RESEARCH CENTRE

Inria Center at Rennes University

IN PARTNERSHIP WITH:

Université Rennes 1, Ecole Nationale Supérieure Mines-Télécom Atlantique Bretagne Pays de la Loire

2022

ACTIVITY REPORT

Project-Team EASE

Enabling Affordable Smarter Environment

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

DOMAIN

Networks, Systems and Services, Distributed Computing

THEME

Distributed programming and Software engineering

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Project-Team EASE

Creation of the Project-Team: 2019 March 01

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Computer sciences and digital sciences

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1 Team members, visitors, external collaborators

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2 Overall objectives

2.1 Presentation

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 TACOMA/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).

3 Research program

3.1 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

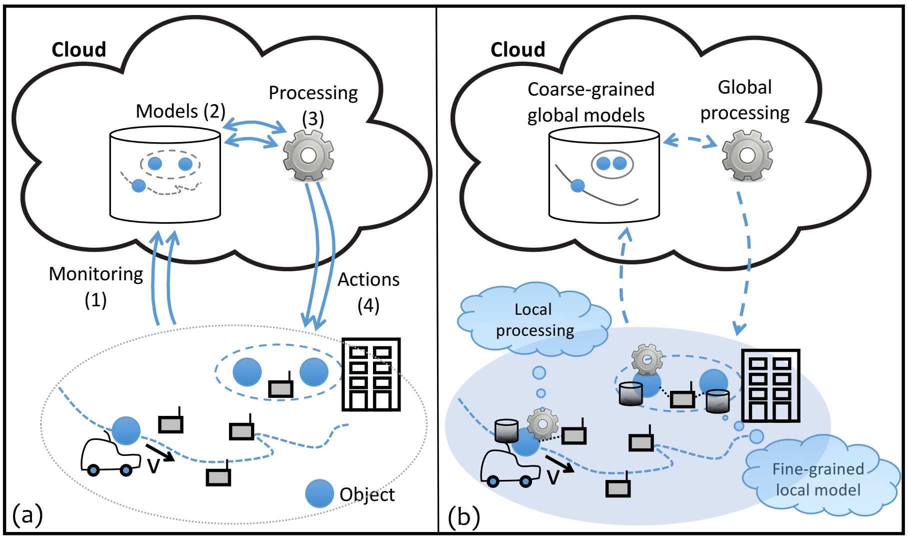

Figure 1: Adaptation processes in pervasive environments

have on automated systems. We "just" have 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.

3.2 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.**

3.3 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**.

4 Application domains

4.1 Pervasive applications in Smart Building

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

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

4.2 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.

4.3 Pervasive applications in uncontrolled environnements

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

RFID technology is to avoid missing tags when reading multiple objects, as reading reliability is affected by various effects such 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**.

4.4 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.

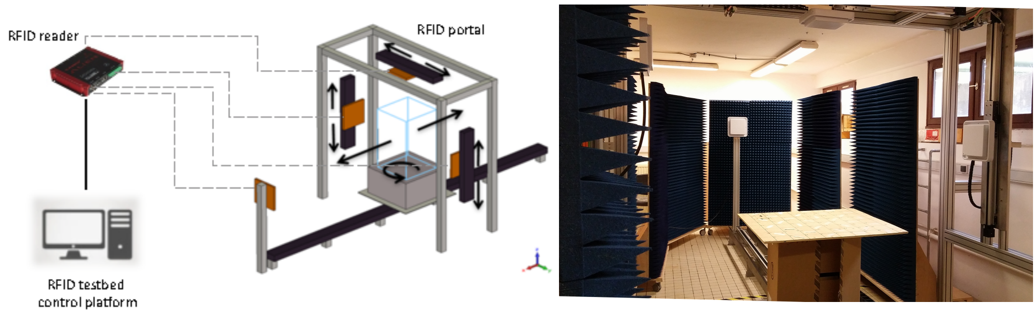

Figure 2: RFID testbed

5 Highlights of the year

EASE team ended on December 31st 2022.

