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Internet of Things Learning: a Practical Case for Smart Building automation

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***Abstract*—The Internet of Things (IoT) is becoming more and more present in our daily lives and affects all areas of activity. More and more devices capable of interacting with each other are being designed and appearing on the market. Learning about IoT technologies is becoming inevitable in education. In this article, we propose a demonstrator to learn, through use cases, the essential concepts of IoT applied to Smart Homes. From basic use cases implemented in a model building, the general public can more easily understand the operating principles of these new applications, which opens the door to the imagination of new ones.**

***Index Terms*—Internet of Things, IoT, Smart building, Demonstrator, General Public, automation**

I. Introduction

The Internet of Things is a new paradigm fundamentally different from the Internet of machines in which a wide range of various smart interconnected devices from a functional and technical point of view are dynamic, distributed, and communication with low throughput. [1] [2]. These devices also named ”nodes”, include sensors, actuators, machines, autonomous devices, drones, and intelligent cameras, etc [3], are generally compact with communication capabilities, identified by their names and addresses, with computing capabilities, powered by batteries or solar panels [1] [4]. Nodes are dynamic and have self-adaptive capabilities, in addition to that they are self-configurable and support interoperable communication protocols. These smart objects can be producers, data-consuming or endorse both roles [5]. The number of devices connected is estimated at horizon of 2021 are about 36 billion, among these 3 billion of smartphone and 1 billion of wearable devices. In the meanwhile, global IP data traffic will increase and should reach 280,000 petabytes per month [6].

Nowadays, popularization related to IoT technologies present a great challenge for educational institutes. Furthermore, General Public is not familiar with the required knowledge of IoT, electronics and related computing. Making familiar IoT for non-initiated public presents an important challenge. For this reason, we aim in this paper to design a demonstrator which lead progressively the General Public from basic use cases to more sophisticated interaction of connected objects together without human intervention. We illustrate in this paper a practical case of Internet of Things dedicated to home automation.

This paper completes the previous version of smart home [7] and smart city [8] practical works for student of engineering. The Smart Home demonstrator presented in this paper is developed for common IoT technologies with a large audience. It has been developed in order to explain the basic concepts of IoT applied to Smart Home to General Public by the concrete implementation of a real use cases.

II. Related works

Other learning materials have already been proposed in the literature. We can list for example the work of Szydlo et al. [9] which use Copernicus board that is an electronic module equipped with 8-bit AVR micro-controller in association with Intel Galileo board. This solution combines the advantage of a micro-controller associated to a microprocessor that allows us to do the experiment: (1) direct connection of sensors to a microprocessor with active query of the state; (2) connection via a micro-controller in order to illustrate event-driven approach.

Mylonas et al. [10] have suggested an educational lab kit based on GAIA, a developing IoT platform that combines sensing, web-based tools and gamification elements to change the behavior of students and teachers in terms of energy consumption in order to obtain sustainable results. GAIA uses hands on approach based of guides an already assembled devices, commercial IoT sensors and actuators to avoid using cables and breadboards. They also use GrovePi connectors simplify connections between elements.

Akiyama et al. [11] present an educational method that achieves stepwise construction of an IoT prototype system divided into IoT device, IoT gateway, network and cloud. In

*Olivier Debauche and Saïd Mahmoudi are co-first authors the first step, the students produce circuit with sensors and actuators. The second step is the range of IoT devices, sensor networks and IoT gateways. The third step adds the Internet and the cloud / server to the composition of the second step. At the fourth step, students construct a system that transmits the commands to the actuator and the data value to the cloud.

