Activity Report 2023

Team EASE

Enabling Affordable Smarter Environment

D2 – Networks, Telecommunication and Services

1 Team composition

Researchers and faculty

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2 Overall objectives

2.1 Overview

The technologies necessary for the development of pervasive applications are now widely available and accessible for many uses: short/long-range and low energy communications, a broad variety of visible (smart objects) or invisible (sensors and actuators) objects, as well as the democratization of the Internet of Things (IoT). Large areas of our living spaces are now instrumented. The concept of Smart Spaces is about to emerge, based upon both massive and apposite interactions between individuals and their everyday working and living environments: residential housing, public buildings, transportation, etc. The possibilities of new applications are boundless. Many scenarios have been studied in laboratories for many years and, today, a real ability to adapt the environment to the behaviors and needs of users can be demonstrated. However mainstream pervasive applications are barely existent, at the notable exception of the ubiquitous GPS-based navigators. The opportunity of using vast amounts of data collected from the physical environments for several application domains is still largely untapped. The applications that interact with users and act according to their environment with a large autonomy are still very specialized.

They can only be used in the environment they had especially been developed for (for example "classical" home automation tasks: comfort, entertainment, surveillance). They are difficult to adapt to increasingly complex situations, even though the environments in which they evolve are more open, or change over time (new sensors added, failures, mobility etc.).

Developing applications and services that are ready to deploy and evolve in different environments should involve a significant cost reduction. Unfortunately, designing, testing and ensuring the maintenance as well as the evolution of a pervasive application remain very complex. In our view, the lack of resources by which properties of the real environment are made available to application developers is a major concern. Building a pervasive application involves implementing one or more logical control loops which include four stages (see figure 1-a): (1) data collection in the real environment, (2) the (re)construction of information that is meaningful for the application and (3) for decision making, and finally, (4) action within the environment. While many decision-algorithms have been proposed, the collection and construction of a reliable and relevant perception of the environment and, in return, action mechanisms within the environment still pose major challenges that the EASE project is prepared to deal with.

Most current solutions are based on a massive collection of raw data from the environment, stored on remote servers. Figure 1-a illustrates this type of approach. Exposure of raw sensor values to the decision-making process does not allow to build relevant contexts that a pervasive application actually needs in order to shrewdly act/react to changes in the environment. So, the following is left up to the developer:

- To characterize more finely raw data beyond its simple value, for example, the acquisition date,the nature of network links crossed to access the sensor, the durability and accuracy of value reading, etc.
- To exploit this raw data to calculate a relevant abstraction for the application,

such as, whether the room is occupied, or whether two objects are in the same physical vicinity.

- To modify the environment when possible.

Traditional software architectures isolate the developer from the real environment that he has to depict according to complex, heavy and expensive processes. However, objects and infrastructure integrated into user environments could provide a more suitable support to pervasive applications: description of the actual system's state can be richer, more accurate, and, simultaneously, easier to handle; the applications' structure can be distributed by being built directly into the environment, facilitating scalability and resilience by the processing autonomy; finally, moving processing closer to the edge of the network avoids major problems of data sovereignty and privacy encountered in infrastructures very dependent on the cloud. We strongly believe in the advantages of specific approaches to the fields of edge computing and fog computing, which will reveal themselves with the development of Smart Spaces and an expansive growth of the number of connected objects. Indeed, ensuring the availability and reliability of systems that remain frugal in terms of resources will become in the end a major challenge to be faced in order to allow proximity between processing and end-users. Figure 1-b displays the principle of "using data at the best place for processing". Fine decisions can be made closer to the objects producing and acting on the data, local data characterization and local processing de-emphasize the computing and storage resources of the cloud (which can be used for example to store selected/transformed data for global historical analysis or optimization). EASE aims at developing a comprehensive set of new interaction models and system architectures to considerably help pervasive application designers in the development phase with the side effect to ease the life cycle management. We follow two main principles:

- Leveraging local properties and direct interactions between objects, we would be able to enrich and to locally manage data produced in the environment. The application would then be able to build their knowledge about their environment (perception) in order to adjust their behavior (e.g. level of automation) to the actual situation.

- Pervasive applications should be able to describe requirements they have on the quality of their environmental perception. We would be able to achieve the minimum quality level adapting the diversity of the sources (data fusion/aggregation), the network mechanisms used to collect the data (network/link level) and the production of the raw data (sensors).

2.2 Scientific foundations

2.2.1 Collecting pertinent information

In our model, applications adapt their behavior (for instance, the level of automation) to the quality of their perception of the environment. This is important to alleviate the development constraint we usually have on automated systems. We "just" have

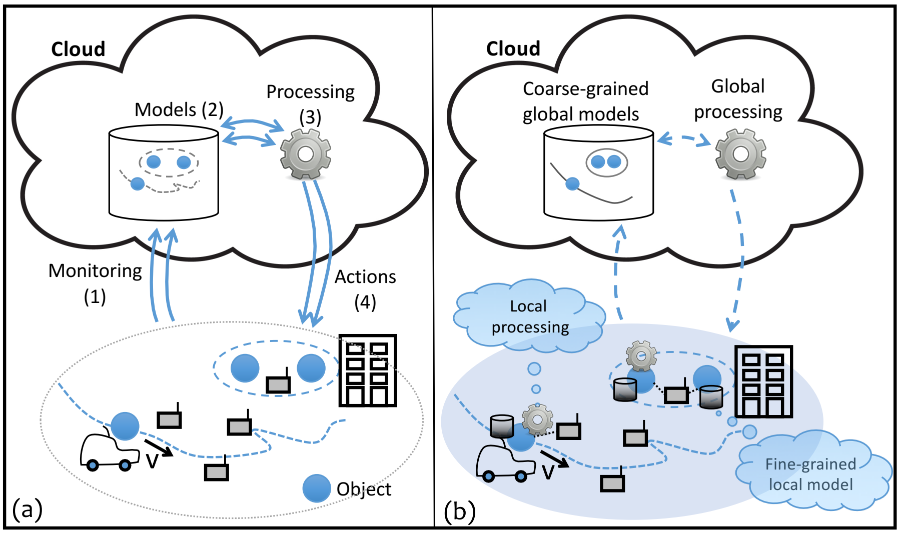

Figure 1: Adaptation processes in pervasive environment

to be sure a given process will always operate at the right automation level given the precision, the completeness or the confidence it has on its own perception. For instance, a car passing through a crossing would choose its speed depending on the confidence it has gained during perception data gathering. When it has not enough information or when it could not trust it, it should reduce the automation level, therefore the speed, to only rely on its own sensors. Such an adaptation capability shift the requirements from the design and deployment (availability, robustness, accuracy, etc.) to the **assessment of the environment perception** which we aim to facilitate in this first research axis.