The project IsiCol has been funded by Region Bretagne and will start at the beginning of January 2023. The taxirail project has been accepted by ADEME in 2022 and will start for the team in 2023.

6 New software and platforms

6.1 New platforms

6.1.1 Platform Pervasive_RFID

Participants: Paul Couderc.

KEYWORDS: Composite objects, RFID

- Partner: Univ. Rennes 1 (IETR - lab bringing together researchers in the electronics and telecommunications)
- Contact: 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).

6.1.2 AgriSense

Participants: Hassan Hammoud, Frédéric Weis.

KEYWORDS: Smart Agriculture, Low-end IoT devices, RIOT, WSNs

- Partner: Inria - INRAe
- Contact: Frédéric Weis

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). Our recent results with this platform are presented in the section 7.

7 New results

7.1 Cooperation between automated vehicles

Participants: Jean-Marie Bonnin *(contact)*, Juliette Grosset.

Industry 4.0 leads to a strong digitalization of industrial processes, but also a significant increase in communication and cooperation between the machines that make it up. The context of factory 4.0 leads more and more to decentralised solutions, as centralisation shows its limits. One of the research areas of Industry 4.0 is the use of autonomous guided vehicles (AGVs), autonomous industrial vehicles (AIVs) and other cooperative mobile robots which are multiplying in factories, often in the form of fleets of vehicles. There intelligence and autonomy are increasing. While the autonomy of autonomous vehicles has been well characterized in the field of road and road transport, this is not the case for the autonomous vehicles used in industry. The establishment and deployment of AIV fleets raises several challenges, all of which depend on the actual level of autonomy of the AIVs: acceptance by employees, vehicle location, traffic fluidity, collision detection, or vehicle perception of changing environments.

Thus, simulation serves to account for the constraints and requirements formulated by the manufacturers and future users of AIVs. Simulation offers a good framework for studying solutions for these different challenges. Thus, we proposed the extension of a collision detection algorithm to deal with the obstacle avoidance issue [1]. The conclusive simulation will allow us to begin experiment in emulation and real conditions. Moreover, we proposed in the paper [2] an agent model to test scenarios in Industry 4.0 environments with a fleet of AIVs. We simulated our proposition of a first step to move towards a resolution of global obstacle avoidance by AIVs with a collective strategy. The results showed the interest of collaboration to increase the collective and individual efficiency of the vehicles in a fleet. It opens the door to more advanced global collective strategies with the possibility of the allocation, scheduling and distribution of tasks between them in real-time after the perception of an obstacle. Finally, we also present in the paper [3] on a method to estimate positions of AIVs moving in a closed industrial environment, the extension of a collision detection algorithm to deal with the obstacle avoidance issue [1], and the development of an agent-based simulation platforms for simulating these two methods and algorithms.

7.2 Risk evaluation for Smart Agriculture

Participants: Jean-Marie Bonnin, Hassan Hammoud, Frédéric Weis *(contact)*.

