Proposition of a Smart Environment Architecture for Ressources Monitoring and Rural Activities Management

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Abstract— **We can find different examples of declared Smart Cities in the world: Barcelona, London, Santander, Padova, Paris, Stockholm, etc. In a Smart Planet context, what is the place of the rural territories? We develop a scientific program called Smart Village - Smart Paese: emergence of Smart territories in a small village of 250 people in Corsica island. The goal is to include rural areas is the global Smart Planet by the development of a robust management system for resources and rural activities management. In this paper, we introduce our definition of a Smart Village and we propose a global architecture with 3 parts: (1) a Wireless Sensors Network (WSN) deployment of 20 nodes (with several sensors) according to different activities (smart water, smart buildings, smart farm, smart agriculture), (2) Data storage and Visualization tools and (3) a prediction system. We describe the wireless network deployment using Long Range (LoRa) technology, the used sensors, and the developed dashboards for the dynamic data display. We introduce also the first development ways of the smart approach with Machine Learning algorithms called Smart Entity Model (SEM) using Smart Village data.**

Keywords- Smart city; Smart village; WSN; Data; LoRa; ML.

I. INTRODUCTION

The emergence of Smart Cities cannot be considered sudden, but as a natural transition brought about by technological developments in the service of citizens, new environmental constraints and the reduction of planetary resources. The Smart Planet vision of [1] is possible by the task automation and the acceleration of Information Technologies (I.T.) development positioned to ensure the realization of revolutionary, real-time, and real-world people-centric applications and services. Nowadays, this common term of Smart City allows (3) us to talk about urban and social innovation, citizen participation and all others common fundamentals. Smart City appears sometimes as a marketing term and it is difficult to discern the reality of these projects.

The WSN take an important place in the development of Smart Cities. The ever more reducing cost of WSNs is allowing to embed them everywhere to monitor and control virtually any space and environment and to form a part of the Internet of Things (IoT) [2]. In the last 10 years, we have seen the development of platforms using WSN in urban space [3] to collect data, to manage the resources, interact with the citizen and provide a model of sustainable development or e-citizenship.

In this context of Smart Planet, it is important to find a place for the rural areas. We can perceive in India and Indonesia a real development of Smart Village concept; a definition of Smart Village could be assigned to Ghandi: a Smart Village accounts a bundle of services delivered effectively to the residents of the village in an efficient manner. We can find the same objective between a Smart Village and a Smart City with the citizen in the heart of the development strategy of the territory thanks, in particular, to robust I.T. infrastructures (communication, storage, security, responsiveness, sensor networks, etc.). The creation of digital, participatory and inclusive services is a permanent goal to control natural, energy, human and economic resources. In this paper, we introduce an WSN architecture and Machine Learning tools for rural resources and activities management.

We provide in this paper, a first global overview of Smart Village applications. Section III, we present the experimental area of Cozzano, a small Corsican village. In Section IV, we introduce the complete architecture for our developed system, which uses LoRa communication, a data visualization tool and a Machine Learning approach for rural activities and resources management. In Section V, we present the first results of our machine learning system called SEM.

II. THE SMART VILLAGE OVERVIEW APPLICATIONS

It is difficult to find robust researches on the Smart Village concept. However, the European commission introduces two important working definitions of rural communities and Smart Village[4]:

- Communities in rural areas can include one or several human settlements, without any restrictions regarding the number of habitants. Rural areas are defined as "predominantly rural areas" according to the urban-rural typology used by the Organization for Economic Co-operation and Development (O.E.C.D.) and Statiscal Office of the European Communities (EUROSTAT).
- "Smart Villages are communities in rural areas that develop smart solutions to deal with challenges in their local context. They build on existing local strengths and opportunities to engage in a process of sustainable development of their territories. They rely on a participatory approach to develop and implement their strategies to improve their economic, social and environmental conditions, in particular by promoting innovation and mobilizing solutions offered by digital technologies. Smart Villages benefit from cooperation and alliances with other communities and actors in rural and urban areas. The initiation and the implementation of Smart Village strategies may build on existing initiatives and can be funded by a variety of public and private sources".