Data characterization. The quality (freshness, accuracy, confidence, reliability, confidentiality, etc.) of the data are of crucial importance to assess the quality of the perception and therefore to ensure proper behavior. The way data is produced, consolidated, and aggregated while flowing to the consumer has an impact on its quality. Moreover, part of these quality attributes requires to gather information at several communication layers from various entities. For this purpose, we want to design **lightweight cross-layer interactions** to collect relevant data. As a "frugality" principle should guide our approach, it is not appropriate to build all the attributes we can imagine. It is therefore necessary to identify attributes relevant to the application and to have mechanisms to activate/deactivate at run-time the process to collect them.

Data fusion. Raw data should be directly used only to determine low-level abstraction. Further help in abstracting from low-level details can be provided by **data fusion** mechanisms. A good (re)construction of meaningful information for the application reduces the complexity of the pervasive applications and helps the developers to concentrate on the application logic rather than on the management of raw data. Moreover, the reactivity required in pervasive systems and the aggregation of large amounts of data (and its processing) are antagonists. We study **software services that can be deployed closer to the edge of the network**. The exploration of data fusion techniques will be guided by different criteria: relevance of abstractions produced for pervasive applications, anonymization of exploited raw data, processing time, etc.

Assessing the correctness of the behavior. To ease the design of new applications and to align the development of new products with the ever faster standard developments, continuous integration could be used in parallel with continuous conformance and interoperability testing. We already participate in the design of new shared platforms that aim at facilitating this by providing remote testing tools. Unfortunately, it is not possible to be sure that all potential peers in the surrounding have a conforming behavior. Moreover, upon failure or security breach, a piece of equipment could stop operating properly and lead to global mis-behavior. We want to propose conceptual tools for **testing devices at runtime in the environment**. The result of such conformance or interoperability tests could be stored safely in the environment by an authoritative testing entity. Then the application could interact with the device with higher confidence. The confidence level of a device could be part of the quality attribute of the information it contributed to generate. The same set of tools could be used to identify misbehaving device for maintenance purposes or to trigger further testing.

2.2.2 Building relevant abstraction for new interactions

The pervasive applications are often designed in an ad hoc manner depending on the targeted application area. Ressources (sensors / actuators, connected objets, etc.) are often used in silos which complexifies the implementation of rich pervasive computing scenarios. In the second research axis, we want to get away from technical aspects to identify **common and reusable system mechanisms** that could be used in various applications.

Tagging the environment. Information relative to the environment could be stored by the application itself, but it could be complex to manage for mobile applications since it could cross a large number of places with various features. Moreover the developer has to build his own representation of information especially when he wants to share information with other instances of the same application or with other applications. A promising approach is to store and to maintain this information associated to an object or to a place, in the environment itself. The infrastructure should provide services to application developers: add/retrieve information in the environment, share information and control who can access it, add computed properties to object for further usage. We want to study an **extensible model to describe and augment the environment**. Beyond a simple distributed storage, we have in mind a new kind of interaction between pervasive applications and the changing environment and between applications themselves.

Taking advantages of the spatial relationships. To understand the world they have to interact with, pervasive applications often have to (re)build a model of it from the exchange they have with others or from their own observations. A part of the programmer's task consists in building a model of the spatial layout of the objects in the surrounding. The term layout can be understood in several ways: the co-location of multiple objects in the same vicinity, the physical arrangement of two objects relative to each other, or even the crossing of an object of a physical area to another, etc. Remotely determining these spatial properties (see figure 1-a) is difficult without exchanging a lot of information. Properties related to the spatial layout are far easier to characterize locally. They could be abstracted from the interaction pattern without any complex virtual representation of the environment (see figure 1-b). We want to be able to rely on this type of spatial layout in a pervasive environment. In the prior years, the members of EASE already worked on **models for processing object interactions** in the physical world to automatically trigger processing. This was the case in particular of the spatial programming principle: physical space is treated as a tuple-space in which objects are automatically synchronized according to their spatial arrangement. We want to follow this approach by considering **richer and more expressive programming models**.

2.2.3 Acting on the environment

The conceptual tools we aim to study must be frugal: they use as few resources as possible, while having the possibility to use much more when it is required. Data needed by an application is not made available for "free"; for example, it costs energy to measure a characteristic of the environment, or to transmit it. So this "design frugality" requires **a fine-grained control** on how data is actually collected from the environment. The third research axis aims at designing solutions that give this control to application developers by acting on the environment.

Acting on the data collection. We want to be able to identify what information are really needed during the perception elaboration process. If a piece of data is missing to build a given information with the appropriate quality level, the data collection mechanism should find relevant information in the environment or modify the way it aggregates it. These could lead to a modification of the behavior of the network layer and the path the piece of data uses in the aggregation process.

Acting on object interactions. Objects in the environment could adapt their behavior in a way that strongly depends on the object itself and that is difficult to generalize. Beyond the specific behaviors of actuators triggered through specialized or standard interfaces, the production of information required by an application could necessitate an adaptation at the object level (eg. calibration, sampling). The environment should then be able to initiate such an adaption transparently to the application, which may not know all objects it passes by.

