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neOCampus: A Demonstrator of Connected, Innovative, Intelligent and Sustainable Campus

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Abstract.

The progress in communication technologies and data storage capacity has brought tremendous changes in our daily life and also in the city where we live. The city becomes smart and has to integrate innovative applications, and technology to improve the quality of life of its citizens. To experiment and estimate these innovations, we show that a university campus is a ground “in vivo” experiments adequate. The infrastructure deployed in the Toulouse III Paul Sabatier University campus, enabling its transformation in a smart and sustainable campus, is detailed. The approach to answer the main challenges a smart campus has to deal with, is described. Some challenges are illustrated with a case study on the balance between the energy efficiency and the comfort in a class.

1 Introduction

The progress in communication technologies and data storage capacity has brought tremendous changes in our daily life. Currently, the connections between people and machines have their speed considerably increased. The IoTs (Internet of Things) with all its connected objects and the mobile smartphones, provides a huge amount of heterogeneous data. The cloud and the farms of servers enable to store always more and more data; currently we speak about trillion gigabytes of data. All these advanced technologies, pervasive networks, are transforming our urban areas in **smart cities**. The possibility to get data from our environment thanks to communications and to analyse them enable better management of the resources and better services to citizens. A promising consequence of the access and the division of the data is to inform better, and thus, to involve the citizens as the **actors** of their city in a transparency way. Some examples are providing feedback on the quality of services, adopting a more sustainable and healthy lifestyle, or participating to different initiatives with other citizens.

Nevertheless, innovative technologies and services must be tested and evaluated before their use application in the city daily life. As it will be motivated in the next section, a university campus is the right scale and the right location to experiment and evaluate them before a complete deployment of innovations in a city. Our aim is to transform our university campus in Toulouse as a large scale and in vivo testing ground. This implies the participation of the university community (students, faculty, and staffs) and a well as companies in original partnerships. It has been conceived and is developed with the strong willingness to share materials, software and results for research, education and projects with companies. The ongoing design of our new campus, called neOCampus, follows some guidance in order to answer the main challenges of smart cities. This new view of the campus as a smart campus can, easily, be replicated in other existing campuses.

In this paper, section 2 provides definitions of smart cities from literature and explains why a campus can be adequate to evaluate experiments. Section 3 defines our vision of a smart campus and describes the smart campus neOCampus. Section 4 goes deeper with the main challenges that arises when dealing with smart cities and explains the approach followed in neOCampus to tackle them. Section 5 presents with a case study, before we conclude in section 6.

2 From Smart City to Smart Campus

Being a multi-disciplinary subject, there is not an accurate and consensual definition of what a smart city is. In general, the definition is related to a specific dimension of the city (like "Intelligent City", "Creative City", etc.) [1]. Most of the time, the use of information and communication technologies is an important part of the design of a smart city. Harrison and all [1] consider that three characteristics are common to all smart cities: instrumented, interconnected and intelligent. Instrumented means that the city can use a large set of data-acquisition systems in order to produce data from the real world. Interconnected means that these data can be used across different services and users in the city, and finally, intelligent emphasizes the ability to analyses and use efficiently these data. The ITU-T FG-SSC (International Telecommunication Union Focus Group on Smart Sustainable Cities) [3] provides a definition based on the analysis of around one hundred definitions. They define a **smart sustainable city** as "*an innovative city that uses Information and Communication Technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects.*" A city is an eminently complex system [1], [2] because it is characterized by multiple dynamics, non-linear relation, feedback, unpredictability, strong inertia... where the non-linearity leads to the impossibility to plan all the consequences of a change, even small.

The concept sends back to a type of urban development capable of answering the evolution or the emergence of the needs for institutions, companies and citizens, both

on the plan economical, social, political, legal, cultural and environmental level. Therefore, the smart city **is not static**, it is alive, evolves with citizens, with policies, with its environment, and must be resilient to answer quickly to new challenges.

The services to be provided to institutions, companies and citizens are based on smart technology and infrastructure. They concern several domains [5]: health, citizens, governance and education, energy, buildings, mobility.

These domains must design solutions in a **different way** comparing with traditional ones, which have developed solutions in a **“siloed” fashion**. The services and the data must be shared to allow a mutual enrichment and to promote innovations. For example the data on the water consumption used for the management of an intelligent building can also inform about activity of an individual.

A university campus is generally spread on several hectares, with a lot of buildings, lawns, and a roads infrastructure for different kinds of vehicles (buses, cars, bicycles...). The buildings are dedicated to different activities: research, education, sports, administration, energy plants, and habitations... In general, a university is well equipped with communication networks, with servers and storage capacity. It is frequented by several types of end-users: students, faculty, staff, and visitors, who work, live and move on the campus. These activities consume energy, water and produce wastes.

