



IN PARTNERSHIP WITH:
Université Rennes 1

Activity Report 2013

Project-Team ACES

Ambient computing and embedded systems

IN COLLABORATION WITH: Institut de recherche en informatique et systèmes aléatoires (IRISA)

RESEARCH CENTER
Rennes - Bretagne-Atlantique

THEME
Distributed Systems and Services

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Project-Team ACES

Keywords: Ambient Computing, Pervasive Computing, Spatial Information Systems, Embedded Systems

ACES project has been evaluated in October 2012 and ended in December 2013. During this final year, the goal was to completely finish our current activities within the BinThatThink project and the collaboration with EDF, and also to continue exploring themes that can lead to the creation of a new project.

Creation of the Project-Team: 2003 January 01, end of the Project-Team: 2013 December 31.

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2. Overall Objectives

2.1. Overall Objectives

Three key phenomena have been changing the nature of computing over the last few years. The first is the popularity of portable devices such as mobile telephones and Personal Digital Assistants (PDAs). Today, around 80% of the French adult population possess their own mobile phone and there is a large variety of smartphones on the market that integrate PDA functionality. The second phenomenon is the large number of embedded systems; these are everyday devices that have their own processor and memory. Estimates suggest that more than 98% of the world's processor's are in embedded system [8], thus facilitating the deployment of a variety of information systems that control physical objects. The third phenomena is the increasing variety of wireless networks available for personal and embedded devices, e.g., Bluetooth, Wifi, GPRS, etc.

The combination of these three phenomena has permitted the emergence of context-aware person-centric applications and collaborative personal environments. These services complement a person's physical ability to interact with her/his environment. They are tailored to the needs, preferences and location of each person carrying a device, and are continually available. Services range from critical, e.g., remote health monitoring [11], to utility, e.g., navigational help, etc. to value-added, e.g., virtual museum guides, smart home, etc.

The domain of person-centric computing is known in research circles as *ambient computing* [12], and several significant research challenges remain. First, to facilitate mobility, ambient computing services should require minimal device manipulation by the device owner. It is crucial that the computing device operate as an extension of the person rather than as a tool. Second, there must be a way of modeling the physical environment so that applications can seamlessly import data from the environment and modify the environment when possible. Third, applications must be able to adapt to the rather limited storage and processing capabilities of mobile devices, as well as to variable and intermittent wireless network coverage.

The ACES (Ambient Computing and Embedded Systems) group is addressing research from two angles:

- *System Support for Continuous Ambient Service Delivery.* A user needs to be able to exploit ambient services as seamlessly as possible. In particular, he should be shielded from the effects of network breaks – something that can be quite common for wireless environments.
- *Programming Models for Ambient Computing.* We have looked at ways of modeling the physical environment in the virtual environment of programs in order to facilitate ambient application development. The goal is to be able to write programs that address and navigate through objects in the physical world as elegantly as a program traditionally manipulates a computer's main memory.

This document overviews our activities in more detail. The section *Scientific Foundations* gives some background to our work in person-centric computing. The section *Application Domains* describes the importance of our research agenda through the presentation of several applications, some of which are being developed in our group. The group's recent results are presented in the section *New Results*.

3. Research Program

3.1. Programming Context

The goal of ambient computing is to seamlessly merge virtual and real environments. A real environment is composed of objects from the physical world, e.g., people, places, machines. A virtual environment is any information system, e.g., the Web. The integration of these environments must permit people and their information systems to implicitly interact with their surrounding environment.

Ambient computing applications are able to evaluate the state of the real world through sensing technologies. This information can include the position of a person (caught with a localization system like GPS), the weather (captured using specialized sensors), etc. Sensing technologies enable applications to automatically update digital information about events or entities in the physical world. Further, interfaces can be used to act on the physical world based on information processed in the digital environment. For example, the windows of a car can be automatically closed when it is raining.