Adapting object behaviors. The radio communication layers become more flexible and able to adapt the way they use energy to what is really required for a given transmission. We already study how beamforming techniques could be used to adapt the multicast strategy for video services. We want to show how playing with these new parameters of transmissions (e.g. beamforming, power, ...) allows to control spatial relationships objects could have. There is a tradeoff to find between the capacity of the medium, the electromagnetic pollution and the reactivity of the environment. We plan to extend our previous work on interface selection and more generally on what we call **opportunistic networking**.

2.3 Application domains

2.3.1 Automation in Smart Cities

The domain of Smart Cities is still young but it is already a huge market which attracts number of companies and researchers. It is also multi-fold as the words "smart city" gather multiple meanings. Among them one of the main responsibilities of a city, is to organize the transportation of goods and people. In intelligent transportation systems (ITS), ICT technologies have been involved to improve planification and more generally efficiency of journeys within the city. We are interested in the next step where efficiency would be improved locally relying on local interactions between vehicles, infrastructure and people (smartphones).

For the future autonomous vehicle are now in the spotlight, since a lot of works has been done in recent years in automotive industry as well as in academic research centers. Such unmanned vehicles could strongly impact the organisation of the transportation in our cities. However, due to the lack of a definition of what is an "autonomous" vehicle, it is still difficult to see how these vehicles will interact with their environment (eg. road, smart city, houses, grid, etc.). From augmented perception to fully cooperative automated vehicle, the autonomy covers various realities in terms of interaction the vehicle relies on. The extended perception relies on communication between the vehicle and surrounding roadside equipments. That helps the driving system to build and maintain an accurate view of the environment. But at this first stage the vehicle only uses its own perception to make its decisions. At a second stage, it will take advantages of local interaction with other vehicles through car-to-car communications to elaborate a better view of its environment. Such "cooperative autonomy" does not try to reproduce the human behavior anymore, it strongly relies on communication between vehicles and/or with the infrastructure to make decision and to acquire information on the environment. Part of the decision could be centralized (almost everything for an automatic metro) or coordinated by a roadside component. The decision making could even be fully distributed but this puts high constraints on the communications. Automated vehicles are just an example of smart city automated processes that will have to share information within the surrounding to make their decisions.

2.3.2 Pervasive applications in uncontrolled environnements

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

RFID technology is to avoid missing tags when reading multiple objects, as reading reliability is affected by various effects such as 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 principles is to enhance existing processes "in situ", unlike the controlled conditions that can be found in industrial processes. Consider for example a logistic application, where RFID tags could be used on items inside a package in order to check for its integrity along the shipping process. Tags would likely be placed randomly on items inside the package, and reading conditions would be variable depending on where the package is checked.

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

- Objects materials (to 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**.

2.3.3 Data collection for precision agriculture

The use of sensor networks can be useful to support environmentally friendly production in the agricultural sector: monitoring of plant cover, plant disease detection, fine-grained plant treatments. Nevertheless, the digital tools used for this type of deployment were not designed to be broadly usable by non-specialists and have not yet established themselves among the agricultural community.

In addition, in agriculture as in many fields, the use of digital technology has mostly been carried out under the paradigm of massive data collection: logging as much information as possible, storing the data and then implementing statistical and IT methods to extract meaningful information. This approach raises problems of energy storage and consumption, increasing the environmental footprint of digital technology and limiting deployments of operational and sustainable systems.

Very small connected objects are now able to execute software codes, to drive many sensors, to send data pair with other devices in their neighborhood and to pre-process data for cleaning/aggregation. Our ambition is to optimize the crop monitoring system from a data and energy perspectives, using generic software mechanisms as close as possible to the sensor node and introducing "intelligence" into the data collection mechanisms.

Our approach is based on the quality of the data produced by the sensor nodes distributed in the environment. Data quality can be broken down into different dimensions: precision, confidence, durability, etc. Characterizing data quality requires the developer of an application to analyze and possibly control how this data is produced and collected. Usually, this task is performed on an ad hoc basis, with a strong dependence on the objectives of the data collection and not very reproducible as the environment in which the sensors are deployed evolves. The challenge is to offer mechanisms that will adapt, without additional software developments, to the many field experiments carried out for precision agriculture.

3 Scientific achievements

3.1 Cooperative ITS & automated vehicles

Participants: Jean-Marie Bonnin, Maxime Cancouet, Élodie Duroy, Juliette Grosset.

3.1.1 Increasing the autonomy of AIVs integrated into a fleet using collective intelligence strategies

The context of Factory 4.0 is increasingly leading to decentralized solutions, as centralization is showing its limits. One of the areas of research in Industry 4.0 is the use of autonomous guided vehicles (AGVs) and autonomous industrial vehicles (AIVs). We want to show that cooperation is useful and necessary to increase their autonomy. Simulation allows us to take into account the constraints and requirements formulated by manufacturers and future users of AGVs. Simulation provides a good framework for studying solutions to these various challenges. For example, we proposed extending a collision detection algorithm to deal with the problem of obstacle avoidance [8]. The conclusive simulation has enabled us to begin experimentation in emulation and in real conditions. In addition, in the article [7] we proposed an agent model for testing scenarios in Industry 4.0 environments with a fleet of AIVs. We simulated our proposal progressively towards a resolution of global obstacle avoidance by AIVs with a collective strategy. The initial results showed the value of collaboration in increasing the collective and individual efficiency of the vehicles in a fleet. This opens the door to more advanced global collective strategies with the possibility of allocating, scheduling and distributing tasks between them in real time following the perception of an obstacle. Finally, in the article [5], we also present a method for estimating the positions of VIAs moving in a closed industrial environment, the extension of a collision detection algorithm to deal with the issue of obstacle avoidance [8], and the development of an agent-based simulation platform to simulate these two methods and algorithms.

