other applications of their group. This mechanism can also be used by application to add some task-relevant information (*e.g.* a medical application can tag resources that have been used by a patient).

6.5. Towards Metamorphic Housing: the on-demand room

Participant: Michele Dominici [contact].

This research activity is supported by Fondation Rennes 1 through the chair "Smart Home and Innovation", since January 2014. This activity is centered on the concept of metamorphic housing (see section 4.2). During the first year, we had identified the goals of the research project, also taking into account the trends of future housing industry, provided by the enterprises and public authorities that support the chair. We also had identified a case study, the on-demand room, to be displayed as the main application of the research results in scientific communications and vulgarization. It consists in a space that is physically shared by a small group of apartments, but is assigned for the sole use of one or few particular ones at the time. The room is designed so as to make occupants feel they did not leave their apartment at all. They seamlessly move from their dwelling to the on-demand room and conversely, without noticing the difference, as the room adapts to their preferences. During 2015, second year of the chair, we organized our work following two main axes: *(i)* solving the research problems, illustrated in the rest of this section; *(ii)* demonstrating the results using mixed reality as combination of virtual reality and off-the-shelf domotic devices, described in section 5.2.2.

The research problems underlying the on-demand room are numerous: we illustrated them in the research report "A Case Study of Metamorphic Housing: The on-Demand Room" [3]. We started by addressing the problems associated with the goal of "plugging" the room into different apartments. This requires to dynamically change the rights to control and customize the room's equipment, including lights, appliances, heating, ventilation and air conditioning systems (HVAC), etc. This must be done in a transparent fashion, so that off-the-shelf devices and appliances can be used.

To solve these problems, we started a collaboration with the DIVERSE team [6]. The goal is to use the Kevoree [7] software framework to dynamically reconfigure the networks and domotic system of the room and of the apartments. When the on-demand room is owned by an apartment, their computer networks are interconnected; appliances, sensors and controllers in the room and the apartment can communicate with each others; devices reflect user preferences. Kevoree will enable these reconfigurations by running on key appliances and dynamically adapting and customizing their behavior to the owner of the on-demand room.

As part of the collaboration, some research goals have already been identified. The underlying challenges will be addressed and the results will be integrated in a comprehensive mixed reality demonstrator. This will represent the final iteration of the ongoing demonstration process, illustrated in the platform section (for more details, see 5.2.2).

7. Partnerships and Cooperations

7.1. National Initiatives

7.1.1. Pervasive_RFID

- Partner: IETR
- Starting: July 2013; ending: July 2016

Pervasive_RFID is a joint effort (within the CominLabs initiative, see http://www.cominlabs.ueb.eu/) started in July 2013 with IETR (institut d'électronique et de télécommunications de Rennes) to study and design innovative RFID reading protocols in the context of pervasive computing applications. Some limitations of existing RFID technology become challenging: unlike standard RFID application scenarios, pervasive computing often involves uncontrolled environment for RFID, where tags and reader have to operate in much more difficult situations that those usually encountered or expected for classical RFID systems.

[6] http://diverse.irisa.fr/
[7] http://kevoree.org/

7.1.2. GLIE - Guidage Lumineux par l'Intelligence de l'Environnement

- Partner: OyaLight
- Starting: December 2014; ending: April 2016

GLIE is a collaborative projet with OYALIGT and TACOMA group. The objective of the project is to design and demonstrate a new service combining connected LEDs provided by OYALIGHT and a software tool developed by TACOMA. By integrating and analyzing data transmitted by the sensors integrated into LEDs, the service must be able to detect a given context and to react accordingly.

8. Dissemination

8.1. Promoting Scientific Activities

8.1.1. Scientific events organisation

8.1.1.1. Member of the conference program committees

- PC member for Ehpwas 2015: 3rd IEEE Int. Workshop on E-Health , 2015, F. Weis

8.1.2. Invited talks

- "L'habitat adaptatif: un pas à franchir vers la ville durable", speech at BATIMAT/Le Mondial du Bâtiment on 5 November 2015. http://visiteur.batimat.com/?IdNode=6564&CurrentNode=11261&Lang=FR&Zoom=cb627eb94499111bd0da1a764a20bc34&KM_Session=b6bc7a1

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

L2/L3: network computing (lectures, tutorials, labs), 250 hours, F. Weis, University Rennes 1

Master : Wireless LANs, F. Weis, 20 hours, M2, Telecom Bretagne

Master: Mobile and Pervasive Computing , 12 hours, P. Couderc, M2, University of Rennes 1

8.2.2. Supervision

PhD in progress: Francisco Javier Acosta Padilla, Auto-adaptation for IoT, 31/01/13, Frédéric Weis and Johann Bourcier

PhD in progress: Adrien Capaine, Vers une plate-forme de LED connectées comme vecteur de services contextuels dans le cadre des bâtiments intelligents, 01/05/15, Frédéric Weis and Yoann Maurel

PhD in progress: Zaineb Lioune, Une Architecture pour des Services e-Santé évolutifs dans le cadre des Maisons Intelligentes, 01/09/14, Frédéric Weis, Tayeb Lemlouna and Philippe Roose