III. Background

In previous works, we have developed a practical approach allowing to progressively learn, by practicing important concepts of IoT applied to smart home [7] and smart city [8]. From basic knowledge of C++ and Python languages and the use of micro-controllers Arduino or its derived and micro-controllers Pycom such as LoPy, students can develop specific IoT related skills and also smart applications in the field of IoT. Nevertheless, our approach was designed for engineering students. In other term, it requires prior technical background which is not adapted for a general public. We have also developed different use cases such as cattle behavior [12] [13] [14], farm animals' behavior [15], the health of beehives [16], connected pivot-center irrigation [17], landslides monitoring [18], bird nesting [19], smart campus [20], urban agriculture [21], elderly and patient monitoring [22], smart poultry [23], AI-IoT [24], urban gardening [21] [25], IoT demonstrators [26] [27] and digital phenotyping [28] [29]

IV. Materiel & Software

Our demonstration hardware is composed of three material package:

- **Smart Home** comprises a Smart Home Automation, a sensor of commercial and Do-it-Yourself sensors which communicate principally with Wi-Fi Protocol.
- **Smart Building** is based on independent shoe boxes in which use cases are implemented. In this package, ESP32 low cost micro controllers are used while an MQTT server plays a central role in exchanges between micro-controllers.
- **Smart Cities** uses ESP32 micro-controllers equipped of LoRa chip that allows to transmit information to The Things Network.

The main devices that compose our material packages are:

1) **MQTT Server:** A Raspberry Pi 4B runs on last release of Raspberry Pi OS and hosts the last release of Apache and Eclipse Mosquitto^{TM} which are respectively a web server and an MQTT server supporting the MQTT protocol versions 3.1 and 3.1.1. MQTT is an extremely lightweight publish-subscribe machine-to-machine protocol where published data is automatically sent to all subscribers. MQTT works similarly to a mailing list.

2) **Smart Home Sensing & Actuating:** A Raspberry Pi 4B runs the last version of Home-Assistant software with ESPHome[1] integration. ESPHome allows to control ESP32 from a simple configuration files and control them remotely through Home Automation systems.

3) **Smart Building Sensing & Actuating:** ESP32-WROOM-32 is equiped with a Wi-Fi interface that allows it to communicate with the local gateway configured in Access Point. We use Arduino IDE to program it in the same way as an Arduino UNO. ESP32-Wroom-32 contains a Xtensa dual-core 32-bit LX6 microprocessor at 240 MHz, 520 KiB SRAM, 4 MiB Flash Memory. Moreover it provides 12-bit SAR ADC up to 18 channels, 2 DAC of 8-bit, 10 GPIO, 4 Serial Peripheral Interface (SPI), and 2 Inter-IC Sound (I^2S), 2 Inter-integrated Circuit (I^2C).

4) **Smart City Sensing & Actuating:** This variant of the previous micro-controller is equipped in addition with a Semtech Sx1276 chip which allows transition of data on a LoRaWan network by means of LoRa frequency modulation at 868 MHz.

5) **Sensors:** The HC-SR04 is a digital sensor using ultrasonic technique to measure the distance with obstacle in centimeters (Fig. 1).

Fig. 1. HC-SR04

The TE174 infrared obstacle detection digital sensor allows the detection of obstacles. The coupling two of these sensors can detect the entry and exit of people in a room (Fig. 2).

Fig. 2. Infrared Sensor

The TSL2591 is a I^2C which measures the intensity of light in Lux (Fig. 3).

Fig. 3. Light Intensity Sensor

The DTH22 is a I^2C sensor that allows to measure the Air temperature in Celsius degree and Relative Humidity expressed in percent (Fig. 4).

[1]https://esphome.io/

Fig. 4. Temperature & Humidity Sensor

The BME680 is a I^2C sensor that measures the temperature, relative humidity and Volatile organic compounds (VOC) concentration (Fig. 5).

Fig. 5. Temperature, Relative Humidity and VOC Sensor

6) **(Optionally) LoRa Gateway:** A mobile gateway composed of a Raspberry Pi 4B and a RAK833 HAT and can be used when no LoRa Antenna of The Things Network is available in the vicinity.

7) **(Optionally) IoT Platform:** Thingsboard Server: a Open Source IoT platform is installed on another Raspberry Pi 4B and can be used to visualize sensing data.

V. Methodology

The learning protocol designed in our demonstrator aims to provide the General Public, makers and hobbyists to discover basic foundations of Internet of Things and related communication protocols. This protocol is composed of three parts. The former is dedicated to Smart Home and illustrates a set of home automation process through different use cases implemented in six rooms of a house model. The second displays the operation of a Smart Building with certain specificities and constraints related to the size and the structure of buildings. The latter develops the foundation of smart city which covers large areas and use high propagation protocols. In following sections, we will describe the different use cases for each domain of applications.

