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Project-Team aces

Ambient computing and embedded systems

Rennes - Bretagne-Atlantique

Theme : Distributed Systems and Services

Activity Report

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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 [11], 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 [14], 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* [16], 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. Scientific Foundations

3.1. Introduction

The following paragraphs give a quick overview of the scientific background of the ACES research activities. Ambient computing and embedded systems are the foundations of person-centric computing. Our group is concentrating on *efficient ambient service delivery* and *programming models*; these are two essential and complementary aspects of ambient computing.

The challenge for ambient and embedded computing is to seamlessly merge information from the physical and virtual worlds, so that programs can act upon and influence the physical world around them. The purpose of a programming model is to represent information as data, and to provide a computational framework for data processing.

3.2. System Support for Continuous Ambient Service Delivery

Mobile networks are becoming increasingly heterogeneous. Global coverage is now well provided by 2G and 2.5G cellular systems, and 3G networks (UTMS) are being deployed in some densely populated areas. Nonetheless, very high data rates (WiMax, WiFi ...) will not be available everywhere in the near future, so the delivery of large amounts of information to people on the move will remain limited and expensive. In this context, the main challenge is to provide services as seamlessly as possible.

3.2.1. Pico-cell Architecture

The past few years have witnessed the rise of the cellular networks. These communication systems were designed with a philosophy of *any-time any-where* service. Users wish to receive and place calls at any location and without delay, to move while talking without interrupting their conversations. This requires ubiquitous coverage, which in turn requires significant infrastructure. A modern cellular system is installed with hundreds of base stations, at a cost of hundreds of millions of euros, in order that a communication link is always available. Such any-time any-where service provision becomes increasingly expensive and suffers from low bandwidth. Covering wide areas with high radio bandwidth requires complex equalization, due to signal attenuation, multi-path fade, and shadowing effects. Sophisticated radio engineering will lead to improved bandwidth, coverage, and mobile access, but this will be expensive, in terms of both capabilities and cost.

In this context, the ACES project has studied an alternate design for wireless networks where intermittent but very high speed is provided to the network through *Pico-cells*. The latter consists of a set of access points (APs), *i.e.* antennas around of which are defined radio cells with limited range (about 100 meters). Those antennas are discontinuously spread on the network area, thus providing a *many-time many-where* service. Actually, the idea of coverage discontinuity brings two major advantages. First, as it implies the use of a fewer number of access points, the architecture deployment will be cheaper. Second, radio cells disjunction hypothesis simplifies the radio frequency band management and avoids interference problems.

Even if this model simplifies network deployment, the connectivity intermittence induces important challenges in order to avoid service disruption. Thus, terminals have to take advantage of the high bandwidth when it is available. For delay tolerant data, a terminal stores data as it passes under a cell. Hence, it may consume the buffered data even when it passes through regions of poor network coverage. Many projects have studied very specific cases where the cells deployment is uniform and data is sent from servers to terminals (down-link). One example of this type of system is studied by WINLAB (Wireless Information Network Laboratory). In this project, cells are equally spaced and the data delivery algorithm is tested in a network with one dimensional system *i.e.* high ways.

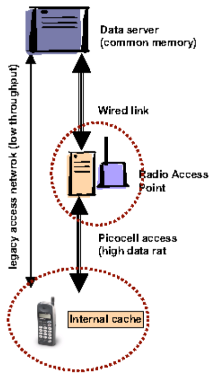

Figure 1. Pico-cell architecture model

Our approach is based on a more general case in which cells are distributed according to the envisaged traffic and data can be exchanged in both directions down-link (from servers to terminals) and up-link (from terminals to servers). The main challenge is to provide system mechanisms and efficient services addressing the specific constraints of this architecture: discontinuous coverage, user unconstrained mobility, high user density. To cope with the discontinuous coverage of the network, we store data (with caching mechanisms) close to mobile user, just before data delivery. Thus, the placement policy of data within the architecture is conditioned by knowledge of people on the move. The goal here is to define a representation of person mobility in the network architecture, and to use this model for placing data using limited and customised flooding mechanisms.

Through this architecture model, we underline the analogy between heterogeneous mobile networks and multiprocessor architectures (for example the mobile device can be considered as a processor). This approach allows us to map and extend existing caching mechanisms, taking into account the specific constraints of a discontinuous mobile network.

3.2.2. System Suppport in future 4G networks

Interactive IPTV, evolving Internet behavior, and more generally new data services (location information services for example) will strongly influence mobile usage. This requires to support high users density at low cost. During the last four years, our first goal was to increase network capacity by using discontinuous coverage combined with system mechanisms (data caching and data distribution). Memory in the network and terminals facilitate service delivery.

