Laboratoire de Génie Electrique de Grenoble

BUILDING A SYSTEM FOR COLLECTING AND PROCESSING ELECTRICAL ENERGY DATA AT LEVEL OF A CITY AND INTERNAL OF BUILDINGS

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Grenoble, 07/2020

ABSTRACT

<u>Project title</u>: Building A System for Collecting and Processing Electrical Energy Data at Level of a City and Internal of Buildings

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With the fourth industrial revolution and the explosion of Big Data, intelligent management systems using smart devices are a trend. These systems help manage stricter and more flexibly, and it also provides accurate and complete information to users. Currently, the management of the electricity network is still in a centralized manner, and there is a problem of decentralization.

With these issues, building a system that enables groups or organizations to operate their own private communication network, while helping users manage their energy consumption. GeeLink is the first step to building that system, this is also my capstone project.

GeeLink – a low-power device - automatic collects and process the electrical energy data before sending this information by LoRa technology to the data center. GeeLink also uses the LoraWAN and MQTT protocol, which are very popular today and are widely used in IoT and Smart Grid applications.

ACKNOWLEDGMENT

This graduation thesis was written in 2020 at G2Elab - Laboratoire de Génie Electrique de Grenoble, France.

First of all, I would like to express my deep gratitude to Assoc. Prof. Benoit DELINCHANT and Research Director Frédéric WURTZ for their patience and eager helps and supervision in every aspect of my Capstone Project as well as their invaluable supports and guidance. I am also very grateful the great technical support from Mr. Jérôme FERRARI throughout my internship.

I would also like to thank Ph.D LE Quoc Huy (Faculty of Advance Science and Technology - Danang University of Science And Technology), the teacher who has always follow, instructs with a great enthusiasm during the process of implementing the project. Thanks to Ph.D Fabien FERRERO for the allowance to use the materials from University of Côte d'Azur.

Besides that, I would like to thank to the people in Cluster MHI of team MAGE for helping me integrate more quickly into the new environment.

Finally, special thanks to Professor Olivier GALLOT-LAVALLEE and Ph.D Christophe BOBINEAU for helping me find this internship.

Grenoble, July 2020

HO Vu Duy Bao

THESIS GUARANTEED

I would like to assure that the Capstone project "BUILDING A SYSTEM FOR COLLECTING AND PROCESSING ELECTRICAL ENERGY DATA AT LEVEL OF A CITY AND INTERNAL OF BUILDINGS" is my researching.

The documents and figures refer to the project have been highlighted in the reference section. The data used in the analysis of the thesis are of clear origin, published according to the regulations that the figures and results presented in this project are completely honest. If I am wrong, I would accept full of responsibility and discipline of the faculty and the university.

Grenoble, June 2020

HO Vu Duy Bao

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Abbreviations

LoRa	Long Range
LoRaWAN	LoRa Wide Area Network
CHIRP	Compressed High Intensity Radar Pulse
IoT	Internet of Things
TTN	The Things Network
ADR	Adaptive Data Rate
DR	Data Rate
SF	Spreading Factor
BR	Bitrate
BW	Bandwidth
RSSI	Received Signal Strength Indication
SNR	Signal-to-Noise Ratio
ToA	Time on Air
JSON	JavaScript Object Notation
MQTT	Message Queuing Telemetry Transport
ABP	Activation By Personalization
OTAA	Over-the-Air Activation
AppEUI	Application identifier
AppKey	Application key
AppSKey	Application Session Key
NwkSKey	Network Session Key
DevEUI	End-device identifier
DevAddr	Device Address
µController	MicroController
TIC	Tele-Communication Customer
Info-TIC	Information from TIC of Linky meter
Alim-TIC	Power supply from Linky TIC

Chapter 1 - Introduction

1.1. Context of the study

Currently with the explosion of technology 4.0, people pay more attention to smart cities. The smart city is characterized by services that rely heavily on an information layer that covers the territory. In this regard, we are faced with two major challenges. The first is interested in building a network of sensors and actuators, all of which could lead to urban monitoring, measurement and visualization in real time of the city's metabolism: energy cadaster of residential and commercial buildings and industrial, monitoring the flow of electric vehicles. The second issue considers the use of digital technology as a support for the development of new practices, new services, new platforms for urban residents. These perspectives point to economic developments, and to bring a comfortable life for the citizen. These orientations are both promising and at the same time carry a share of risk. Therefore, it is important for us to support these developments with experiments, researches which will facilitate the construction of appropriate and reliable systems and products, as well as receive people's acceptance of the use of digital technologies.

In the smart city, the building is an important node. They are more and more monitored, for the simple purpose of monitoring the building or the occupants (comfort / health), security, diagnosis, and even intelligent control (use of optimization and models predictive). The number and accessibility of this data also allows us to envisage radical changes in the creation of services and the provision of tools for comfort and energy efficiency in buildings. Thanks to the multiplication of sensors, it is possible to access complex quantities to be measured such as the occupation by correlation of multiple sources of information, to reduce uncertainties (e.g. redundancy, average value), to access quantities spatially distributed (e.g. temperature). Today, when wired sensor installations are planned for construction, only wireless technology can support this IoT revolution in buildings and throughout their lifetime (minimum 50 years). Unfortunately, current solutions such as Z-Wave, NB-IoT or ZigBee, have a much reduced range within buildings (10 to 20m depending on the configuration of the interior walls). LoRa is a “rising-star” technology which considerably increases the range and therefore reduces or even eliminates the mesh of walkways within buildings.

In addition to the instrumentation and equipment of buildings with a view to monitoring and optimizing performance, energy is also a major social issue, through its environmental and economic impact. The energy distribution networks, whether it is the electric vector, the heat, or the gas are today still managed centrally and have badly anticipated the problem of decentralization. This decentralization introduces a complex set of producer/consumer actors, much more difficult to manage, and the current managers seem very blind. It is necessary to implement measurements at the various nodes of these energy networks, and LoRa technology provides the spatial coverage required for this type of application. In addition, on the basis of this technology, groups or organizations can operate their own private communication network. Thus, for example, it should make it possible to support the energy transition with citizen initiatives for localized management of energies such as collective self-consumption.

This is the framework of my project, I am required to collect and process energy data at level of city and internally for buildings. In the other words, it means that I am preparing for the establishment of the infrastructure to build a smart city in the future.

1.2. Objective of the project

The scenario that the project is going to research would be the development of open source technologies and open hardware that allow citizens to store and access their data histories from their safe, allowing them to share this data within a community, or to authorize access to third parties offering energy management services.

This project will be based on wireless communication, namely on the Lora infrastructure. It needs to meet two main requirements:

- At the level of scale: the need to build internal LoRa infrastructure up to the size of the Grenoble metropolitan area
- About the constraints: long-range radio frequency communication, and through building structures that weaken the signal.

The basic requirement of this project are :

- Collection and secure transmission of data within GreEn-ER and the city
- Backup in a digital safe with secure access to data by API

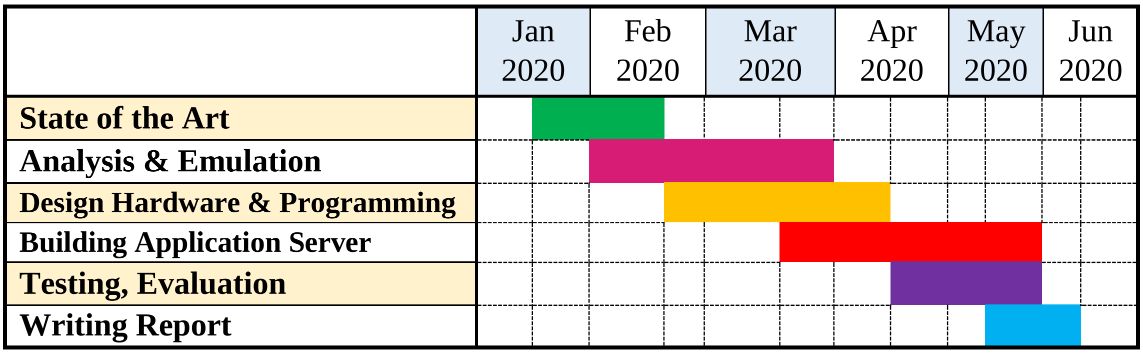
- Data processing (collecting and calculation of indicators)
- Data visualization (dashboard and chronograms)

1.3. Organization of the thesis

This thesis is divided into five chapters :

- The first chapter is an introduction about this Capstone project as well as the labrotory, the context of study and the milestone of the project.
- The second chapter is a resume of review of literature which presents one by one element needed for reading this thesis.
- The system is analyzed in the third chapter to build the hardware.
- The fourth chapter focuses on LoRa and Servers, on the communication between the components of the system.
- The final chapter talks about the outcome of this project, with the conclusions and evaluation.

1.4. Milestone of the project



1.5. Presentation of the laboratory

1.5.1. G2Elab Overview

Electrical Engineering is playing a central and unifying role, reinforced in recent years by the key societal challenge that energy represents. In this context, the Grenoble Electrical Engineering Laboratory (G2Elab) encompasses a scientific scope that extends from materials and devices to the design and management of electrical energy systems. In this field, the activities of G2Elab can be summarized by the following keywords: electrical energy, materials for electrical engineering, innovative processes and systems, modelling and design.

With around 100 permanent staff, around 100 PhD students and more than 70 master students, post-docs and visiting professors, G2Elab has established itself as a significant national and international actor at the heart of the energy efficiency of electrical energy devices and systems.

1.5.2. Organization of G2Elab

The G2Elab is organized into 5 research teams and 2 transversal research groups. With their recognized scientific skills, they have long been used to organizing themselves to bring together people and resources for the research projects they are called upon to handle. G2Elab maintains and develops its potential for experimental resources, particularly within the strategic framework of research platforms. It invests humanly and financially in the construction of training / research structuring poles, capable of moving from concept to demonstrator. This development involves the contribution of shared technical centers on a laboratory scale, in the fields of mechanics, electricity, electronics, instrumentation and IT.

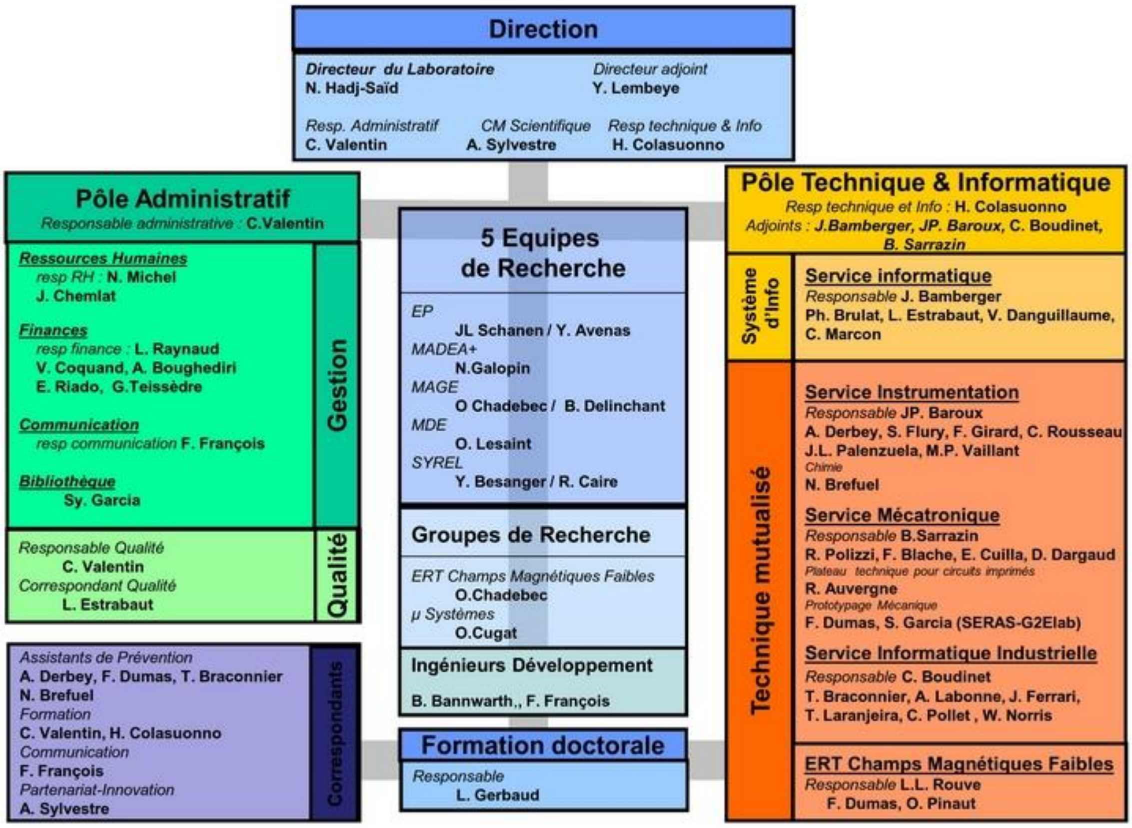


Figure 1.1*: Organization of Departments in G2Elab* [1]

Chapter 2 – State of the Art

Before thinking of implementing a project, we need to clarify the requirements and purposes of the project. So in the first month, I researched and studied the project-related documents. My project is the continuation of an unfinished project at G2Elab based on the results which my tutor provided me.

I already summarized the theories of telecommunication, the protocols of communication as well as tools and software in the shortest way to help the readers have the basic knowledge about the project.

