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Internet of things in health care: case of cardiovascular diseases in Congo Brazzaville

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Abstract

In this paper, we present the implementation of a system to prevent cases of cardiovascular disease by allowing patients to have optimal monitoring at a lower cost every day. To achieve this, a system containing a connected cardiogram was designed through telecommunications and digital technology. The results obtained are encouraging insofar as this system facilitates the permanent monitoring of the evolution of heart rhythm in patients. It also enables telemedicine for all doctors, physists and professors in Africa, as the number of specialists is very low. But broadband usage in Africa is about 46%; in Congo Brazzaville, for example, it is 5%, with internet costs very high compared to international offers and the Congolese minimum wage. This work is an important detail to take into account in the development of our work in order to reduce the costs of this digital surveillance as much as possible.

Introduction

It is unacceptable that some members of society are exposed to death, disability, illness and impoverishment for matters that could be dealt with at little cost. With technological advances in telecommunications, the transfer of information across a network is very fast, so the need to have information in real time is becoming a major concern. The IoT (Internet of Connected Things) is one of these advances and is now at the center of gravity of several fields, such as agriculture, intrusion detection, home automation, health, and many others; in this article we are interested in health, particularly in cardiovascular diseases.

Cardiovascular disease is the leading cause of death in the world. More people die each year from cardiovascular disease than from any other cause. An estimated 17.7 million deaths are attributable to cardiovascular disease, accounting for 31% of all deaths worldwide. Of these deaths, an estimated 7.4 million are due to coronary heart disease and 6.7 million to stroke (2015 figures).

In this article, we set up an optimal real-time prediction and monitoring system for cardiovascular patients in order to intervene and manage them quickly and efficiently.

Connected objects make it easier to monitor the evolution of heart rhythm in patients. But the broadband penetration rate in Congo is less than 5% and the costs of internet are very high compared to international offers and the Congolese SMIC, which is an important detail to take into account in the development of our work in order to reduce costs as much as possible so that we can facilitate widespread use. We will use the LoRa protocol which is based on LoRaWAN network technology, which will use existing GSM networks as gateways.

I. Technology used for implementation

I.1. Description of the LoRa technology

LoRaWAN is a communication protocol for the Internet of Things, which uses a proprietary spread spectrum modulation technique called LoRa. The protocol is intended to be simple, inexpensive to implement and energy-efficient, but does not allow high data rates. The target of LoRaWAN is clearly long-range, low-cost, low-power communications rather than high-speed communications, which are more CPU and energy-intensive [1].

I.2. Architecture

A LoRaWAN network consists of low-power wireless devices that communicate with application servers through gateways. The modulation technique used between the devices and the gateways is LoRa. The communication between the gateways and the servers is established via the IP protocol using an Ethernet or 3G backhaul network.

In the network sense, the devices are not connected to the gateways, they only serve as a relay to reach the server managing their application. The packets sent by the devices are retransmitted by the gateways after only adding information about the quality of the received signal.

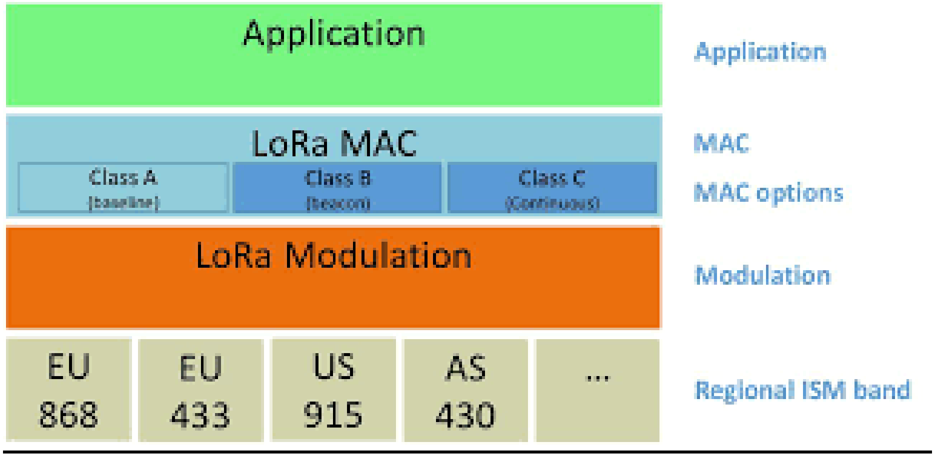


Figure 1: LoRa protocol network layer [1]

It is possible to retransmit the same message from a device, in which case it is duplicated in the collection network, with the server hosting the application ensuring the duplication of packets. This particularity allows, in particular, the localization of equipment by comparing the different arrival times for the same duplicated packet.

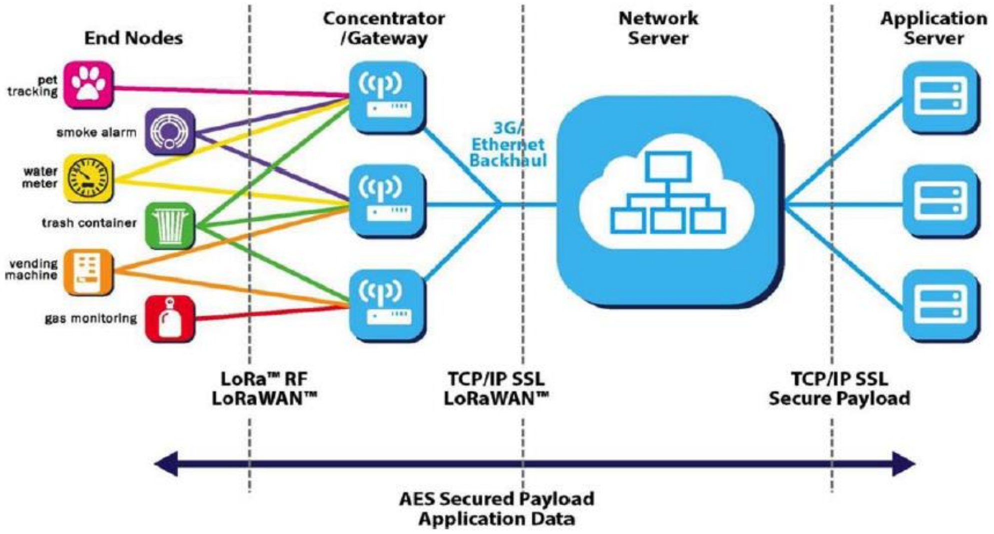


Figure 2: LoRaWAN architecture [1]

LoRaWAN does not allow direct dialogue between two connected objects. If such a dialogue is to take place, it is done through the application server. However, a 2017 study by Konstantin Mikhaylov shows that enabling LoRaWAN, if the end devices are close enough, improves their energy consumption by reducing the spreading factor needed to receive data [3].