It is now possible to go further. The 4G infrastructure operator will mix several technologies: large umbrella cells (3G, Wimax, DVB-based infrastructure), and numerous pico cells. In 4G context, the infrastructure will be much more distributed, and mobile terminals will have to collaborate with several entities in the network to perform service delivery. In other words, mobile terminals will become an active part of a complex information system distributed between several components in the architecture.

We study system mechanisms to improve the terminal's integration in the network: ability to attach simultaneously several networks, capacity to opportunistically push data according to network conditions ...Terminal efficiency will depend on the number of technologies they can work with.

We have started to work on this problem by studying new possibilities offered by a large scale broadcast network coupled with a cellular network. We consider at first the future DVB-SH standard (satellite services to handheld devices) which is an hybrid (satellite/terrestrial) architecture. It is defined as a system for IP based media content and data delivery to handheld terminals, via satellite. Satellite transmission guarantees wide area coverage. Moreover, it is coupled with terrestrial gap fillers assuring service continuity in areas where the satellite signal cannot be received (built-up areas for example). In the context of our future works, a DVB-SH broadcast network is combined with a third generation network. Actually, this convergence will take benefit of 3G network characteristics, especially upload link, to enable added-value services and applications, which will be interactive and more personalized. For example, one could decide to deliver some classical 3G contents over DVB-SH path. This scenario occurs especially when contents or services suddenly become very popular, thus their transmission may take benefit of the large broadcasting capacities offered by a DVB network. The decision to switch a flow to the DVB-SH path could be based on the flow size and nature and on the number of subscribers. The design of dynamic flow insertion over the DVB-SH network involves multiple mechanisms and raises several open issues.

3.3. Programming Models

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.

3.3.1. Programming Context

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.

3.3.2. 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 [13] tuple-space model. Each information item is a *tuple*, which is a sequence of typed data items. For example, `<10, 'Peter', -3.14>` 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 `<int, 'Peter', float>`. 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 [12], IBM's T-Space [17]) 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 2 shows an example of a physical tuple space, made of tuples arranged in the space and occupying different spaces.

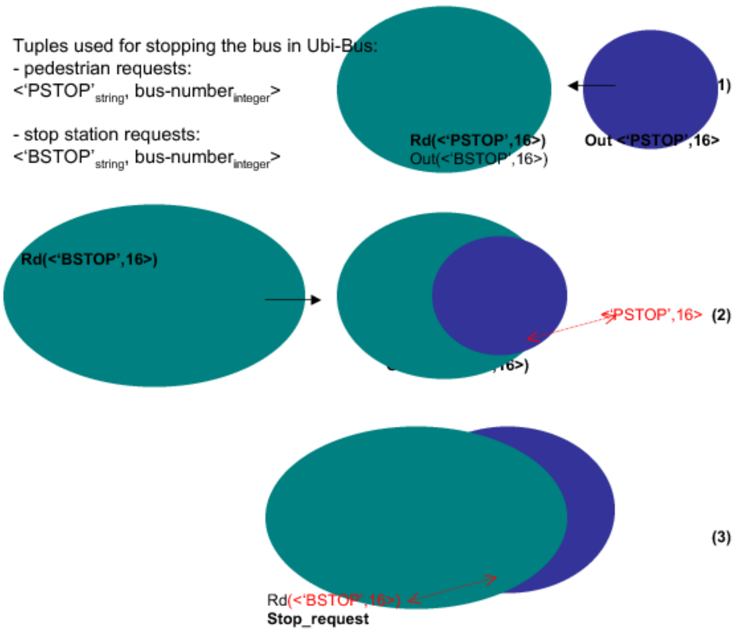

Figure 2. Physical Tuple Space

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 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.

3.3.3. 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

4.1. Introduction

The research tasks conducted in the ACES project lead to the development of many softwares. These developments are mainly realized, or at least initialized within the framework of industrial collaborations, and so they are attached to the application domains covered by the project.

4.2. SmartMuseum User Device Software

The general objective of the SMARTMUSEUM project is developing solution and IT services for user interest dependent (profiled) access to digitalized cultural information that is relevant in particular physical location. Within this project ACES developed the User Device (UD) software that is the main interaction point to the system for the mobile user. The main objective of this software was to provide the user with relevant object information, either browsing it online through connecting to a URL (specified on the RFID tag or composed from museum URL) or just reading the basic object information from the RFID tag. Our application presents object information in most relevant and suitable way for the user (text, audio, video, voice synthesis, multilingual support), considering the limitations of the UD screen and time constraints of the user. It is also able to collect statistical information based on the user actions (time spent and feedback) for updating user profile.