Based on the potential of WSN and the previous definitions, we decide to focus on the WSN possible applications using smart technologies [5] for rural communities needs. Digital agriculture [6], Smart farming or Precision Agriculture (PA) [7] aim to optimize agricultural processes in order to give growers a more detailed overview of the ongoing situation in their cultivation area, and/or coordinate the actions in such way that optimizes energy consumption, water use and the use of chemicals.

Recent works have focused on these research activities and developed different solutions using WSN [8][9] or a combination of IoT- Machine Learning algorithms [10]-[12]

The development of animal tracking solutions can help to manage rural activities. Indeed, since the 1960s the scientists have used electronic tags to track animals [13].

Nowadays, the low cost and the performance of devices clearly favor the use of WSN to collect different kinds of data (GPS, Temperature, acceleration) to help the breeders to adapt their exploitation (animal health, crossing alert) [14][15].

The need to know the environment conditions is important in the development of rural activities and economy: natural water quality [16]-[18], air quality [19][20], etc.

In the previous works and examples, we can observe that telemetry is the main axis in the use of WSNs, and the list of activities is not exhaustive. However, we can distinguish different possibilities offered by the WSNs. We propose in the following section a deployment of WSN for telemetry using LoRa communication in a small village in Corsica.

III. EXPERIMENTAL AREA AND SMART VILLAGE DEFINITION

The village of Cozzano is located in the center of the Corsica island at 650m, surrounded by a pines forest, chestnut trees and oaks, in a green valley with many streams illustrated in Figure 1. With 250 people, the municipality tried to lead a strategy towards a sustainable development. As a result of this last point, the village is organized around four power generation systems: a hydroelectric power plant on drinking water, a hydroelectric power plant on a river, biomass boiler for communal buildings and solar panel on social housing.

Figure 1. Village of Cozzano (Corsica island)

According to the definitions in the previous sections, we build the concept of Smart Village around four axes:

1. Sustainable development: to promote development of renewable energies, to manage natural resources, to reduce global energy consumption;
2. Infrastructure and digital services: to develop a wireless network and different services around this network;
3. Rural activities: to improve agricultural activities to promote precision agriculture and smart farming;
4. Education and citizenship: to include school and citizens in the project, to inform citizens, to develop inclusive, participatory and collaborative actions.

To contribute to these objectives in the Smart Village context, we propose different steps in Smart Village building:

1. Build a wireless network infrastructure that has low energy consumption to connect different kinds of devices;
2. Deploy of a WSN to collect environmental data such smart water, smart building, smart weather, and smart rural activities;

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3. Display data for decision support in the several activities, to inform the people, and to include the citizens in the Smart Village strategy;
4. Improve the system with prediction algorithms of the observed system evolution;
5. Create services for the data users.

These 5 axes are presented in the following section.

IV. APPROACH OF SMART VILLAGE ARCHITECTURE

According to our previous development process, we present the developed approach for the Smart Village. In Figure 2, we provide a basic representation of the different systems in the Smart Village:

- smart water
- smart farm
- smart agriculture
- smart public buildings

Figure 2. Basic representation of Smart Village

To reach these objectives, we build a WSN based on LoRa communication. Our architecture is divided in five blocks, as illustrated in Figure 3:

- Collect environmental data with a LoRa WSN (including people's survey);
- Store data in an indexed datacenter;
- Display the data with different dashboards according to the different activities of Smart Village (smart water, smart agriculture, smart building, etc.) or citizen categories (children, elderly, mayor and municipal council);
- Use the database for the evolution prediction of the observed systems;
- Create services for the citizens according to the dashboards: air and water quality with real-time information, real-time weather and prediction, information for the activities school.