A) *Smart Home*

In this part, nodes are connected to concentration nodes by means of classic Internet protocols such as Ethernet, Wi-Fi or low propagation communication protocols such as Bluetooth, Zigbee, Xbee, etc. Home Assistant is an open source platform able to interface a wide panel of commercial sensors and actuators but also DIY sensors and actuators, and retrieve data from external services. In our Smart Home demonstrator, we use Philips Hue and a ESPHome a system which controls ESP32 networks. Both are supported by Home Assistant, a open source home automation.

1) **Health of Plants:** In this use case, we show the concentration data on central nodes before forwarding data to an IoT Platform Home Assistant (see fig. 6).

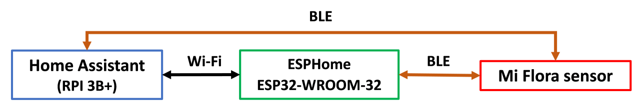

Fig. 6. Health of Plants Use Case Schema

We have connected a Xiaomi Mi Flora sensors (see fig. 7) to a ESP32[2] that play the role of gateway between the sensor and Home Assistant. Mi Flora Sensor measures soil moisture, sensor send data with Bluetooth Low Energy to the ESP32 which forwards them to the Home Assistant via a Wi-Fi transmission.

Fig. 7. Xiaomi Mi Flora sensor.

2) **Ambient conditions:** In this use case, we illustrate the direct sensing by an ESP32 and the sending of data to an IoT Platform (see fig. 8).

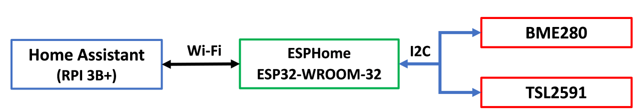

Fig. 8. Ambient conditions Use Case Schema

A Bosch Sensortec BME280 measuring temperature, humidity, and air pressure and a TSL2591 sensing light level. Both are connected via I^2C bus to an ESP32 that transmits data to Home Assistant.

3) **Connected Lighting:** This use case, show the integration of commercial device using proprietary technologies with an IoT Plaform (see fig. 9).

We have installed a Philips Hue connection bridge connected to the Ethernet Network. Philips Hue can

[2]https://esphome.io/components/sensor/xiaomi_miflora.html

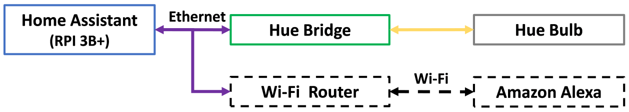

Fig. 9. Connected Lighting Use Case Schema

be control directly via un smartphone or via Home Assistant or eventually with an Amazon echo.

B) *Smart Building*

In this part, sensors are connected in more important mesh using traditional Internet protocols such as Wi-Fi and Ethernet but also other specific protocols such as KNX, ZWave, etc.

A building model composed of six independent rooms has been achieved (see Fig. 10). Each room use two ESP32 Wi-Fi (ESP32-WROOM-32): one for the sensing and the other for the actuating. A 13nd ESP32 achieves the sensing of common data for all rooms. Data sensing by this ESP32 are the rain detection. They also integrate a DS3231 - Precision Real Time Clock.