The initial application, developed in 2009, has been extended with a contextual and multimodal information diffusion system. We have implemented a proactive service (1) with the ability to sense the profile of nearby visitors, using RFID and WLAN connectivity, (2) that adapts the information content to the target user, and finally (3) that distributes automatically the information to several devices, collective devices like large wall panels disseminated in museum or directly to digital guide carried by visitors. More precisely, our objective was to offer the possibility to mobile device to receive automatically contextual information. A proactive service senses the environment and spontaneously adapts its behavior to the local context. The interactions between the mobile device and the SmartMuseum server can be seen as "push" type. The notion of "context" considered here refers to a description of a physical situation in the museum; a physical situation may be described by low descriptors such as raw sensor values (GPS position, RFID, etc.), but these one are usually not directly relevant for an application. Here we proposed to use RFID disseminated in the museum in combination with WLAN connectivity for designing a location service in the museum. And context-awareness requires higher level description that can be used easily by service. For example, an application shouldn't have to do only position computation if the goal is to determine what is the language spoken by nearby people. So we use existing parameters (mainly the spoken language) extracted from the existing user's profile used by the initial pull mode. Of course, monitoring the environment to identify people and using user's profile parameters raises a strong privacy concern. Our results are presented in [10], [4] and [5].

The functionalities of this software have been demonstrated during the final review of the the SmartMuseum project, in the Malta Heritage Museum.

4.3. Coupled Objects Device Software

We have designed new applications and services based on the physical coupled object paradigm. But in order to convince everybody of the novelty of this concept it is important to have concrete implementations. To reach this goal we have build a general platform, Ubi-Ware, which allows us (i) to create physical coupled objects using different RFID technology (UHF, HF), (ii) to check this integrity of these objects into physical spaces, this operation could be done using fixed antenna or mobile one installed on PDA. Figure 3 gives the software architecture of applications based on the physical coupled object notion.

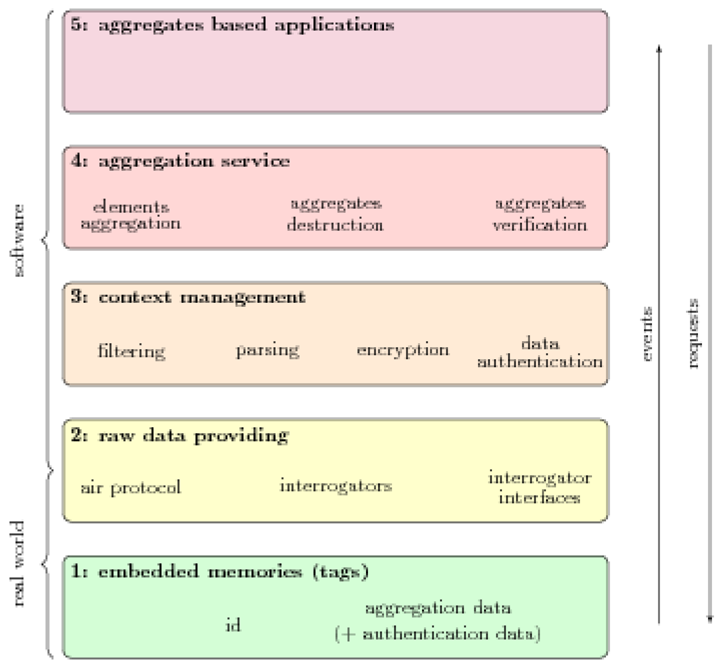

Figure 3. Global architecture layers

In the Ubi-Ware software architecture, reads of fresh data are propagated using an event-driven model, from the first to the last layer. Raw data that are physically written on the tag memory (layer 1) are read by the raw data providing layer (layer 2). Layer 3 is in charge of filtering, parsing, decrypting and authenticating those data. It builds a virtual context upon those data and notifies the upper layer (layer 4: aggregation service) of any of its changes. Every time a context notification is sent, the aggregation service (layer 4) searches for aggregates structures in the context and notifies aggregates based applications (layer 5) of any structure change. Each level can also ask for lower level operations to the previous layers. As an example, a checking algorithm from layer 4 can ask for tag data authentication to layer 3 before notifying layer 5. Initial version of this platform has been already designed and implemented. Now we are working on a final one, which could be used outside of our EPI.