This real-world and virtual-world integration must permit people to implicitly interact with their surrounding environment. This means that manual device manipulation must be minimal since this constrains person mobility. In any case, the relative small size of personal devices can make them awkward to manipulate. In the near future, interaction must be possible without people being aware of the presence of neighbouring processors.

Information systems require tools to *capture* data in its physical environment, and then to *interpret*, or process, this data. A context denotes all information that is pertinent to a person-centric application. There are three classes of context information:

- The *digital context* defines all parameters related to the hardware and software configuration of the device. Examples include the presence (or absence) of a network, the available bandwidth, the connected peripherals (printer, screen), storage capacity, CPU power, available executables, etc.
- The *personal context* defines all parameters related to the identity, preferences and location of the person who owns the device. This context is important for deciding the type of information that a personal device needs to acquire at any given moment.
- The *physical context* relates to the person's environment; this includes climatic condition, noise level, luminosity, as well as date and time.

All three forms of context are fundamental to person-centric computing. Consider for instance a virtual museum guide service that is offered via a PDA. Each visitor has his own PDA that permits him to receive and visualise information about surrounding artworks. In this application, the *pertinent* context of the person is made up of the artworks situated near the person, the artworks that interest him as well as the degree of specialisation of the information, i.e., if the person is an art expert, he will desire more detail than the occasional museum visitor.

There are two approaches to organising data in a real to virtual world mapping: a so-called *logical* approach and a *physical* approach. The logical approach is the traditional way, and involves storing all data relevant to the physical world on a service platform such as a centralised database. Context information is sent to a person in response to a request containing the person's location co-ordinates and preferences. In the example of the virtual museum guide, a person's device transmits its location to the server, which replies with descriptions of neighbouring artworks.

The main drawbacks of this approach are scalability and complexity. Scalability is a problem since we are evolving towards a world with billions of embedded devices; complexity is a problem since the majority of physical objects are unrelated, and no management body can cater for the integration of their data into a service platform. Further, the model of the physical world must be up to date, so the more dynamic a system, the more updates are needed. The services platform quickly becomes a potential bottleneck if it must deliver services to all people.

The physical approach does not rely on a digital model of the physical world. The service is computed wherever the person is located. This is done by spreading data onto the devices in the physical environment; there are a sufficient number of embedded systems with wireless transceivers around to support this approach. Each device manages and stores the data of its associated object. In this way, data are physically linked to objects, and there is no need to update a positional database when physical objects move since the data *physically* moves with them.

With the physical approach, computations are done on the personal and available embedded devices. Devices interact when they are within communication range. The interactions constitute delivery of service to the person. Returning to the museum example, data is directly embedded in a painting's frame. When the visitor's guide meets (connects) to a painting's devices, it receives the information about the painting and displays it.

3.2. Spatial Information Systems

One of the major research efforts in ACES over the last few years has been the definition of the Spread programming model to cater for spacial context. The model is derived from the Linda [10] tuple-space model. Each information item is a *tuple*, which is a sequence of typed data items. For example, $\langle 10, \text{'Peter'}, -3.14 \rangle$ is a tuple where the first element is the integer 10, the second is the string "Peter" and the third is the real value -3.14. Information is addressed using patterns that match one or a set of tuples present in the tuple-space. An example pattern that matches the previous tuple is $\langle \text{int}, \text{'Peter'}, \text{float} \rangle$. The tuple-space model has the advantage of allowing devices that meet for the first time to exchange data since there is no notion of names or addresses.

Data items are not only addressed by their type, but also by the physical space in which they reside. The size of the space is determined by the strength of the radio signal of the device. The important difference between Spread and other tuple-space systems (e.g., Sun's JavaSpaces [9], IBM's T-Space [13]) is that when a program issues a matching request, only the tuples filling the *physical space* of the requesting program are tested for matching. Thus, though SIS (Spatial Information Systems) applications are highly distributed by nature, they only rely on localised communications; they do not require access to a global communication infrastructure. Figure 1 shows an example of a physical tuple space, made of tuples arranged in the space and occupying different spaces.