I.3. Modulation of LoRA

Modulation is mainly carried out on the **ISM 868 MHz** radio bands in Europe and **915 MHz** in North America, while the Congo has not yet defined any frequency bands. The use of CSS modulation for the Internet of Things was patented by Cycléo, a French company that was acquired by Semtech in 2012. This modulation allows a distance between a gateway and a device of up to 5 km in urban areas and 15 km in rural areas [2].

The range of a LoRa communication is determined by its bandwidth, the output power of the signal and the spreading factor (SF). Spreading the signal increases its range, at the expense of throughput, as it is transmitted over a longer period of time. The spreading factor is usually set by the server when connecting a terminal device to the network, by sending a request to measure the signal-to-noise ratio.

LoRa defines the spread spectrum factor **(SF)**, expressed by the formula:

$$\boldsymbol{SF = log_2\left(\frac{R_c}{R_s}\right)} \tag{1}$$

with **Rc** being the rate of the transmitted message (Chirp) and **Rs** the rate of the symbol to be transmitted.

The following diagram illustrates the impact of signal spreading on the range and throughput of a LoRa communication (for the **868 MHz** band).

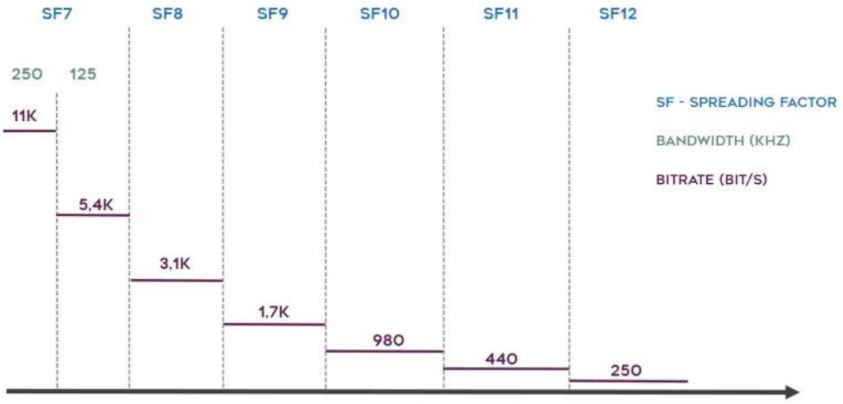


Figure 3: LoRa: Impact of spreading factor on range and throughput [10]

A LoRaWAN, based on LoRa modulation in the 868 MHz frequency band, supports 6 spreading factors (SF7, SF8, SF9, SFlO, SFll, SF12) as shown in the diagram above. The different SFs are orthogonal, which means that several frames can be received at the same time on the same channel provided they use a different SF. If two frames are received at the same time by a gateway with a difference of less than 6 dB on the same channel and with the same FS they will be lost as they cannot be differentiated [10].

I.4. LoRaWAN protocol

LoRaWAN is a media access control protocol. It is simpler to operate than cellular technologies which rely on powerful and therefore more expensive terminal equipment than that used in the Internet of Things. It is based on an ALOHA type of operation, so when a device must send data it does so without checking whether the channel it is going to use is available and retransmits the message after a random time if it has been lost [10].

The protocol defines 3 classes of equipment (A, B and C). Class A must be implemented in all equipment for compatibility. Equipment can change class during operation.

- Class A: has the lowest energy consumption. When the equipment has data to send, it does so without control and then opens two successive listening windows for possible messages from the server.

- Class B: This is a compromise between energy consumption and the need for two-way communication. This equipment opens reception windows at intervals programmed by periodic messages sent by the server.

- Class C: has the highest energy consumption but allows for two-way communication that is not programmed. The equipment has a permanent listening window.

In order to operate on the network, each equipment must be activated. Two activation procedures are possible:

- **Activation By Personalization (ABP):** The encryption keys are stored in the devices;
- **Over The Air Activation (OTAA):** The encryption keys are obtained through an exchange with the network.

I.5. Geolocation

Thanks to several gateways around them and powerful processing algorithms, it is possible to set up a geolocation system using **LoRa** technology without using any **GPS**, which is not the case in this article.

II. Application to health: the case of a connected diagram

As the Congo has not defined the standards for LoRaWAN, we aligned ourselves with the one established in Europe using the 868 Mhz band in order to set up our small-scale LoRaWAN network, which only has a gateway and is composed of

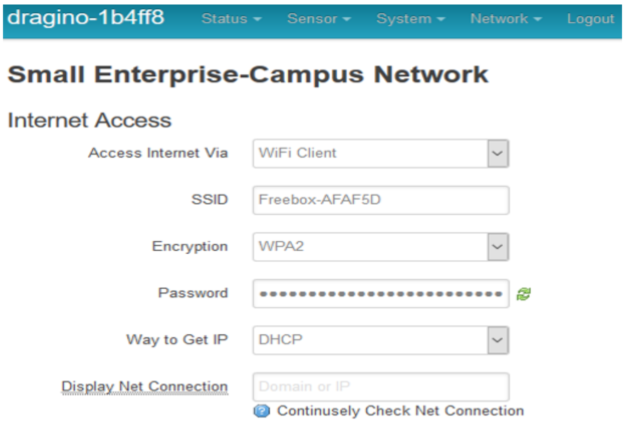
- a gateway and an internet network access point
- an application server;
- our connected health object for functional testing, called Life.