We then proposed a dynamic task allocation strategy in Vehicle-To-Everything (V2X) cooperation mode with the infrastructure in particular [4]. All communications between AIVs and the infrastructure are based on ITS technologies. The CAM, DENM and CPM messages have been transposed for use in an industrial context [6]. A poster was prepared for the "Colloque IMT" and is a summary of the results: from a global point of view, from simulation to real experiments. The efficient management of AIVs requires a global approach that considers several factors, including operational availability, energy consumption, collaboration between VIAs and the infrastructure, and their adaptation to changing conditions. Our current research focuses on the challenges associated with energy management for VIAs. Preliminary work was presented as a poster at the "Journées Françaises de Logique Flou", presenting our various simulations of the deployment of fleets of autonomous industrial vehicles based on fuzzy agents. We are interested in the use of fuzzy agents to manage the levels of imprecision and uncertainty involved in modelling the behaviour of simulated vehicles.

3.1.2 Cooperative Perception Infrastructure

In the context of the Maxime Cancouet's PhD, a first phase of bibliography resulted in two state-of-the-art reports on the detection of abnormal behaviors of a cooperative perception infrastructure; and on trust management within cooperative perception infrastructures. Also, during the state-of-the-art research phase, an idea was identified within the standardized ETSI ITS Collective Perception Message (CPM) and led to a patent application of which he is the principal author. This bibliography phase was also useful for defining the tools of the SELFY project, for which he has partial responsibility, shared with the project manager. Brainstorming on the tools and methods to be implemented for SELFY also led to another patent application of which he is a co-author. Following an initial phase of development of SELFY tools, a first publication strategy was devised, also defining part of his future developments within the SELFY project. Also, still within the framework of the SELFY project, a dataset (intended to be published as open data before the end of the project) containing video images and LiDAR point clouds of a real scene as well as the precise positions of objects in the scene was generated, allowing the experimentation of a first method for evaluating a cooperative perception infrastructure. This work led to a conference article which was submitted in April. More recently, he has also been involved in contributions from the SELFY project to the ETSI CPM standard, notably as the principal author of a contribution (ETSI reference: ITSWG1(24)000135) to be presented in May 2024.

Results:

- 2 patent applications (content information is not public yet):
  - As the main author (application number: GB2313683.1) the 07/09/2023
  - As a co-author (application number: GB2314983.4) the 29/09/2023
- An ETSI ITS contribution (ITSWG1(24)000135) on CPM implementation of Canon CRF with YoGoKo: "CPM implementation in SELFY project (CRF-YGK)" to be presented in May 2024
- A poster for an internal event at IMT Atlantique: "PhD: Monitoring of a cooperative perception infrastructure" presented the 15/11/2023

3.2 Risk evaluation for Smart Agriculture

Participants: Jean-Marie Bonnin, Hassan Hammoud, Frédéric Weis.

3.2.1 Monitoring of in-field risk of infection events using smart IoT nodes

The use of IoT has mostly been carried out under the paradigm of massive data collection, where IoT devices (IoT nodes) collect data from the environment through sensors and transmit it to servers for further analysis and storage. However, this approach is costly, often unnecessary in terms of time and space, and challenging to modify and deploy.

To address these issues, IoT sensor nodes should go beyond their traditional role (reading from sensors and transmitting to server), to perform local data analysis and manipulation. Traditional node architecture has been evolving over the past few years towards more powerful microcontrollers (MCUs) that provide enhanced trade-offs solutions between processing capacity and energy consumption. This hardware evolution has been concomitant with a software evolution. In addition to a network stack, they are now capable of running fully-fledged operating systems, and offer software primitives and application programming interfaces (APIs).

It is possible to limit the local analysis to a few nodes, and then extending observations to neighboring nodes only when necessary to adapt the data collection strategies dynamically. Optimizing the exploitation of local processing capabilities should not compromise the operational lifespan of the deployed monitoring system. Furthermore, within the specific domain of agro-ecology, the sensors employed may exhibit high energy consumption.

We set out to test the use of programmable sensor nodes in a setting approaching areal case, through an experimental approach.

- We select an infectious model well recognized within the community of phytopathologists.
- We designed a generic architecture, relying on an MCU capable of running a full-fledged operating system and able to drive different types of sensors.
- We implemented this model on the MCU and propose a scenario in which the model is executed across nodes organized within a mesh network.
- We conducted experiments with this scenario, evaluating two key points: the nodes' ability to reliably obtain the expected observations and the impact of this scenario on the energy consumption of the nodes.

3.3 Mediation Infrastructure for Ephemeral Interactions in Smart Environments

Participants: Jean-Marie Bonnin, Paul Couderc, Marriam Issa.

Interactions take several forms from continuous to intermittent and short-lived data exchange. The arrival of a node to a location would raise the event of requesting or providing a service. This service could be a piece of information or a safety warning. The data to be exchanged will no longer be relevant when the nodes are no longer in proximity. Thus, this defines a local and ephemeral interaction scheme.

Traditional networking approaches address this by first establishing a connection and then forming routes among the nodes. However, this does not reflect to the application the physical context of the nodes, and incurs a burden of adding unnecessary traffic and processing while exchanging configuration messages. Thus there is a need for communication paradigms that are tailored to the particular case of ephemeral interactions.

One can find in the literature previous works implementing ephemeral communication, relying on abundant and easy to implement technologies, such as WiFi and BLE. In particular, within these two technologies, data is embedded in discovery packets. These packets are exchanged before any connection is established and regardless of the state of connection of nodes.

During discovery, nodes broadcast advertisement packets and other nodes scan for these packets. WiFi Beacon Stuffing and BLE connectionless mode are two popular techniques to realize communication without association.

This work tackles the following points:

- Establish an in-depth analysis of WiFi Beacon Stuffing and of BLE connectionless mode, being two popular and abundant enablers for communication without association, or association-less communication. This has been done in the first year and resulted in a survey journal article in 2024.
- Conduct an experimental comparison between WiFi Beacon Stuffing and BLE connectionless mode, over the same environment, in particular on ESP32 hardware.
- Develop a communication protocol, that deals with data storage and exchange at the application level, while relying on association-less communication.
- Build on top of the proposed communication protocol to generalize its accommodation to several usecases, and technologies.

4 Software development

4.1 Pervasive RFID

Participants: Paul Couderc.

