Internet of Things: learning and practices. Application to Smart City

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***Abstract*—Internet of things (IoT) is a massively growing industry in todays times. In fact, more and more devices able to interact together have been recently designed and launched in the market. All the objects that we use in our daily lives are becoming smarter. Everybody agrees that the education has been dramatically changed by the internet over the past few years. Therefore, learning Internet of Things technologies is becoming unavoidable in education. It makes possible for the learners to gain knowledge from anywhere at any time. It allows students and teachers to stay connected with different means, checking messages and upcoming events. IoT can be considered as a new method for managing the teaching environment with advanced tools and establish a rapid communication between the students and teachers in the classroom. Most educators agree that it plays a crucial role in changing the educational landscape. While teachers and instructors away from the classroom, still interact with their students and even replying to posts. In this paper, we propose a practical approach allowing to progressively learn, by practice the essential concepts of Internet of Things applied to Smart Cities. From basic knowledge of python language and the use of microcontrollers Pycom such as LoPy, students can develop skills and also smart applications in the field of Internet of Things. We are interested, throughout this manuscript, to teach it to the scientific community and provide experiments on how to build architectures wherein at each layer lies a plethora of devices and services communicating to make an integrated solution. This can be a good start in the right direction and move further up the aisle to open up a new research area.**

I. Introduction

Internet of Things is considered as the next information revolution, and we estimate the number of devices connected at horizon of 2020 at 50 billion [1]. The Internet of objects is fundamentally different from the Internet of machines. The Internet networks of objects are dynamic, distributed, low throughput and composed of large quantities of heterogeneous objects from a functional and technical point of view [2] and [3].

The Internet of Things includes a wide range of various smart interconnected devices such as sensors, effectors, machines, autonomous devices, drones, intelligent cameras, etc. [4]. Smart objects are generally compact devices with communication capabilities, identified by name and address, with computing capabilities, powered by batteries or solar panels [2] and [5]. Connected objects are dynamic and have self-adaptive capabilities and very variables amount of data that can go up to 1,000,000 data by second in the case of a GPS for example. They can also be self-configurable and support interoperable communication protocols. These objects can be producers of data, data-consumers or endorse both previous roles, perform control or monitoring actions. The produced data are mainly eventual and temporal [3], connected objects can take the roles of sensors, actuators, controllers, or activity monitors [6].

Nowadays, learning activities related to Internet of Things technologies present a great challenge for educational institutes. Furthermore, all Master specialization are not familiar with the required knowledges of Internet of Things, electronics and related computing. Teaching Internet of Things for non-initiated public presents an important challenge. Hence, this paper is dedicatted to the scientific to make the learning process of IoT much easier. It aims to design a new protocol of practical works which lead progressively students from basic knowledge in Python programming and Low-Power Wide-Area communication protocol to the interaction of connected objects together without human intervention.

The learning protocol dedicated to Internet of Things, presented in this paper, is developed for Architect Engineer Master Student at the University of Mons (Belgium). We propose to explore different sensing methods in order to gradually lead students to understand different concepts and methodologies used in the Internet of Things.

This paper completes the first learning protocol dedicated to Smart Home [7].

II. Related Work

Others learning dispositive have already been proposed such as Gonzalez et al. in 2008, which proposed an architecture based on using a NOKIA 6131 NFC mobile phone and some RFID tags [8] in order to interact with physical space. Gómez et al. 2013 proposed an architecture composed of integrates NFC, QR code technology identication and communication protocols (3G or 4G) to interact with physical objects [9]. Fernandez et al. 2015 used led RGB, Arduino and Raspberry Pi for teaching Internet of Things to children from 10 to 12 years [10].

Another author wrote a book about internet of things along with step-by-step tutorials designed for Raspberry Pi [11].

This book explores state-of-the-art solutions for Internet of Things using different communication protocols, patterns, C# and Raspberry Pi. It aims to enhance our understanding about the capabilities and differences between popular protocols and communication patterns and how they can be used, and should not be used, to create secure and interoperable services and things.

More recently, He et al. [12] developed a learning dispositive for undergraduate students composed of Raspberry Pi, Arduino and a set of sensors supporting Zigbee. We also previously proposed a learning and practice dispositive for smart home [7].

III. Material & Software

Our learning hardware is composed of three material thematic packages:

- The first one is distributed individually or by groups of two students and contains LoPy material;
- The second package contains PyCom material where the objective is to extend capabilities of LoPy in order to use sensors;
- The third thematic package is composed of a common connected material using Ethernet connections to actuate related devices.