II.1. Design of the wireless network used

In order to minimise costs while taking into account reasonable performance, we opted for the Dragino LG01-P as the LoRa Gateway.

Figure 4: Dragino LG01-P

The **LG01-P** is an open source single-channel LoRa gateway. It allows the LoRa wireless network to be connected to an IP network via WiFi, Ethernet or 3G/ 4G cellular via the optional LTE module. It can support single frequency limited LoRaWAN protocol and custom LoRa transmission protocol. It has a WiFi interface, an Ethernet port and a USB host port.
In opting for the latter, we configured it to set up the network settings to connect to a WiFi access point and also set the LAN interface as the configuration interface; and also enable support for **LoRaWAN**; and also connect it to the network server by configuring the frequency settings.



Small Enterprise-Campus Network

Internet Access

Access Internet Via: WiFi Client

SSID: Freebox-AFAF5D

Encryption: WPA2

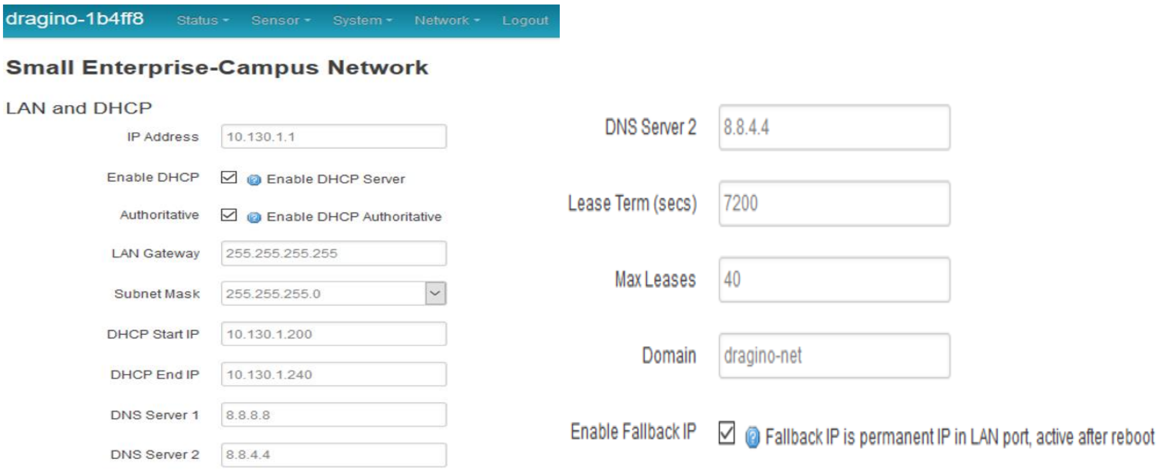
Password: ••••••••••••••••••••••••••

Way to Get IP: DHCP

Display Net Connection: Domain or IP

Continusely Check Net Connection

Figure 5: Configuring the settings of the wifi access point



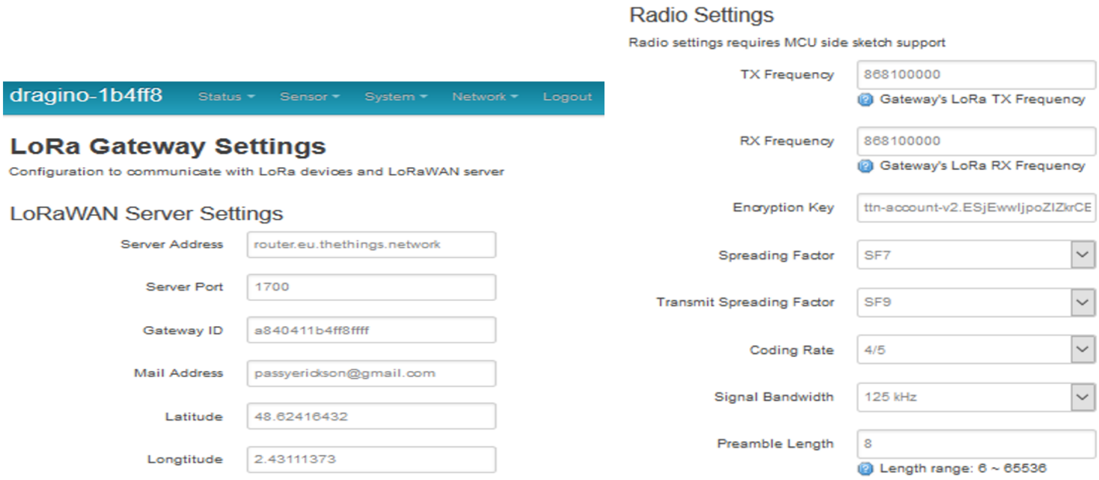
Small Enterprise-Campus Network

LAN and DHCP

IP Address: 10.130.1.1
Enable DHCP: ☑ Enable DHCP Server
Authoritative: ☑ Enable DHCP Authoritative
LAN Gateway: 255.255.255.255
Subnet Mask: 255.255.255.0
DHCP Start IP: 10.130.1.200
DHCP End IP: 10.130.1.240
DNS Server 1: 8.8.8.8
DNS Server 2: 8.8.4.4

DNS Server 2: 8.8.4.4
Lease Term (secs): 7200
Max Leases: 40
Domain: dragino-net
Enable Fallback IP: ☑ Fallback IP is permanent IP in LAN port, active after reboot

Figure 6: LoRaWAN Gateway Configuration



LoRa Gateway Settings

Configuration to communicate with LoRa devices and LoRaWAN server

LoRaWAN Server Settings

Server Address: router.eu.thethings.network
Server Port: 1700
Gateway ID: a840411b4ff8ffff
Mail Address: passyerickson@gmail.com
Latitude: 48.62416432
Longtitude: 2.43111373