2.1. LoRa and IoT architecture

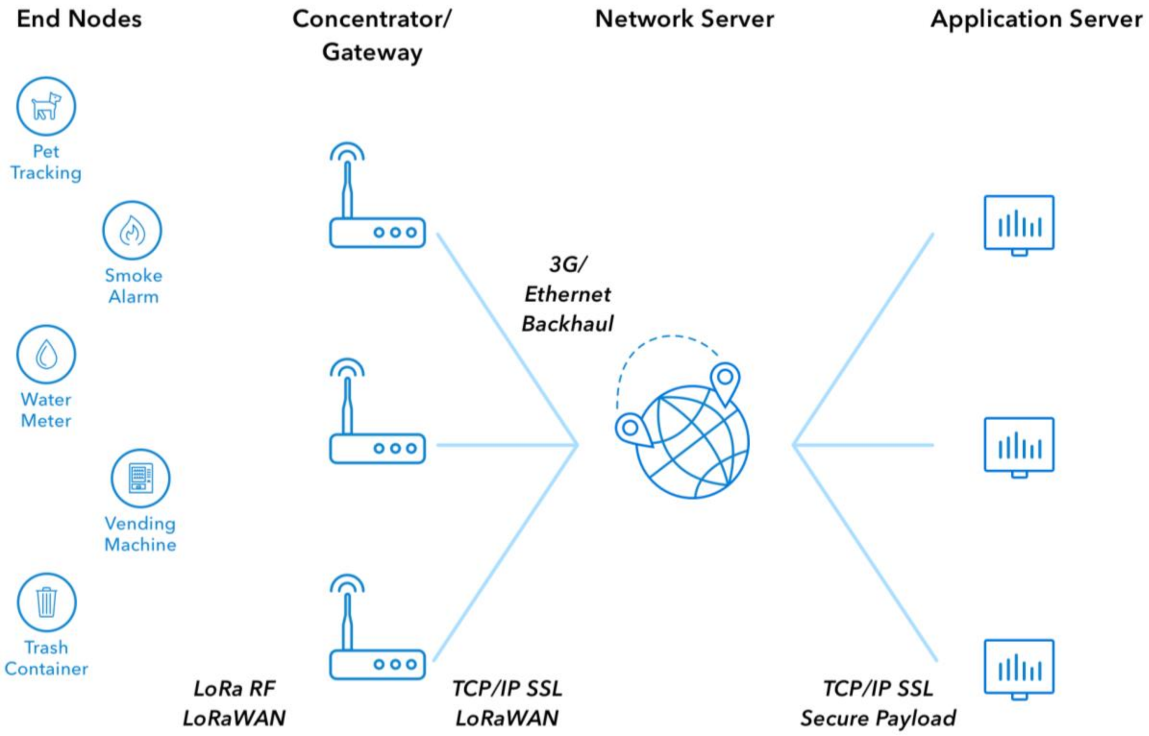


Figure 2.1*: An typical IoT architechture* [2]

2.1.1. What is LoRa Technology?

LoRa is a combination of two major concepts: LoRa spread spectrum modulation (Physical layer) and LoRaWAN (network protocol).

LoRa spread spectrum modulation:

Developed by Semtech, built in to SX127x transceiver ICs and SX13xx gateway baseband chip allows multiple receive channels. LoRa provides the core long range capability up to 5km range in urban environment, up to 15km suburban.

LoRaWAN network protocol:

Defined by IBM & Actility before made open by the LoRaWAN-Alliance. This protocol provides a cellular-like network (aka large-star topology) with these parameters:

- Spreading Factor (SF): Programmable SF: 7, 8, 9, 10, 11, 12.
  The higher the SF the more information transmitted per bit; therefore higher processing gain
- Bandwidth (BW): Programmable signal BW: 125 kHz, 250 kHz, 500 kHz
  For a given SF, a narrower BW is increased receive sensitivity; however, increased ToA
- License free Sub-GHz Frequency : in France is EU863-870 MHz

2.1.2. ADR (Adaptive Datarate)

Adaptive Data Rate (ADR) is a mechanism for optimizing data rates, airtime and energy consumption in the network. Each end-device hase to optimize for fastest data rate and maximize network capacity based on RSSI, SNR as reported by the gateway. Nodes decide if ADR is used or not. We increase DR to minimize on-air time and decrease DR to increase transmitted energy per bit.

2.1.3. LoRaWAN Gateway

Data is “passed through” the gateway, it means that gateway just forwards the data to servers. Gateway connect to Network Server via standard IP connection (TCP/UDP) and listens to multiple channels at the same time.

2.1.4. Uplink and Downlink

In LoRa networks, communications are bidirectional.

- Uplink is a signal from end device to gateways. The uplink airtime is limited to 30 seconds per day (24 hours) per device.
- Downlink is a signal from gateway to end end device. The downlink messages are limited to 10 messages per day (24 hours) per device.

2.1.5. Network Server

The main purpose of network server is authenticating data. If data is addressed to network server, data is processed; else data will be forwarded to application server. Beside that, network server connect to the application server via Internet conncetion. However, I used MQTT protocol to connect these two servers in my project.

2.1.6. End-Device Activation (Joining the Network)

Before an end-device can communicate on the LoRaWAN network, it must be activated.

The goal of the device activation process is to obtain these indentifications:

- Device Address (DevAddr) : a 32-bit unique (network-wide) identifier
- Network Session Key (NwkSKey): used by the network server to authenticate the device
- Application Session Key (AppSKey): used by the application server to decrypt data from application server.

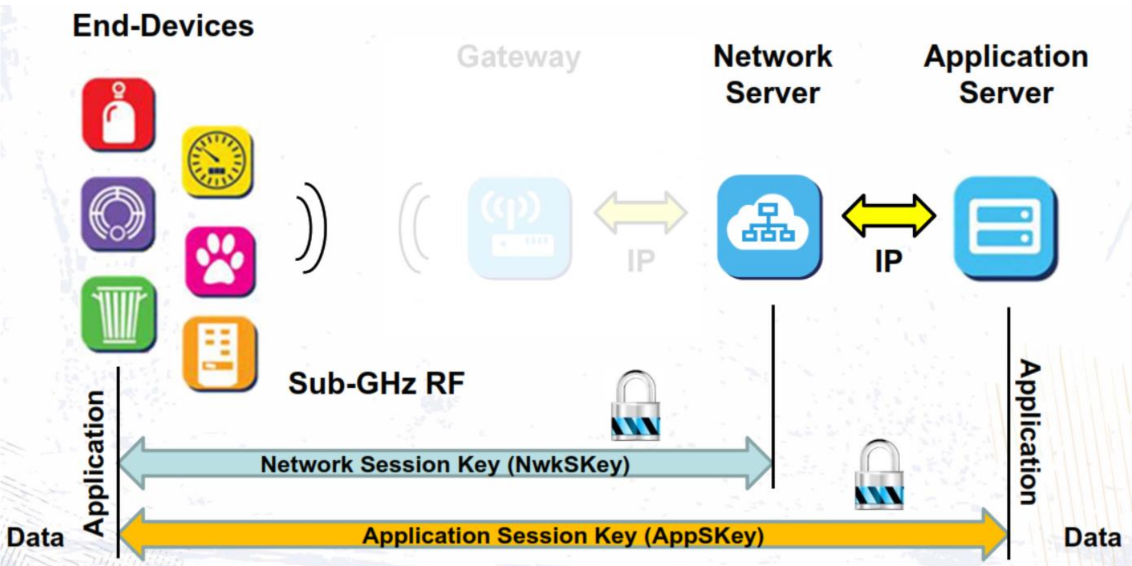


***Figure 2.2**: Keys Usage* [3]

2.1.7. Activation (Join) Methods

To exchange the information, two activation methods are available:

- Over-the-Air Activation (OTAA): This method based on globally unique identifier and uses over the air message handshaking, it also supports roaming.
- Activation By Personalization (ABP): At production time the sharing keys stored and locked to a specific network.

2.1.8. SNR

Signal-to-Noise Ratio (SNR) is the ratio between the received power signal and the noise floor power level. The noise floor is an area of all unwanted interfering signal sources which can corrupt thetransmitted signal and therefore re-transmissions will occur.

- If SNR is greater than 0, the received signal operates above the noise floor, and otherwise. Normally the noise floor is the physical limit of sensitivity, however LoRa works below the noise level.
- Typical LoRa SNR values are between: -20dB and +10dB.

2.2. Communication Protocol

2.2.1. UART (Universal Asynchronous Receiver-Transmitter)

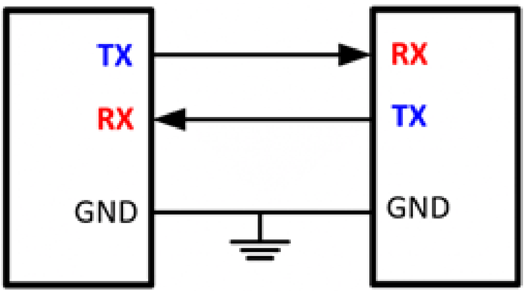


Figure 2.3: *UART commucation protocol*

UART is a computer hardware device for asynchronous serial communication in which the data format and transmission speeds are configurable. The electric signaling levels and methods are handled by a driver circuit external to the UART. A UART is usually an individual (or part of an) integrated circuit (IC) used for serial communications over a computer or peripheral device serial port. One or more UART peripherals are commonly integrated in microcontroller.

2.2.2. SPI (Serial Peripheral Interface)

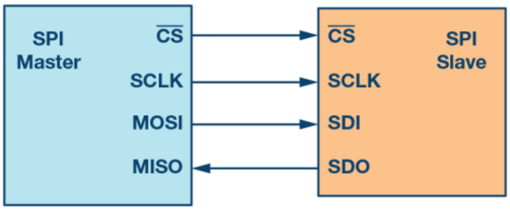


Figure 2.4: *SPI protocol*

SPI is a synchronous serial communication interface specification used for short-distance communication, primarily in embedded systems.

SPI devices communicate in full duplex mode using a master-slave architecture with a single master. The master device originates the frame for reading and writing. Multiple slave-devices are supported through selection with individual slave select (SS), sometimes called chip select (CS), lines.

2.2.3. MQTT

MQTT (Message Queuing Telemetry Transport) is a publish-subscribe network protocol that transports messages between devices. The protocol usually runs over TCP/IP; however, any network protocol that provides ordered, lossless, bi-directional connections can support MQTT. It is designed for connections with remote locations where a "small code footprint" is required or the network bandwidth is limited.

2.2.4. TCP/UDP

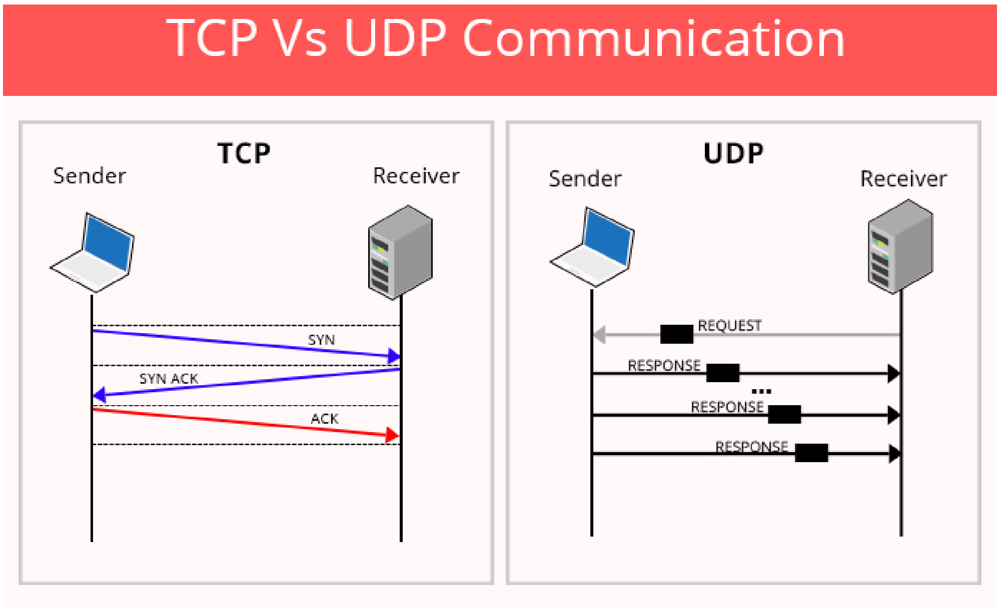


Figure 2.5: *TCP and UDP* [4]

There are two types of Internet Protocol (IP) traffic. They are TCP or Transmission Control Protocol and UDP or User Datagram Protocol. TCP is connection oriented – once a connection is established, data can be sent bidirectional. UDP is a simpler, connectionless Internet protocol. Multiple messages are sent as packets in chunks using UDP.

2.2.5. Node-RED

Node-RED is a flow-based development tool for visual programming developed originally by IBM for wiring together hardware devices, APIs and online services as part of the Internet of Things. Node-RED provides a web browser-based flow editor, which can be used to create JavaScript functions. Elements of applications can be saved or shared for re-use. The runtime is built on Node.js. The flows created in Node-RED are stored using JSON. In 2016, IBM contributed Node-RED as an open source JS project.

2.2.6. InfluxDB

InfluxDB is an open-source time series database (TSDB) developed by InfluxData. It is written in Go and optimized for fast, high-availability storage and retrieval of time series data in fields such as operations monitoring, application metrics, Internet of Things sensor data, and real-time analytics.

2.2.7. Grafana

Grafana is a multi-platform open source solution for running data analytics, pulling up metrics that make sense of the massive amount of data, and monitoring apps through customizable dashboards. Grafana allows you to query, visualize, alert on and understand your metrics no matter where they are stored. Create, explore, and share dashboards with your team and foster a data driven culture.

Chapter 3
Analysing System and Building Hardware

In the first part of this chapter, we need to recall about the requirements and functions of the project:

- Retrieve the electrical consumption from a smart electrical meter
- Using the available sources from meter - No-need to use an external power
- Transmit received data to server by LoRa wireless techonology.
- Dashboard visualization the information

Based on those requirements, in this chapter I will analyze and devide the first two demands into 6 sections as follows:

- Linky smart meter and TIC
- Rectifier and Regulator
- Demodulation and Decoding
- MicroController
- LoRa module
- PCB Antenna LoRa

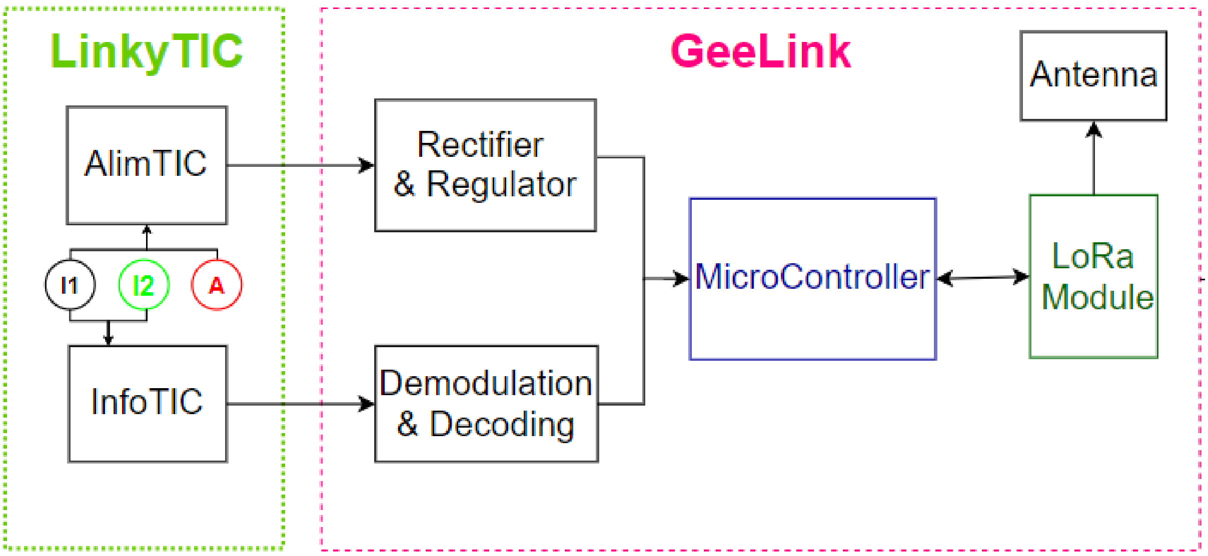


***Figure 3.1**: LinkyTIC and Geelink function blocks*

The third and the last requirements will be presented in the next chapter.