As an example of the power of this model, consider two of the applications that we have developed using it.

- *Ubi-bus* is a spatial information application whose role is to help blind and partially blind people use public transport. When taking a bus, a blind person uses his PDA to signal his intention to a device

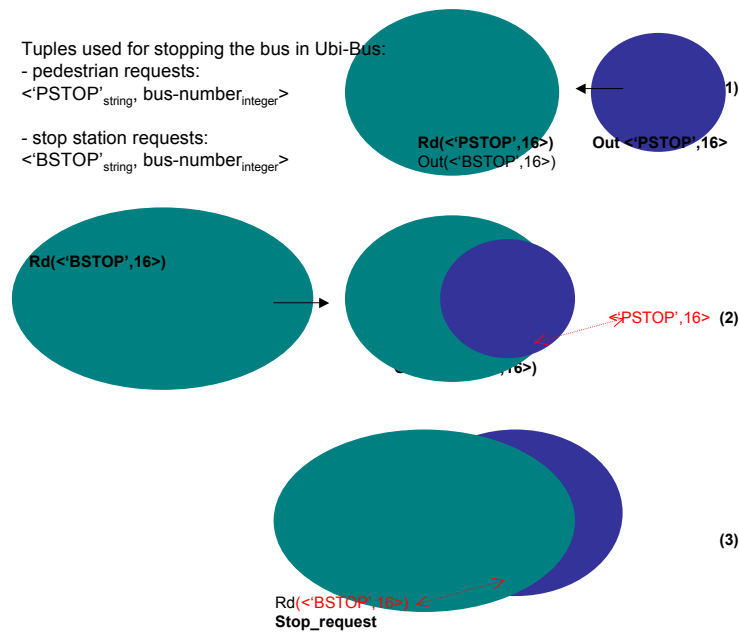


Figure 1. Physical Tuple Space

embedded in the bus stop; this device then contacts the bus on the person's behalf. This application illustrates how data is distributed over the objects of the physical world, and generally, how devices complement human means of communication.

- *Ubi-board* is a spatial information application designed for public electronic billboards. Travel hotspots like airports and major train stations have an international customer base, so bill-board announcements need to be made in several languages. In Ubi-bus, a billboard has an embedded device. When a person comes within communication range of the billboard, his device sends a request to the billboard asking it to print the message in the language of the person. In the case where several travellers are in proximity of the billboard, the board sends a translation of its information message to each person. The Ubi-board application illustrates personal context in use, i.e., the choice of natural language, and also how actions can be provoked in the physical world without explicit intervention by the person.

3.3. Coupled objects

Integrity checking is an important concern in many activities, both in the real world and in the information society. The basic purpose is to verify that a set of objects, parts, components, people remains the same along some activity or process, or remains consistent against a given property (such as a part count).

In the real world, it is a common step in logistic: objects to be transported are usually checked by the sender (for their conformance to the recipient expectation), and at arrival by the recipient. When a school get a group of children to a museum, people responsible for the children will regularly check that no one is missing. Yet another common example is to check for our personal belongings when leaving a place, to avoid lost. While important, these verification are tedious, vulnerable to human errors, and often forgotten.

Because of these vulnerabilities, problems arise: E-commerce clients sometimes receive incomplete packages, valuable and important objects (notebook computers, passports etc.) get lost in airports, planes, trains, hotels, etc. with sometimes dramatic consequences.

While there are very few automatic solutions to improve the situation in the real world, integrity checking in the computing world is a basic and widely used mechanism: magnetic and optical storage devices, network communications are all using checksums and error checking code to detect information corruption, to name a few.

The emergence of ubiquitous computing and the rapid penetration of RFID devices enable similar integrity checking solutions to work for physical objects. We introduced the concept of *coupled object*, which offers simple yet powerful mechanisms to check and ensure integrity properties for set of physical objects.