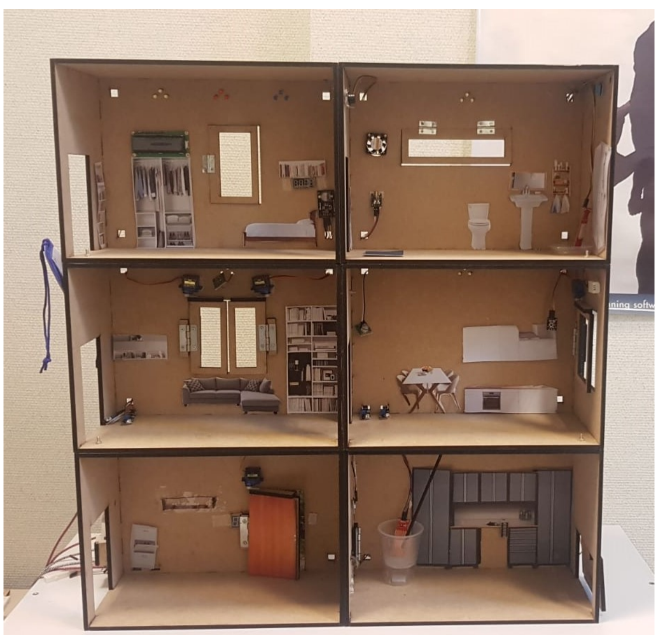

Fig. 10. Smart Building Model

1) **Kitchen:** This room implements a DHT22 temperature and air humidity sensor that open automatically the window with a servo-motor when the temperature in the kitchen exceeds 26°C. The opening and closing of the windows can also be achieved manually. The kitchen led lighting turns on automatically when the presence of a person is detected. However, this manipulation can also be activated or deactivated manually. The light intensity sensor (TSL2591) allows to vary led intensity (see fig. 11).

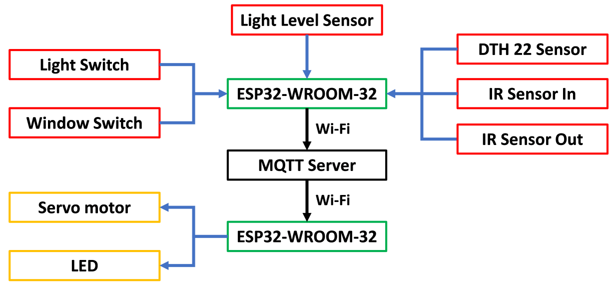

Fig. 11. Kitchen Use Case Schema

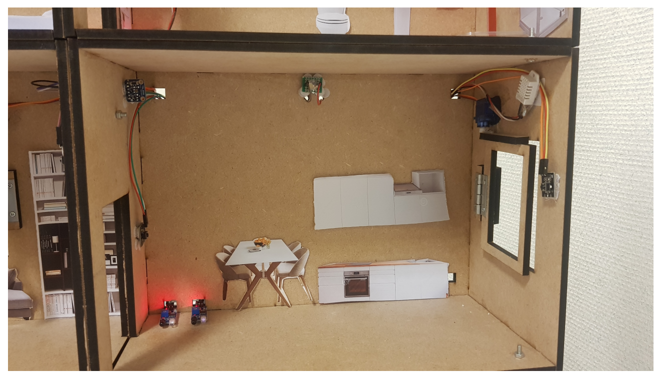

Fig. 12. Kitchen

2) **Bathroom:** The first use case of the bathroom is based on a CO sensor and a water level sensor which measure respectively the concentration of carbon monoxide and detect water leak that activates the buzzer in case of exceeding of the threshold. The second evaluates the light level [Lux] and turn on / off the light in function of this level. Two IR Sensors detect the entrance or the exit of persons in the bathroom and turn on/off the light. The light can also be tuned on/off by means of the Light Switch. The latter uses a DHT22 sensor that measures the temperature and Air Humidity and turns on/off the fan (see fig. 13).

3) **Bedroom:** A DHT22, temperature and Air humidity Sensor controls opening and closing of the windows in function of temperature and humidity limits. The window can also be opened or closed with the Window Switch. Two IR sensors detect entrance and exit of people and turns on/off the led lighting. A switch provides an manual switch on/off of the led light.

Two screens show information. The former one shows date and hours retrieved from MQTT Server and the second displays information from local sensors (see

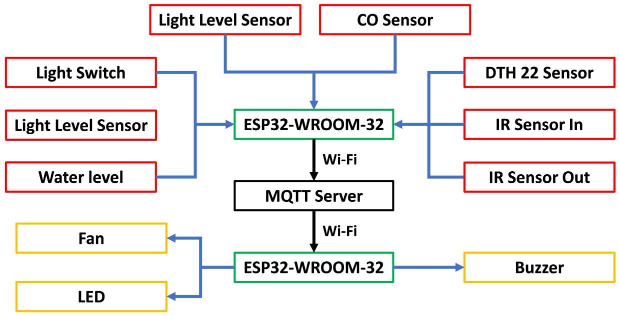

Fig. 13. Bathroom Use Case Schema

Fig. 14. Bathroom

fig. 15).