3.1. Introduce the Linky smart meter

The Linky smart meter is an electricity meter which is widely rollouted throught France since 2010. It participates in the initial part of the project, enabling in particular to retrieve historical electricity energy consumption data and to control customer's domestic appliances. The Linky smart meter is also able to receive orders and transmit information remotely.

Figure 3.2*: Linky smart meter in France* [5]

Linky has been designed as an "infrastructure" that should benefit every user on the electricity network. End-consumers will have easy access to information about their actual consumption, and be able to manage it better, receive bills based on their actual consumption.

Electricity suppliers will be able to determine the length of their billing periods, based on actual consumption, be able to diversify their price offering and adapt it more closely to their customers' needs. Electricity producers will have better visibility on periods when they have produced electricity, be able to use simplified electrical equipment, given that Linky allows the metering of both their production and their consumption.

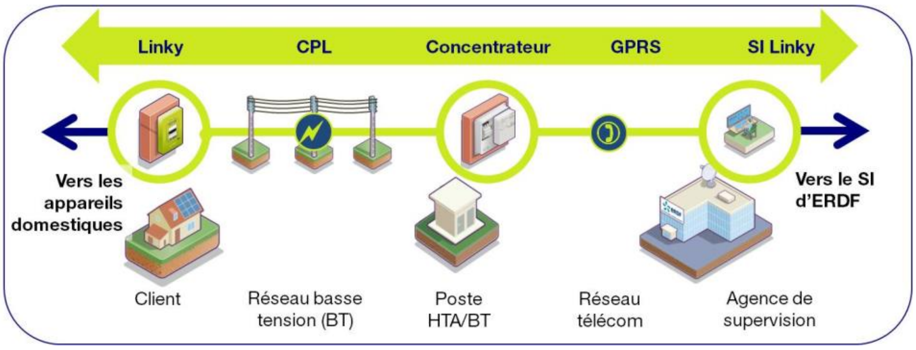


Figure 3.3*: The Linky Architecture* [6]

3.2. LinkyTIC

Linky meter is equipped a digital tele-information output, called TIC (Télé-Information Client/Tele-Information Customer).

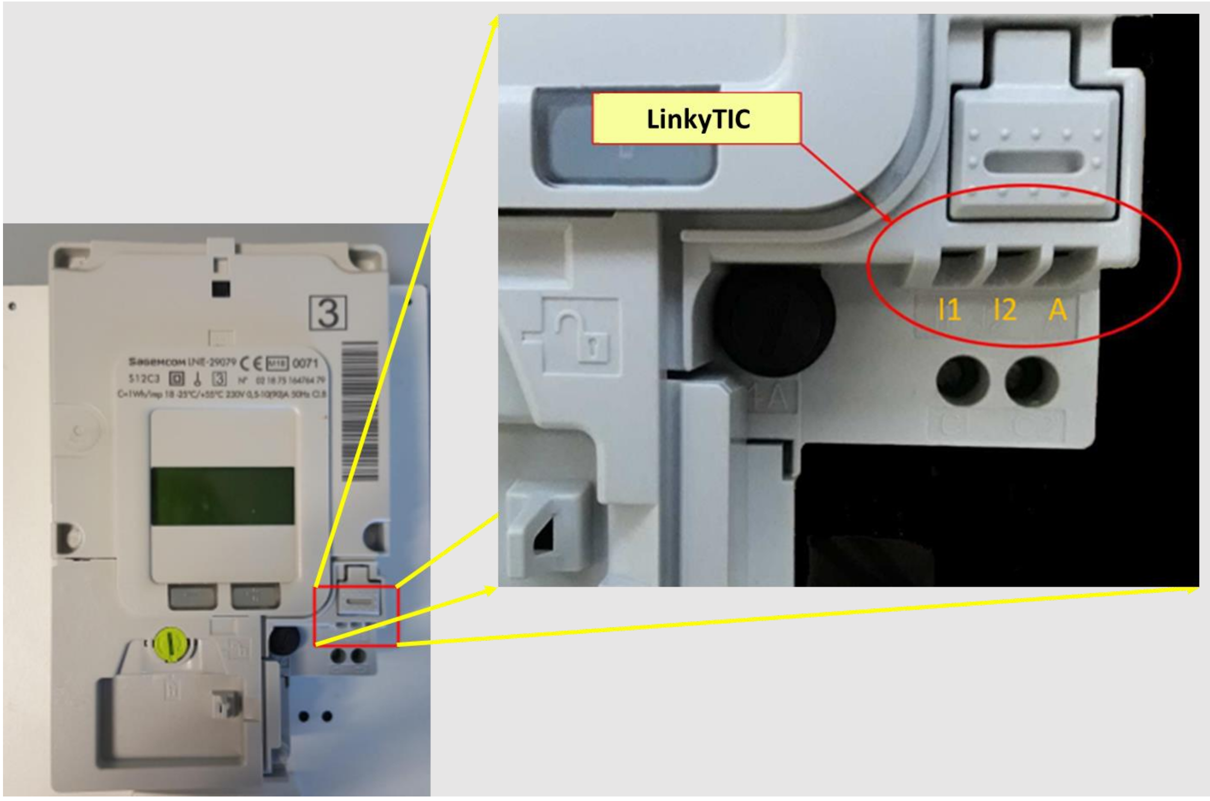


Figure 3.4: *TIC on Linky meter*

LinkyTIC is a terminals which has 3 pins I1, I2 and A with:

- I1: the common pin
- A : the TIC power pin
- I2: the information pin

The essential part of my project is working with TIC which continuously broadcasts the electrical consumption parameters updated by the counter. This output is the asynchronous type and information is transmitted in series on the line.

3.3. Power supply from TIC

The LinkyTIC output has a power supply on pins **I1** and **A**. These pins can be used as power source for a tele-information transceiver attached to the meter. In my project, this device is called GeeLink, the name represents G2Elab and Linky.

According to the catalogue from French Electricity Supplier ENEDIS, we can consume some of the most important specifications about LinkyTIC's power supply which is called **Alim-TIC** in my report:

Specification	Value
Power source	Minimum **130 mW**
Voltage	6Vrms +/- 10% (max 12V peak)
Frequency	50 kHz

Table 3.1: *Specification of Alim-TIC* [7]

To respect the characteristics above, the LinkyTIC are tested on resistive loads between 225 and 335 Ω; the aim being that the guaranteed power is always greater than **130 mW**. However, from this catalogue, there is no information about the output waveform.

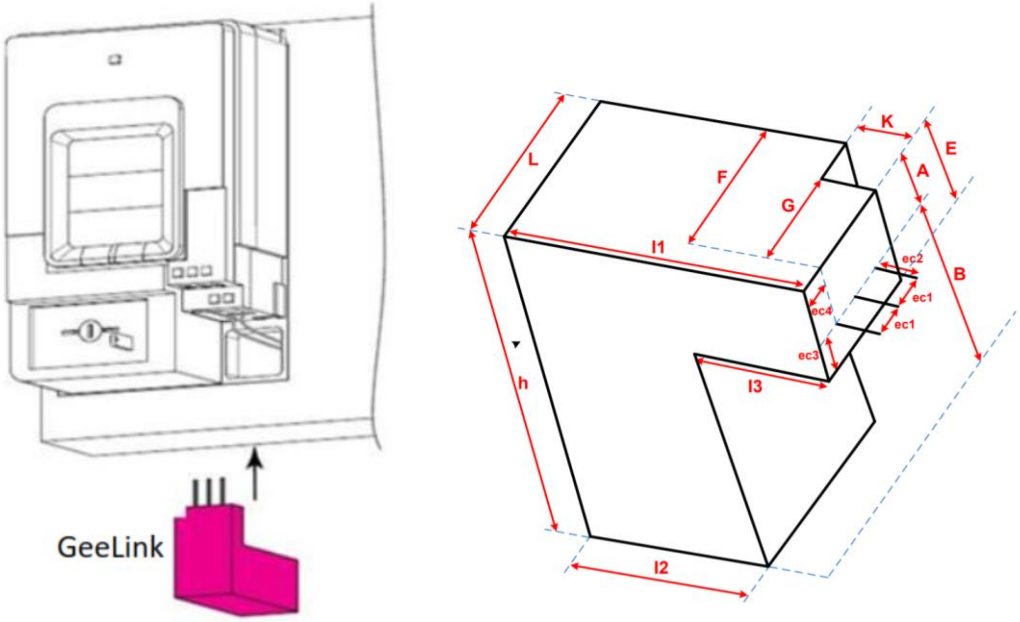
In the following section, I will present the components and how to build GeeLink base on these specifications.

3.4. Selecting µController and LoRa module

3.4.1. µController

We can easily found that the power supply from Linky is extremely small, just only 130mW. Due to this problem, choosing a µController that operates at 5V as usual is not wise. Therefore, my decision is using a µController that fully meets the following functions:

- Working voltage smaller than 5V, specifically in my project, is 3.3V
- Full range of common hardware protocols
- Small, compact and powerful performance
- Satisfy the dimension requirements in the following figure



Dimensions en (mm)															
I1	I2	I3	A	B	h=B+A	F	L=F+ec4	G	K	ec1	ec2	ec3	ec4	E=A+ec3	ec5 et ec6
49.5	27	22.5	9.7	48.3	58	24.5	30	16.2	9	5.08 ±0.1	15 +1/-0	7	5.5	16.7	5

Figure 3.5*: Space available for customer transciever module*

There are many diffenrent µController which matching those first conditions like LoPy, ESP-32, STM32 Nucleo board… but the best choice is Arduino Pro Mini 3.3V 8MHz because of its Mini-size (18x33mm) and the Low-Power mode that could be able to solving the tiny power problem of Alim-TIC.

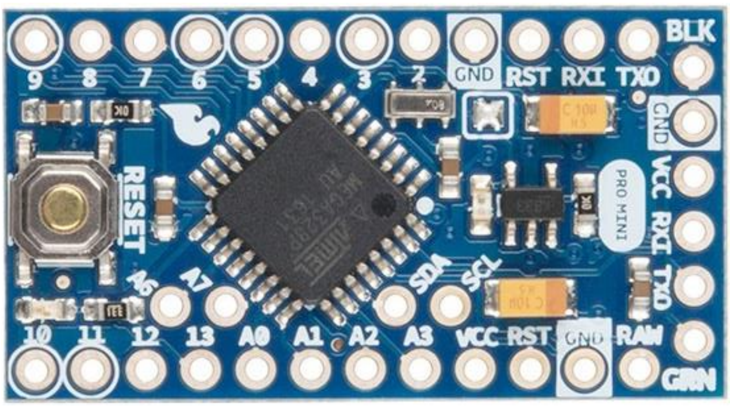


Figure 3.6*: Arduino Pro Mini 3.3V 8MHz* [8]

Arduino Pro Mini 3.3V 8MHz Feature:

- ATmega328 running at 8MHz with external resonator (0.5% tolerance)
- Low-voltage board needs no interfacing circuitry to popular 3.3V devices
- USB connection off board
- Over current protected
- DC input 3.3V up to 12V

3.4.2. LORA Module

On the RF market recently, there are so many types of LoRa module such as: RF-LORA-868-SO from Semtech, RN2483 from Microchip, RFM95W from HopeRF… It is a little bit difficult for me in the first period to make a choice. For the first two examples, we can only use UART protocol then we are not able to deeply configure into the other parameters of LoRa. Hence, RFM95W is the most suitable solution for the telecommunication part because it communicate with µController by SPI protocol.

Figure 3.7: *RFM95W LoRa module* [9]

RFM95W features:

- 168 dB maximum link budget.
- +14 dBm high efficiency PA.
- Programmable bit rate up to 300 kbps.
- High sensitivity: down to -148 dBm.
- 127 dB Dynamic Range RSSI.
- Modue Size：16*16mm

3.5. Rectifier and Regulator

After selecting µController and module LoRa, we will solve the problem of Alim-TIC. Unfortunately, for some objective reasons I was unable to work directly with the Linky meter for almost half of the time of project so I used a temporary solution to continue my work by using a function generator (un "Générateur de Basses Fréquences" – a GBF in French).

Figure 3.8*: A function generator GBF in G2Elab*

From this generator, I can have an equivalent power supply of LinkyTIC. Output voltage is 6 V_{rms} , the frequency is 50 kHz (information from catalogue) and the waveform I choose here to emulate is Sinusoid. After that I have the result displayed on an oscilloscope:

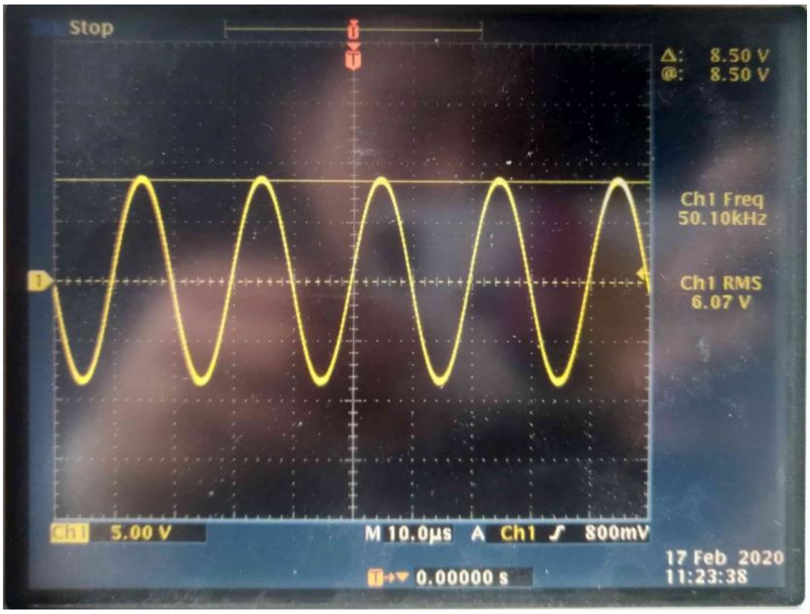


Figure 3.9*: Emulation TIC Power Supply on oscilloscope*

With the specifications above, I have to rectify AC signal to DC signal for supplying Arduino Pro Mini and RFM95W module.