Due to their size, users and mixed activities, university campuses can be considered as districts or small cities. The two main motivations to experiment innovative services and technics in the context of smart cities in a campus are based on its community. Firstly, the university community is usually aware about innovations. Consequently, it is easier to form evaluation groups, to experiment the use of new cyber-physical systems, or new services, and to involve people in experiments. Then, the university community is able to design these new services and technics and therefore to design the campus of the future.

3 neOCampus: a Smart Campus

The first question to ask about smart campus is: what is a smart campus, and the second question is how to create and develop it for impacting positively its users? This section gives our point of view on these two questions and then presents neOCampus.

3.1 Definition of a Smart Campus

A **smart campus** is an existing University campus with its end-users, having high quality infrastructures for communication and data storage and numerous software and material devices interconnected (IoT). The smart campus is a digital campus, sustainable and intelligent campus, allying innovative teaching equipment, sensors, and systems of communication, storage, location, simulation. Innovative materials used in the university buildings and outside can increase the quality of life of the users and reduce the

consumptions of resources. The fact to be smart is not a static state, and it means that the campus must continuously evolve and self-adapt to its environment: the end-users, the technologies, the transportation, the city.... in being sustainable.

In a smart campus, the end-users must be involved, they are actors to reach the objectives. Researchers and students have a main role in the transformation of the campus. The smart campus equipment will be based on marketed materials and it will be enriched by the last researches stemming from the research laboratories, favouring a short circuit between the research and the potential applications. The operation of research done in the laboratories of the university, supported by the equipment has for objective to design products and services associated to the ambient socio-technical systems.

A smart campus must be qualified as connected, innovative, sustainable and self-adaptive.

The main constraints to create a smart campus are in one hand to deal with the existing buildings, existing infrastructure and functioning, and on the other hand to not be able to predict of what will be made the campus of the future in the 2030s. Therefore, it must be incremental, open and deals with interoperability. **Incremental** in the sense where a device (material or software) can be added without questioning what already exists. It is considered as **open** because it will remain operational while integrating new products of the digital technology of the market and the products stemming from research. The campus will be permanently innovative because the innovations will be added as they will exist. The **interoperability** means that the different elements of the system can communicate and interact. The campus will favour open source software and open hardware.

The operation neOCampus (www.irit.fr/neocampus) started in June, 2013. The teachers-researchers and the researchers of 11 laboratories of the UPS: CESBIO, CIRIMAT, ECOLAB, IRIT, LA, LAAS, LAPLACE, LCC, LERASS, LMDC, PHASE intervene in neOCampus. These laboratories aim to cross their skills to improve the comfort to the everyday life for the university community while decreasing the ecological footprint of buildings and by reducing the costs of functioning (fluid, water, electricity...).

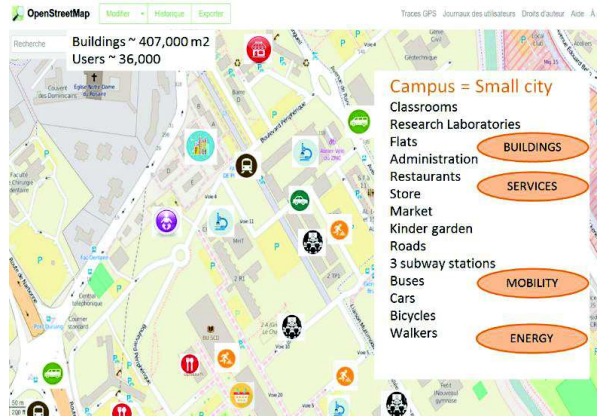


Fig. 1. Toulouse III Paul Sabatier University Campus

The Toulouse III Paul Sabatier University, within the framework of the operation neOCampus, which aims at building the campus of the future at the level services and quality of life is a platform for innovative experiments done at large scale and “in vivo” (with real end-users, in real situations) and welcome partnerships with companies. The heart of these collaborations is a research and innovation project. In this context, companies can benefit of the neOCampus platform, the novelty is that after the project the materials and software stay in the campus to upgrade it and will be used in other projects. Of course, juridical convention are signed to guarantee the intellectual properties.

The campus of Paul Sabatier University (figure 1) extends over around 150 ha and contains more than 407 000 m² of buildings, with 36 000 users who frequent it daily. Inside the campus, several solutions of mobility exist: pedestrian, bicycles, vehicles, buses and subway. The services provided in the different buildings are: administration, education, research, catering, housing, a market, a kinder garden. All the activities on the campus consume 140 GWh a year and produce 23 250 tons of CO₂ (diagnosis made in 2010).