The main devices that compose our material package are:

1) **Nano LoRa Gateway:** A LoPy implanted on an extension board with one antenna WiFi and one antenna LoRa that ensures the transmissions of package LoRaWan on Internet via the Wireless network. We use the source code provided by PyCom on GitHub[1] to achieve the gateway (Fig. 1). This LoRa / Wi-Fi gateway is used in case of a The Things Network gateway is not available in close proximity. In this case, the Nano Gateway can be deployed to a gateway that is connected to The Things Networks. This latter is a free community LoRaWan network.

Fig. 1. Nano Gateway LoRaWan

2) **MQTT Server**: A Raspberry Pi 3 B+ with the last release of Raspbian that hosts the last version of Eclipse Mosquitto^{TM}, which is a lightweight of the MQTT Server supporting the MQTT protocol versions 3.1 and 3.1.1. The MQTT Server provides a publish / subscribe messaging service in order to distributes external data to subscribers.
3) **LoPy devices:** Each couple of students received an individual kit composed of an LoPy (Pycom), an USB cable, an expansion board 3, a Pysense board (Fig. 2), a bread board, a temperature and humidity sensor DHT22, a set of resistors, breadboard and a set of cables. PyCom microcontrollers are equipped by a Dual Processor Espressif ESP32 chipset, a hardware floating point acceleration, support hash/ encryption SHA, MD5, DES, AES and is provided of 2 UART, SPI, 2 I^2C, I^2S, micro SD card and a Real Time Controller (RTC) at 32.768Hz. The deep sleep mode consumption is only of 10 μA and the hibernation mode 1 μA. Furthermore, all these microcontrollers weighs only 7g and support SSL/TLS and WPA enterprise. The firmware of each LoPy must be upgraded before beginning to code[2] in version 1.18.1 r1 or higher. The firmware of the Pysense must be upgraded in version 0.0.8 or higher[3] before using it.

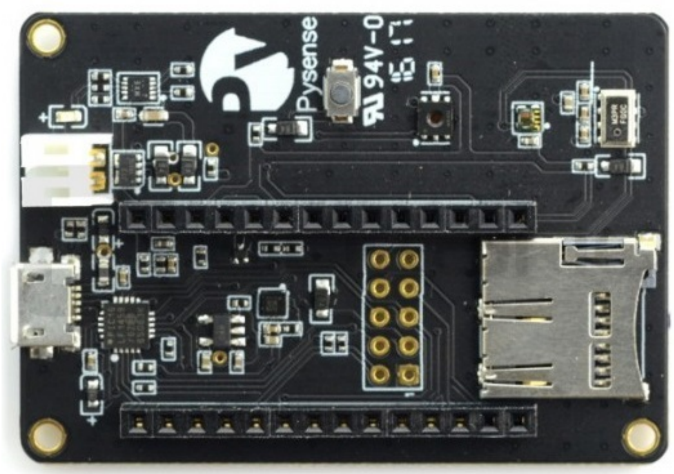

Fig. 2. Pysense

4) **Actuation material:** The actuation material that we used contains on one hand a Connected Relay Module, which allows to activate a set of 16 Relay Module Card by mean of a web module WEB_Relay_Con V.1 (GeekTechnesNC1601) (see Fig. 3). The Web module is especially connected on network with Ethernet interface. Each relay can be switched on or off from a simple formatted url[4]. Each relay is individually isolated by an optocoupler, which isolates the relay control circuits in

[1] https://github.com/pycom/pycom-libraries/tree/master/examples/lorawan-nano-gateway

[2] https://docs.pycom.io/chapter/gettingstarted/installation/firmwaretool.html

[3] https://docs.pycom.io/chapter/pytrackpysense/installation/firmware.html

[4] https://www.banggood.com/Ethernet-Control-Module-With-16-CHs-Relay-For-Arduino-LAN-WAN-WEB-Server-RJ45-Android-iOS-p-1189019.html

12Vdc from the voltage actuated by relays, which can go up to 230Vac / 30A. The Web module is powered by 5Vdc.