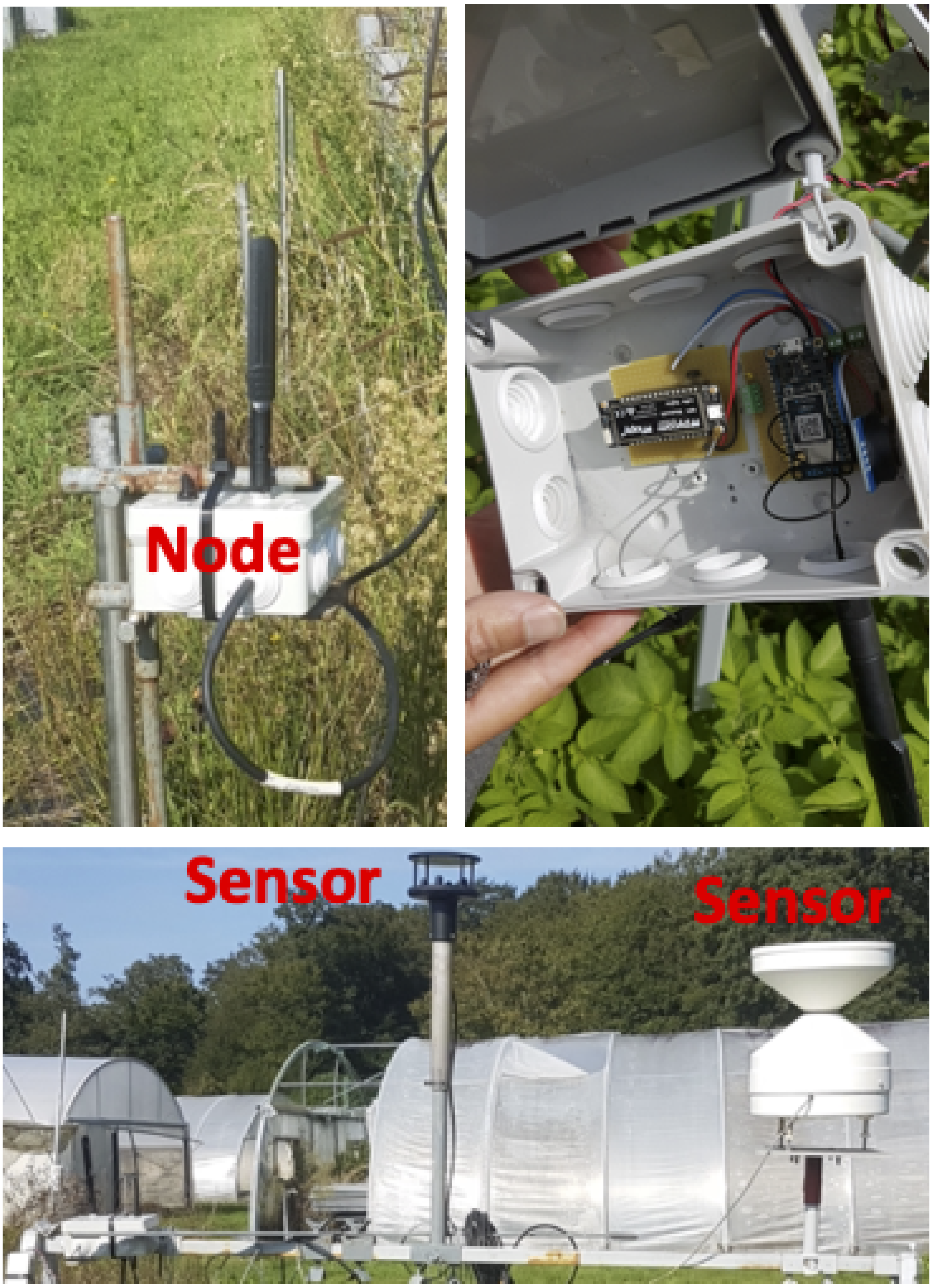

Figure 3: AgriSense Platform in an experimental field of INRAE

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.

To integrate software services in these nodes, we relies on open source operating systems providing consistent APIs & SDKs. Traditional OS such as Linux cannot run on the limited resources of low-end IoT devices. For the last year, we have focused our efforts on the deployment of an open / stable / sustainable platform exploiting low power nodes running with RIOT. RIOT is an OS developed by a growing open source community. It offers a developer-friendly programming model and APIs, similar to what is found in Linux. It is based on a micro-kernel architecture. The network stack implements the main IoT standards (6LoWPAN, IPv6, RPL, CoAP etc.). It therefore has all the characteristics of a modern OS targeting the low-end IoT nodes.