Essentially, coupled objects are a set of physical objects which defines a logical group. An important feature is that the group information is self contained on the objects which allow to verify group properties, such as completeness, only with the objects. Said it another way, the physical objects can be seen as fragments of a composite object. A trivial example could be a group made of a person, his jacket, his mobile phone, his passport and his cardholder.

The important feature of the concept are its distributed, autonomous and anonymous nature: it allows the design and implementation of pervasive security applications without any database tracking or centralized information system support. This is a significant advantage of this approach given the strong privacy issues that affect pervasive computing.

4. Software and Platforms

4.1. Software and Platforms

4.1.1. *THE GAME: THeory of Evidence in a lanGuage Adapted for Many Embedded systems*

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 has been developed within the ACES-EDF collaboration (see 6.1.1), and is published under apache licence (<https://github.com/bpietropaoli/THEGAME/>). It is maintained and experimented by Aurélien Richez within a sensor network platform developed by ACES since June 2013.

5. New Results

5.1. Self-describing objects

Participants: Michel Banâtre, Nebil Ben Mabrouk, Paul Couderc [contact], Yann Glouche, Arnab Sinha.

Coupled objects enable basic integrity checking for physical objects, and use cases were demonstrated for security and logistics applications. In these applications, high reliability in the RFID reading infrastructure is assumed for the system to work. This suggests another idea for coupled objects: using control data structures distributed over the physical objects in order to improve the reliability of RFID reading protocols. This is the purpose of the Pervasive_RFID project, in collaboration with the IETR which is described in more details below 7.1.2.

Another development in the line of the coupled objects principles 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, coupled 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 analyzing 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.

An application of self-describing objects has been proposed in for waste management, in the context of the bin that think project 7.1.1. A generic graph structure applicable to RFID systems for supporting self-describing objects is proposed in Arnab Sinha's thesis document (to be defended in April 2014).

5.2. Pervasive support for Smart Homes

Participants: Andrey Boytsov, Michele Dominici, Bastien Pietropaoli, Sylvain Roche, Frederic Weis [contact].

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*. ACES 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.

5.2.1. A multi-level context computing architecture

Computing context is a major subject of interest in smart spaces such as smart homes. Contextual data are necessary for services to adapt themselves to the context and to be as efficient as possible. Contextual data may be obtained via augmented appliances capable of communicating their state and a bunch of sensors. It becomes more and more real with the development of the Internet of Things. Unfortunately, the gathered data are not always directly usable to understand what is going on and to build services on them. In order to address this issue, we studied a multi-level context computing architecture divided in four layers:

- *Exploitation layer*: the highest layer, it exploits contextual data to provide adapted services
- *Context and situation identification layer*: this is what analyzes ongoing situations and potentially predicts future situations
- *Perception layer*: it offers a first layer of abstraction for small pieces of context independent of deployed sensors
- *Sensing layer*: it mainly consists of the data gathered by sensors

In this architecture, every layer is based on the results of its underlying layers. In 2013, we studied several methods that enable the building of such levels of abstractions (see figure 2). The first level of abstraction coming to mind when describing what people are doing in a Home is high level abstractions such as "cooking". Those activities are then the highest level abstraction we want our system to be able to identify.

We proposed to use plan recognition algorithms to analyze sequences of actions and thus predict future actions of users. It is, in our case, adapted to identify ongoing activities and predict future ones. There exist different plan recognition algorithms. However, one interested us particularly, PHATT introduced by Goldman, Geib and Miller. In order to understand how PHATT is working, it is important to understand the hierarchical task network (HTN) planning problem which is "inverted" by the algorithm to perform plan recognition. It consists in automatically generating a plan starting from a set of tasks to execute and some constraints. In our case, we are able to predict future situations depending of the previously observed situations. To give an example, if we want to predict that the situation dinner will occur soon, it is sufficient to have observed situations such as cooking and/or setting the table. The performances of PHATT have been evaluated by Andrey Andrey Boytstov and Frédéric Weis. These results will be published in 2014.