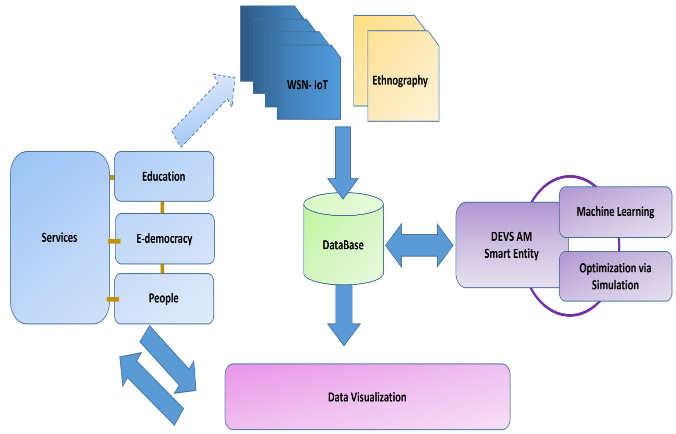

Figure 3. Block scheme of Smart Village objectives interactions

A. LoRa Network infrastructure

The wireless network is built around a central sink based on the church roof using LoRa technologies, as illustrated in Figure 4. In this program, we would like to build a homogeneous, robust and long-range network with a low power consumption technology. LoRa develops an approach based on the following two distinct layers: (1) a physical layer, based on the radio modulation technique (868 MHz for Europe), called CSS (Chirp Spread Spectrum) and (2) a MAC layer protocol (LoRaWAN) that provides access to LoRa architecture [21].

Figure 4. LoRa Antenna for the Smart Village on the church roof (left) and second rescue antenna with solar panel (right)

The technology offers a mix of long range, low power consumption and secures data transmission. The choice of LoRa is clearly in the philosophy of the Smart Village program and allows us to manage the network and devices performances. The network deployed is a local private network and we manage the global system using a carrier grade network server. This choice allows us to study the best possible coverage and to adapt the network. To supplement the main antenna, a second LoRa Gateway visible in Figure 4 is deployed on a distant hill about 4 km from the village of Cozzano to offer greater network coverage. In our system, we collect different kinds of data from a WSN and the collected data is stored in a database. The data are stored in a database according to the different applications of the Smart Village, as illustrated in Table I and Figure 5.

TABLE I. SENSORS FOR SMART VILLAGE APPLICATIONS

Application	Type	Input	Precision	Operating temperature	Accuracy
Smart Agriculture	Soil temperature	Negative temperature coefficient		-30°C to 80°C	0,4°C
Smart Agriculture	Soil humidity	Electric Voltage	Capacitive		± 3%
Smart Air	Ozone	Serial Data Interface at 1200 baud	Detection threshold 0,02 ppm		
Smart Air	Fine particle	Electric Voltage	Sensor by laser scattering	-20°C to 50°C	0,0 to 999,9 mg/m3
Smart Building	Door opening	Electric Voltage	Magnetic aperture detector	-20°C to 70°C	
Smart Water	pH	Serial Data Interface at 1200 baud	Combined electrode (pH / reference) with special glass - reference Ag/AgCl, gel electrolyte (KCl) -		Measuring range (0-14 pH)
Smart Water	RedOx	Serial Data Interface at 1200 baud	Combined electrode (RedOx / reference), platinium tip / reference Ag/AgCl, gel electrolyte (KCl)		Resoluion 0,1 MV ; accuracy ± 2 mV
Smart Water	Dissolved oxygen	Serial Data Interface at 1200 baud	Optical measurement by luminescence	-10°C to 60°C	± 0,1 mg/L - ± 0,1 ppm ± 1%
Smart Weather	Pyranometer	Electric Voltage		-40°C to 70°C	Spectral range 360nm to 11200nm
Smart Weather	Raingauge	Counter		-20°C to 60°C	
Smart Weather	Wind (force and direction)	Counter			Wind speen accuracy ± 5% ans wind direction ± 7%
Smart Weather / Smart Building	Relative humidity	Numerical	Antiradiation shelter	-40°C to 70°C	± 2 to 4%
Smart Weather / Smart Building	Temperature	Numerical	Antiradiation shelter	-20°C to 60°C	(25°C) : ± 0,3°C / (5°C to 40°C) : ± 0,4°C / (-40°C to 70°C) : ± 0,9°C
Smart Weather / Smart Building	Pressure	Electric Voltage	0,15 to 1,15 Bar / Max Value : 4 Bar / Sensibility : 45 mV/Kpa	0°C to 85°C	0,2 Vcc