We used an open hardware and software platform:

- Offering very fine mechanisms for energy management: the developer is able to put the nodes into the deepest sleep mode, and to wake them up in a synchronized way whenever necessary. Even in the presence of a very energy-intensive sensor, consumption of a node does not exceed a few microamps.
- Accelerating the integration of complex sensors. A set of libraries facilitates interactions between hardware and OS. The sensor is seen as a simple source of data.

This year, we worked on data quality with a team from INRAE. More specifically, we were interested in approaches to assess the risk of disease on plants, using our platform.

We have developed a simple generic infection model to predict pathogen infection periods. The model is designed to be used in forecasting pathogens that do not have extensive epidemiological data.

Most of the existing models require an epidemiological data set based on a large amount of data, measured over a long period. Our approach relies on locally measured cardinal temperatures and humidity duration. The model uses a temperature response function that is scaled to the minimum and optimum values of the required surface wetness duration.

The algorithm is capable of running for several weeks on a communicating object (a MCU) of very small size. All the nodes are synchronized and wake up from time to time to perform local processing.

Our software environment is based on a limited number of nodes that measure local data (humidity + temperature) and evaluate the pathogen risk. If the risk increases locally, the nodes are able to dynamically extend the measurement area and improve the global quality of the evaluation. This principle is illustrated in the figure 4.

8 Bilateral contracts and grants with industry

8.1 Bilateral contracts with industry

- **Project: C4M**
- Partner: YoGoKo

Participants: Jean-Marie Bonnin, Élodie Duroy.

- Starting: Sept 2021 - Ending: October 2023
- Abstract: 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

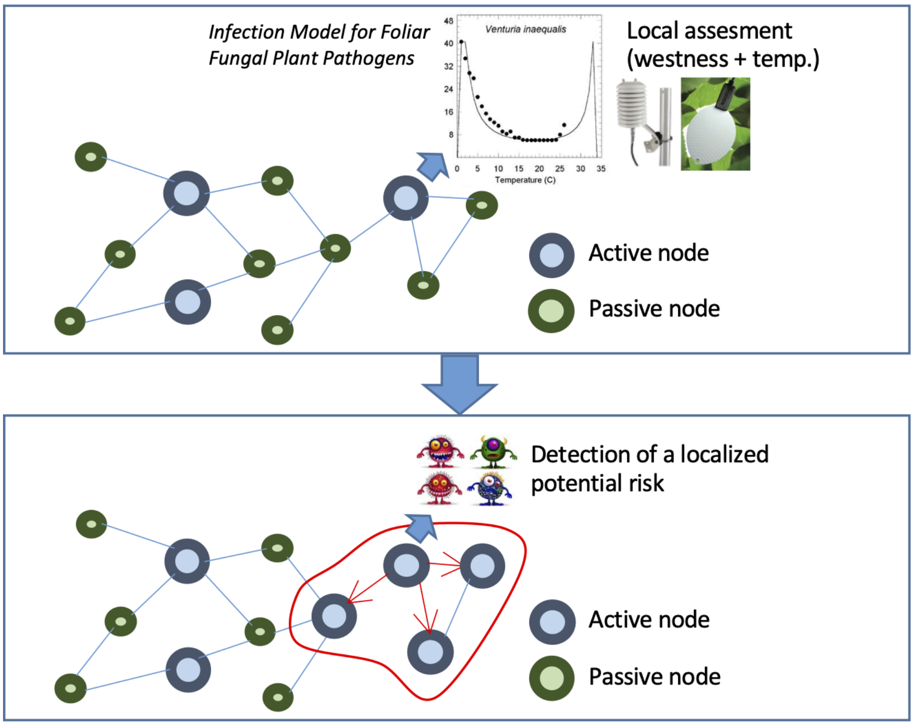

Figure 4: Detection of plant diseases

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. Rania Haj Mansour will be in charge of working on the the implementation in the linux architecture of the advanced interface selection mechanism (results of the SIMEHet project). Thanks to this tight integration within the Linux networking architecture we will perform a comprehensive evaluation of the mechanism in real situation.