5.2.2. Propagation of BFT

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. For this purpose, we adopted the belief functions theory (BFT). 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. Since the BFT requires a substantial amount of computations, we proposed to reduce as much as possible the number of evidence required to compute a context attribute. Moreover, the number of possible worlds, *i.e.* the number of possible states for a context attribute, is also an important source of computation. Thus, reducing the number of possible worlds we are working on is also important.

It is especially problematic when working on embedded systems, which may be the case when trying to observe context in smart homes. Thus, with this objective in mind, we observed that some context attributes could be used to compute others. By doing this, the number of gathered and combined evidence for each context attribute could be drastically reduced. This principle is illustrated by Figure 3: the sets of possible worlds for "Presence" and "Posture" are seen as subsets of "Sleeping". So we proposed and implemented a method to propagate BFT through a set of possible states for a context attribute.

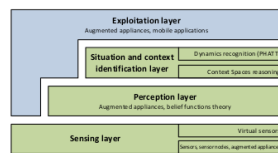


Figure 2. Multi-level context computing architecture

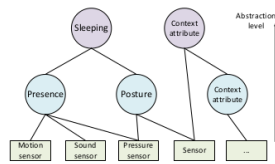


Figure 3. Propagation of Belief Functions Theories

5.2.3. Definition of virtual sensors

In our multi-level architecture, the sensor measures may be imperfect for multiple reasons. The most annoying reasons when deploying a system are biases and noisy measures. It requires fine tuning each type the system is deployed in a new environment. In order to prevent from doing this work again and again at levels where models are hard to build, we proposed to add a new sublayer to the sensing layer (see Figure 2): virtual sensors. Instead of modifying high level models, we created sensor abstractions such as motion sensor, sound sensor, temperature sensor, etc. It is particularly convenient when working with typed data such as temperature or sound level. It is possible to use different brands of sensors for sensors of the same type. Thus, those sensors, even if they are measuring the same physical event, can return very different data due to their range, sensibility, voltage, etc. By creating abstraction of sensors, it is possible to build models directly from typed data simplifying even more the building of models as those data have are understandable by humans. Those virtual sensors are built very simply from common heuristics and can be used for ias and noise compensation, Data aggregation and Meta-data generation.

It is also possible in these virtual sensors to implement fault and failure detection mechanisms using the BFT. It enables the detection of fault in the case of sensors of the same type. At higher level, those mechanisms will detect inconsistency between sensors of different types which is not of the same utility. Thus, those virtual virtual sensors, without disabling any features in our architecture, bring more stability for our models. Moreover, by keeping the virtual sensors very simple, they are easy to adapt and tune in a new environment and the overhead in terms of computation is reduced to the minimum and does not really impact the global system performance. Finally, the fine tuning part is always reduced to this level of our architecture and nothing else has to be changed when we move the system from one environment to another.

6. Bilateral Contracts and Grants with Industry

6.1. Bilateral Contracts with Industry

6.1.1. Energy saving mechanisms in smart homes using ambient computing principles

- Partner : EDF - R&D
- Starting: 01/06/2010, ending : 01/10/2013

This project is funded by EDF group, leading energy producer in Europe. It started in June 2010 and ended in October 2013. Its goal is to study the use of ambient computing principles for the management of electricity consumption in residential habitat. It focusses on two main objectives: (1) to define scenarios based on home people activities, and (2) to propose an implementation of these scenarios using ambient computing mechanisms studied in the Aces project.