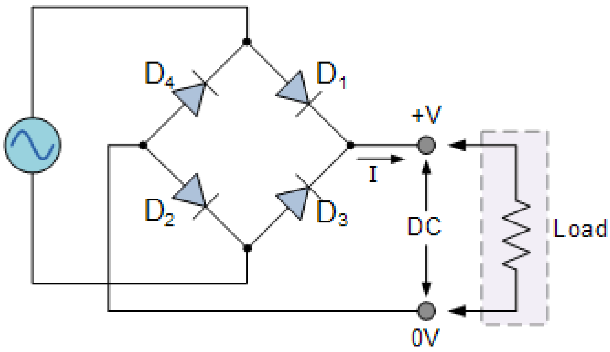


***Figure 3.10**: A typical rectifier circuit* [8]

The most effective and simpliest way is the Diode Bridge Rectifier like DB104, DB107 and so on.

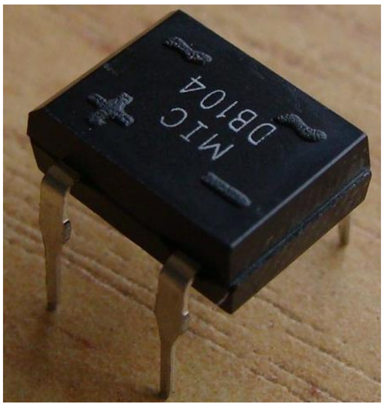


***Figure 3.11**: Diode Bridge Rectifier DB104* [9]

However, this kind of bridge is use for the usual purpose at 50-60 Hz but the frequency of LinkyTIC is 50 KHz, so I have to choose another type of diode that each one can cover this frequency. I've found many types of diode to rectifier and my choice is 1N4148 because of its specifications: the **Fast Switching** Diodes, popularity and the most convenient is available in G2Elab.

***Figure 3.12**: Diode 1N4148*

To be more clearly, we have the Reverse Recovery Time of diode 1N4148 is 4ns ~ 250MHz. Hence it could totally meet the given requirements:

Characteristic	Symbol	1N4148	1N4448	Unit
Non-Repetitive Peak Reverse Voltage	V_{RM}	100		V
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	75		V
RMS Reverse Voltage	$V_{R(RMS)}$	53		V
Forward Continuous Current (Note 1)	I_{FM}	300	500	mA
Average Rectified Output Current (Note 1)	I_O	150		mA
Non-Repetitive Peak Forward Surge Current @ t = 1.0s @ t = 1.0μs	I_{FSM}	1.0 2.0		A

Electrical Characteristics @T_A = 25°C unless otherwise specified

Characteristic	Symbol	Min	Max	Unit	Test Condition
Maximum Forward Voltage 1N4148 1N4448 1N4448	V_{FM}	— 0.62 —	1.0 0.72 1.0	V	I_F = 10mA I_F = 5.0mA I_F = 100mA
Maximum Peak Reverse Current	I_{RM}	—	5.0 50 30 25	μA μA μA nA	V_R = 75V V_R = 70V, T_J = 150°C V_R = 20V, T_J = 150°C V_R = 20V
Total Capacitance	C_T	—	4.0	pF	V_R = 0, f = 1.0MHz
Reverse Recovery Time	t_{rr}	—	4.0	ns	I_F = 10mA to I_R =1.0mA V_R = 6.0V, R_L = 100Ω

Figure 3.13:*1N4148 necessary characteristics* [10]

The DC voltage no load after a diode bridge rectifier without the filter capacitor is: $V_{Out} = 2 \times \frac{V_{rms} \times \sqrt{2}}{\pi} = 2 \times \frac{6 \times \sqrt{2}}{\pi} = 5.4\,Volts$, with sinus wave input from GBF but my goal is a stable DC signal 3.3 Volts.

Therefore, the next step of the process is converting the DC output from 5.4 V to 3.3 V. On the other hand, the power of Alim-TIC is 130mW so the current throught regulator is very small (≈0.04 Ampere). It means that the heat power is not a problem in this application. We can create a fixed output 3.3V using a Linear Regulator by different ICs like AMS1117-3.3 or LD1117. Nonetheless, the most suitable IC using for regulation purpose, in the context of building a prototype, is LM317. We can comfortably adjust the output voltage by this IC.

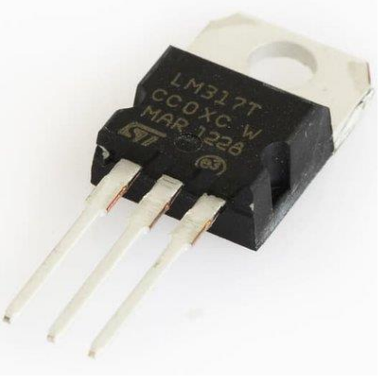


Figure 3.14: *IC LM317*

When all the components are selected, I started to build the circuit by combining the rectifier and the regulator. This is the schematic circuit designed on the open-source EDA/CAD software - KiCad.

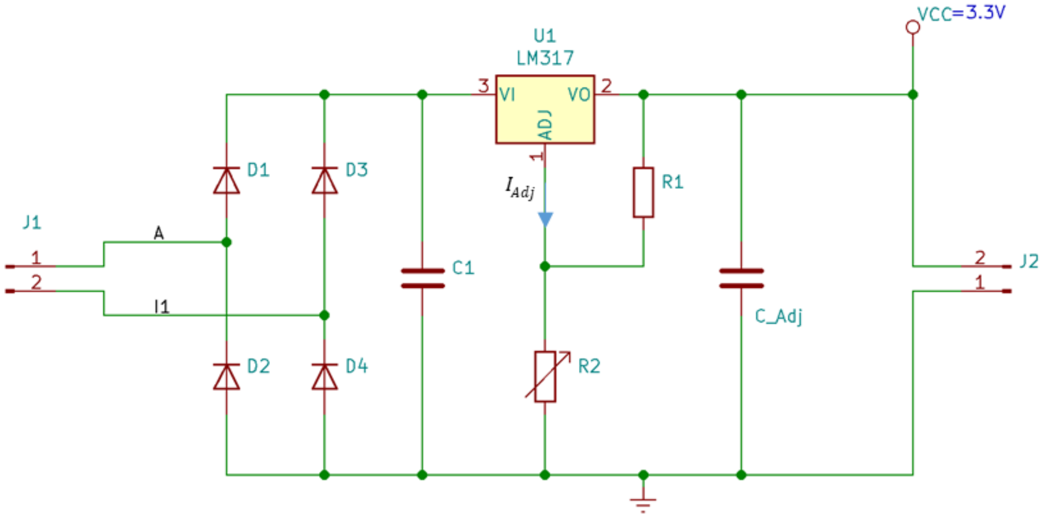


Figure 3.15*: Combination of Diode Bridge and Linear Voltage Regulator*

In this schematic, resistor R_1 and variable resistor R_2 are required to set the output voltage. C_1 is a 1 µF tantalum capacitor which provides sufficient bypassing for this application, especially when adjustment and output capacitors are used. C_{ADJ} improves transient response and its minimum value is 10 µF. It prevents amplification of the ripple as the output voltage is adjusted higher.

According to the datasheet, we have the equation to calculate V_O :

$$V_O = 1.25 \times \left(1 + \frac{R_2}{R_1}\right) + I_{Adj} \times R_2$$

I choose **R_1 = 240 Ω** as the recommend from Texas Instruments. I_{Adj} is maximum 100 µA and is negligible in my application. Moreover, Output $\boldsymbol{V_O}$ must be **3.3 $\boldsymbol{Volts}$**. Hence we can easily calculate that $\boldsymbol{R_2}$ **= 390 Ω**.

After having the value of components, I used KiCad PCB tool to design PCB layout and 3D model of this part, including Diode Bridge and the LM317 regulator as the images below.

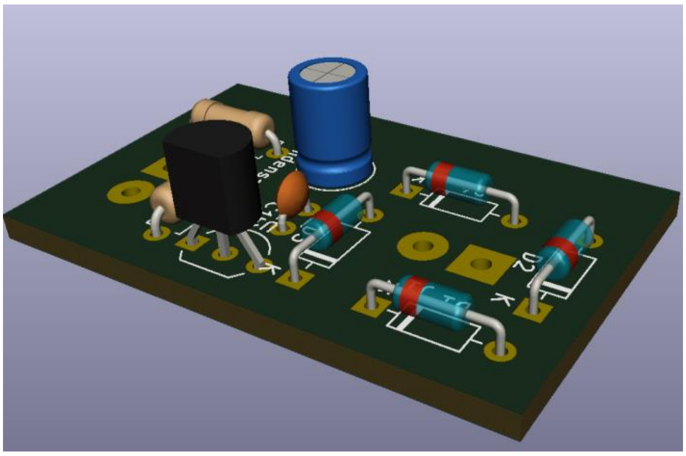


***Figure 3.16**: PCB design and 3D model on KiCad*

This model helps me easier to verify the output signal and print the PCB circuit. The real circuit is even smaller than an 1 euro coin. It is adaptive to the dimension to intergrate in the space of LinkyTIC.

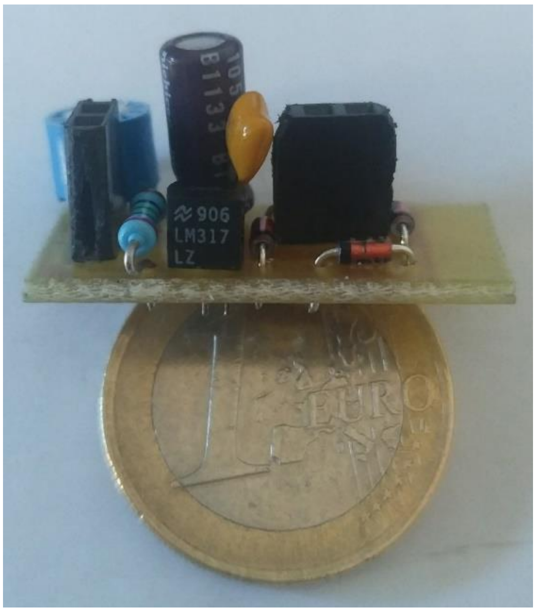


***Figure 3.17**: PCB board compares to an 1 euro coin*

In the printed circuit, I have chosen IC LM317 Package 3-Pin TO-263 instead of Package 3-Pin TO-220 because size of TO-220 was too large for the space of LinkyTIC. Moreover, the power consumption on the IC is just only:

$$I_{reg} \times (V_i - V_O) = 40\ mA \times (5.4 - 3.3)\ volts = 0.084\ W.$$

So we don't need the heat dissipation due to the heat generation on IC LM317.

Then I checked the signal of DC no-load output from the emulation power source of GBF with an oscilloscope :

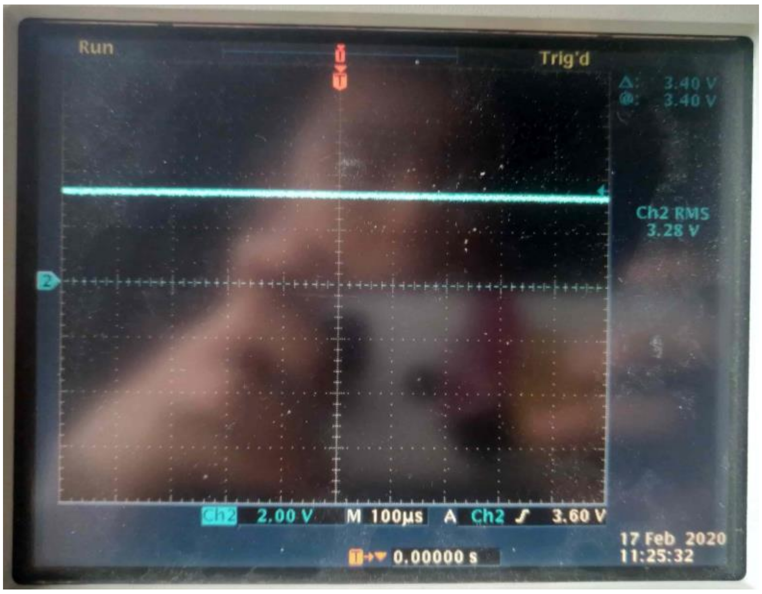


Figure 3.18: *Result of Output from LinkyTIC to supply for GeeLink*

I also tested the operation of this circuit with Arduino Pro Mini at 3.3V:

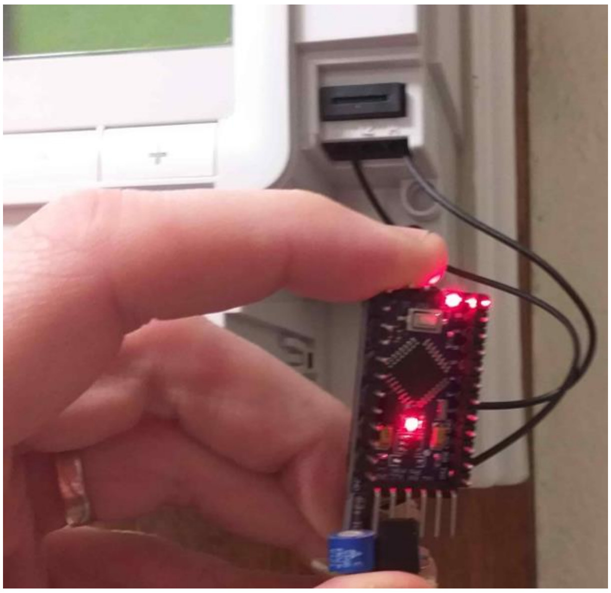


Figure 3.19*: Testing with Arduino Pro Mini*

So Arduino Pro Mini can work with the power source from LinkyTIC through this mini circuit, but we have to make sure this power is enough for the entire device GeeLink.

3.6. *Power Consumption of Arduino Pro Mini & module RFM95W*

3.6.1. Arduino Pro Mini at 3.3V 8MHz

The power of Alim-TIC is extremely tiny. Meanwhile the ATmega328P chip on Arduino Pro Mini continuously execute several million instructions per second when it is in Active Mode. Further, the On-Board Peripherals Analog to Digital Converter (ADC), Serial Peripheral Interface (SPI), Timer 0,1,2, Two Wire Interface (I2C), USART, Watchdog Timer (WDT), and the Brown-out Detection (BOD) consume power.

To save that power, the ATmega328P MCU supports a number of sleep modes and unused peripherals can be turned off. The sleep modes differ in what parts remain active, by the sleep duration and the time needed to wake-up (wake-up period). It means that we need to think about a mode that consume less energy on the µController.

3.6.2. Sleep Mode on Arduino Pro Mini

In my project, I used the Low-Power library from RocketScream which is simple to use but very powerful.

The statement: "LowPower.powerDown(SLEEP_8S, ADC_OFF, BOD_OFF); " puts the MCU in SLEEP_MODE_PWR_DOWN for 8 seconds, depending on the first argument. It disables the ADC and the BOD. Power-down sleep means that all chip functions are disabled till the next interrupt. Further, the external oscillator is stopped. Only level interrupts on INT1 and INT2, pin change interrupts, TWI/I2C address match, or the WDT, if enabled, can wake the MCU up. So with the single statement, you will minimize energy consumption. Therefore, the function **powerDown** will shut down everything.