The RFID experiment testbed has been designed and deployed in collaboration with IETR (see Figure 2). This system allows both interactive testing as well as long running experiments of RFID reading protocols. It comprises a software platform allowing fine control over all the dynamic aspects influencing RFID readings: movements for target and antenna, RFID reader configuration, and smart antenna configuration (diversity and power control).

It will be used and developped in the context of IsiCol project.

4.2 AgriSense

Participants: Hassan Hammoud, Frédéric Weis.

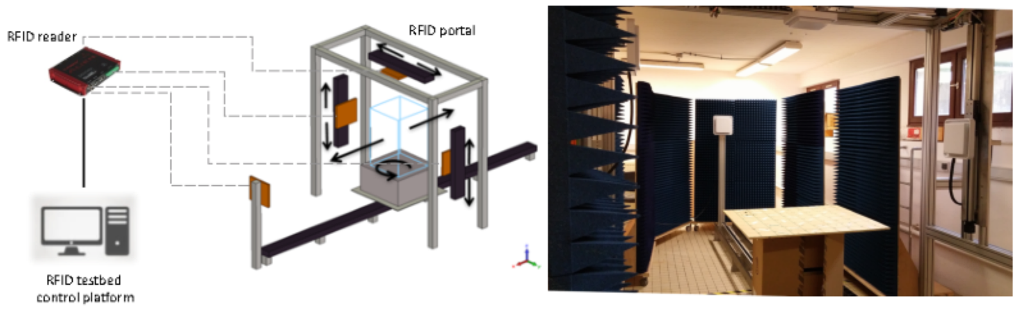

Figure 2: RFID Platform

This platform is developed in the framework of a collaboration between EASE and the Demecology (Dynamics-Evolution-Modeling-Ecology) team of INRAe, which carries out work in plant epidemiology. The general objective is to develop precision monitoring solutions for their experimental vegetal plots.

The use of these very small objects (microcontrollers - MCU) for crop monitoring is promising. But it poses different problems, which we studied using this platform. Our hardware architecture is based on a very generic "on-the-shelf" MCU. The latter offers a fairly limited number of I/O interfaces: GPIO port, UART, etc. However, the environmental sensors used for crop monitoring have very variable features: digital or analog, using specialized communication protocols (e.g. SDI12), and can be particularly energy intensive (e.g. dielectric sensors measuring wetness). To address this issue, we designed an hardware architecture ensuring a stable link between the MCU and different types of sensors. This architecture is based on the design of a low-cost PCB, allowing to efficiently operate any type of sensors. This architecture is open (we are talking about an "open PCB"), very low cost, and can be easily adapted to different MCU architectures.

Our hardware and sofware architectures has been validated in a real field with different sensors. The experimentation lasted several weeks (see Figure 3).

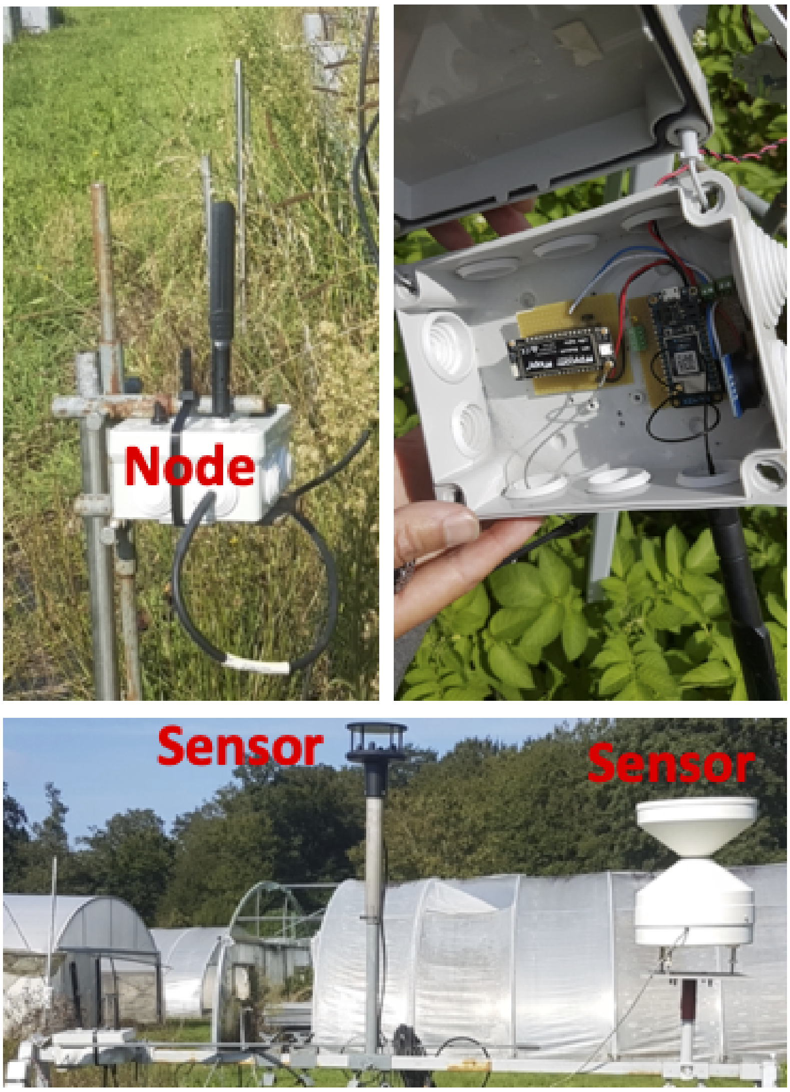

Figure 3: AgriSense Platform in an experimental field of INRAe

5 Contracts and collaborations

5.1 International Initiatives

5.1.1 European InDiD project

Participants: Cesar Vargas, Jean-Marie Bonnin.