5. New Results

5.1. Introduction

The ACES project is currently very active in three main research activities

- Definition of continuous services for 3G/DVB networks
- System architectures for pervasive computing

In the following we give the major research results we got from these activities.

5.2. Efficient switched services over a DVB-SH / 3G network

Participants: Azza Jedidi, Frédéric Weis [contact].

The architecture studied in the scope of this work is based on a unidirectional DVB-SH broadcast network, coupled with a third generation cellular network. DVB-SH provides users with a variety of services, which could be classified in several categories. It offers real-time applications. Examples are TV-like broadcasting, live broadcasting and notification, which consists in broadcast notifications sent according to the preferences of the user (notifying a football fan of the retransmission of his preferred team matches for instance) and games, like real-time quizzes or multiplayer online role-playing games, etc. It also provides applications to download. For large general audiences, data file purchase services are offered, either on a subscription basis, such as downloading every morning the electronic version of the user's newspaper, or on an impulsive purchase basis, like for films, books and audio CD purchase.

Besides, one of the main characteristics of the Internet world is its bidirectionality, permitting full interactivity to users. In this work, a DVB-SH broadcast network is combined with a third generation cellular network (3G network) to ensure this bidirectionality, as shown in Figure 4. Actually, this convergence takes benefit from 3G and DVB networks. 3G network characteristics, especially upload link, enable added-value services and applications that are interactive and more personalized. DVB-SH is provided with a very high bandwidth capacity that allows unidirectional IP-TV channels broadcast. We identified two scenarios of services that could be realized:

1. DVB-SH offers an important broadcast capacity. A residual bandwidth in the DVB-SH path may still be available because of the variable bit rates of served flows. Our first service scenario focuses on this small residual bandwidth and its potential utilization. The idea is to realize an efficient switching of IP popular services, coming from 3G networks, to the residual bandwidth of DVB networks. The goal is to use the architecture in order to provide interactive low cost services over DVB networks.
2. The second scenario considers classical DVB channels, including TV programs and advertisements spots. We enhanced such a TV service through the definition of personalized advertisements spots, that better fit user interests and localization. Obviously, advertisements are here given as an example of personalized service, but other types of contents could be proposed. In this scenario, the personalized content is sent over 3G, while the DVB content is still broadcasted. The terminal entity receives both contents, but plays only the personalized one. An important issue here will be the synchronization of flows to be read.

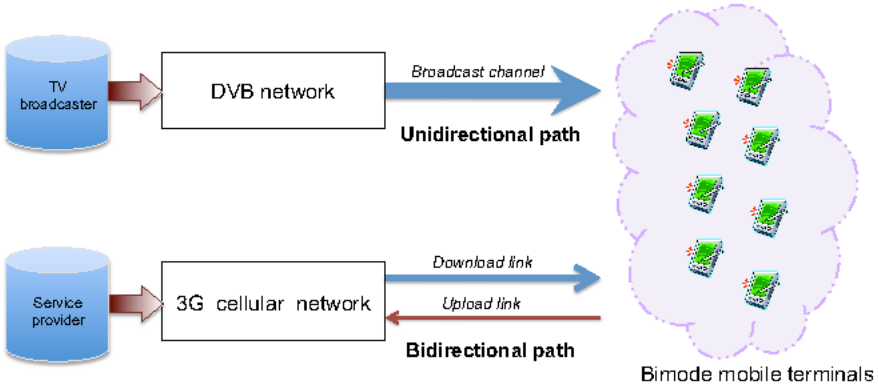

Figure 4. IP data switch

In 2010, we concentrated our efforts on the second scenario.

In this scenario, we considered a DVB TV channel proposed to users in two versions.
The Basic service. This is the "classical" DVB channel. The content is made of TV programs and advertisements which are broadcasted to all subscribers. In this service, the same advertisement spot is received by all users.
The Premium service. In this version of the service, the same TV programs are still broadcasted to users. However, during the advertisements, users receive advertisements sequences that correspond to their main interests. In this scenario, a user provides a profile that indicates his main interests when subscribing.