3.2 Architecture

Toulouse III Paul Sabatier University has the advantage to have the appropriate management of a large part of its infrastructures. The university already has a good quality digital communication network on a large number of its buildings and main data storage capacity. Several classrooms are equipped with various sensors and actuators. Data from those sensors are geared toward the neOCampus main server through the neOCampus network, an IoT dedicated network that spreads over almost all buildings of the campus. In addition, neOCampus also benefits from the CloudMIP platform (<http://cloudmip.univ-tlse3.fr/>), a powerful OpenStack platform that is part of the France-Grilles federated cloud initiative. On its own, CloudMIP features 280 physical cores, 1.6TB RAM and enables up to 45TB of persistent data.

From an infrastructure point of view, the neOCampus platform features three major equipments:

- a 16 cores, 64GB RAM and 2.7TB of high speed storage main server,
- a brand new 45TB storage server shared with the CloudMIP platform,
- a both wired and wireless dedicated IoT network.

The main server holds the MQTT broker that enables all of the sensors/actuators /ambient applications to get connected together. The sensors/ actuators get tied to the IoT network through devices like Raspberry Pi and ESP8266. These devices get authenticated through a powerful mechanism on the main server involving the sensOCampus application (<http://sensocampus.univ-tlse3.fr>) and a database.

In addition, a wireless LoRaWAN network is on way to get deployed at the scale of the campus. It will enables LoRa devices to send back data from the sensors in a range > 2km. Data will then get routed to the neOCampus main server.

It is to mention that a lot of time has been dedicated to the ability for the devices to get either fully reinstalled or updated through the network in an automatic way. This is part of the sensOCampus features.

The sensors deployed in the classrooms enable to collect ambient parameters (temperature, CO₂, hygrometry, luminosity, presence, sound), in addition to energy-meters (lighting system and power-plugs), thermal camera, cameras, and air flow meters. Actuators are able to control the lights, the blinds and some displays.

One of the requirements was the ability to either connect digital sensors (i2c bus) but also industrial and building sensors featuring an analog output (0-10v): this aim was reached through a home-made open-source PLC, the neOCampus concentrators <http://neocampus.univ-tlse3.fr/projets/concentrator>.

4 Challenges for Smart Campus

In this section, the different challenges to design a smart campus are described. Designing a smart campus asks to tackle some challenges: social, economical, juridical and technological. We focus on challenges to reach the smart city/campus objectives with the digital and technical point of view. As previously said, the smart campus is a complex systems and by consequence, all applications/services/systems are plunged into a complex context. This complexity leads the designed systems to cope with the following challenges: the large scale and maintenance, the non-linearity, the openness, the heterogeneity, the cognitive overload, the privacy of data and the unpredictable dynamics.

4.1 Large-scale and Maintenance

Smart campuses are deemed to generate huge masses of data. For instance, an energy management of all the buildings of the campus has to collect an amount of data from various and numerous sensors (temperature, electricity, heating, water, lights...) in each rooms/buildings. A centralized management system seems to be not relevant to take quickly a decision. In neOCampus, the solution proposed is based on the distribution of the control, a bottom up approach and has to rely on autonomous unit (agent)

taking local decisions. The control is distributed inside the devices of the system. To maintain all these devices, it is also needed to provide self-healing property to the devices and to use collective behaviour between the devices for detecting failures.

4.2 Non-linearity

When a small change in the input of a system may result in a big change in its output, the system is said non-linear. Controlling such a system is a difficult task. Unfortunately, voltage in smart grids, heating in buildings and housing, traffic, and many smart cities/campuses systems we seek to control are non-linear. In a linear system, the distribution of data is such that it can be exactly abstracted using only simple mathematical functions. On the contrary, machine-learning algorithms have to be sophisticated and fine-tuned to be able to learn non-linear patterns and perform with contextual data from smart campus [6].

4.3 Openness

A system is said open when its components may dynamically enter and exit the system. With the IoTs, smart campuses are inherently open [8]. New devices, new sources of contextual data, are continually added, and some old ones are deleted, or suffer fatal failures. An intelligent algorithm designed to handle contextual data in a smart campus/city should be able to easily incorporate new sources and delete old ones. For instance, sensors measuring the luminosity are added in different locations in an instrumented classroom to get more detailed information. They add their data to the management system, which had learnt the optimal behaviours to balance energy consumption and comfort. Now, it has to incorporate this new data source to its decision making process in an autonomous way. Otherwise, administrators would have to reset and restart the whole learning process. It would be very time costly. Such openness can lead difficulty for many types of machine-learning algorithms, particularly artificial neural networks and evolutionary algorithms.

4.4 Heterogeneity

Contextual data in smart campuses include a large variety of data types, whether they are numerical or not, continuous or discrete, multidimensional or not. Not all algorithms are able to deal with such heterogeneity. While numerical data are usually easily handled by current algorithms, modelling and treating ontologies and abstract concepts is a whole field of research. If some algorithms work very well with continuous numerical data, they are utterly unable to deal with data like the colour of an object, the smell of an animal, or more abstract concepts like the emotion of people. Sophisticated methods have to be employed to process together heterogeneous data in a single algorithm. The heterogeneity appears also when several devices designed by different companies or laboratories have to communicate or to interact. In neOCampus, we promote the use of open sources software and open sources hardware to facilitate the implementation of communications.