Figure 5. WSN deployment (water, agriculture, water quality, weather, buildings)

This system is complemented by dedicated tools for smart farming with a LoRa GPS tracker.

B. Tracking system

One of the rural activities of this Corsican area is free-range pigs farming. We developed a GPS tracker called AMBLoRa, illustrated in Figure 6. Based on LoRa communication, the system will help the farmers to know the position of the animals [22] and we apply this on a pigs farming, as showed in Figure 7. These trackers are energy consumption optimized to have a lifetime battery of one year. This tool aims to limit the farmer's movements and allows him to rethink his farm organization with new services, such as the real-time monitoring.

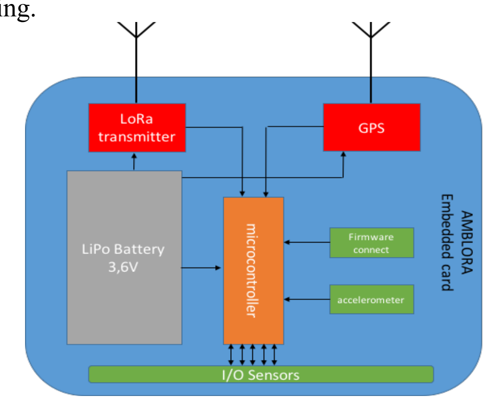

Figure 6. Block diagram of the proposed wireless embedded card

All pigs positions are sent to the gateway and stored in the database. These data are used to create real-time dashboard, which is presented in the following section.

Figure 7. Pig with AMBLoRa GPS Tracker

C. Discussions on WSN and LoRa gateway deployment

The development of the LoRa network revealed some difficulties. Indeed, power outages are common in a rural area and we had data loss because of the unpowered antenna. We tried to limit these problems by using a second antenna with solar panel (weather dependent). This was enough to increase the resilience of a system, but it did not make the system 100% reliable.

For the signal range, theoretically, it should cover tens of kilometers. However, this does not take into account the topography and the vegetation cover which very strongly reduces to just a few kilometers.

D. *Visualization system*

To display in real-time the collected data from database, we developed an information system with Web interface for the visualization. This architecture is built on an indexed database. All the data collected are stored and indexed to allows a dynamic visualization.

This architecture is based on Elasticsearch [23], a real-time distributed search and analytics engine. It is built on a full-text search-engine library called Apache Lucene. To visualize the data, we use the Kibana tool [23]. Kibana is a data visualization software on top of the ElasticSearch engine. It provides a number of tools to display information, like dashboards, queries, filters and time ranges. Information stored in an ElasticSearch cluster can be visualized as interactive plots such as pie charts, histograms, text, maps, etc. We develop different dashboards according to the different activities such as: weather, air quality, smart water, smart agriculture, smart building and smart farm. In Figure 8, we can see an example of a dashboard built with Kibana, with different information for the farmer and a heat map with last pigs positions. We can also have the signal quality from the LoRa devices using a Received Signal Strenght Indication (RSSI).