Then we have chosen to consider personalized advertisements. Obviously, other customized services and contents could be proposed. The personalized contents are stored in 3G content servers. DVB-SH TV channel delivers Electronic Service Guide (ESG) messages announcing its programs and services. A mobile user receives the ESG messages and decides to subscribe to the TV channel. He can choose either the Basic or the Premium service. In this scenario, the user chooses to subscribe to the Premium version of the service. As a consequence, a subscription request and a user profile are delivered to the subscription module, through 3G uplink. The user profile indicates user's main interests. In our approach, users have actually to choose from a list of possible interests. Their choice is transmitted to the subscription module, which is located in a Unicast Broadcast Router (UBR), as shown in Figure 5. This router is the central equipment of our DVB-3G converged network. We designed this equipment to manage the DVB-3G network services (subscription, flow scheduling, signalization, synchronization, etc.). The UBR corresponds to the Service Management entity in DVB IP DataCast standard. In our scenario the UBR contains the list of Premium service users and their interests. After subscription, the user starts receiving the broadcasted DVB channel. In this step, all subscribers (Basic ones and Premium ones) receive the same TV program, over the DVB path. On 3G side, there are several content servers, providing different content thematics.

Before advertisement start, DVB server sends a notification message to each of its 3G personalized content servers. We use an ESG message for this notification. This signalization message notifies of the scheduled time of the next advertisement. At advertisement time, the DVB TV program is interrupted and the DVB advertisement spot starts. Basic service mobile users receive and play this spot, in their terminal. Premium service mobile users continue receiving the DVB flow on their terminal. Actually, the reception of the DVB channel is not interrupted during the advertisement. At the same time, they receive and play a personalized advertisement through 3G unicast. The terminal receives both advertisements (the DVB one and the 3G one)

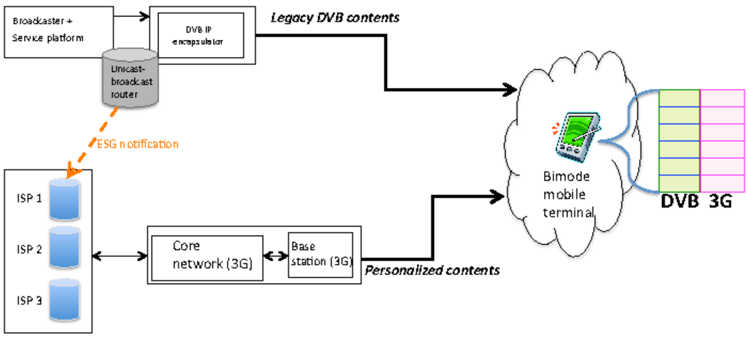

Figure 5. Coupling DVB with 3G network

but only plays the personalized 3G one. In this scenario, we assume that user terminal is bimode and manages two memory areas one for DVB flows and the other for 3G flows, as presented in figure 5. At advertisement start, the terminal player switches from the DVB memory area to the 3G one, so that it plays the personalized content. At advertisement end, the terminal returns back to playing its DVB memory area content.

In this scenario, we have adressed several challenging issues. First, at least a part of the customized 3G advertisement should be available on terminal 3G memory area and ready to be played right on time. Then, the terminal player should possess an accurate and precise synchronization information in order to operate a smooth and seamless switching. Moreover, we defined the appropriate signalization messages to ensure the communication between the different involved equipment and last but not least we had to consider the network scalability problems when the number of Premium users increases. All this points are presented in [1] and [6].

5.3. System architectures for pervasive computing

Participants: Michel Banâtre, Paul Couderc [contact], Minh Ho, Michele Dominici, Bastien Pietropaoli, Frédéric Weis.

We are interested in three aspects in pervasive computing: the first is pervasive computing system support, where we study how generic mechanisms based on physical structures and processed can be proposed. The second is the support for collaborative capture. The third is the study of coupled objects.

5.3.1. Pervasive support at core system level

Pervasive computing involves tight links between real world activities and computing process. While the perception of the real world events can be handled entirely by the application, we think that ad hoc approaches have limitations, in particular the complexity and the difficulty to re-use the code between applications. Instead, we promote the use of system level abstraction that leverage on tangible structures and processes. Important properties of this approach is that applications are, by design, operating in an implicit way (“in the background” of physical processes). They also often exhibits simpler architectures, and “natural” scalability in the sense that being build upon existing real-world process, they are strongly distributed design that relies essentially on local interactions between physical entities.

We applied this approach to "Smart Homes". A Smart Home is a residence equipped with computing and information technology 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. In a classical "logical" approach, all the intelligence of the Smart

Home is condensed in a single entity that takes care of every device in the house. The sensors distributed in the environment have to send back all the gathered data to the central entity, that takes all the burden of parsing the sensitive information and infer the policies to be implemented. Our vision is instead focused on a physical approach, where every device carries a part of the global intelligence: every single entity can analyze the part of information sensitive for its goal, derive useful data, and communicate meaningful information to the other devices (see Figure 6).