- **Project: Agri-BIoT**
- Partners: Inria - IMT-A

Participants: Jean-Marie Bonnin, Paul Couderc.

- The project was stopped in March 2022 following the sudden death of its owner.

Abstract: A startup project (Agri-BIoT) involving Inria and IMT Atlantique people is getting ready with edge computing solutions targeting agriculture applications. A core component of the solution is an RFID based local storage infrastructure for in situ annotations and data tracking. An important innovation in this project is to bring autonomous and efficient solutions to farmers, under their control, unlike most competitors solutions depending on remote infrastructures.

The team is contributing to this project with its experience in developing RFID based distributed storage and operating RFID in adverse conditions.

The projet had been selected and founded in the Inria Startup Studio.

9 Partnerships and cooperations

9.1 International initiatives

9.1.1 Inria international partners

Informal international partners

- **University of Tokyo, Tsukada Lab**

  Participants: Jean-Marie Bonnin, Juliette Grosset.

- Abstract: We already organized joint seminars (Jean-Marie Bonnin went to Tokyo in February 2020 and we had a seminar between the two teams in 2021) but the current situation prevent us from developing the collaboration further. 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, Juliette Grosset will go to Tokyo in April 2023 to 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. Jean-Marie Bonnin will go to Tokyo for three weeks next summer.

9.2 European initiatives

9.2.1 Other european programs/initiatives

- **SECUR**

  Participants: Jean-Marie Bonnin.

- Starting: Jan 2022; Ending: June 2022
- Partners: 10+ industrial partners
- Abstract: 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.

- **X2Rail-3/X2Rail-5**

  Participants: Jean-Marie Bonnin.

- Starting: mid 2019; Ending: Dec 2023
- Partners: Thales, Alstom, Hitachi Rail STS, AZD, Bombardier, CAF, CEIT, Deutche Bahn, DLR, HaCon, Indra, Kontron, Mermec, NetworkRail, Railenium, SNCF Réseau, Trafikverkert, Siemens

- Abstract: 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.

9.3 National initiatives

- **InDiD**

  Participants: Jean-Marie Bonnin.

- Starting: mid 2019; Ending: Dec 2023
- Partners: 20+ French partners including cities (Paris, Grenoble...), road operators, transport operators, academics (incl. IMT Atlantique) and industrials
- Abstract: 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.

9.4 Regional initiatives

- **Chantier 3.0**

  Participants: Jean-Marie Bonnin, Christophe Couturier, Paul Couderc.

- Starting: Jan 2019; Ending : Dec 2022
- Partners: Agemos, YoGoKo, IMT Atlantique
- Abstract: Co-founded by "Région Bretagne" Chantier 3.0 is a "PME Project" aiming at increasing safety of workers in construction sites and road works. In these scenarios, vehicles represent a danger for the workers. Knowing the position of the vehicles and workers, it is possible to alert workers who are located in a safety perimeter around the vehicles. The project addresses the challenges of 1) precise localisation with low or medium cost wearable devices and 2) of dynamically setting up a reliable communication network in harsh environments mixing indoor and outdoor conditions.

  The key technologies used to solve theses issues include: fusion of localisation data (GPS, acceleration integration, location anchors, angle of arrival and time of flight of radio signals), opportunistic short range broadcast communications, ITS communication protocols and system integration. EASE brings it expertise in all of theses domains in order to enhance the reliability of the system, to make it affordable and to pave the way for its standardisation.

10 Dissemination

Participants: Jean-Marie Bonnin, Paul Couderc, Frédéric Weis.