Radio Settings

Radio settings requires MCU side sketch support

TX Frequency: 868100000
Gateway's LoRa TX Frequency
RX Frequency: 868100000
Gateway's LoRa RX Frequency
Encryption Key: ttn-account-v2.ESjEwwIjpoZIZkrCE
Spreading Factor: SF7
Transmit Spreading Factor: SF9
Coding Rate: 4/5
Signal Bandwidth: 125 kHz
Preamble Length: 8
Length range: 6 ~ 65536

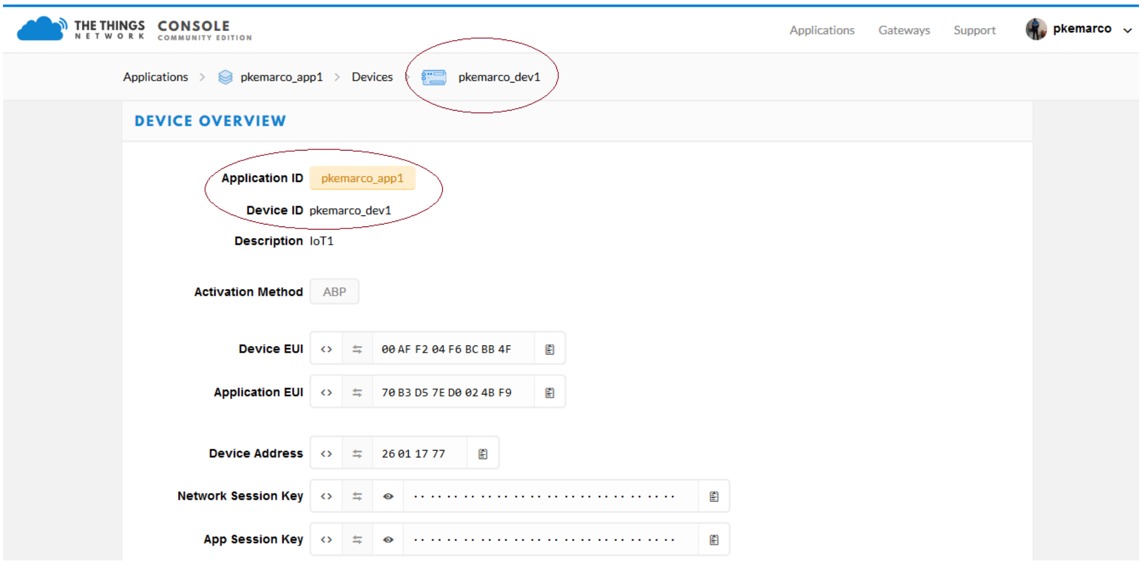
Figure 6: Dragino LoRaWAN server configuration and radio settings

These interfaces provide users with flexible methods to connect their sensor networks to the Internet. It uses the OpenWrt open source system, the user is free to modify the source file or compile the system to support their custom applications.
In opting for the latter, we configured to :

- set up the network parameters to connect to a Wi-Fi access point and also define the LAN interface as the configuration interface;
- enable support for LoRaWAN;
- link it to the application server by also configuring the frequency parameters.

II.2. Network server

We chose The Things Network as our network server. This is a worldwide open-source community network for the Internet of Things using LoRa technology. It is possible to use this network freely but it is also possible to help extend the network by deploying gateways. The latter will serve as a network server. And the data it receives will be routed to the application server of our choice. To use it, we need to create an account, register our gateway, create an application, and define within an application the connected objects that will use it.



Application ID pkemarco_app1
Device ID pkemarco_dev1
Description IoT1
Activation Method ABP
Device EUI 00 AF F2 04 F6 BC BB 4F
Application EUI 70 B3 D5 7E D0 02 4B F9
Device Address 26 01 17 77
Network Session Key ································
App Session Key ································

Figure 7: TTN GateWay with our connected object

Rule of thumb: 30 seconds of waiting time per device per day for 10 bytes of payload, this translates into (approximately) :

- 20 messages per day at SF12
- 500 messages per day at SF7

III. Results and discussion

III.1. Constitution

Lifee is the name given to our autonomous connected object, which has been totally set up by our design. Its role is to retrieve the heart rate of its user as well as its geographical coordinates and then, after a display on its screen, sends these data through the internet via our LoRaWAN network set up for this purpose. This data, once on the internet, stored on servers can be used by doctors and even to generate alerts in the event of detection of problems for rapid intervention.

III.2. Pulse acquisition

In order to send the heartbeat, we first need to obtain it. This is a complex process that has already had various solutions. To do this, we chose to use a low-cost lighted pulse sensor. This works a bit like an optocoupler in that it emits light that will pass through the skin and reflect back to its photoreceptor and allow it to scan for variations in light levels and it is on the basis of these variations in light levels that it determines the heart rate of its user.

The problem with the heart rate monitor is that it is sensitive to noise from external light and even if it is not connected to a user, it still provides values. So, to remedy this, we have coupled it with a button that will specify whether it is placed on a person or not and allows the central processing unit to know whether the data from the sensor should be taken into account or not.

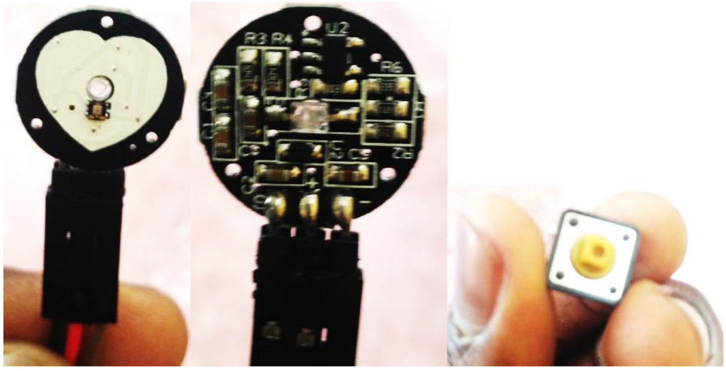


Figure 8: Pulse sensor with its specification button

This sensor generates an analogue signal within the limits of its power supply. Supplying it with 5V, the sensor thus generates a signal ranging from **0V** to **5V** showing variations in heart rate. The black wire is ground, the red wire is **VCC** and the brown wire is the output pin, **Vs**, producing an analogue signal based on pulse rate [8].