Most existing smart home solutions were designed with a technology-driven approach. That is, the designers explored which services, functionalities, actions and controls could be performed exploiting available technologies. This led to solutions for human activity recognition relying on wearable sensors, microphones or video cameras. Those technologies may be difficult to deploy and get accepted in real-world households, because of convenience and privacy concerns. Many people have concerns on carrying equipments or feeling observed or recorded while living their private life. This could seriously impact the acceptability of the smart home system or reduce its diffusion in real households. To avoid such kind of issues, we designed our system with an acceptability-driven approach. That is, we selected technologies that respond to the constraints of a real-world deployment of the future smart home system, namely, convenience and privacy concerns. We decided to take a very conservative approach, choosing technologies that are as unobtrusive as possible, in order to explore the frontiers of what can be done in a smart home with a very limited instrumentation. Following the same considerations, the adopted technologies and techniques had to guarantee a fast and easy configuration, ultimately allowing a plug-and-play deployment. All these aspects have been studied and experimented using a hardware/software platform maintained by Sylvain Roche. This platform integrated results of two PhDs defended in 2013 (Michele Dominici and Bastien Pietropaoli), and has been used for a demonstration in June 2013 at EDF. A part of software developments is now published under apache licence (see 4.1.1) and used by the team.

The new results in 2013 are presented in section 5.2.

7. Partnerships and Cooperations

7.1. National Initiatives

7.1.1. *Bin That Thinks*

- Partners: ACES (Inria Rennes) and POPS (Inria Lilles), Veolia Propreté, and Etineo (a start up company focused on M2M communications and ambient networking)
- Starting: November 2010; ending: December 2013

BinThatThinks is an ANR project funded by the ANR Ecotech program, that is ended in December 2013. It aimed at sorting domestic waste at early stage in order to reduce costs and risks in waste sorting center, as well as helping citizens to adopt environment respectful. To this end, Bin That Think introduced a new system for (1) identifying the waste which involve a reject during waste collection, (2) detecting incompatible products and (3) implementing a reporting infrastructure enabling an efficient management/planning of the waste collecting process.

An infrastructure of smart bins was designed. This infrastructure leverage on waste identification mechanism based on self describing objects, helping user to sort their waste correctly, using either QR codes or RFID technologies. Wastes are grouped in smart bags, that can be read to determine their content. A given bin can accept or reject wastes depending on the sorting policy, or to prevent hazardous conditions to happen. Waste identification and wastes/bins interactions were the main focus of ACES in the project. The second important aspect of the project is the communication infrastructure, which was studied by Inria Fun. Smart bins are connected together using ambient networks taking advantage of the city streets topology: this allow the balanced use of short range and low power communication interface between the nodes and cellular communication interface, prolonging the life of the network. A thesis on this topic was defended in November 2013. A prototype was implemented and integrated as a demonstrator Etineo, a company specialized in M2M communications.

7.1.2. *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.

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.



Figure 4. BinThatThink general architecture

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.

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). We propose to address this issue with an original approach based on integrity checking, developed by ACES.

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, 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 mis-read (by using data redundancy) and to help the reading protocol by integrating hints about the tag set collection being read.

Our objective is to study extensively by experimentation the behavior 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 should enable faster and more efficient inventory protocols, as we have shown in [3] where some first results of this approach are presented.

The first step in the project is the implementation of an experiment test bed in order to support the experiment campaign. This task involves a significant engineering effort, which is ongoing. The following figures shows the elements of the testbed being built, featuring multi-axis mobile RFID antenna that we will driven by the high level protocols to use radio diversity, and a target container which will support custom designed arrangement of tags that are challenging to read by standard RFID configurations.

8. Dissemination

8.1. Scientific Animation

8.1.1. Program committees

- PC member for SCW 2013: Spatial Computing Workshop, 2013, M. Banâtre.
- PC member for SCW 2014: Spatial Computing Workshop, 2014, M. Banâtre.
- PC member for ruSMART 2013: The 5th conference on Smart Spaces, M. Banâtre.