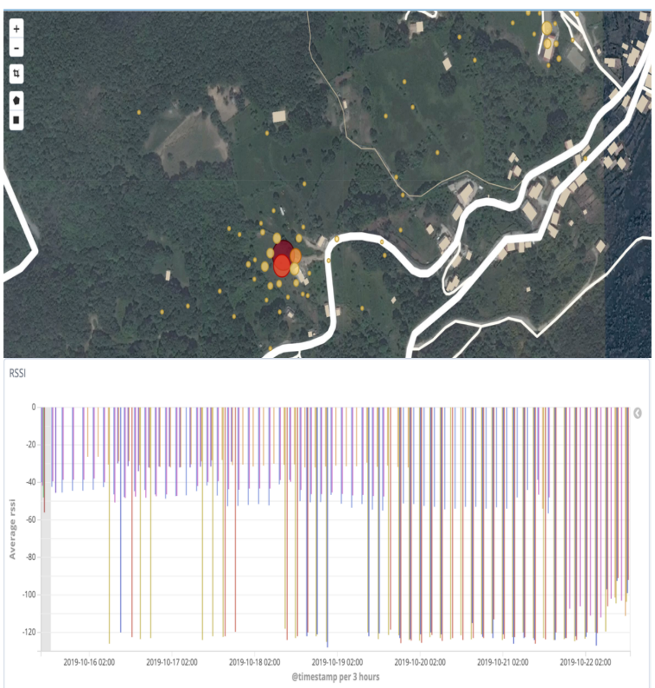

Figure 8. First Kibana tracking visualization based on Elasticsearch engine

We have presented the LoRa architecture, the deployment of WSN and the dashboards for the real-time visualization of the data collected using our architecture. However, to become a smart system, our approach needs to predict the behavior of the observed system to help in the resources and activities management.

V. MACHINE LEARNING SYSTEM CALLED SMART ENTITY

To reach our objective of a real smart system, we developed a model to predict behaviors evolution of observed systems using popular Machine Learning (ML) Libraries. The prediction must help to manage the village environment and to provide decision support for the municipality. Our ML system is based on a model called Smart Entity Model (SEM). This model must be generic and be able to treat all kinds of data collected on the Smart Village.

The SEM [24] is a generic model based on modeling approach using Discrete Event System Specification (DEVS) Formalism. DEVS is a modelling and simulation formalism proposed by B. P. Zeigler [25] in the 70s. The main DEVS objective is to provide an explicit separation between modeling description and simulation core. The formalism is based on two mains concepts: Atomic Model (AM) and Coupled Model (CM). AM describes the system behavior in a modular way and CM describes the system structure by abstraction levels and model encapsulations. This genericity of model description provides a reusable abstract simulator independent of the studied systems. The model is defined with a fixed number of inputs and outputs ports in order to maintain a high level of interoperability.

As represented in Figure 9, the collected data are stored in the database. These data become the SEM AM inputs (XE) and they are used as dataset to select the best ML algorithms for the prediction of the observed system according to the most popular libraries [26]-[29]. The XE dataset is divided in two parts: 80% for the training process of ML algorithms and 20% for the prediction comparison test. SEM defines a ratio between the predicted data and the actual data and gives a score for each ML algorithm. The best algorithm is chosen to build the prediction model. This selection is made every thousand new data entries.

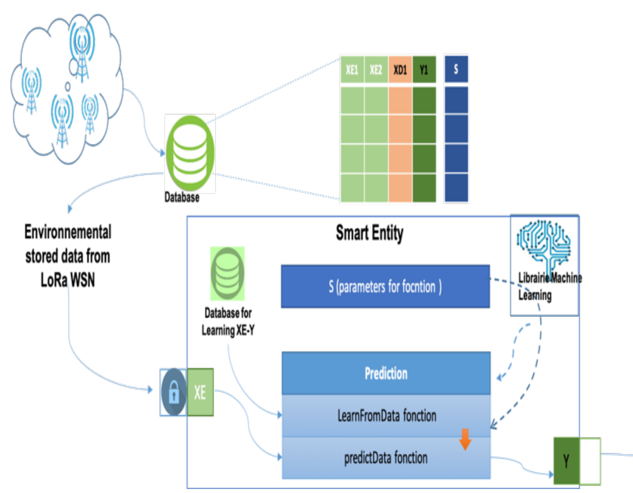

Figure 9. SEM for the prediction

Figure 10 and Figure 11 show the first results of prediction according to the collected by the WSN on the Smart Village project. We can see in Figure 10, the prediction of air temperature by hour. The diagram in Figure 11 shows the prediction of air temperature by day.