III.3. Pulse processing

The signal generated from the sensor is an analogue signal, but our system is digital. Therefore, we need to perform the conversion with an ADC. To do this, we decided to use an Arduino Uno, which is a microcontroller prototyping board that has a CAN. The latter will not only convert the generated signal into a digital value, but will also produce a real value of the pulse represented by this signal. The Arduino Uno is powered by 5V, has an Atmega328P that runs at 16MHz, 32KB of Flash, 1KB of EEPROM, 2KB of SRAM, 14 digital inputs/outputs with 6 supporting PWM and 6 analogue pins (with a CAN) [7].

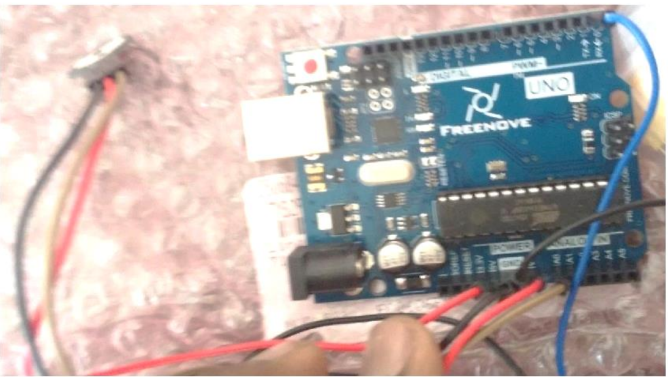


Figure 9: Arduino Uno for signal conversion and processing

The pulse thus converted by the Arduino follows the following pattern:

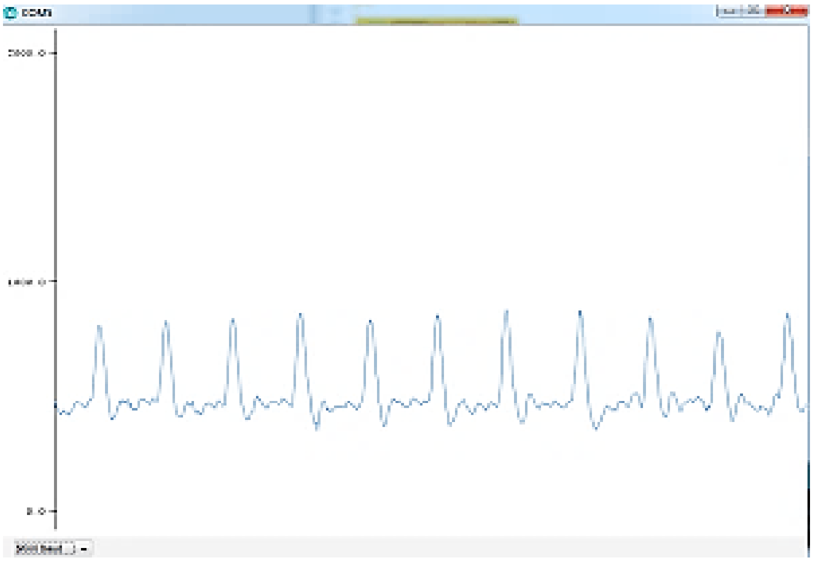


Figure 10: Pulse signal shape.

To be able to determine the actual pulse we had to develop a substantial computer program. The Vs pin of the sensor is connected to the A0 pin of our Arduino. This pin has an analogue-to-digital converter. Once the processing is complete, the pulse obtained is sent via pin 17 emulating a UART link with the central board of our system which will take care of the transmission [5].

III.4. Geolocation Geolocation

Lifee needs to retrieve not only the pulse but also the geographical position. To do this, we used the Ublox NEO-6M module. It looks like this:

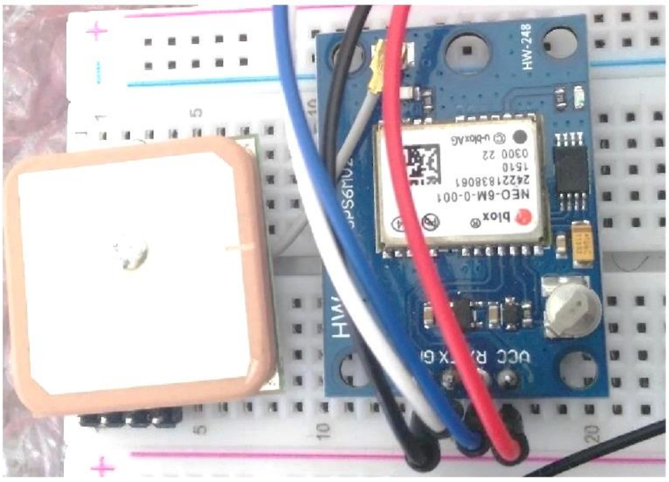


Figure 11: Ublox NE0-6M GPS module

Once the geolocation data has been acquired by this module, it sends it to our control unit via UART. However, the latter can only determine its position when it receives data from at least 3 geolocation satellites. Because of this, it can take a certain amount of time before it provides geolocation data.

III.5. The central office

Earlier we determined the pulse rate and the geographical position. Now we need to display this data on the OLED screen and send it. To do this, we opted for the Heltec ESP32 LoRa Kit development board, which has an extremely powerful ESP32 microcontroller with integrated Bluetooth/Wifi coupled with a LoRa module and an OLED display. The latter already has links to the OLED display and the integrated LoRa module, so everything else is determined by the computer code.