With a 3.3 V Arduino Pro Mini, I had the results only approximate 2 mA instead of more than 6 mA when using LowPower.powerDown instead of delay. But how I reduce the current consumption down to 0.09 mA will be explained in the next section.

3.6.3. Disable Power Led To Save More Energy

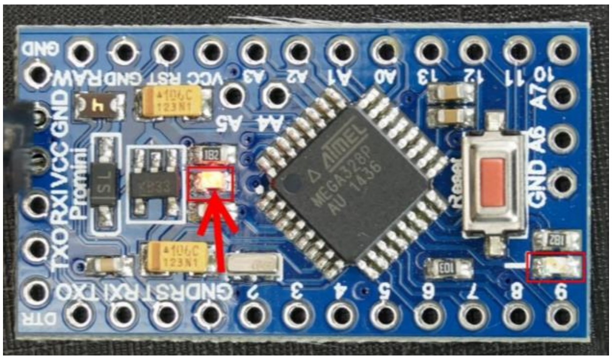


Figure 3.20: *The Power LED removed to save energy*

Without the power LED, at 3.3V, Arduino Pro Mini uses about 1.5 mA less in Active mode. However the ATmega328P cannot control the power LED. Thus, to disable the LED, I need to make a small hardware modification by cutting one of the two tiny traces which connect to the power LED or remove directly the power LED.

I measured with two boards to make sure the results were as more objective as possible. This is the average result of 10 tests for each board :

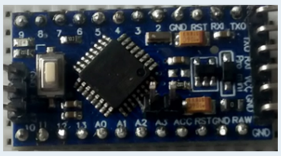
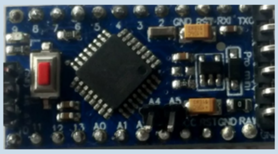
Only Arduino Pro Mini @3.3V (8Mhz)	Keep power LED		Removed power LED	
	"Active" mode	Low-Power mode	"Active" mode	Low-Power mode
	6,34 mA	1,86 mA	4,18 mA	83,4 µA
	5,48 mA	1,45 mA	3,96 mA	81,6 µA

Table 3.2: *Current consumption of Arduino Pro Mini in different modes*

From this table, we can confirm that current from LinkyTIC emulated by GBF (40mA) is enough for Arduino Pro Mini.

3.6.4. Module RFM95W

Communication is always the most energy-consuming-part in an electronic device. In my GeeLink, RMF95, supplied at 3.3V, which consumes **1,6 mA** (max 1,8mA according to datasheet).
However, **80 mA** is the current which the module needs to transmit the request to join into LoRa network, the activation process which I've already mentioned in last chapter.

Therefore the power from LinkyTIC (130mW) is not afford to supply for GeeLink.

About this problem, the simpliest solution is adding a battery but it is not appropriate in my project. My idea is using the capacitor C_{adj} in the regulator (Figure 3.15) as the energy-storage component for the joining request of RFM95W. Suppose that GeeLink needs 80mA in 1 second, so we calculate the value of capacitor C_{adj}.

The power that RFM95W needs : $80mA \times 3.3V = 264mW \approx 0.3W$

$\rightarrow$ $Storage\ energy\ in\ 1\ second\ E_s : 0.3W \times 1s = 0.3J\ (joule)$

$\rightarrow$ $Capacitance\ C = \frac{2 \times E_s}{V^2} = \frac{2 \times 0.3}{3.3^2} \approx 0.055$ (F).

However, there are no ordinary capacitor which contains 0.055 Farad.
In this situation, I will test the respone of output voltage from LinkyTIC with load here are a Arduino Pro Mini 3.3V 8MHz and a LoRa module RFM95W.

- In the case of Cadj is a series of the **5 capacitors 4700 µF** which are available in G2Elab :

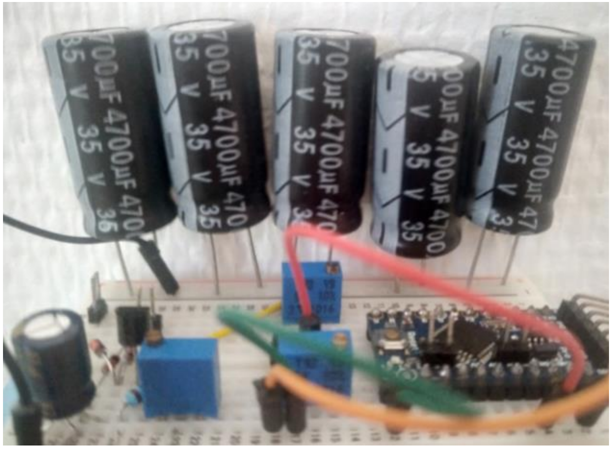


***Figure 3.21**: Series of 5 capacitors 4700 µF*

From these 5 capacitors, we have the total capacitance is: $5 \times 4700\mu F = 0.0235$ (F). It means that RFM95 just uses 80mA to request for joining in only **0.5 second.**

- Moreover, I have thought about solving the issue above with a **Super Capacitor** in the circuit as the figures below.

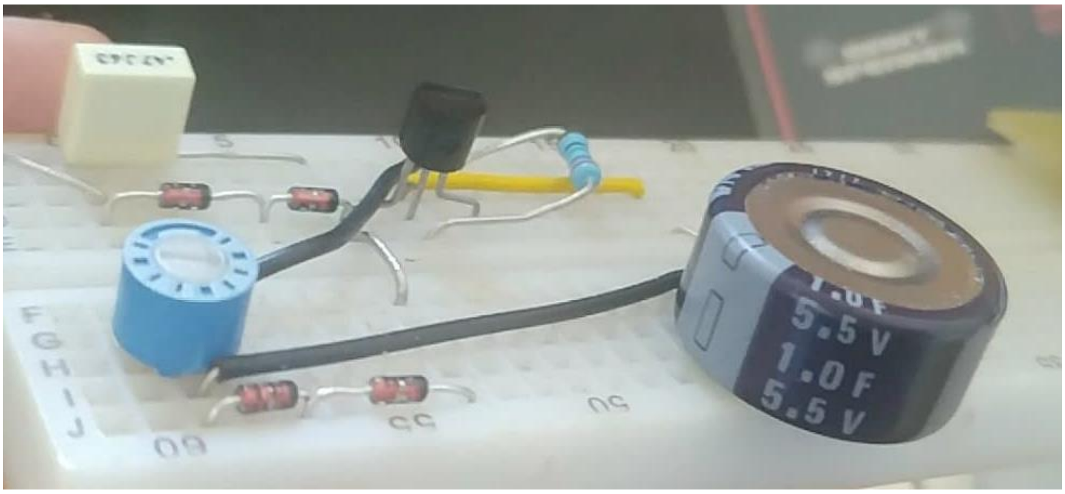


Figure 3.22: *Super Capacitor 1F*

However, there are two problems with the charging and discharging of the Super capacitor.

- It takes a long time to recharge the super capacitor with the charging current is 35mA (came from the GBF).
- The big voltage drop when using the super capacitor.

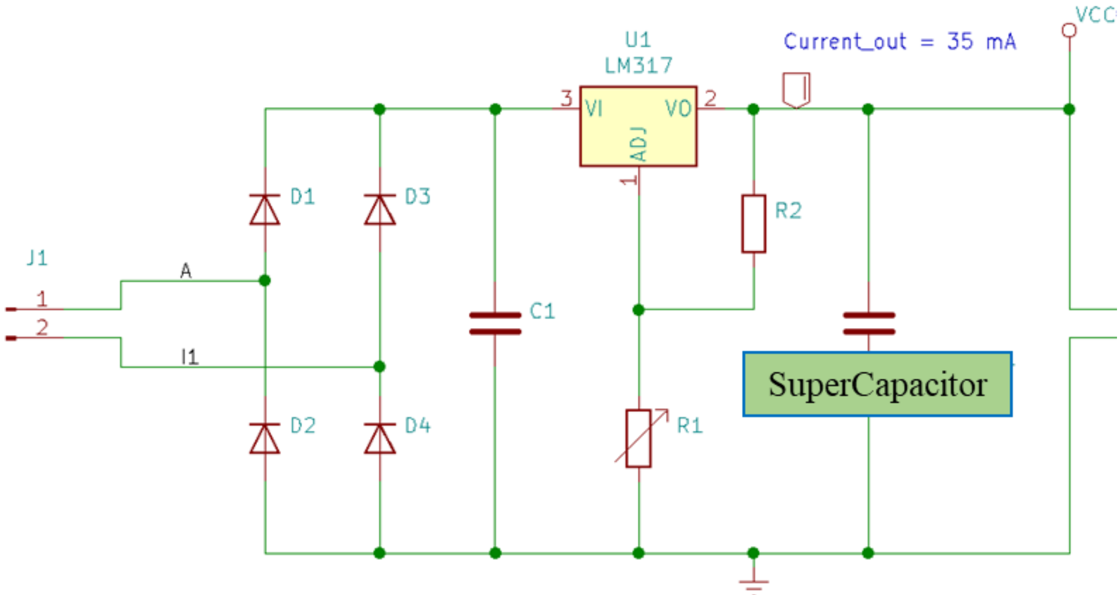


Figure 3.23: *Schematic with Super Capacitor*

Before analyzing those problems, I would like to remind a bit that the ATmega328P and RFM95W can work between these limits of voltage:

- Minimum : 2,7 Volts
- Maximum : 5.5 Volts (regardless the regulator on itself)

Comeback to the time to charging and discharging the super capacitor, I measured at a lot of voltage supply (VCC) level by adjust the variable resistor R_1 and got the following inferences:

- Time to fully charge from 0V to VCC for the super capacitor is **14 minutes**
- From the moment when the joining request is completed until the voltage rises back to VCC, the process takes **6 minutes**.

The following table is a summary of my measurements (in Volts):

Voltage supply **(VCC)**	**4.15**	**3.9**	**3.82**
Minimum Voltage during the request (**V_p**)	2.97	2.85	2.73
Voltage after the request (**V_a**)	3.86	3.71	3.65

***Table 3.3**: The voltage measurement of super capacitor*

From the table, the average transmission voltage drop (= VCC - Vp): **1.1 Volts**. Therefore, the minimum VCC to supply for GeeLink in this case must be the minimum working voltage (2.7 V) plus the voltage drop (1.1 V) = **3.8 Votls.**

<u>These are the some illustrations of the transmission process:</u>

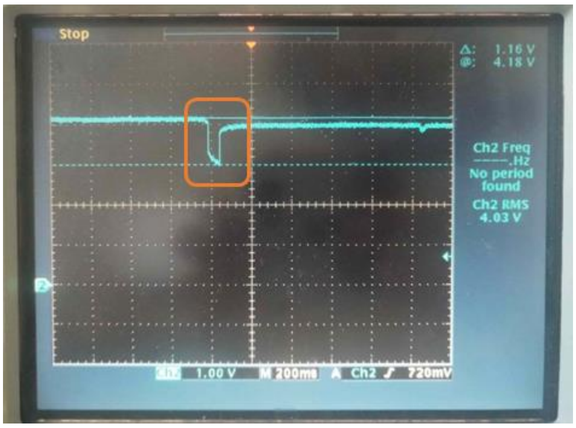


Figure 3.24.a: *VCC = 4.2V*
Voltage drop during the request ≈1.1V

Figure 3.24.b: *VCC = 4.2V*
Voltage drop after the request = 0.2V

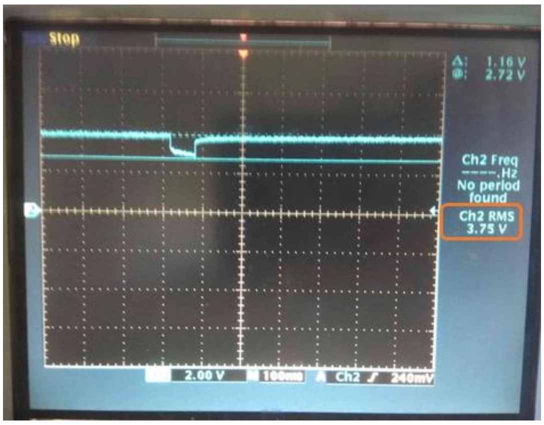


Figure 3.24.c: *VCC = 3.8V (minimum)*
(the shape is a little different because of the ratio)

➢ Check one more time with the series of **5 capacitors 4700 µF** and this is the statistic:
- Time to fully charge from 0V to VCC for the super capacitor is **15 seconds.**
- From the moment when the joining request is completed until the voltage rises back to VCC, the process takes **5 seconds**.