- Project type: European CEF (Connection Europe Facility) funding with only French partners
- Dates: 2019–2023 (extended until June 2024)
- PI institution: IMT / IMT Atlantique
- Other partners: 20+ French partners including cities (Paris, Grenoble...), road operators, transport operators, academics (incl. IMT Atlantique) and industrials

InDiD is one of 13 French projects out of 148 European projects selected by the European Commission within the framework of the last Connecting Europe Facility (CEF) call for proposals. The project benefits from a co-funding rate of 50% on behalf of the European Union. It follows the Smart Cooperative Transport Systems projects SCOOP@F, C-ROADS France and InterCor. The project aims at expanding the coverage of use cases deployed in previous projects (emergency braking, accident, work...) and develop new use cases dealing with urban area, but also use cases of increased perception for autonomous vehicle. In addition, it deals with high definition digital mapping of the infrastructure. Connectivity along with mapping shape the digital infrastructure of tomorrow, an essential addition to the physical infrastructure. InDiD aims at continuing the deployment of Cooperatives Intelligent Transport Systems on new road experimentation sites in order to expand the services coverage offered by the infrastructure. Pilot sites are located on 4 main French geographic areas, on the Mediterranean side, in the south-west area, at the centre and in the north of France.

5.1.2 European X2Rail project

Participants: Jean-Marie Bonnin.

- Project type: H2020 super program
- Dates: 2019–2023
- PI institution: IMT Atlantique as a subcontractor to Railenium
- Other partners: Thales, Alstom, Hitachi Rail STS, AZD, Bombardier, CAF, CEIT, Deutche Bahn, DLR, HaCon, Indra, Kontron, Mermec, NetworkRail, Railenium, SNCF Réseau, Trafikverkert, Siemens

This European project aims to continue the research and development of key technologies to foster innovations in the field of railway signalling, telecommunication, testing methodologies and Cyber Security, as part of a longer term Shift2Rail IP2 strategy towards a flexible, real-time, intelligent traffic control management and decision support system.

The actions to be undertaken in the scope of X2Rail-3 are related to the following specific objectives:

- To improve line capacity and to achieve a significant reduction of the use of traditional train detection systems by means of the introduction of the Moving Block together with train positioning;
- To overcome the limitations of the existing communication system by adapting radio communication systems which establish the backbone for the next generation advanced rail automation systems;
- To ensure security among all connected signalling and control systems by developing new cyber security systems dedicated to railways;
- To analyse new signalling concepts (Virtual Coupling) that potentially would be able to improve line capacity, reduce LCC and enhance system reliability;
- To improve standardization and integration of the testing methodologies reducing time to market and improving effectiveness in the introduction of new signalling and supervision systems;
- To ensure the evolution and backward compatibility of ERTMS/ETCS technologies, notwithstanding of the required functional enrichment of the future signalling and control systems.

In this project, we act on behalf of the RAILENIUM IRT (as a sub-contractor). Discussions are ongoing with RAILENIUM in order to reinforce the cooperation between them and IRISA/Inria.

5.1.3 The SECUR project

Participants: Jean-Marie Bonnin.

- Project type: Euro NCAP
- Dates: 2019–2023
- PI institution: IMT Atlantique as a subcontractor of UTAC
- Other partners: 10+ international industrial partners

In this project, we act on behalf of UTAC (a leading international group in the fields of mobility) as a sub-contractor.

The European New Car Assessment Programme (Euro NCAP) aims to encourage, by a consumer approach, ever more safety on the roads thanks to the use of new inter-vehicle communication solutions. The SECUR project aims to study the potential of connectivity, especially of V2X technologies, to improve the safety of different road users. Coordinated by UTAC, the SECUR project expect to push a proposal for V2X testing and assessment protocols to the Euro NCAP. To this end, the industrial consortium brings together some twenty international stakeholders, from the entire automotive and V2X ecosystem, who share knowledge and collaborate through workshops and working groups.

5.2 National Initiatives

5.2.1 Region Bretagne: IsiCol

Participants: Paul Couderc, Jean-Marie Bonnin.

- Project type: Region Bretagne
- Dates: 2019–2023
- PI institution: Inria
- Other partners: Ekolis (lead), Samea-Innovation

In collaboration with Samea, and Ekolis, ISICOL strives to improve transport logistics through the use of RFID (Radio Frequency IDentification) technology. Known for its ability to facilitate identification, tracking, and data collection through electronic tags attached to objects, RFID technology holds great promise for improving traceability and supporting logistics processes. Despite its growing adoption, the transport industry, particularly in the road transport sector, remains prone to inefficiencies where the integration of RFID solutions proves challenging.

ISICOL, an acronym for "Integrated Solutions for Intelligent Control and Logistics", addresses these pressing challenges by introducing an autonomous RFID reader portal, a pivotal element in the traceability process. With a focus on real-time monitoring and management of goods, ISICOL aims to mitigate issues such as loss, theft, and logistical discrepancies that plague the industry. The main ISICOL's objective is to develop a battery-powered RFID solution with a smart reading protocol, capable of adapting to dynamic loading and unloading scenarios while ensuring robust reliability. The project also involves establishing experimental environments that replicate real-world conditions using the INRIA-IETR's standalone pervasive-RFID platform, which occupies a room in the IETR laboratory.

Ultimately, the final goal of this project will be to ensure continuous tracking by integrating RFID technology into the vehicle, ultimately achieving enhanced traceability and reliability in the management of transported goods.

Within the ISICOL project, our team will use the advanced capabilities of Inria's automated RFID platform. Our upcoming efforts are manifold, encompassing the proposal of intelligent RFID UHF tag reading mechanisms to ensure a 100% reading rate while simultaneously optimizing energy consumption. Additionally, our focus going forward extends to optimizing message compression protocols and implementing robust data encryption techniques, ensuring the integrity and security of transmitted information.

The project officially started at the beginning of 2023, but we could not begin serious work until the start of the following year due to hiring delays.

5.2.2 Region Bretagne: Alpha

Participants: Jean-Marie Bonnin, Juliette Grosset.