10.1 Promoting scientific activities

Scientific events: organisation

- CUT - Conference CAID - New Research Developments on autonomous vehicules: Crossing disciplinary views, Rennes, J.-M. Bonnin

Member of the conference program committees

- PC member of eHPWAS 2022, F. Weis

10.1.1 Invited talks

- " Véhicules Autonomes et Coopératifs", January 2022, ENSSAT Lannion, J.-M. Bonnin
- "Cybersécurité pour véhicules connectés et autonomes", Forum Mobilités Transitions, Rennes, May 2022, J.-M. Bonnin
- "Colloque IMT Mobilité : Communications hétérog̀enes pour les ITS coopératifs (C-ITS), Les sciences de l'information au service des nouvelles mobilités," Palaiseau, October 2022, J.-M. Bonnin
- Collecte de données agile dans un contexte de parcelles connectées, Journée “Réseaux de capteurs, phénotypage et modélisation” du Réseau Modélisation et Statistique en Santé des Animaux et des Plantes (ModStatSAP), December 2022, J.-M. Bonnin

Scientific expertise

- Member of the scientific council of the Id4Car cluster, J.-M. Bonnin
- Scientific advisor of the YoGoKo startup, J.-M. Bonnin
- Scientific committee of Id4Car, J.-M. Bonnin
- Management comimitee 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

10.2 Teaching - Supervision - Juries

10.2.1 Teaching

- L2/L3: network computing/cybersecurity /wireless networks (lectures, tutorials, labs), 250 hours, F. Weis, Univ. Rennes 1
- Master 2: Wireless LANs, F. Weis, 30 hours, M2, IMT Atlantique
- Master 2: Pervasive computing and IoT system architectures, 4 hours, P. Couderc, Univ. Rennes 1
- Master 2 : Mobility management in the Internet, JM. Bonnin, IMT Atlantique
- Master 2 Smart Mobility : Communications for ITS, JM. Bonnin, IMT Atlantique
- Master 2 IoT: Smart City, JM. Bonnin, ENSI Tunis
- Continuous training: Communications for Autonomous and Cooperative vehicle, Communications for ITS, JM. Bonnin, IMT Atlantique

10.2.2 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, Frédéric Weis and Jean-Marie Bonnin

11 Scientific production

11.1 Major publications

[1] N. Ben Mabrouk and P. Couderc. 'EraRFID: Reliable RFID systems using erasure coding.' In: *IEEE International Conference on RFID 2015*. San Diego, United States: IEEE, Apr. 2015. URL: https://hal.inria.fr/hal-01247089.

[2] P. Couderc and Y. Maurel. 'Location corroboration using passive observations of IEEE 802.11 Access Points'. In: *CCNC 2019 - 16th IEEE Consumer Communications & Networking Conference*. Las Vegas, United States: IEEE, Jan. 2019, pp. 1–7. DOI: 10.1109/CCNC.2019.8651873. URL: https://hal.inria.fr/hal-01954122.

[3] R. Silva, J.-M. Bonnin and T. Ernst. 'Opportunistic Networking for ITS'. In: *ITS 2016 : Intelligent Transport Systems: Past, Present and Future Directions*. Nova publisher, 2017, pp. 59–86. URL: https://hal.archives-ouvertes.fr/hal-01635357.

11.2 Publications of the year

International peer-reviewed conferences

[4] J. Grosset, A.-J. Fougères, M. Djoko-Kouam and J.-M. Bonnin. 'Collective obstacle avoidance strategy - an agent-based simulation approach'. In: *ASPAI'2022 Conference Proceedings*. ASPAI' 2022 - 4th International Conference on Advances in Signal Processing and Artificial Intelligence. Corfu, Greece, 19th Oct. 2022. URL: https://imt-atlantique.hal.science/hal-03958445.

Other scientific publications

[5] J. Grosset, J.-M. Bonnin, A.-J. Fougères and M. Djoko-Kouam. 'Stratégies d'Intelligence Collective pour des Véhicules Industriels Autonomes Efficaces: De la simulation vers des expérimentations réelles'. In: Colloque de l'Institut Mines Télécom « Les sciences de l'information au service des nouvelles mobilités ». Palaiseau, France, 13th Oct. 2022. URL: https://imt-atlantique.hal.science/hal-03958928.