The following table is a summary of my measurements (in Volts):

Voltage supply **(VCC)**	**4.15**	**3.59**	**2.93**
Minimum Voltage during the request (**V_p**)	3.91	3.36	2.73
Voltage after the request (**V_a**)	4.02	3.47	2.79

Table 3.4*: The voltage measurement of series 5 capacitors*

From the table, the average transmission voltage drop (= VCC - Vp): **0.2 Volts**. Therefore, the minimum VCC to supply for GeeLink in this case must be the minimum working voltage (2.7 V) plus the voltage drop (0.2 V) = **2.9 Votls.**

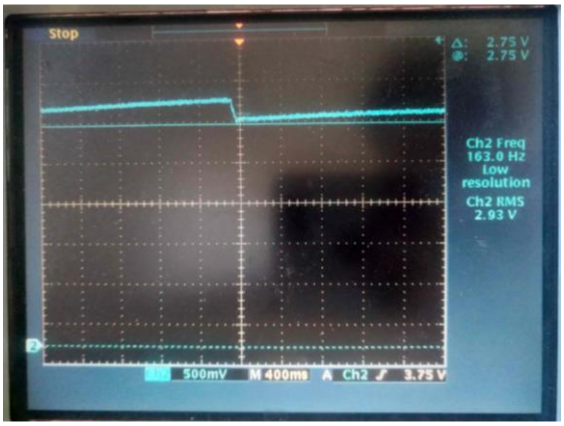


Figure 3.25: *The illustration with VCC = 2.95V*

With those measurements, the power problem of Alim-TIC can be solved by Sleep-mode on Arduino Pro Mini, in other words, µController will sleep after a transmission to save enough energy in the Super Capacitor or the capacitors and use that storaged energy for the next round.
The algorithm diagram below is used to describe this process in detail :

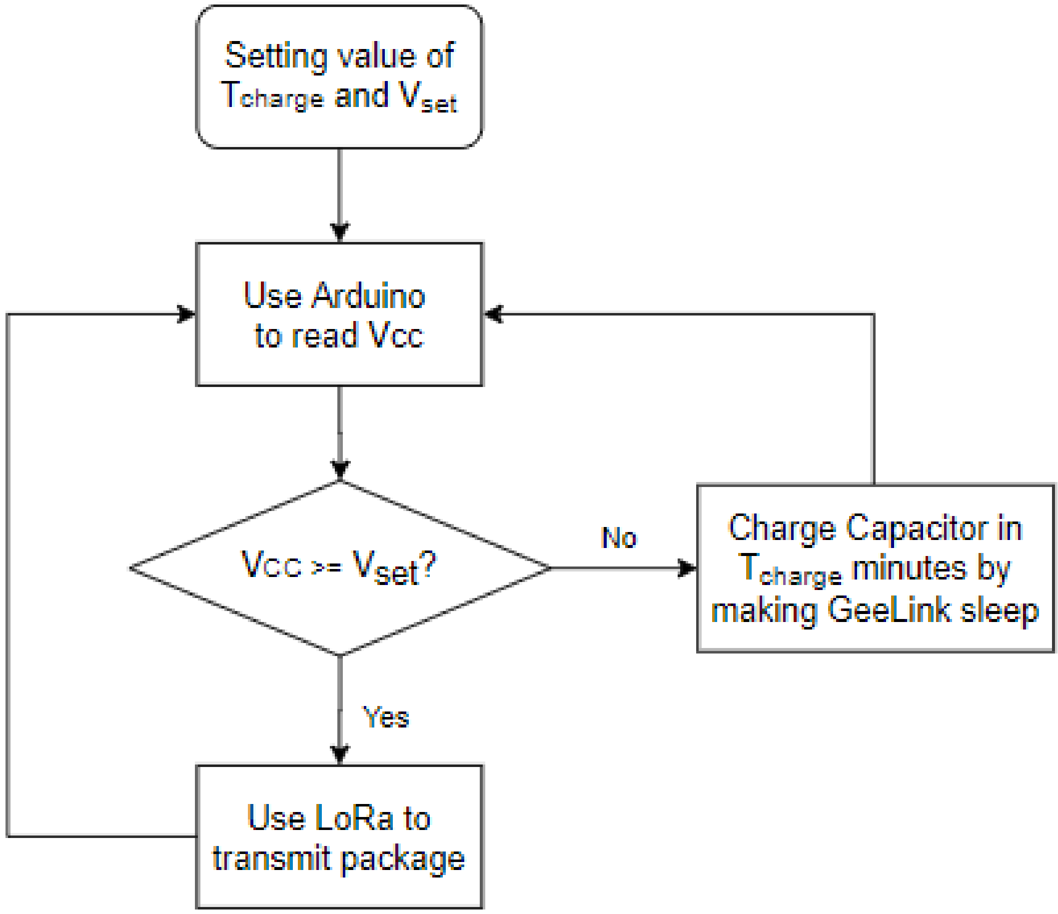


***Figure 3.26**: Charging the Capacitors Process*

➔ We have a clear difference in energy consumption in two cases.
In short, a big capacitor is not ALWAYS good, it's better than just big enough !

3.7. PCB Antenna Measurement and Design for LoRa 868MHz

Antenna plays as an essential role in telecommunications. There are no wireless application can work without an antenna and so is LoRa technology.

***Figure 3.27**: RFM95W and the antennas* [11]

In the European countries, the LoRa Alliance has defined frequency band for the usage of LoRa is EU863-870 band. The end devices in this band will operate from 863 to 870 MHz and use a channel data structure to store the information of at least 16 channels. The channels in this band can be attributed freely by the operator; however the three default channels; 868.10, 868.30, 868.50 are mandatory to be implemented in every European end-device. Other channels can be freely distributed across the allowed frequency range on a network per network basis.

In my test, I used 2 prototypes of the PCB antenna. The first one has not been tuned for frequency 868MHz (1) (results of the previous project). The second antenna is the PCB antenna on UCA board which is an open-source tuned antenna of Professor Fabien FERRERO from Université Côte d'Azur (2).

The two devices with their antennas have these same these indicators: Spreading Factor, Frequency, Bandwidth, Placement, Payload's size…

These are the results came from the same gateway in Grenoble by the two devices:

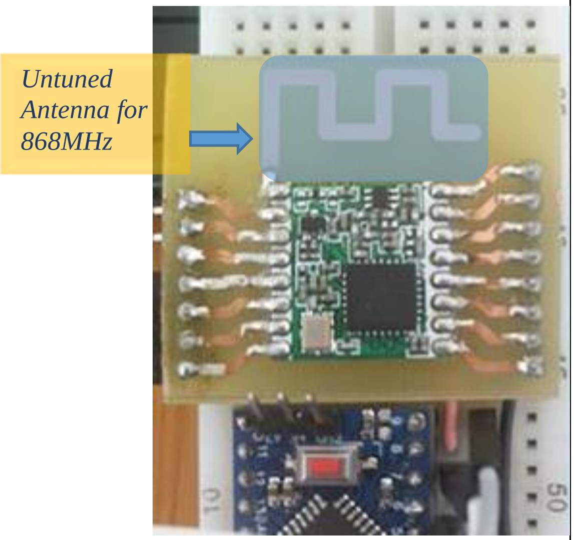
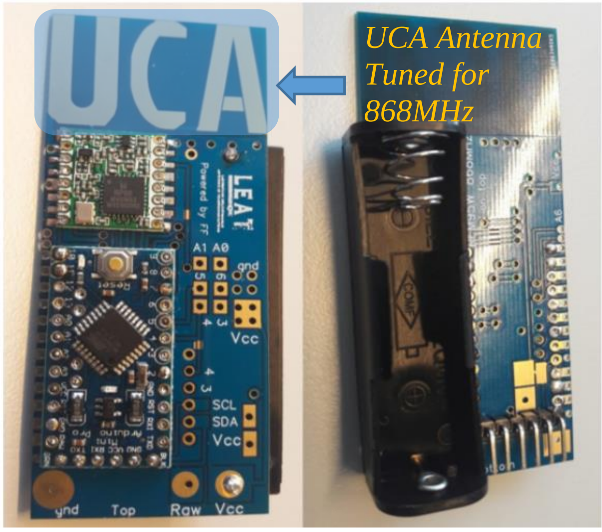
(1) 	(2) 
"gtw_id": "eui-7276fffffe019843", "timestamp": 1837446020, "time": "2020-04-07T12:36:52.079998Z", "channel": 5, "rssi": -114, "snr": 3	"gtw_id": "eui-7276fffffe019843", "timestamp": 3080636588, "time": "2020-04-07T12:57:35.270895Z", "channel": 5, "rssi": -109, "snr": 7,
"gtw_id": "eui-7276fffffe019843", "timestamp": 2222077324, "time": "2020-04-07T12:43:16.711404Z", "channel": 6, "rssi": -113, "snr": 1,	"gtw_id": "eui-7276fffffe019843", "timestamp": 2865843692, "time": "2020-04-07T12:54:00.477943Z", "channel": 6, "rssi": -105, "snr": 8
"gtw_id": "eui-7276fffffe019843", "timestamp": 2031682276, "time": "2020-04-07T12:40:06.316306Z", "channel": 5, "rssi": -114, "snr": 3,	"gtw_id": "eui-7276fffffe019843", "timestamp": 2871017043, "time": "2020-04-07T12:54:05.651295Z", "channel": 0, "rssi": -108, "snr": 10,
"gtw_id": "eui-7276fffffe019843", "timestamp": 2411104020, "time": "2020-04-07T12:46:25.73815Z", "channel": 7, "rssi": -114, "snr": 2,	"gtw_id": "eui-7276fffffe019843", "timestamp": 761699931, "time": "2020-04-07T13:30:31.302046Z", "channel": 0, "rssi": -105, "snr": 8,
"gtw_id": "eui-7276fffffe019843", "timestamp": 2721140747, "time": "2020-04-07T12:51:35.774959Z", "channel": 0, "rssi": -116, "snr": 1,	"gtw_id": "eui-7276fffffe019843", "timestamp": 756526620, "time": "2020-04-07T13:30:26.128734Z", "channel": 7, "rssi": -103, "snr": 9

Figure 3.28: *Summary of antenna Measurement*

It's easy to find that:

- The maximum RSSI (Received Signal Strength Indicator) of (1) is always smaller than the minimum RSSI of (2)
- The SNR (Signal to Noise Ratio) of (2) is always much larger than (1).

This is the reason why an antenna which is tuned for a specific frequency is a very important component in data transmission by LoRa.

Recognizing the importance of antennas, I did some research and redesigned the DN038 - PCB antenna for 868 MHz frequency based on open-source research of Texas Instrument by using KiCad.

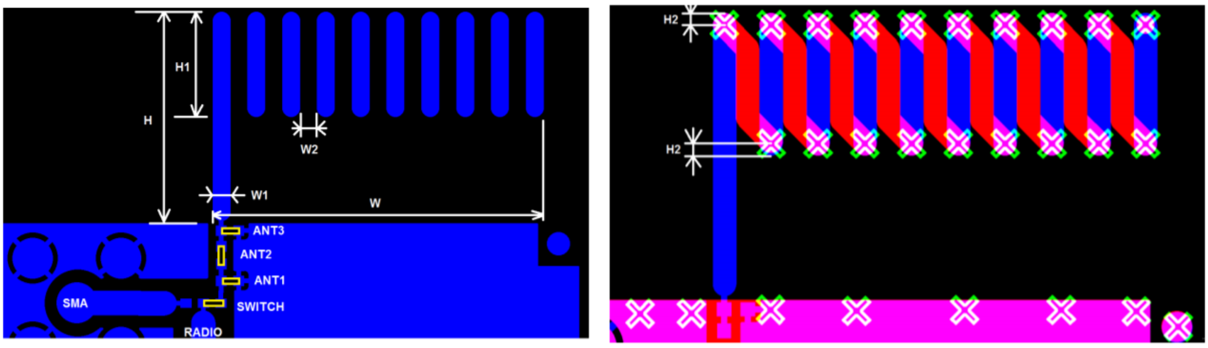


***Figure 3.29**: The open-source Antenna DN038* [12]

For this important component of GeeLink, I not only redesigned the antenna, but also integrated the RFM95W's footprint for more convenience of the measurement.

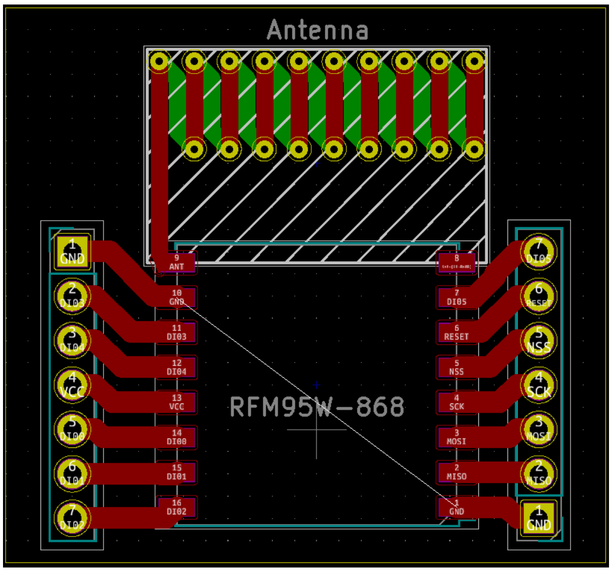


***Figure 3.30**: PCB Antenna 868 MHz*

This is the front and back view of my antenna's design on KiCad

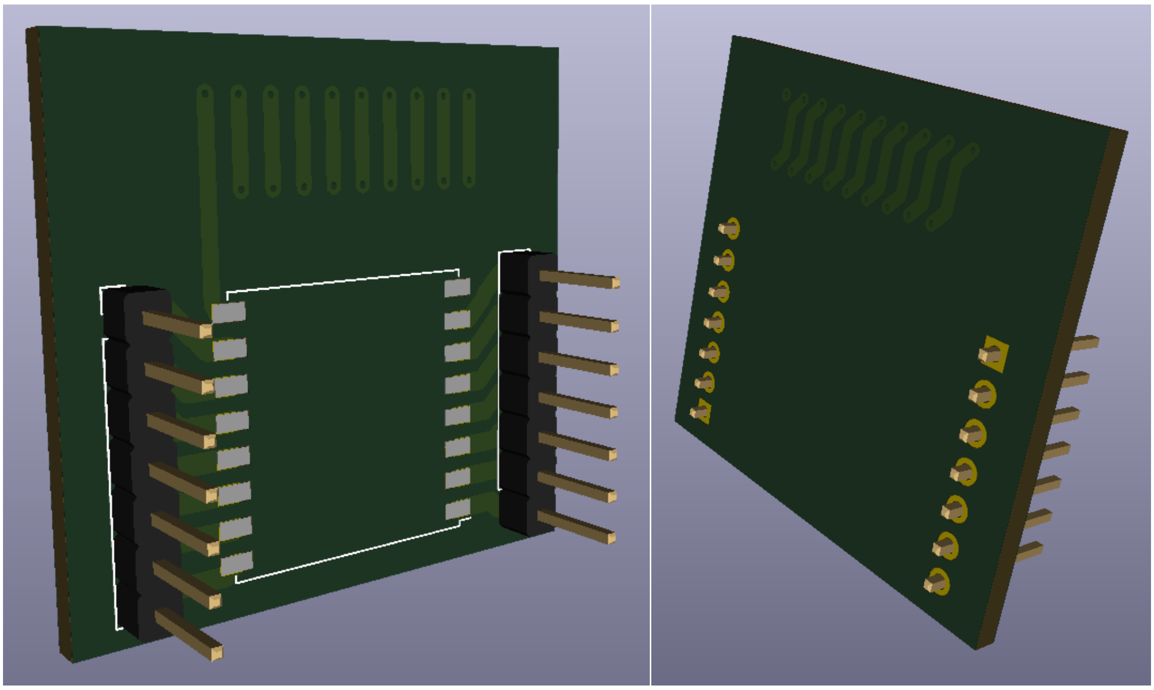


***Figure 3.31**: 3D models of PCB Antenna 868 MHz*

3.8. Conclusion

Chapter two and chapter three cover all the hardware to build my system, which includes LinkyTIC and GeeLink as shown in Figure 3.31. Chapter four will cover the process of sending data from Linky to the application server

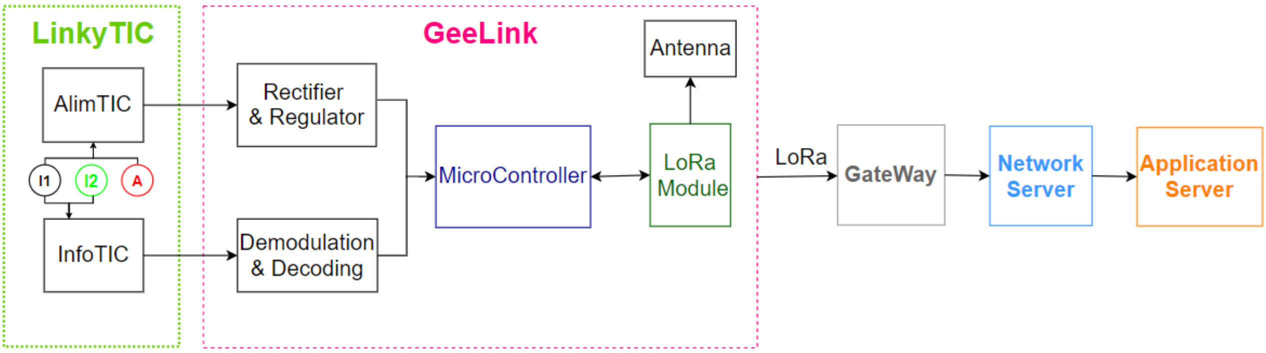


***Figure 3.32**: The whole system function block diagram*

Chapter 4 – From LoRa to Application Server

In this chapter, I will process the data from LinkyTIC and transfer those data to the server using LoRa Technology. From now, the signals obtained from LinkyTIC will be called Info-TIC which are sent on pins I1 and I2 of LinkyTIC.