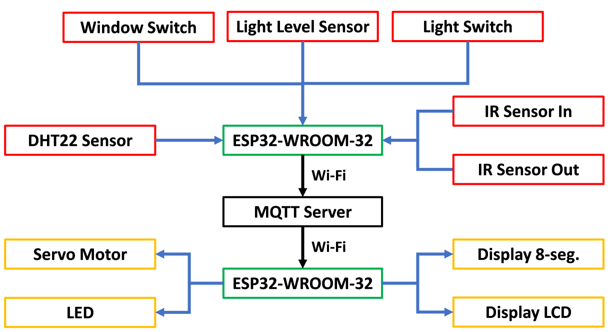

Fig. 15. Bedroom Use Case Schema

4) **Garage:** Three use cases are implemented in this Box. The main one uses a distance sensor to detect the car entrance and opened/closed the door of the garage. The second uses a water level sensor and displays the level of water on the Vu-meter Display. The third, detects the presence of humans in the garage and turns on the light. The light is turned off when they exit the garage (see fig. 17)

5) **Living Room:** This room implements two use cases. The first case allows to detect the presence of one person by means of two Infra-red sensors and activate the light when a people enters in the room. The light is turned off when the person exits the room. The light can be turned on/off manually by pushing on the light switch (see fig. 19)

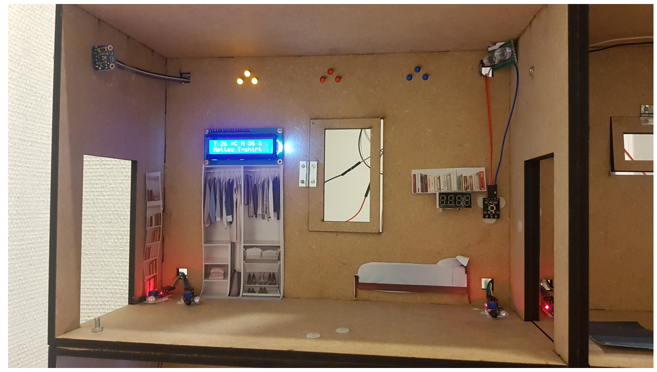

Fig. 16. Bedroom

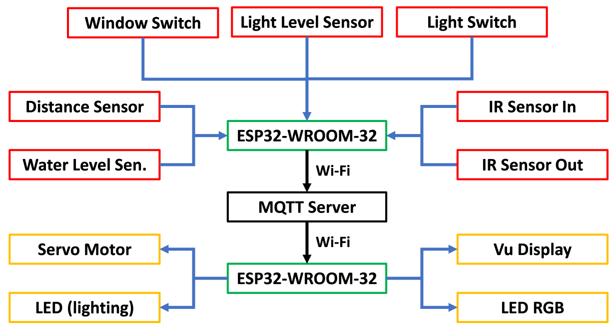

Fig. 17. Garage Use Case Schema

6) **Entrance:** In this room, the number of peoples is counted by a couple of IR sensors and is showed on the 8-segments display. A switch allows to prevent when a mail is received in the mailbox and a led is turned on in this case. Two switches allow to turn on/off the light or the window (see fig. 21)

7) **Greenhouse:** As shown in fig. 23, the first ESP32 measures soil moisture with three Irrometer Watermark