- Project type: Region Bretagne

- Dates: 2023-2025
- PI institution: IMT Atlantique
- Other partners: Alstef (lead), ECAM, Secure-IC

This two-year project focuses on revolutionizing airport baggage transport through the implementation of Automated Guided Vehicles (AGVs) fleets to replace or enhance traditional conveyor-based technology. BAGXONE is Alstef Group's innovative AGV designed for the automated transport of hold baggage at airports. With a pilot BAGXONE project successfully commissioned at Belgrade Airport in late 2023, Alstef Group aims to elevate its solution by incorporating the latest technological advancements into its AGVs. The primary research areas encompass system performance, operability, energy efficiency, safety, and cybersecurity. The Alpha project plays a pivotal role in optimizing the AGV system's performance, emphasizing the expertise in Artificial Intelligence and robot fleet management contributed by IRISA EASE team and ECAM Rennes. Research initiatives involve the creation of algorithms to streamline AGV routes and missions, enhance inter-vehicle communication, and implement intrusion detection measures to fortify system security. Collaborative efforts with Secure-IC will integrate cutting-edge cybersecurity solutions into BAGXone, ensuring the highest level of protection.

The project officially started in the summer of 2023, but we could not begin serious work until the start of the following year due to hiring delays.

5.3 Bilateral industry grants

5.3.1 PhD (CIFRE with CANON CRF): "Surveillance d'une infrastructure de perception coopérative"

Maxime Cancouet's thesis started at Canon Research Centre France (Canon CRF) in April 2023 under a CIFRE agreement. It is focused on the monitoring of a cooperative perception infrastructure. More precisely, the objective is to find and develop means to evaluate the infrastructure-obtained data and provide some proof of trust to the users of these data.

In this scope, Maxime participates in the European research project SELFY (https://selfy-project.eu/) in which the Canon CRF team is involved, with objectives similar to those of the thesis allowing progress in harmony on both the thesis and the project. Indeed, this three-year project involving several European companies and universities aims to develop a toolbox improving the resilience and ensuring the security of data from CCAM systems (Cooperative Connected Automated Mobility).

5.3.2 Prefiguration of the C4M (Cooperation for Mobility) lab

Participants: Élodie Duroy, Jean-Marie Bonnin.

- Project type: French "Plan de Relance"
- Dates: 2023-2025

- PI institution: IMT Atlantique
- Other partners: YoGoKo

Following the work done in the SIMEHet contract last years, we decided to launch a common lab with YoGoKo. It will take time to be fully established, but we already start to strengthen our collaboration. The name of the common lab is Cooperation for Mobility (C4M) and it aims at studying direct interactions between vehicles, with road/street infrastructure, and with pedestrian and vulnerable road user. We will mainly focus our work on the Urban ITS context but we could also be involved in evaluating V2X technologies with use-cases of interest (rail way, industry, etc.).

Using the "plan de relance" of the French government we hire for two years one Engineer in September 2021 and another one should start in March 2022. They will spend half of their time in the YoGoKo premises on YoGoKo projects and the other half with the EASE team to work on common projects. Elodie Duroy, will be mainly involved on the mechanism we need to exchange information and to deal with it in the vehicle using ML and AI technics.

5.4 Collaborations

5.4.1 PhD: Increasing the autonomy of AIVs integrated into a fleet using collective intelligence strategies

Participants: Juliette Grosset, Jean-Marie Bonnin.

One of the challenges of Industry 4.0 is to develop and optimise the circulation of data,products, and materials within production companies. To achieve these challenges, multiple solutions have been identified, including the use of AGVs and other autonomous mobile robots. The introduction and deployment of fleets of autonomous industrial vehicles (AIVs) in companies remains problematic on several levels:

- acceptability to employees,
- localization of vehicles,
- traffic fluidity,
- perception by vehicles of changing environment,
- and therefore dynamic, environments, and so on.

As a result, autonomy is reduced to predetermined trajectories. In this thesis co-funded by Region Bretagne, our partner ECAM (Alain-Jérôme Fougères) and us are interested in the ability to exchange information between the different AIVs in a fleet, as this would make it possible to improve this autonomy at various levels:

- adaptation to traffic constraints, particularly when the environment of the VI-Achanges over time (dynamic environment of storage areas, production lines, etc.);

- decision-making, even when the information available to the AIV is incomplete,uncertain or available but fragmented;
- V2X communication: with other AIVs in the fleet, with the infrastructure or withpeople interacting with the AIV;
- reducing energy impact, whatever the traffic constraints.

The main objective of this work is to propose solutions for increasing the autonomy of AIVs integrated into a fleet using collective intelligence strategies.

5.4.2 Collaboration with the Tsukada's Lab at University of Tokyo

Participants: Juliette Grosset, Jean-Marie Bonnin.

We already organized joint seminars between our teams on the Cooperative ITS topics. In 2023, we were able to resume our cooperation and Juliette Grosset spent 3 months at Tokyo from Appril to June and Jean-Marie spent one week at the end of July. Two master student from Tokyo spent two month at Rennes at the end of the year.

We would like to have a common PhD student who could spend part of his time on each side. Even though they are more interested in automated vehicles in urban environment, We work on some aspects of the interaction between infrastructure and autonomous vehicle that could also be useful in plant scenario. The idea is to apply cooperative perception principles to AGV. We have a common publication that should be submitted in 2024.