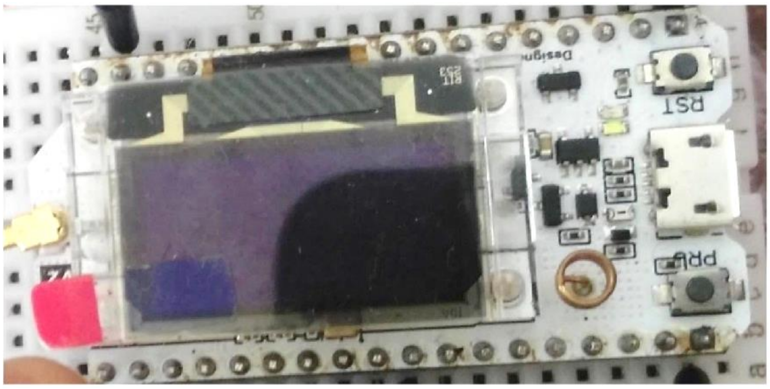


Figure 12: Heltec card in the centre of the system

The latter communicates with the GPS module and the Uno card to retrieve the pulse in UART.

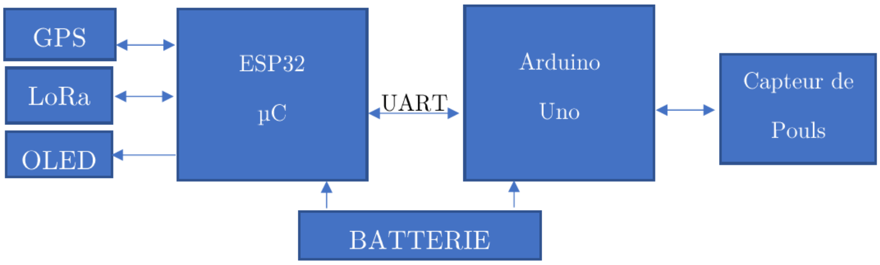


Figure 13: Lifee: Diagram

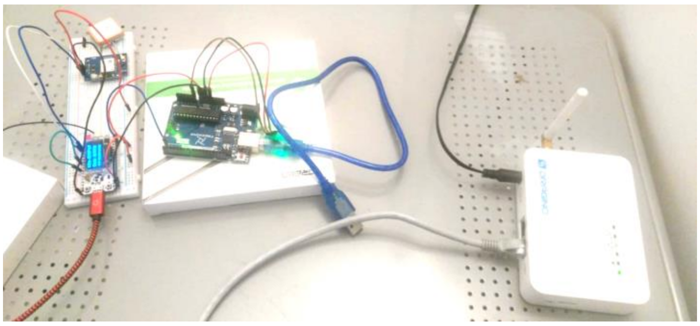


Figure 13: Life + Gateway + Central Board

III.6. Data transmissions

Lifee transmits pulse and GPS position data at regular intervals with interruption. The data is coded on 10 bits, thanks to a clever way to fit everything in this low load to lessen the transmission time. The string is as follows [4]:

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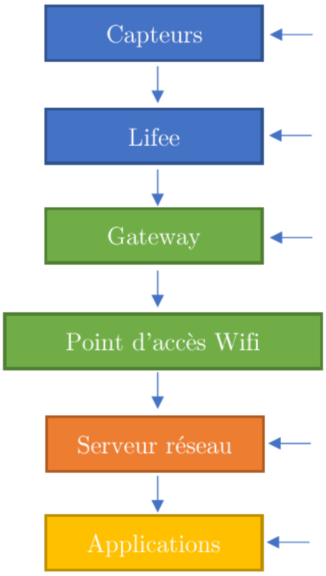


Data acquisition (pulse and positions)

Data formatting, display on the screen and transmission to the gateway at the frequency of 868.1 Mhz

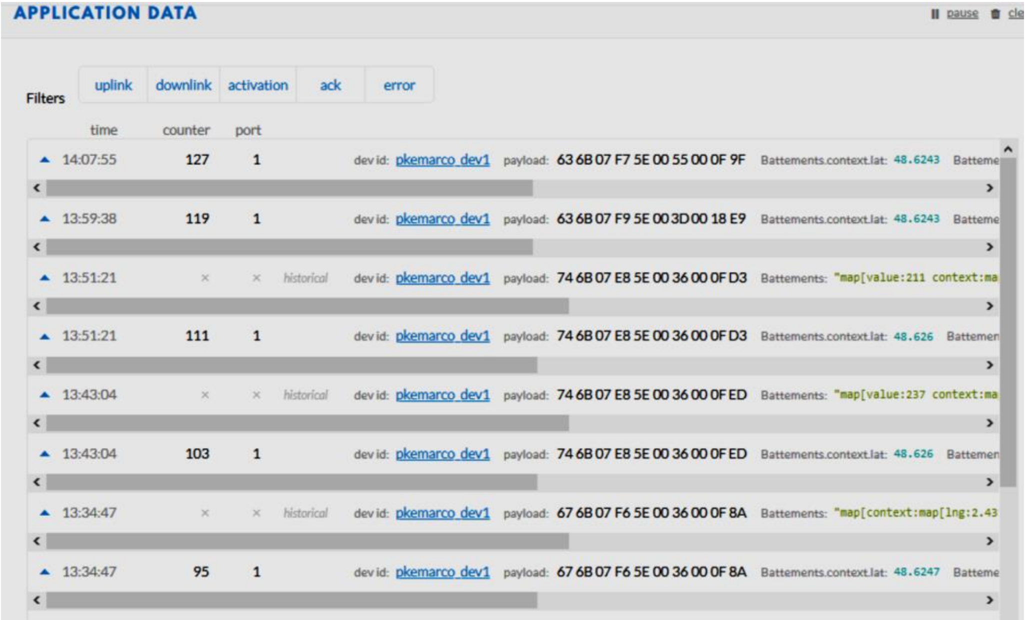
Receiving data from the nodes and transmitting it to the network server via the Wifi access point