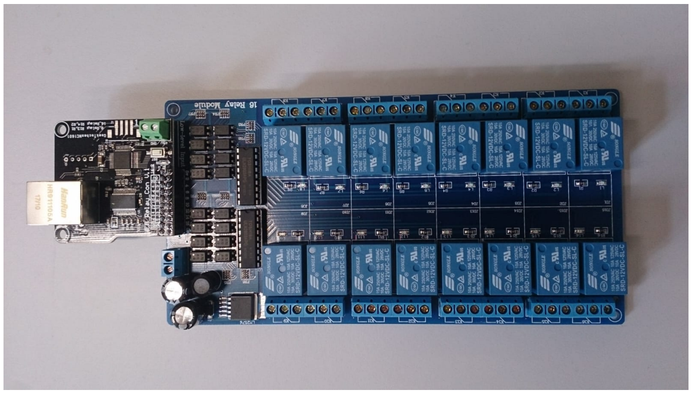

Fig. 3. Relay module with its Ethernet module

On the other hand a M-Duino PLC Arduino ARDBOX PLC 20 I/Os RELAY HF (see Fig. 4) based on an Arduino Leonardo used for each group of students which provides: 1 Serial Peripheral Interface (SPI), 1 Inter-Integrated Circuit (I^2C), 1 RS485 serial communications (Half-Full Duplex), 1 USB port, 10 digital inputs (5-24 Vdc) with 6 configurable by software in Analogs input (0-10 VDC), 8 outputs (Relay 220 VAC).

Fig. 4. M-Duino PLC Arduino ARDBOX PLC 20 I/Os RELAY HF

In terms of software, Atom[5] 1.32.0 and higher with the Pymakr Atom Package[6] 1.4.5 and higher are used to provide a relationship between the different control chains. The installed application allows to program respectively Pycom microcontrollers and upload application on devices by mean of an usb connection between a computer and the expansion board.

Node-Red [13] is used to provide a relationship between different control chains. This application is installed on the top of Node.js [14] LTS 8.x and allows to interconnect a system objects.

[5]https://flight-manual.atom.io/
[6]https://atom.io/packages/pymakr

IV. Methodology

The learning protocol designed in our practical work aims to allow to students to connect devices like LoPy to a computer and achieve some sensing actions according to the information gathered from the connected devices. In the remaining of this section we will describe the different steps of this process:

A. *First connection in LoRaWan*

The aim of this first experimentation is to familiarize students with the foundation of programming on LoPy and Atom with Pymakr package manipulation and establish a connection with the LoRaWan Network.

This stage needs a personal computer with Atom with Pymakr package installed, 1 LoPy, 1 pigtail, 1 antenna LoRaWan, 1 USB cable A male - micro B male.

At this stage, students use a LoPy, which is directly connected to a personal computer by a USB cable. The first manipulation consists to create a free account on The Things Network. Then, they create a new application and add the device in this application with an activation method Over-The-Air Activation (*OTAA*). This activation method provides a better security level than Activation By Personalisation (ABP) (*ABP*) method.

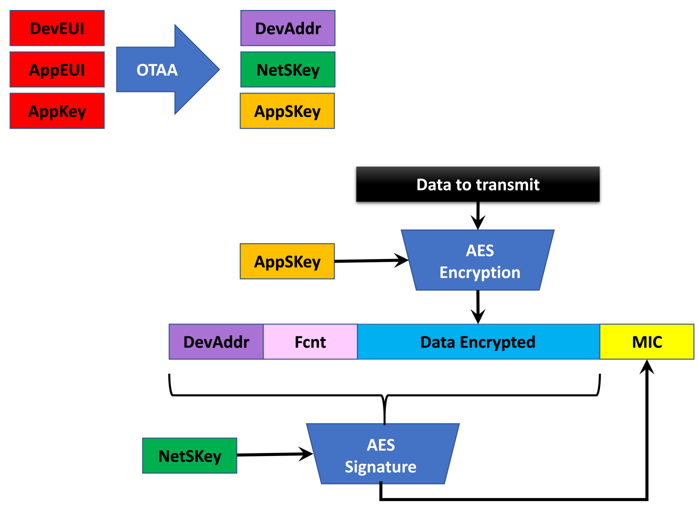

Fig. 5. Flowchart of authentication and transmission of data

The Things Network provides in return on one hand an Application Identification (*AppEui*) and on the other hand an application key (*AppKey*). Students upload a software provided to them on the LoPy, which displays the identification in hexadecimal of the device (*DevEui*). This key must be modified in The Things Network in the corresponding device previously registered in the console. These mandatory parameters allow to create three others (*DevAddr*, *NetSKey*, *AppSKey*), which are needed for the authentication and the double encryption of the device data (see Fig. 5).