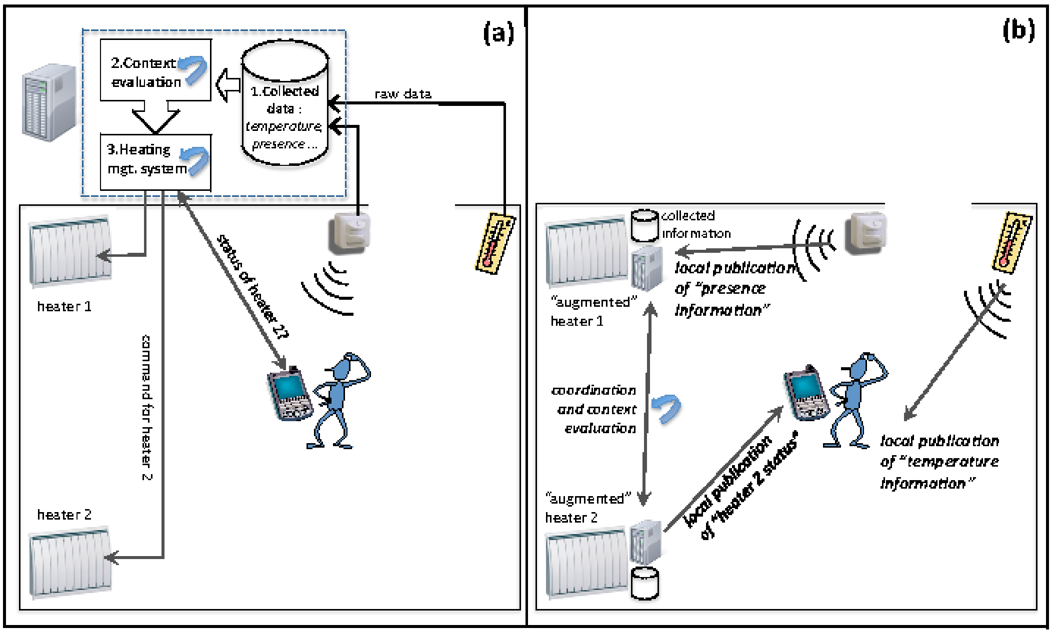

Figure 6. Logical (a) and physical (b) approach in Smart Homes

Considering a home scenario, we discover that many of the daily living appliances and objects can be augmented with computational, communication or sensing capabilities without much effort. This results in a new potential for application development and deployment, without an increase in the perceived "complexity" of the environment from the inhabitant point of view. Appliances that can be augmented with communication and computational capabilities in a typical home scenario include, among others, electric heaters, lights and white goods (ovens, refrigerators, washing machines, dishwashers, etc.). Even parts of the house like doors, floors or electrical systems can be augmented with sensing capabilities. Leveraging these smart objects, we can move the complexity of the system from a central unit to several, distributed devices. The application logic is thus performed directly by the entities of the real world. This approach has the following important characteristics and advantages:

1. There is no more need for an exhaustive collection of information coming from sensors disseminated in the whole house, but a local processing can be performed by the smart appliances. This allows using lighter and less expensive communication infrastructures. Furthermore, this results in a decentralization of the system, which allows users to interact directly with the augmented appliances, reducing the need for a central management unit.
2. The fact that information is collected locally and comes directly from the physical objects enhances its value. A new importance can be given to every communication and new criteria can be adopted to filter the events: information acquires a new, physical meaning. Therefore, the computation, the application logic and the entire system "enter" inside the physical world, becoming a part of it. The processing of sensor readings and events becomes easier, more immediate and there is no more need of complex machine learning and statistical analysis techniques.
3. The environment and inhabitants are instrumented in a lighter way but, exploiting the augmented objects, the system is still able to retrieve the needed context information. The system is therefore characterized by an easier and less costly deployment and by a higher degree of acceptance by the inhabitants.

Our first results are presented in [8].

5.3.2. Collaborative capture

The ubiquity of personal multimedia capture devices such as mobile phones brings new opportunities, such as the novel concept of *collaborative* or *distributed capture* [15]. Distributed capture consists in using a collection of personal devices dispersed throughout to capture data of an event or a reality as a distributed sensing infrastructure, and exchanging and synchronizing the resulting aggregate to increase the global quality.

An important challenge raised by this concept is to ensure coherency of the data being captured when merging fragments. For example, merging an audio stream captured by a device with a video captured by another raises temporal coherency issue [15]. Another example would be a swarm of robots collecting data using their onboard sensors, in order to make a map. This application raises spatial coherence issue as the spatial references of the data collected by an indivudal robot are dependant on sensor accuracy, such as robots odometry.