Decoding the information and transmitting it to the application server

Use of data

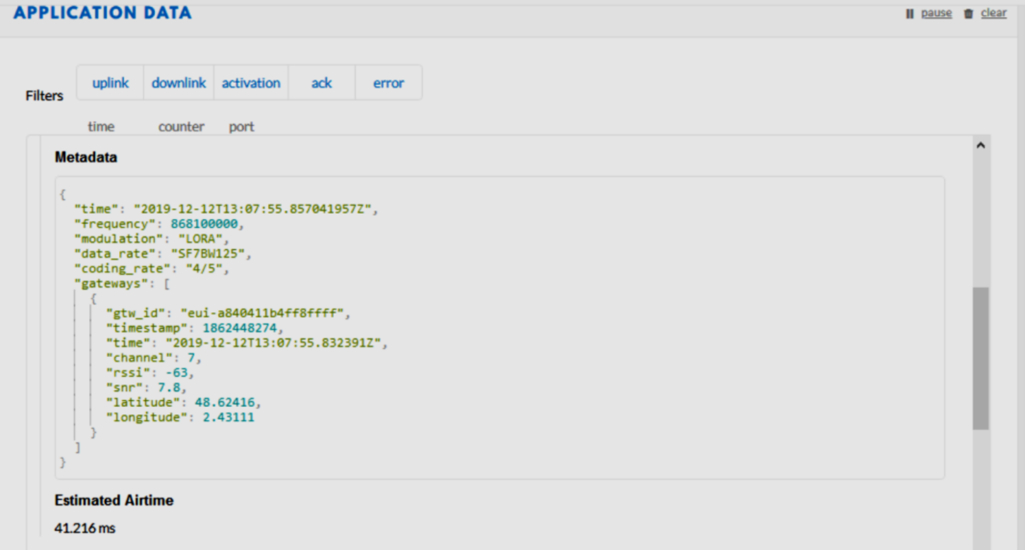
The transmission is done at the 868.1 MHz frequency from Lifee to the Gateway. This communication, according to our configuration, is unidirectional. The data is then sent by Wifi to the network server which then transmits it to the applications.

At the server level, it is necessary to develop a computer code which will be able to recover all the information sent. This gives us :



time	counter	port				
14:07:55	127	1		dev id: pkemarco_dev1	payload: 63 6B 07 F7 5E 00 55 00 0F 9F	Battements.context.lat: 48.6243 Batteme
13:59:38	119	1		dev id: pkemarco_dev1	payload: 63 6B 07 F9 5E 00 3D 00 18 E9	Battements.context.lat: 48.6243 Batteme
13:51:21	×	×	historical	dev id: pkemarco_dev1	payload: 74 6B 07 E8 5E 00 36 00 0F D3	Battements: "map[value:211 context:ma
13:51:21	111	1		dev id: pkemarco_dev1	payload: 74 6B 07 E8 5E 00 36 00 0F D3	Battements.context.lat: 48.626 Battemen
13:43:04	×	×	historical	dev id: pkemarco_dev1	payload: 74 6B 07 E8 5E 00 36 00 0F ED	Battements: "map[value:237 context:ma
13:43:04	103	1		dev id: pkemarco_dev1	payload: 74 6B 07 E8 5E 00 36 00 0F ED	Battements.context.lat: 48.626 Battemen
13:34:47	×	×	historical	dev id: pkemarco_dev1	payload: 67 6B 07 F6 5E 00 36 00 0F 8A	Battements: "map[context:map[lng:2.43
13:34:47	95	1		dev id: pkemarco_dev1	payload: 67 6B 07 F6 5E 00 36 00 0F 8A	Battements.context.lat: 48.6247 Batteme

Figure 14: TTN - Batch of received data



Metadata

```
{
  "time": "2019-12-12T13:07:55.857041957Z",
  "frequency": 868100000,
  "modulation": "LORA",
  "data_rate": "SF7BW125",
  "coding_rate": "4/5",
  "gateways": [
    {
      "gtw_id": "eui-a840411b4ff8ffff",
      "timestamp": 1862448274,
      "time": "2019-12-12T13:07:55.832391Z",
      "channel": 7,
      "rssi": -63,
      "snr": 7.8,
      "latitude": 48.62416,
      "longitude": 2.43111
    }
  ]
}
```

Estimated Airtime

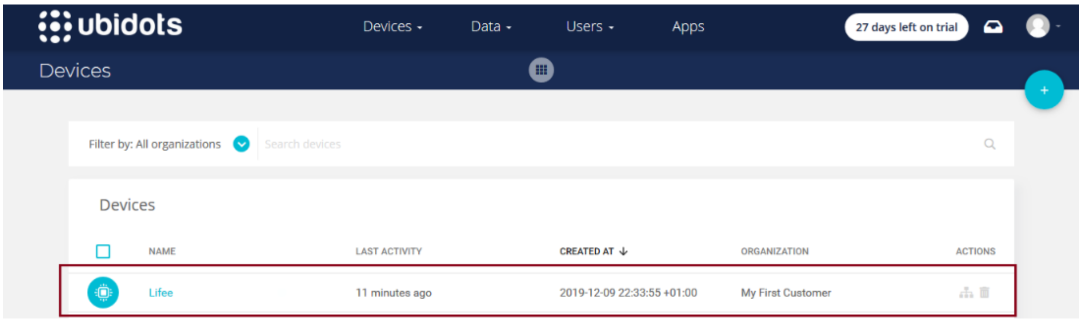
41.216 ms

Figure 15: Data reception delay algorithm

According to our tests, the data sent by Lifee is well received by the network server and is well decoded, but as it stands is unusable. In order to be able to exploit them, we need to transmit them to an application that will be able to process them again and represent them graphically in the form of a dashboard for better management. To do this, we chose to use the services of Ubidots, which allowed us to do this for free.