4.1. Characteristics of the Info-TIC

4.1.1. Physical layer:

The signals presented on the Info-TIC are prepared by Amplitude Shift Keying (ASK) method. They are characterized by the following parameters:

- Vevh1 is the maximum voltage of carrier wave for the transmission of a "1"
- Vevl0 is the minimum voltage of carrier wave for the transmission of a "0"
- Vevh0 is the maximum voltage of carrier wave for the transmission of a "0"
- Tev1 is the minimum guaranteed time during that the voltage of carrier wave lower than Vevh1
- Tev0 is the minimum guaranteed time during that the voltage of carrier wave is between Vevl0 and Vevh0
- Vel0 and Vev0 are not the extreme values of the carrier wave's voltage, but rather the "low" and "high" limits guaranteeing the correct operation

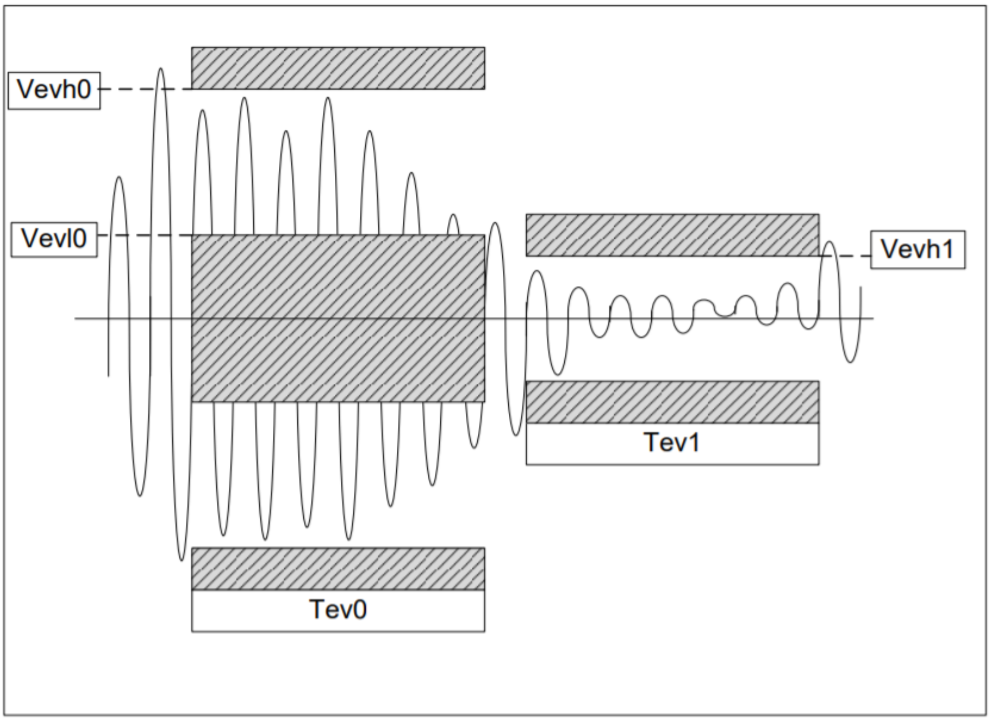


Figure 4.1: *An illustration of bit transmission from Info-TIC* [7]

According to the catalogue of Linky meter, these specifications of physical signals (open circuit) from Info-TIC are summarized:

- Vevh0 = 25 Volts
- Vevl0 = 0.8 Volts
- Vevh1 = 0.4 Volts
- Tev0 = Tev1 = 50 µs

4.1.2. Historic and Standard mode of LinkyTIC

Info-TIC can be configured in two modes:

Historic mode :

Specification	Value
Transmission	Binary with a carrier modulated at 50kHz
Carrier frequency	50kHz
Unidirectional	From Linky to GeeLink
Transmission rate	1200 bauds
Time for one bit	833 us per bit
Coding logic	Negative : if the carrier is present, the bit is 0, otherwise 1

Table 4.1*: Info-TIC in Historic mode* [7]

Standard mode :

Specification	Value
Transmission	Binary with a carrier modulated at 50kHz
Carrier frequency	50kHz
Unidirectional	From Linky to GeeLink
Transmission rate	9600 bauds
Time for one bit	104 us per bit
Coding logic	Negative : if the carrier is present, the bit is 0, otherwise 1

Table 4.2*: Info-TIC in Standard mode* [7]

4.1.3. Details of the data transmission process from the Info-TIC

The characters are transmitted on 10 bits whose composition is as follows:

- 1 Start bit logic 0
- 7 bits to represent the character in ASCII
- 1 parity bit
- 1 Stop bit logic 1
- Bits are transmitted from LSB (Least Significant bit) to MSB (Most Significant bit)

Example:

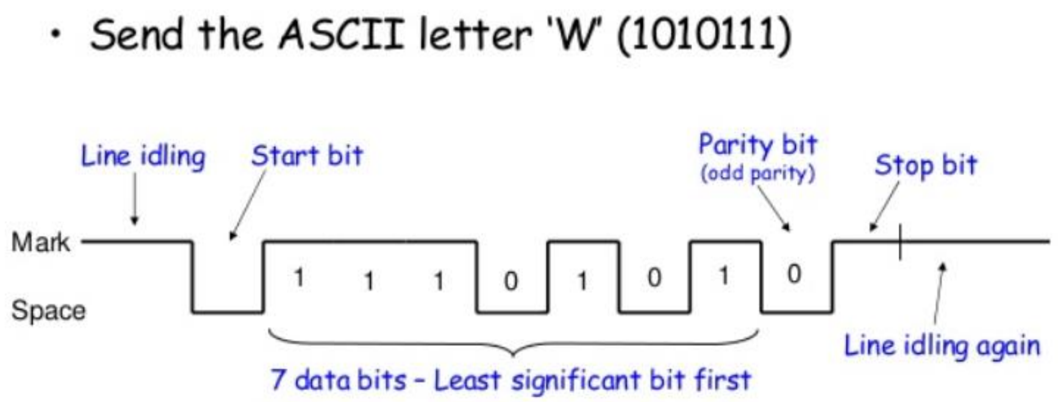


Figure 4.2*: Sending an ASCII character on Info-TIC*

Transmitted data is preceded by a label allowing to identify it (for example: BASE is the label for the "Overall Index of Linky"). Information groups can be made up of 7 to 9 parts (depending of the timestamp), a start character (line feed), a label, several separators (horizontal tab), the data, a checksum, and a closing character (carriage return).

Note: Checksum = (S1 & 0x3F) + 0x20 with “S1” is the group of characters from label to the space before checksum.

LF(0x0A)	**Label**	*SP(0x20)*	**DATA**	*SP(0x20)*	**Checksum**	*CR(0x0D)*
‘ ’	**BASE**	‘_’	**935669889**	‘_’	**A**	‘ ’

Tableau 4.3*: An example information group*

The delay between 2 successive information groups of the same frame must be less than 33.4 ms.

Frame principles

Linky transmits the frames, composed of several information groups. The frames are transmitted one after the other continuously. A delay without transmission is provided between the end of a frame and the begining of the next. Its duration is between 16.7 and 33.4 ms.

Example of a frame from LinkyTIC in Histotic mode :

ADCO 270622224349 B
OPTARIF HC.. <
ISOUSC 30 9
BASE 002633208 #
PTEC HP..
IINST 002 Y
IMAX 090 G
PAPP 00868 (
HHPHC C .
MOTDETAT 000000 B

IMAX is always equal to 90 A in case of Linky meter single phase.

In my project, these following indexes are essential indexes that I will collect and transmit to the server. It means that we can overlook the others:

- **IINST** : instantaneous current in A,
- **PAPP** : apparent power in VA,
- **BASE** : Linky general index in Wh.

4.2. Demodulation and Decoding Info-TIC

With all the specifications in the previous section, we need to demodulate the ASK signals from LinkyTIC. The most effective way is taking advantage from an optocoupler: electrical isolation to protect GeeLink and to demodulate digital signals of Info-TIC.

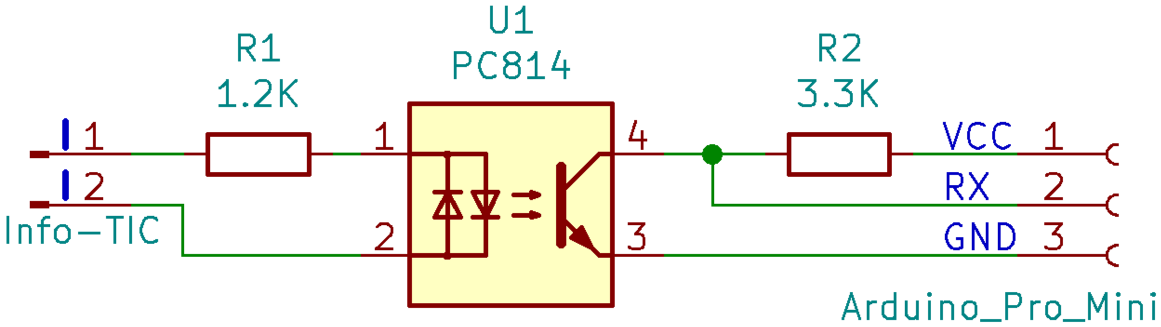


***Figure 4.3**: Schematic demodulation circuit*

Based on this schematic, I can design the 3D model of this circuit as the image below:

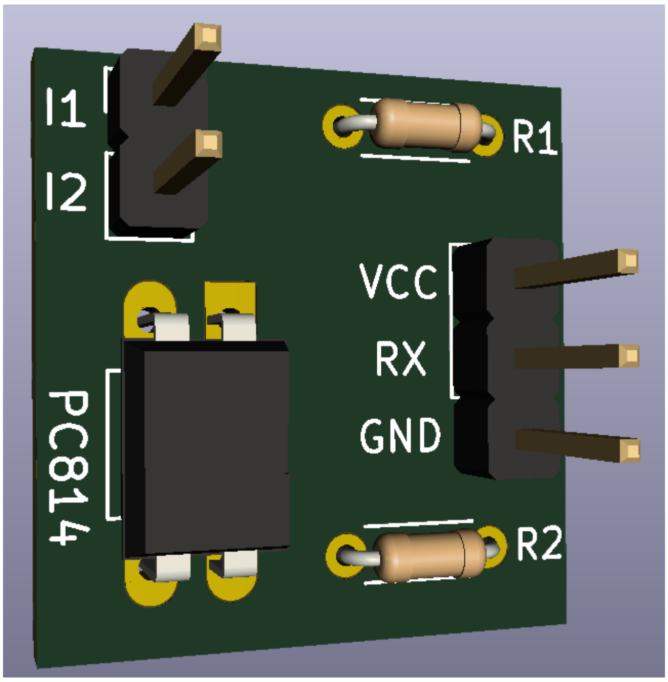


***Figure 4.4**: 3D model of demodulation module on KiCad*

Info-TIC's binary signals after the demodulation will be communicated with Arduino Pro Mini by UART protocol. In Historic mode, baudrate for UART from LinkyTIC to GeeLink is 1200 bauds.

When the hardware is ready for data collection, I will describe the entire process of GeeLink operation through the algorithm diagram below

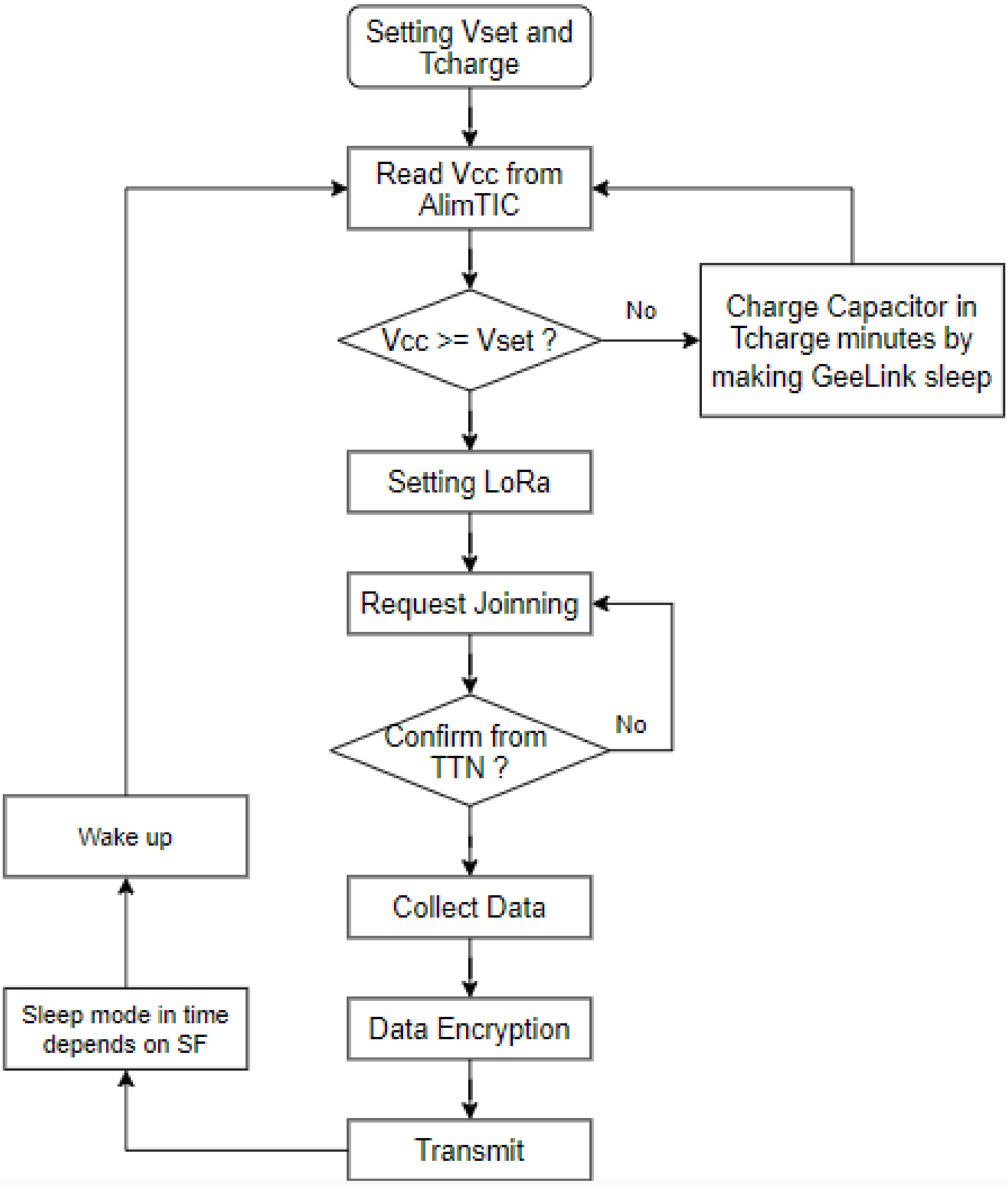


***Figure 4.5**: Algorithm diagram of the operation process of GeeLink*

4.3. The Things Network Server (TTN)

Data from GeeLink will be transmitted by LoRa to the network server for decoding the encrypted data first. After that, the information will be stored in application server. In my system, the most facilitate LoRaWAN infrastructure for developing and experimenting is The Things Network (TTN) server.