8.2.3. Juries

Frédéric Weis was in the following PhD examination committees:

Abdulkader BENCHI, Middleware Systems for Opportunistic Computing in Challenged Wireless Networks, University Bretagne Sud (PhD referee)

Osama ABU OUN, Conception d'une plate-forme multi-échelle hybride pour évaluer les performances des systèmes orientés Internet des Objets, University Franche-Comté (PhD referee)

8.2.4. Internship

Master 2 Internship, 6 months: "Enhancing a Web Administration GUI for Smart Home devices", Charles Ferron

Master 1 Internship, 4 months: "Synchronization between connected LEDs", Youness Aghazzaf

8.3. Popularization

8.3.1. Hack'Archi

Organized as part of the "Architecture de la Transformation" call for proposals, the Hack'Archi was an open workshop held in Paris-Belleville school of architecture (ENSA) on 4 and 5 December 2015. About 90 students in disciplines as diverse as architecture, sociology, urbanism and engineering gathered for this 24-hours "architectural hackathon'". Students were organized in small teams of 5 or 6 members to work on enriching the preselected projects, proposed by the social landlords.

During the Hack'Archi, Michele Dominici was the representative of the project led by NEOTOA (a french social landlord) and helped 6 students in architecture, sociology, urbanism and engineering proposing new ideas about the on-demand room. We had in charge the leadership and coordination of the students. Our team was awarded the first prize of the Hack'Archi [8].

8.3.2. Miscellaneous

- Atelier de l'Innovation, Fondation Rennes 1. https://fondation.univ-rennes1.fr/actualite/neotoa-nouveau-partenaire-de-la-fondation-0.
- "Un habitat très prospectif | Espace des sciences". Date accessed: 16 December 2015. http://www.espace-sciences.org/sciences-ouest/335/dossier/un-habitat-tres-prospectif.
- Pitch at "Rencontres Inria - Industrie and Meito", 21 May 2015. http://videos.rennes.inria.fr/InriaMeito2015/index-pitchInriaMEITO2015.html
- Fondation de l'Université de Rennes 1 - Chaire Habitat Intelligent et Innovation. Date accessed: 16 December 2015. http://www.legrand.fr/formation/fondation-universite-rennes1-chaire-habitat-intelligent-innovation_5746.
- Live video interview at Festival des Sciences, "Samedi en direct du plateau TV du Village des sciences'". https://www.youtube.com/watch?v=MDkKd4Pl5vQ&feature=youtu.be&t=4541.
- Website of the chair "Habitat Intelligent et Innovation". On-line since October 2015. https://fondation.univ-rennes1.fr/la-chaire-habitat-intelligent-et-innovation.

9. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

[1] Y. GLOUCHE, A. SINHA, P. COUDERC. *A Smart Waste Management with Self-Describing Complex Objects*, in "International Journal On Advances in Intelligent Systems", June 2015, vol. 8, n^{o} 1 & 2, pp. 1-16, Invited journal, https://hal.inria.fr/hal-01198382

Conferences without Proceedings

[2] N. BEN MABROUK, P. COUDERC. *EraRFID: Reliable RFID systems using erasure coding.* , in "IEEE International Conference on RFID 2015", San Diego, United States, IEEE, April 2015, https://hal.inria.fr/hal-01247089

[8] Hack'Archi : retour sur 24h d'innovations - Lab CDC. Date accessed: 16 December 2015. http://labcdc.caissedesdepots.fr/hackarchi-etudiants-et-professionnels-autour-dun-meme-defi/

Research Reports

[3] M. DOMINICI, M. BANÂTRE. *A case study of metamorphic housing: the on-demand room*, IRISA, January 2015, n^O PI-2026, 17 p. , https://hal.inria.fr/hal-01109341

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[5] B. M. COUDERC PAUL, B. MATHIEU. *Ubi-Board: A Smart Information Diffusion System*, in "8th International Conference, NEW2AN and 1st Russian Conference on Smart Spaces, ruSMART 2008", St. Petersburg, Russia, September 2008

[6] T. DENOEUD. *A k-Nearest Neighbor Classification Rule Based on Dempster-Shafer Theory*, in "IEEE TRANSACTIONS ON SYSTEMS. MAN, AND CYBERNETICS", May 1995, vol. 25, pp. 804–813

[7] M. DOMINICI, B. PIETROPAOLI, F. WEIS. *Experiences in managing uncertainty and ignorance in a lightly instrumented smart home*, in "International Journal of Pervasive Computing and Communications", 2012, vol. 8, n^O 3, pp. 225-249 [*DOI :* 10.1108/17427371211262635], https://hal.inria.fr/hal-00787049

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[9] B. PIETROPAOLI, M. DOMINICI, F. WEIS. *Virtual Sensors and Data Fusion in a Multi-Level Context Computing Architecture*, in "16th International Conference on Information Fusion (FUSION 2013)", Instanbul, Turkey, July 2013, https://hal.inria.fr/hal-00927092