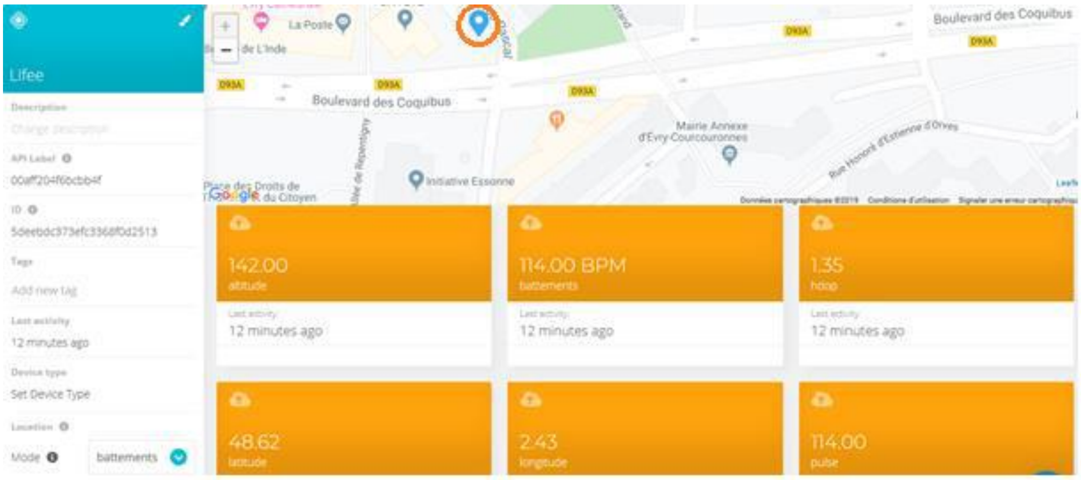
Ubidots is a web application allowing to acquire the received data and the GPS data in order to set up a map, showing the geographical position of the patient to a few meters, but also displaying the heart rate.

As seen previously, we integrated Ubidots into our application on TTN and configured it with the key provided by Ubidots at account creation. Thus, we were able to define our object on Ubidots as follows [9]:



☐	NAME	LAST ACTIVITY	CREATED AT ↓	ORGANIZATION	ACTIONS
	Lifee	11 minutes ago	2019-12-09 22:33:55 +01:00	My First Customer	

Figure 16: Ubidots with our connected object lifee, 11 minutes ago


Lifee

Description
Change description

API Label
00aff204f6bcbb4f

ID
5deebdc373efc3368f0d2513

Tags
Add new tag

Last activity
12 minutes ago

Device type
Set Device Type

Location

Mode: battements

142.00 altitude — Last activity: 12 minutes ago

114.00 BPM battements — Last activity: 12 minutes ago

1.35 hdop — Last activity: 12 minutes ago

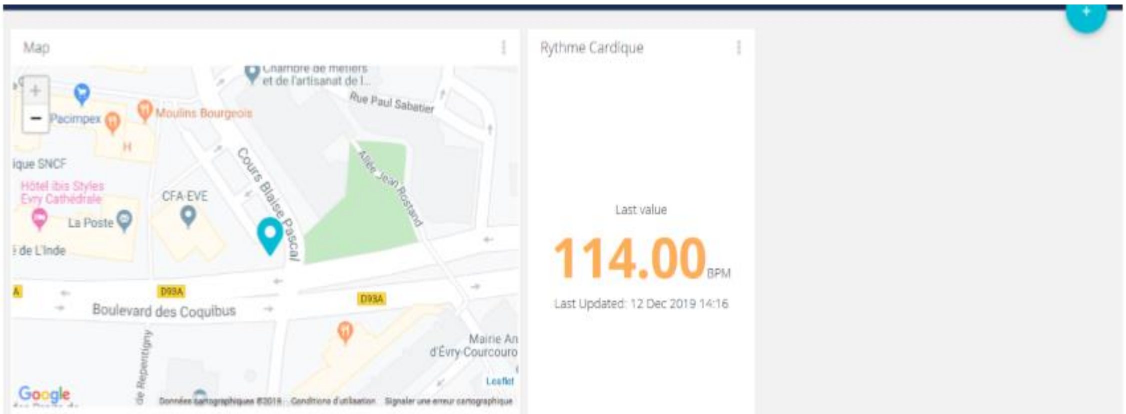
48.62 latitude

2.43 longitude

114.00 pulse

Figure 17: Retrieving GPS data from Lifee on ubidots

We can thus observe that, after configuring Ubidots, the platform has drawn up a map with our GPS location on it (blue cursor) and defined widgets containing all the data that has been transmitted by Lifee. Another important point is that we can also build dashboards summarising all the data received in an efficient way (GPS + Pulse).

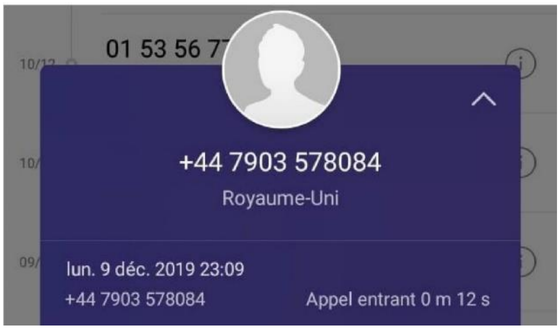

Map

Rythme Cardique

Last value
114.00 BPM
Last Updated: 12 Dec 2019 14:16

Figure 19: Creation of an event when the Pulse is below 70 beats per minute

And while testing, we received a call from Ubidots (from the UK) speaking French following the voice synthesis done via the configuration of our event because the pulse rate was well below the set value.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+44 7903 578084 Appel entrant 0 m 12 s

Figure 20: Ubidots: Call from UK (call from SIP application) because pulse < 70

Conclusion

Throughout this study, we have demonstrated that the internet of connected things in health in the case of cardiovascular disease is a very encouraging solution in the process of patient monitoring. The theme being topical, based on the Internet of thing and LoRa technology, with a strong economic and social potential, has enabled us, thanks to telecommunications and digital technology, to provide a viable solution to the health problems linked to cardiovascular diseases in the world in general and in Congo in particular.

This research work has brought a lot of knowledge, pushing us each time to the limits and beyond our height on research. Despite the difficulties encountered during the studies and tests, we were always able to overcome them and managed to produce a result that met expectations and, later on, it would be a pleasure to be able to go even further while revealing more and more the interest of this type of device in providing monitoring and prevention solutions to our patients.

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