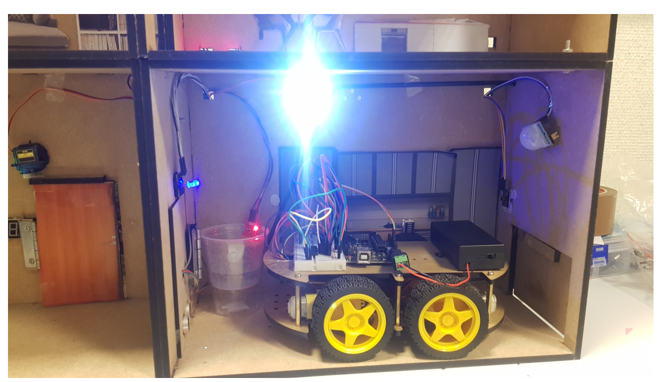

Fig. 18. Garage

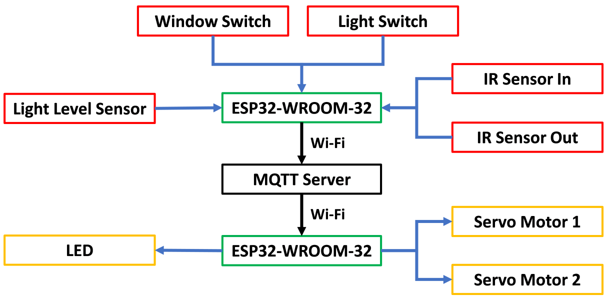

Fig. 19. Living Room Use Case Schema

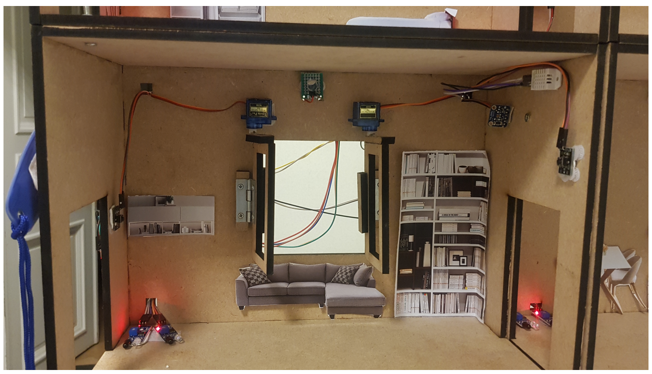

Fig. 20. Living Room

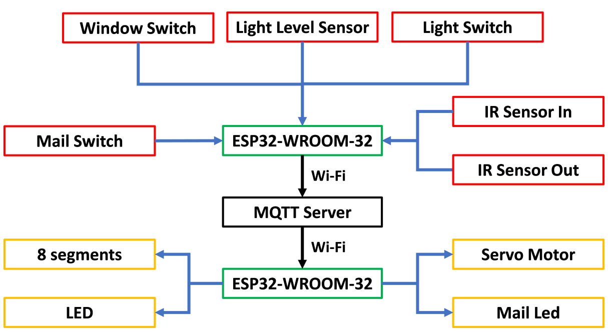

Fig. 21. Entrance Use Case Schema

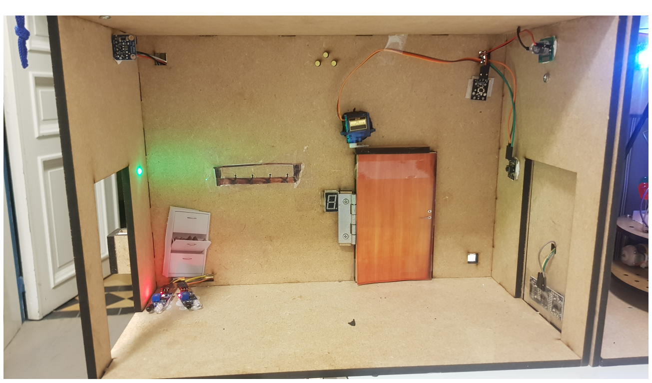

Fig. 22. Entrance

SS200 situated at depth 15, 25 and 35 cm. In addition a Dallas Semiconductor DS18B20 measures the soil temperature. This ESP32 acquires temperature, air pressure, air humidity with sensor BME280 Bosch SensorTec and Light Intensity with a TSL2591. All data is transmitted to the MQTT Server.

According to the values received from the first ESP32 via MQTT subscription, the second actuates via a 4-relays respectively two horticultural led ribbons, a peristaltic pump and an exhaust fan.