Students received a program where they must add AppKey and AppEui parameters before uploading it in the LoPy. The RGB led of the LoPy indicates the connection state of LoRaWan Network and allow students to verify visually the correct configuration of the material. The red color indicates the initialization state, flashing red indicates the connection attempts and the blue color a established connection with the LoRaWan Network. Students achieve this stage in approximately 30 minutes.

B. First transmission of data

The aim of this second application is to transmit data coming form a single sensor to the LoRaWan Network. As in the first stage students receive a code to complete with AppKey and AppEui before to upload in the LoPy.

This stage needs a personal computer with Atom with Pymakr package installed, 1 LoPy, 1 pigtail, 1 antenna LoRaWan, 1 expansion board, 1 breadboard, 1 Distance sensor HC-SR04, 1 set of cables for breadboard male-male, 1 USB cable A male - micro B male.

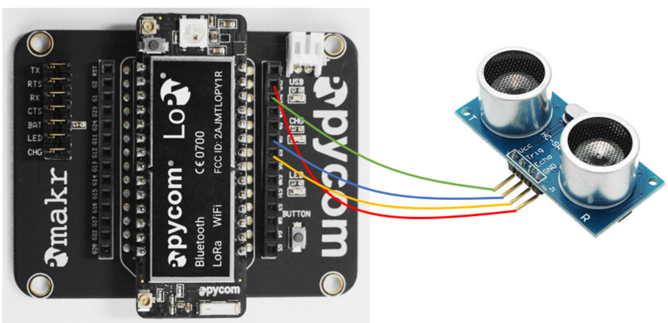

Fig. 6. Implantation schema of the HC-SR04

Students must also implement the Node Red flowchart below. As shown in Fig. 7, a node MQTT using server address: *eu.thethings.network:1883* retrieve data from TTN. The user and the password to use are respectively: the application id and the default key. The function parse data in JSON and convert them from base64 to ASCII characters. Finally, a debug node allows to see decoded data.

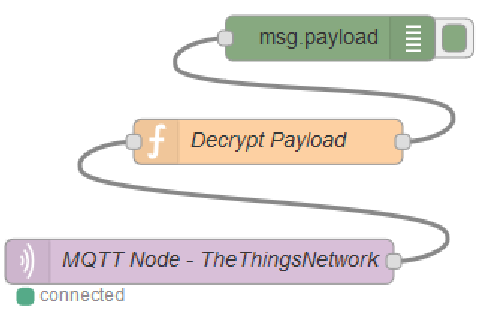

Fig. 7. Node Red Schema used to decode the HC-SR04 data

Students achieve this stage in approximatively 40 minutes.

C. Transmission of multi data from one sensor

The aim of this third experimentation is to transmit several data from a unique sensor to the LoRaWan Network.

This stage needs a personal computer with Atom with Pymakr package installed, 1 LoPy, 1 pigtail, 1 antenna LoRaWan, 1 expansion board, 1 breadboard, 1 DHT22, 1 set of cables for breadboard male-male, 1 USB cable A male - micro B male.

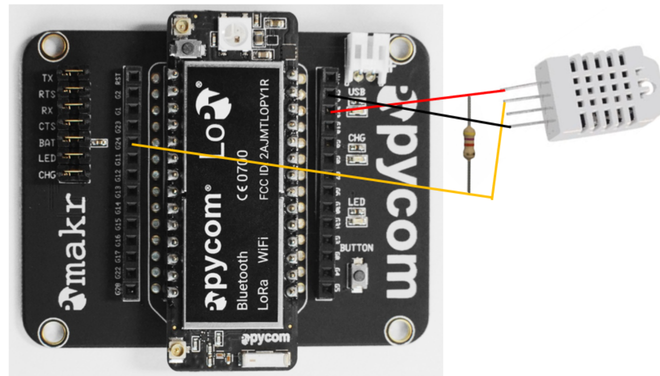

Fig. 8. Implantation schema of the DHT22

At this stage, students implement one temperature and relative humidity sensor with a resistor in serial on a LoPy and then create a basic program to connect to the LoRaWan gateway and send the value measured by the temperature sensor (see Fig. 8). Then, they adapt the Node-Red flowchart of the previous exercise to add a new splitting data and show a debug node to show splitted data (see Fig. 9).