We were working on the problem of spatial coherence in the context of a collaborative photographic application, inline with the previous research done with Xavier Le Bourdon, and some preliminary results were published in 2009. However, more progress on this topic would require a Ph. D student to follow up the work done with Xavier Le Bourdon, which has not been a priority in the team.

5.3.3. Coupled Objects

The concept of *coupled objects* 3.3.3 is a simple yet powerful pervasive computing approach to check or ensure integrity properties in real-life. In can be used to check for lost objects, to avoid or reduce thieft, to provide integrity checking and accountability in logistic, to help in waste management and so on.

We developed the Ubi-Check system, which allows to ensure that a set of physical objects remains complete as it enters or leaves controlled area. A particular application of the system finds its way for airport security: objects or tools that are not authorized in boarding areas still introduced by workers operating maintenance in these areas. Ubi-Check can ensure that a set of objects that has entered the area is complete when it leaves the area. This application is currently experimented at the Geneva airport. We are investigating the use of similar principles in the context of waste management and recycling where it is important to ensure the conformance of the returned products. A new research project, "BinThatThink", has been launched on this topic.

We also developed and experimented several advanced prototype applications for the logistic domain. With the development of E-commerce, a difficult issue is rising: ensuring that a package that is delivered to its destination match the recipient expectation, and ensuring accountability in case of a problem. Currently, when a package is not complete once shipped, it is difficult to determine whether the fault was from the sender, the recipient, or at some level during the shipping. Coupled objects offers an elegant solution to this problem, mostly transparent to the information systems of the different parties involved in the process which is a major point: as the system relies on data structure self contained into the physical objects being transported, the integrity properties can be checked in an autonomous way. This system, Ubi Post, is currently the object of discussion with potential industrial users. Finally we have also experimented this idea to support bike park access control. Briefly speaking the "key" use to enter in or to go out is the physical object made of the bike and its owner. Such a system have been built and demonstrated in a partnership with SenseYou INRIA spinoff.

Physical coupled object implementation is based on the used of RFID tags which are attached to each component of the resulting object. Even if integrity checking systems based on RFID tags could face various security issues, it appears that RFID tags are highly exposed to various attacks, which could compromise the service. To bring solutions which take into account these attacks, we have investigated new researches in order to see how our security applications based on physical coupled objects can be strengthened in order to resist those attacks. The identified attacks require some specific hardware and knowledge in RFID. But, since RFID will be more and more used, anyone may have a tag interrogator in its mobile phone in a few years. Generally speaking, an attacker could, (i) alter data in a genuine aggregated tag that would lead to a non genuine data error, (ii) write data in a new tag "from scratch" (without cloning), (iii) clone a tag. It would lead to a non genuine tag error, (iv) link a user with tag identifiers by reading tag IDs and visually observing, this could help to track a user and cause a user localisation error. We have investigated solutions which combine different techniques such as, specifics tags (Allien Higs3), cryptographic software technique, permanent monitoring in order to detect RF destruction, and finally physical user authentication based on biometrical data. These solutions are detailed in our research report "Physical aggregated objects and dependability" we have just published.

6. Contracts and Grants with Industry

6.1. National contracts

6.1.1. Définition d'un service de gestion de l'énergie dans le cadre de l'habitat résidentiel en s'appuyant sur les principes de l'informatique diffuse

- Partner : EDF - DER
- Starting: 01/06/2010, ending : 01/06/2013

The objective of this new 3 year project is to study the use of ambient computing principles for the management of electricity consumption in residential habitat. The objective is (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. The first results are presented in section 5.3.1.

6.1.2. Système d'Information Voyageur Embarqué : SIVE

- Partner : Kerlink, Innes, Loustic
- Starting: 01/12/2008, ending : 01/05/2010

The SIVE project aims to create an embedded information system for public transportation users. The project mainly focuses on inner-city and inter-city transportations such as bus or subway. Information received by the users are multimedia, context dependent and customized. Considered means of diffusion are various such as screens in a bus or users' cellphones.

6.1.3. 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: November 2013

Bin That Think is a research project funded by the ANR Ecotech program, which aims 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 introduces 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. Bin That Think will use RFID and embedded sensors to enable waste containers as an intelligent waste infrastructure and a network of smart sensors.