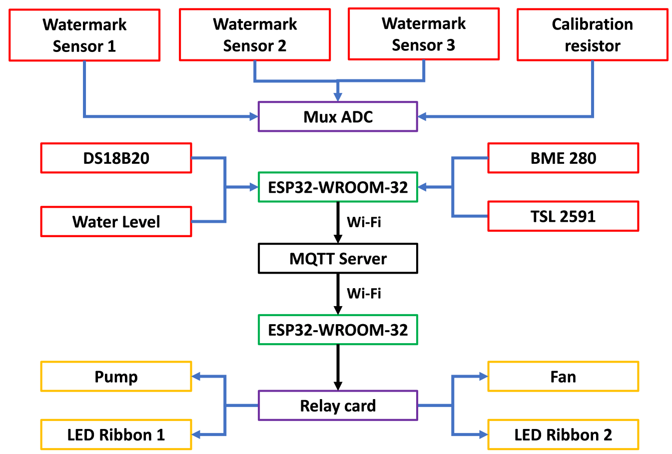

Fig. 23. Greenhouse Use Case Schema

C) *Smart City*

In the context of smart city, specific protocols such as LoRaWAN, SigFox, Ingenu, and Weigthless. are used. All these protocols come with trade offs between throughput and propagation. In addition, Internet protocols high throughput based on cellular network such as 3G, 4G and nearly 5G can be used but also low throughput protocols based on the same technology such as NB-IoT.

1) **Connected trash:** In this use case, the level of waste in the trash is evaluated with a HC-SR04 sensor (see fig. 24).

2) **Quality of Life:** This use case is composed of two nodes. The first is ESP32-Lora V2 for the sensing and an ESP32-WROOM-32 for the actuating. The actuating node is equipped with a BME680 sensor Bosh Sensortec that transmits temperature, relative humidity, and reacts to most volatile compounds polluting indoor air (one exception is for instance CO_2) level in the air and transmit their to the Things Networks by LoRa frequency modulation. An HTTP integration in The Things Network publish data by mean of POST request to MQTT server is achieved. The second node

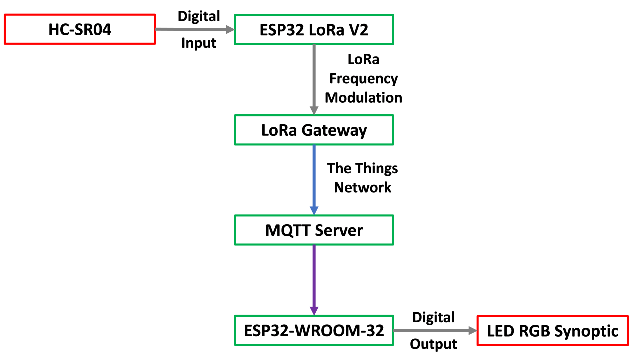

Fig. 24. Quality of Life Use Case Schema

subscribes to topics of the MQTT server, receive data and allow to control an RGB led in function of threshold values. In addition, the ESP32-Lora V2 is also equipped of a TSL2591 that measures the light level in lux with an operating range between 0 and 88,000 lux, and a CO_2 sensor using the NDIR technology (non-dispersive infrared) with a temperature compensation and an operating range from 0 to 5,000 ppm (parts per million), with an accuracy of ± 50ppm + 3% of the reading (see fig. 25).

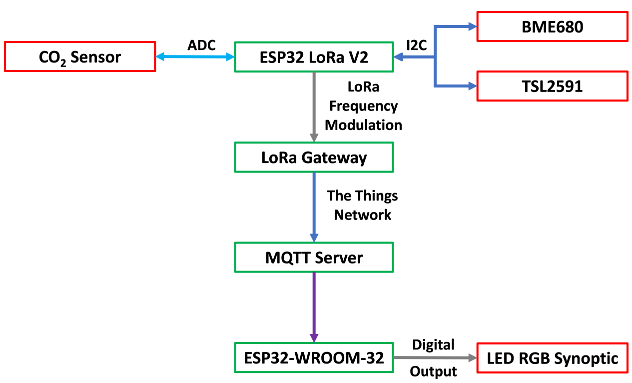

Fig. 25. Quality of Life Use Case Schema

VI. Conclusion

In this paper, we come up with several use cases implemented in three demonstrators to allow learning basic concepts of Internet of Things applied to a simple Smart Home, and then for a Smart Building and finally for a smart city. With this approach the General Public perceives the interaction between objects and understands the pros and cons of Internet of Things in their lives.

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