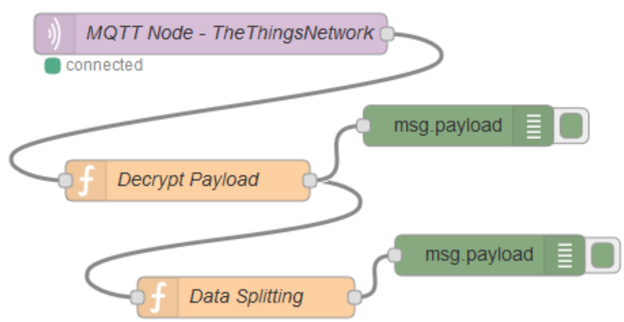

Fig. 9. Node Red Schema used to decode the DHT22 data

Students achieve this stage in approximatively 40 minutes.

D. Use of multiple sensors

The aim of this fourth experimentation is to collect data from multiple sensors and send data on The Things Network which are retrieved by Node-Red to show them in a dashboard.

This stage needs in addition to the material used in the previous exercise, a Pysense board. This board is used in replacement of the DHT22 to register temperature, ambient light, barometric pressure and humidity data.

The LoPy is extracted from the Expansion Board and plug in the Pysense Board (see Fig. 10). Student must implement

Fig. 10. LoPy with Pysense

the Node-Red flowchart below to create a dashboard[7] in Node-Red (see Fig. 11).

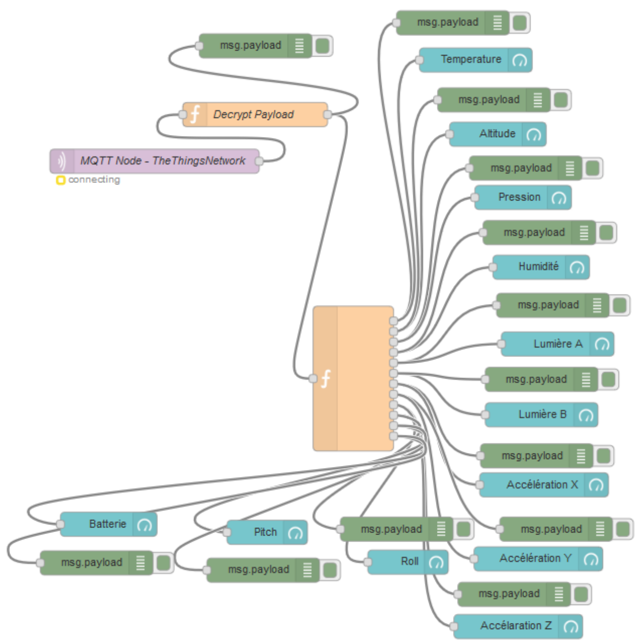

Fig. 11. Node Red Schema used to dashboard the Pysense

The dashboard in Node-Red uses Gauge Node split into different groups. The Fig. 12 shows the presentation of the expected board.

Students accomplish this stage in approximatively 90 minutes.

E. Chain sensor to actuator

In the final stages, students have learned to send data on the LoRaWan Network (The Things Network - TTN), retrieve data to create a dashboard on Node-Red. In the Internet of Things, actuators generally controlled remotely are used to perform actions on the external environment in reaction of stimuli.

[7]https://flows.nodered.org/node/node-red-dashboard

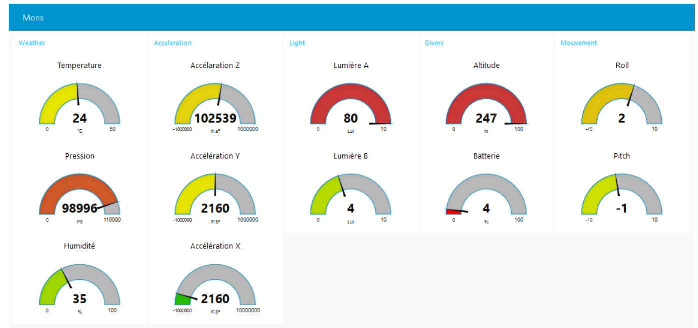

Fig. 12. Node Red Dashboard

The aim of this experimentation is to use Node-Red to control an actuator connected with an USB cable to personal computer and turn on or off a relay which opens or closes a circuit powered according to the value of the sensor transmitted via the LoRaWan protocol to TTN.