6.2. European Initiatives

- Title: Smartmuseum
- Partners: Competence Centre of Electronics-, Info- and Communication Technologies, ELIKO (Estonia), Helsinki University of Technology TKK (Finland) Kungliga Tekniska Högskolan KTH (Sweden), Webgate JSC, (Bulgaria), Heritage Malta, (Malta), Institute and Museum of the History of Science, (Italy), Apprise, (Estonia).
- Starting: end of 2007; ending: April 2010

The general objective of the SMARTMUSEUM project is developing solution and IT services for user interest dependent (profiled) access to digitalized cultural information that is relevant in particular physical location. The activities of the project are addressing personalised approach to cultural exploration, including cultural tourism. The future smart museum IT infrastructure and services, which are capable of increasing bidirectional interaction between multilingual European citizens and cultural heritage objects taking full benefit of the multi source digitalized cultural information. By doing this, priorities are set on: Improving structured and user competence dependent access to the vast repository of cultural heritage, Improving the meaning and individual experience people receive from cultural and scientific resources, Bringing personalized cultural experience closer to non-expert community, Making real reuse of experiences related with cultural heritage access for variety of interest groups.

7. Dissemination

7.1. Animation of the scientific community

7.1.1. Program committees

- PC member of the 3rd IEEE Conference on Smart Spaces (ruSMART 2010), M. Banâtre.
- PC member of 2010 International Conference on Ambient Systems, Networks and Technologies (ANT-2010), M. Banâtre.
- PC member of 2011 International Conference on Ambient Systems, Networks and Technologies (ANT-2011), M. Banâtre.
- PC member of SEUS 2010, The 8th IFIP Workshop on Software Technologies for Future Embedded and Ubiquitous Systems October 2010, Austria, P. Couderc.
- PC membre of the 14th International Symposium on Wireless Personal Multimedia Communications (WPMC'11), F. Weis

7.1.2. Organizing and reviewing activities

Michel Banâtre is member of the "Comité d'Evaluation des programmes" ANR and member of the expert scientific committee for ECOTECH (Production Durable et Technologies de l'Environnement).

7.2. Teaching activities

- IFSIC, Responsibility of the lecture on Ambient Computing and Distributed Operating Systems in "DIIC 3 ARC" (final year of masters) (M. Banâtre, P. Couderc and F. Weis).
- IFSIC, 6 hours of lectures on Ambient Computing and Mobile Communications in final year of masters (M. Banâtre and F. Weis).
- Ecole des Mines de Nantes, Responsability of the lecture on distributed systems (final year of masters) computer science department (M. Banâtre).
- ENST Bretagne, Lecture on Wireless LANs (final years of masters) (F. Weis).
- ENSEIRB (Bordeaux), Conference on Mobile communications and ambient computing, final year of masters, (M. Banâtre).
- École Centrale de Paris (ECP), Conference on Mobile communications and ambient computing, final year of masters, (M. Banâtre).
- École Centrale de Paris (ECP), 6 hours of lectures on Mobile communications and ambient computing, final year of masters, (M. Banâtre and F. Weis).

7.3. Internship supervision

We have supervised the following internships in 2010:

- Jean-Francois Verdonck (3rd year Mines de Nantes). Subject: Intelligence ambiante pour un local à vélo sécurisé.
- Fabrice Ben Hamouda (1st year ENS ULM). Subject: Physical aggregated objects and dependability.

7.4. Seminar

- Solutions à la sécurité fondées sur l'informatique ambiante. Application à la gestion de garages à vélos". Journées sur l'analyse et les perspectives de l'Internet des Objets, organisées par le CITC-EuraRFID Lille, 25-26 Octobre 2010 (Michel Banâtre).

7.5. Industrial transfers

In accordance with the goals of the Institute, the ACES group spent a great deal of time and effort on seeking to transfer its research results on ambient computing and security to potential users. Our motivation stems from our observation that producing innovative research results, even those protected by patents, is no longer sufficient for a modern research team. It is essential to convince industry that solutions are robust, scalable and most importantly, address a problem that real users are faced with.

This research approach necessitates the development of several prototypes that are tested in real environments. It also necessitates a continuous technology watch to ensure the validity of submitted patents, as well as verification of existing patents and research reports. Although this activity is, traditionally, unusual for a research team, it becomes inevitable if results are to have a real impact in the ambient computing applications currently being deployed.

Our technology transfer efforts have been successful as a part of ACES group created a start-up company called SenseYou in July 2008. Its current business is based on the exploitation of INRIA patents and software dedicated to "physical object coupled principle" and their application in security area. This identification of industrial partners able to exploit the potential industrial transfer behind their new ideas about "physical coupled objects" is done in a closed cooperation with ACES group members. A first deployment has been done last June with Geneva Airport. Due to our current discussions with potential partners, we think that there is a strong probability of successful transfer beginning of next year (airport security control, bike-park access control).

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