4.5 Cognitive Overload

The end-user on the campus can employ a lot of connected objects and can rapidly be overloaded. It takes a lot of time before obtaining satisfactory conditions. For example, before each class the teacher has to adjust a lot of devices: videos, tablet computers, lights, blinds, heatings... Firstly, he has to learn a lot of users' guides, and then he has to spend time to control all these elements before his class. It is the reason why in neOCampus, we want to experiment providing autonomy for all devices in the system. This means that each device has the capacity to perceive, take a decision and act as an agent in a multi-agent system. The price of Arduino or Raspberry Pi enables this today.

4.6 Privacy

Smart campuses are able to collect and gather large amounts of information, and this could harm the privacy of citizens [9]. Yet, whatever the services brought by new connected technologies, nobody should have to give up its privacy. Data should not be used outside of what, the considered services need. In neOCampus, a good alternative to enforce this would be for the data to be processed physically close to its source, and not being transferred and stored when it is not necessary, for example by leaving the execution of the processing of a scene on the video camera.

4.7 Unpredictable Dynamics

Due to the changes in the weather, attendance levels, traffic, users' preferences, and so on, the smart campus has to deal with dynamics. Current algorithms can easily find predictive relationships in smooth linear and complete data set. However, in the real world, the way data change is difficult to handle, and often unpredictable. The dynamics you have learnt at a given time may not be true sometimes later. This stems from several factors such as non-linearity, partial perception (there is not always a sensor for every relevant data), unreliable or missing data, failures, openness, and so on. In neOCampus, we develop new machine-learning algorithms to perpetually self-adapt to the ever-changing data. These algorithms are based on self-adaptive multi-agent systems [6], [10].

5 In Vivo Experimentation: the Case Study consOCampus

The aim of the consOCampus application is to balance energy consumption and comfort regarding the luminosity in a classroom. The classroom is equipped with several sensors: luminosity, temperature, presence detection (through video camera and local treatment) and several effectors acting on the lights and the blinds. Each sensor and effector is embedded on a Raspberry Pi and agentified, and are called agents (figure 2).

In this version, the agents do not communicate directly but use the MQTT broker. One agent subscribes to one or several agents and by consequence when an agent sends a message all subscriber agents receive it.

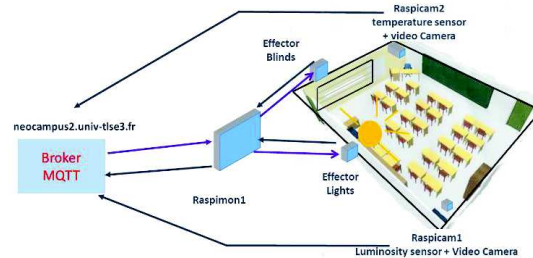


Fig. 2. consOCampus in a classroom

Each agent is autonomous and is able to make a decision in cooperating with the other. Therefore, in this ambient application, the devices are autonomous and have to decide alone what they have to do. This is very different from the pre-established scenarios provided by commercialized applications.

The blinds and the lights interact to be able to decide which device has to act. The blinds have to decide if they have to open or shut down and the lights have to decide if they must be on or off. In function of the temperature, the presence of people in the room and the luminosity, the blinds and the lights have not to act all together: open the blinds and switch off the lights. The behaviour of these agents is based on a cooperative behaviour developed in the Adaptive Multi-Agent Systems theory [11].

We have launched different experiments where a human acts to modify the luminosity in the room in hiding or lighting the luminosity sensor. We have observed that the blinds always open the first and then if it is not sufficient the lights switch on. The next version of this experiment is to enable the system to learn the right behaviour in observing the human activity [12].

6 Conclusion

Today, the cities are in a mutation to become smart in using ICTs and IoTs. In this paper, we motivated the fact that a University campus is a small city where innovative applications and technology can be experimented and evaluated “in vivo” and at large scale. The campus is a great ground of in vivo experiments and large scale. To be smart and sustainable, it has to be built to deal with the following main challenges: the large scale and the maintenance, the non-linearity, the openness, the heterogeneity, the cognitive overload, the privacy of data and the unpredictable dynamics. The campus of Toulouse III Paul Sabatier University is currently built to take into account these challenges. All devices are agentified and are able to perceive information in their environment, to autonomously decide and to act. neOCampus is incrementally built and includes the last results of research from the laboratories of the university. It is also accessible to companies to enable them to experiment and evaluate their innovation in cooperation with researchers.

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