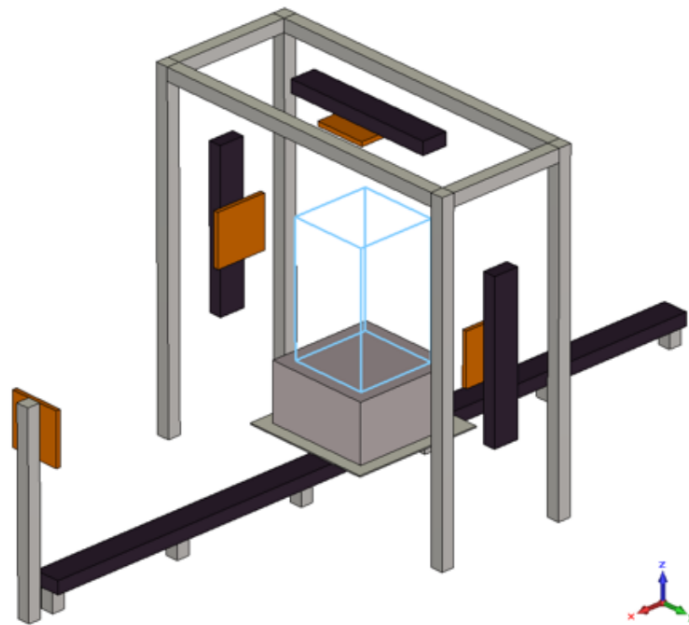


Figure 5. Overview of the Pervasive RFID testbed

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

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

Master : Ambient Computing and Mobile Communications, F. Weis, 6 hours, M2, university of Rennes, France

Master : Wireless LANs, F. Weis, 8 hours, M2, Telecom Bretagne, France

Master : Mobile communications and ambient computing, M. Banâtre, 4 hours, M1, Ecole Centrale de Paris, France

8.2.2. Supervision

PhD: M. Dominici, Context Management in Smart Homes, 01/11/09, M. Banâtre and F. Weis, defended in June 2013

PhD: B. Pietropaoli, Proximate interactions and data fusion in Smart Homes, 01/10/10, M. Banâtre and F. Weis, defended in December 2013

PhD: Minh Ho, Indoor localization mechanisms for ambient computing systems, 01/11/08, M. Banâtre and F. Weis, defended in December 2013

PhD in progress: Arnab Sinha, Pervasive control systems for smart waste management solutions, 14/12/10, M. Banâtre and P. Couderc, to be defended in April 2014

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

8.2.3. Juries

Michel Banâtre was in the following PhD examination committees:

B. Pietropaoli, Proximate interactions and data fusion in Smart Homes, University Rennes 1, (director)

Minh Ho, Indoor localization mechanisms for ambient computing systems, University Rennes 1, (director)

Frédéric Weis was in the following PhD examination committees:

M. Dominici, Context Management in Smart Homes, University Rennes 1, (co-director)

B. Pietropaoli, Proximate interactions and data fusion in Smart Homes, University Rennes 1, (co-director)

Minh Ho, Indoor localization mechanisms for ambient computing systems, University Rennes 1, (co-director)

Paul Couderc was in the following PhD examination committees:

PhD, Tony Ducrocq, Auto-organisation des réseaux sans-fil multi-sauts dans les villes intelligentes, University of Lille 1, (examiner)

9. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

- [1] M. DOMINICI. , *Contributing to energy efficiency through a user-centered smart home*, Université Rennes 1 and Université européenne de Bretagne, June 2013, <http://hal.inria.fr/tel-00869455>

- [2] B. PIETROPAOLI, *Reconnaissance de contexte stable pour l'habitat intelligent*, Université Rennes 1, December 2013, <http://hal.inria.fr/tel-00917776>

International Conferences with Proceedings

- [3] Y. GLOUCHE, P. COUDERC. *A Smart Waste Management with Self-Describing objects*, in "The Second International Conference on Smart Systems, Devices and Technologies (SMART'13)", Rome, Italy, W. LEISTER, H. JEUNG, P. KOSKELAINEN (editors), IARIA, June 2013, <http://hal.inria.fr/hal-00924270>
- [4] B. PIETROPAOLI, M. DOMINICI, F. WEIS. *Propagation of Belief Functions through Frames of Discernment : Application to Context Computing*, in "The 26th International FLAIRS Conference", St. Pete Beach, United States, May 2013, <http://hal.inria.fr/hal-00927088>
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