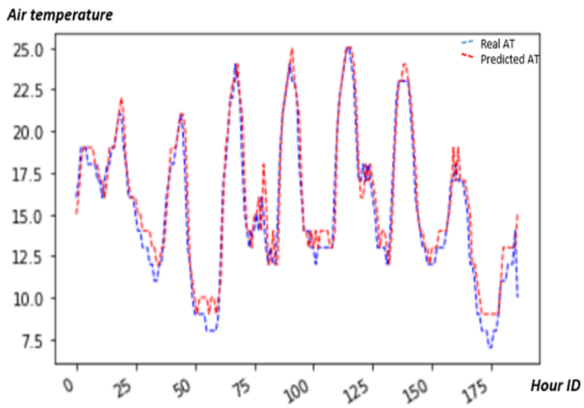

Figure 10. Hourly Prediction outputs on Smart Village Air temperature

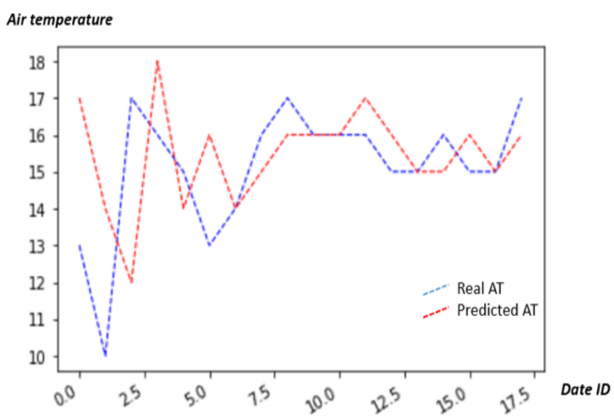

Figure 11. Daily Prediction outputs on Smart Village Air temperature

VI. Conclusion

This paper introduces the first research and development (R&D) steps of a scientific program called Smart Village - Smart Paesi, emergence of Smart Territories. We propose a definition of a Smart Village and our global architecture according to 4 parts: (1) a WSN built around a LoRa Gateway, (2) a database, (3) a data displays interface and a (4) prediction system to anticipate the evolution of the observed systems: water, air, weather, building, agriculture and farm.

We deployed a WSN based on LoRa communication to observe different systems in the village (weather, water quality, agriculture, air quality, buildings, farm). All the collected data are stored in a dynamic database using the Elasticsearch engine. The data are also used to supply a ML/DL model called Smart Entity Model to predict the evolution of observed systems. We also built dashboards to display the data according to the different observed applications.

This first step of R&D is quite conclusive for many reasons:

- The network architecture is robust enough to collect regularly the data without major communication problems and to obtain a resilient network architecture to provide a real Quality of Service (QoS) on the Smart Village;
- LoRa Technology capacities (coverage, long range, low power consumption) allow us to develop different applications for the Smart Village;
- The first results of SEM are sufficient to validate the first step of our smart approach.

The future objectives in the project are as follows:

- New deployment of WSN based on LoRaWAN communication technology to observe other Smart Village systems (public lighting, waste) and improvement of network architecture;
- Integrate and develop several SEM (for all observed systems) as a Web service directly connected to the database.
- Reduce energy consumption to improve battery lifetime of LoRa devices;
- Develop dashboards for all activities;
- Cozzano's municipality supports this project by providing access to its infrastructures, its building for researchers and organizing events in the field of sustainable development.

Citizen are involved in the research program and they are proactive through different events. During regular meetings, field surveys, or interviews realized by the students of the University of Corsica, people expose the impacts of the project on their living environment, their needs or their wishes. We also included the school in a project through a school journal for the project information dissemination.

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