In this step, we will use for each group: 1 programmed M-Duino with its 12 Vdc power supply, 2 USB cable A male - micro B male, 1 LoPy mounted on a Pysense board, 1 pigtail, 1 antenna LoRaWan, 1 red led, 1 breadboard, 1 resistor of 4.7 Kohm, 1 set of cables for breadboard male-male, 1 Power supply 4 x AA batteries and 1 personal computer. Each group of students make a circuit with the red led, the resistance and the 6V power supply on a breadboard and verify that the led light. This circuit is then interrupted and connected to the relay R1 of M-Duino. Node-Red and its extension module TTN[8] will be used to retrieve data from TTN. The exceeding of a threshold value is verified and the relay is activated or not in function of the parameter value. Both strings are provided to students which must send them to M-Duino via Node-Red to activate or deactivate the relay R1. Students must implement the flowchart shown in the Fig. 13

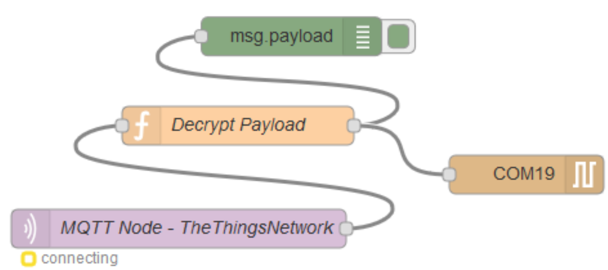

Fig. 13. Node-Red schema to turn on/off relay on the M-Duino

Students achieve this stage in approximatively 40 minutes.

F. Multi sources of data

In the previous stage, we have seen the implementation of a chain from sensor to actuator. In the Internet of Things data

[8]https://www.npmjs.com/package/node-red-contrib-ttn

are not only coming from sensors of the application but from other sources that must be considered to take a better decision.

The aim of this stage is to use, simultaneously, on the one hand, data from sensors transmitted by a LoRaWan network and on the other hand an open data external source accessible via an MQTT server.

In this step, each group of students will use: 1 USB cable A male - micro B male, 1 LoPy mounted on a Pysense board, 1 pigtail, 1 antenna LoRaWan, 1 personal computer and in common for all groups a Connected Relay Module connected to the local network by means of an Ethernet cable. Each group of students received two URL associated to a relay of the Connected Relay Module to respectively turn on or off the relay. The URL must be sent using Node-Red to the Ethernet device. The Fig. 14 shows the scheme, which must be implemented in Node-Red to retrieve date from a device. The App and the Device Id must be customized in the TTN node. External data are available by subscription to a topic of the MQTT Server hosted by the Raspberry Pi 3 B+.

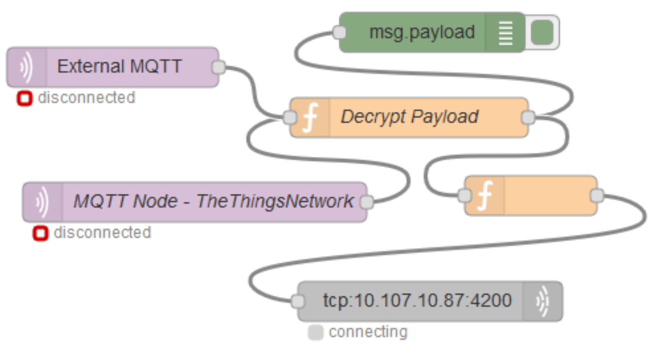

Fig. 14. Node-Red schema to turn on/off the Ethernet device

Students achieve this stage in approximatively 50 minutes.

V. Conclusion

The learning protocol proposed in this paper lead students in a first time to be able to manipulate an LoPy directly connected to their own computer. This learning protocol use successively individual and integrated sensors on a board to send data by LoRa modulation to a gateway of The Things Network. Then, an integration with a Cayenne database is used to store data and at the end create a dashboard. The next stage use Node-Red to interface The Thing Network with a local USB actuator. Finally, Node-Red is used to interface TTN network with an Ethernet device and subscribe to external data by mean of MQTT protocol. The proposed protocol has been experienced with 2^{nd} Master Engineer students specialized in Architecture of the Faculty of Engineering at the University of Mons. Indeed, on of the main weakness of our approach is to be dependent on LoPy Pycom with the risk of unavailability, disappearance or incompatibility with future versions of the hardware. The disappearance of LoPy microcontrollers is less likely. Therefore, it is necessary to be independent of the manufacturers in order to perpetuate practical works.

The learning and practice of Internet of Things allows to advance the state of this technology amongst the whole community in order to emerge new use cases and open the doors of news research nuggets in the field of Smart City.

As future work, we plan to: (1) replace LoPy microcontroller by FiPy which support SigFox and NB-IoT protocols (2) exploit GPU Tegra Mobile Processors that offers high computation power thanks to the exploitation of GPU processors in parallel [15] [16]. In addition to the high performance, the parallel implementations would offer lower power consumption [17] as result of the fast treatment.

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