6 Dissemination

6.1 Promoting scientific activities

6.1.1 Scientific Events Selection

Member of Conference Program Committees

- PC member of eHPWAS 2023, ISCC 2024, F. Weis
- PC member of ICASET 2024, PIMRC'24 Track 2 - Networking & MAC, ... J.-M. Bonnin

Reviewer

- PIMRC'23, ICC'23 ... J.-M. Bonnin

6.1.2 Invited Talks

- 31/01/2023, 4h, Talk on Collaborative autonomous vehicles, ENSSAT
- 29-30/03/2023, Comparison of V2X communication technologies, Final Event SECUR Project, UTAC
- 26/07/2023, Presentation of the E4SE team activities at University of Tokyo
- 9/10/2023, AI Enhanced Healthcare Roundtable, at First Rennes School of Business Summit : Leading Sustainability Transformations
- 2/11/2023, The Evolution of Smart Mobility Technologies, Keynote at ICSGTEIS'23

6.1.3 Exchanges

- Two-week stay of Mohamed Rabi Naimi (PhD student and teacher at University Djillali Liabes (Sidi Bel Abbés, Algérie): Analyse des paramètres en temps réel des politiques d'équilibrage de charge des ordonnanceurs MPTCP
- One-week visit of Yanis Patias (Associate professor at Sofia University "St. Kliment Ohridski"), Erasmus Teachers Mobility

6.1.4 Leadership within the Scientific Community

- Management commitee of PRACom, J.-M. Bonnin
- Conseil de perfectionnement ECAM, J.-M. Bonnin
- Co-director of the Knowledge in Society program at CUT (Center for Unframed Thinking) by RSB (Rennes School of Business).

6.1.5 Scientific Expertise

- Member of the scientific committee of the Id4Mobility cluster, J.-M. Bonnin
- Scientific advisor of the YoGoKo startup, J.-M. Bonnin
- Management commitee of PRACom, J.-M. Bonnin
- Conseil de perfectionnement ECAM, J.-M. Bonnin
- Expert for CSV board of "Pôle Images et Réseaux", projects reviewing and selection, strategic roadmap definition, P. Couderc

6.1.6 Research Administration

6.2 Teaching, supervision

6.2.1 Teaching

- L2/L3: network computing/cybersecurity /wireless networks (lectures, tutorials, labs), 250 hours, F. Weis, Univ. Rennes
- Continuous training: Wireless LANs security, F. Weis, 30 hours, Télécom Paris
- L3/M1/M2: networking and wireless networks
- Continuous training: Coopetative ITS architecture, Autnomous vehicles
- Master Smart Mobility : Communication for cooperative ITS (Ecoles des Ponts, Telecom Paris)

6.2.2 Supervision

- PhD in progress: Juliette Grosset, Interactions between Automatic Guided Vehicles, September 2021, Jean-Marie Bonnin
- PhD in progress: Hassan Hammoud, Agile Data Collection for Smart Agriculture, March 2022, Frédéric Weis and Jean-Marie Bonnin
- PhD in progress: Mariam Issa, Mediation infrastructure for ephemeral interactions in smart environments, November 2022, Paul Couderc and Jean-Marie Bonnin
- PhD in progress : Maxime Cancouet, Surveillance d'une infrastructure de perception coopérative, Jean-Marie Bonnin

6.2.3 Juries

- PhD defense, "Méthode Déterministe pour l'Amélioration de la Sûreté dans les Réseaux Véhiculaires Intelligents", Imen Zidi, Tunis, May 17th 2023

- PhD qualifying exam board (UFES/Brazil), "Intelligent Road Intersections: A Case for Time-Critical Digital Twins", Víctor Manuel García Martínez, May 31 2023

- PhD defense, "Contribution to security and privacy in the Blockchain-based Internet of Things: Robustness, Reliability, and Scalability", Julio Cesar Perez, Avignon, December 18th

6.3 Popularization

- 23/05/2023, Quelle ville pour demain ?, conférences publiques du CUT, Rennes

7 Bibliography

Articles in referred journals and book chapters

[1] C. Couturier, J.-M. Bonnin, "Interactions locales pour les ITS coopératifs : opportunités et contraintes", *in: Contrôle et Gestion des Systèmes de Transport Intelligents et Coopératifs*, ISTE, to appear in 2024, p. 30pp.

[2] C. Couturier, J.-M. Bonnin, "Local Interactions for Cooperative ITS: Opportunities and Constraints", *in: Cooperative Intelligent Transport Systems, coordinated*, Wiley, to appear in 2024, p. 30pp.

[3] N. I. Er, K. D. Singh, C. Couturier, J.-M. Bonnin, "Towards a simple and efficient vehicular delay tolerant networks routing protocol for data collection in smart cities", *TELKOMNIKA (Telecommunication Computing Electronics and Control) 22*, 1, 2024, p. 65–75.

[4] J. Grosset, A.-J. Fougeres, M. Djoko-Kouam, J.-M. Bonnin, "Multi-agent simulation of autonomous industrial vehicle fleets - dynamic task allocation in V2X cooperation mode", *Integrated Computer-Aided Engineering 31*, 3, to appear in 2024, p. 249–266.

[5] J. Grosset, A. Ndao, A.-J. Fougeres, M. Djoko-Kouam, C. Couturier, J.-M. Bonnin, "A cooperative approach to avoiding obstacles and collisions between autonomous industrial vehicles in a simulation platform", *Integrated Computer-Aided Engineering 30*, 1, 2023, p. 19–40, https://hal.science/hal-03923202.

[6] J. Grosset, A. Ndao, A.-J. Fougeres, M. Djoko-Kouam, C. Couturier, J.-M. Bonnin, "Collision and obstacle avoidance for industrial autonomous vehicles - simulation and experimentation based on a cooperative approach", *Advances in Robotics and Automatic Control: Reviews 3*, to appear in 2024.

Publications in Conferences and Workshops

[7] J. Grosset, A.-J. Fougères, M. Djoko-Kouam, J.-M. Bonnin, "Collective obstacle avoidance strategy - an agent-based simulation approach", *in: ASPAI 2022: 4th International Conference on Advances in Signal Processing and Artificial Intelligence*, Corfu, Greece, October 2022, https://imt-atlantique.hal.science/hal-03958445.

[8] J. Grosset, A.-J. Fougères, M. Djoko-Kouam, C. Couturier, J.-M. Bonnin, "Simulation of a collision and obstacle avoidance algorithm for cooperative industrial autonomous vehicles", *in: 2nd IFSA Winter Conference on Automation, Robotics & Communications for Industry 4.0 (ARCI' 2022)*, Andorra la Vella, Andorra, February 2022, https://imt-atlantique.hal.science/hal-03958464.