TTN is an OPEN, free-to-use community network server. TTN's mission is to build a decentralized, open and crowdsourced data network owned and operated by its users. It is also the easiest LoRaWAN infrastructure to use for developing and experimenting with the Internet of Things.

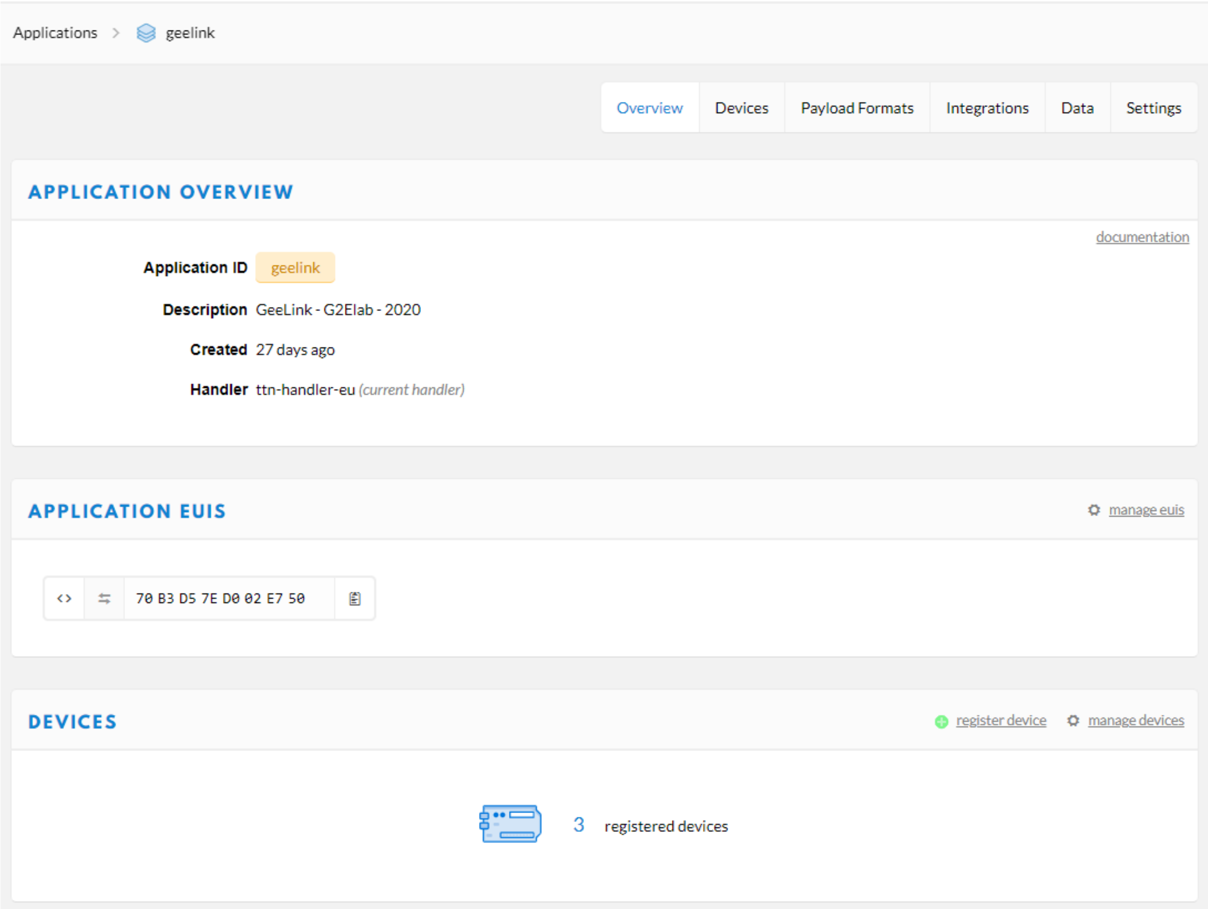


***Figure 4.6**: TTN Application Overview*

4.4. ABP and OTAA

In LoRaWAN network protocol, to activate an end-device, there are two methods – Joining method:

- Activation by Personalization (ABP): In the cases that might need to hardcode the DevAddr as well as the security keys in the device. This means activating a device by personalization (ABP). This strategy might seem simpler, users can skip the join procedure, but it has some downsides related to security.
- Over-the-Air Activation (OTAA): is the preferred and most secure way to connect with The Things Network. Devices perform a join-procedure with the network, during which a dynamic DevAddr is assigned and security keys are negotiated with the device.

→ In terms of security, ABP method is not be guaranteed like OTAA so I just applied OTAA in GeeLink.

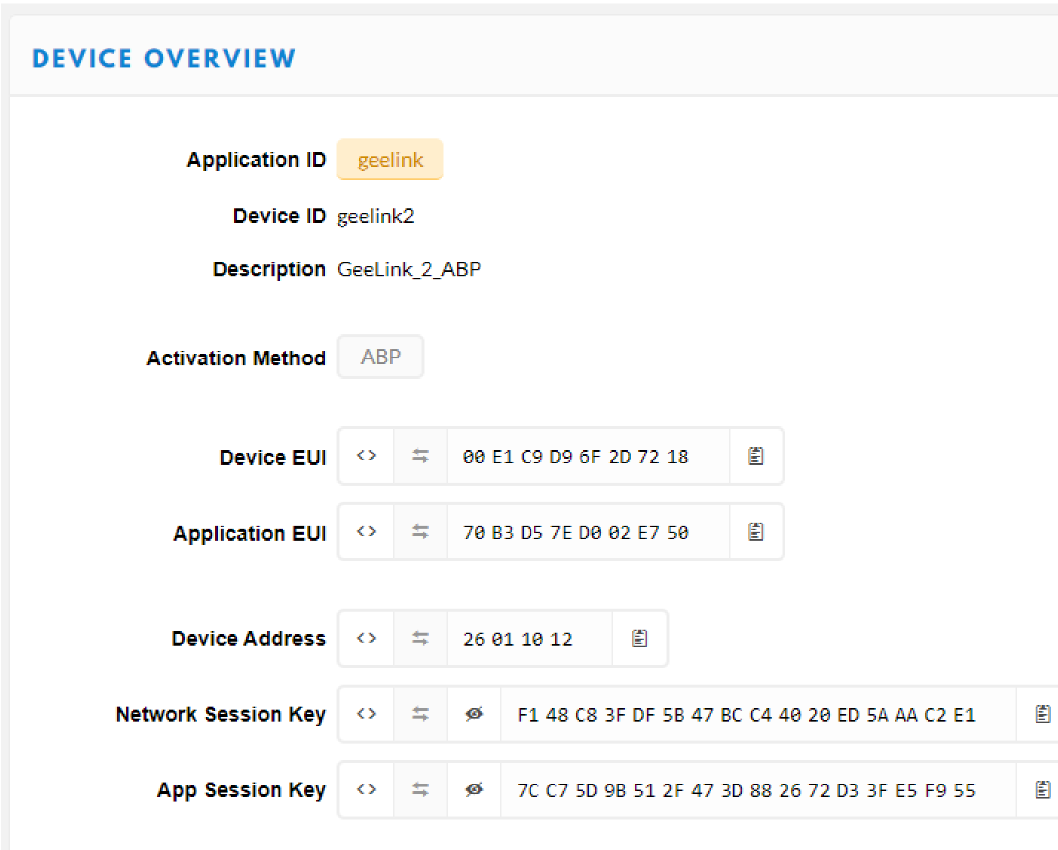


Figure 4.7: *ABP device on TTN*

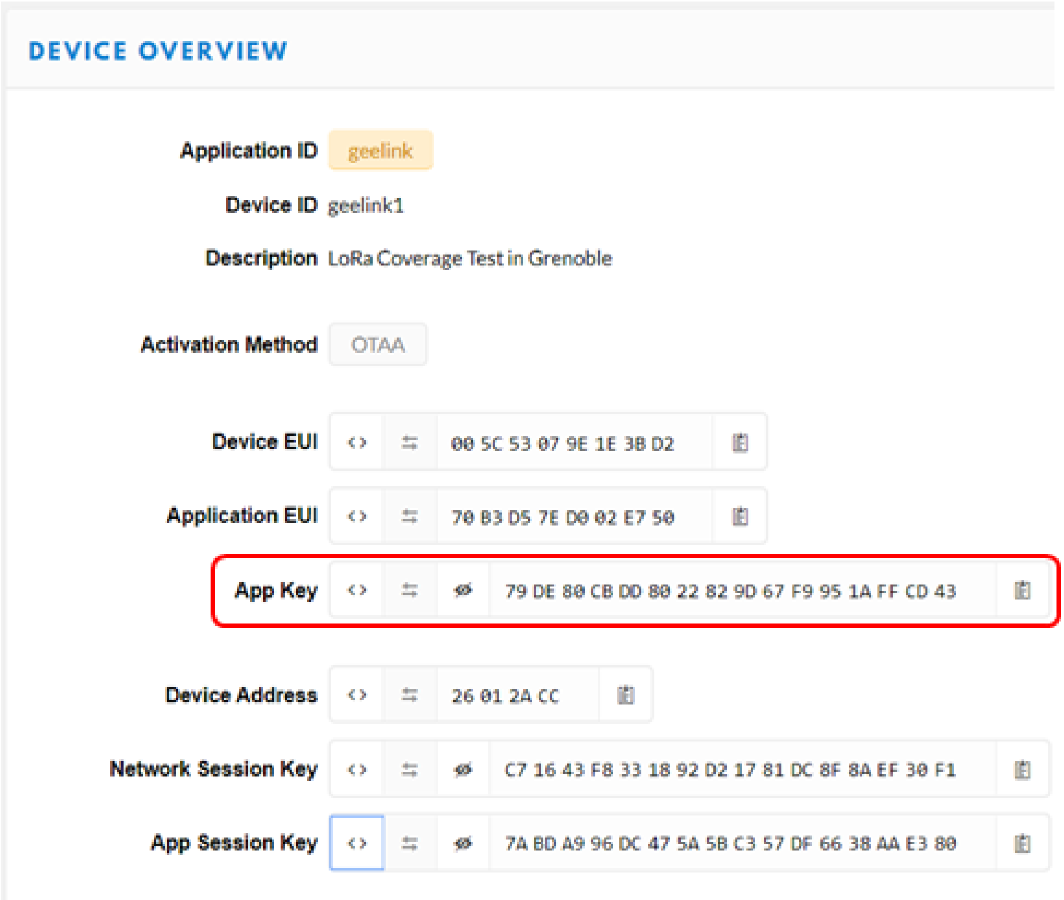


Figure 4.8: *OTAA device on TTN*

Detail Explaination for OTAA Join procedure of an OTAA end device

- GeeLink transmits Join Request to application containing these parameters: Globally unique end-device identifier (DevEUI), Application identifier (AppEUI), Authentication with Application key (AppKey)
- GeeLink receives Join Accept from application server
- GeeLink authenticates and decrypts Join Accept
- GeeLink extracts and stores Device Address (DevAddr)
- GeeLink derives these Security Keys: Network Session Key (NwkSKey) and Application Session Key (AppSKey)

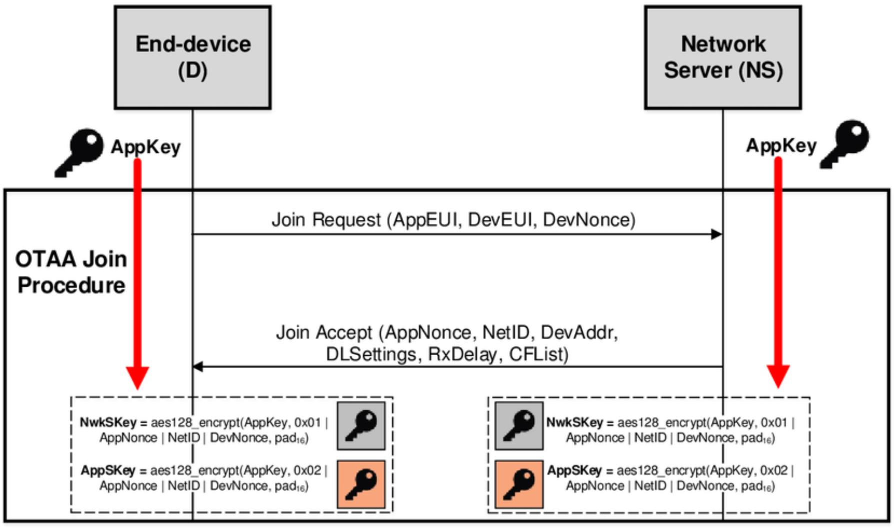


Figure 4.9*: Overview of the OTAA Join procedure* [13]

Before the data from GeeLink can reach the network server, it has to be forwarded by a LoRaWAN gateway which connects to the network server by UDP internet protocol.

4.5. Coverage of a LoRaWAN with TTN Mapper

Installing the infrastructure to monitoring the electrical consumption data must be included measuring the coverage of LoRaWAN network at an area. During the time to implement my project, I have also checked the LoRaWAN coverage in Grenoble by TTN Mapper.

TTN Mapper is a tool used to map the coverage of a LoRaWAN network.

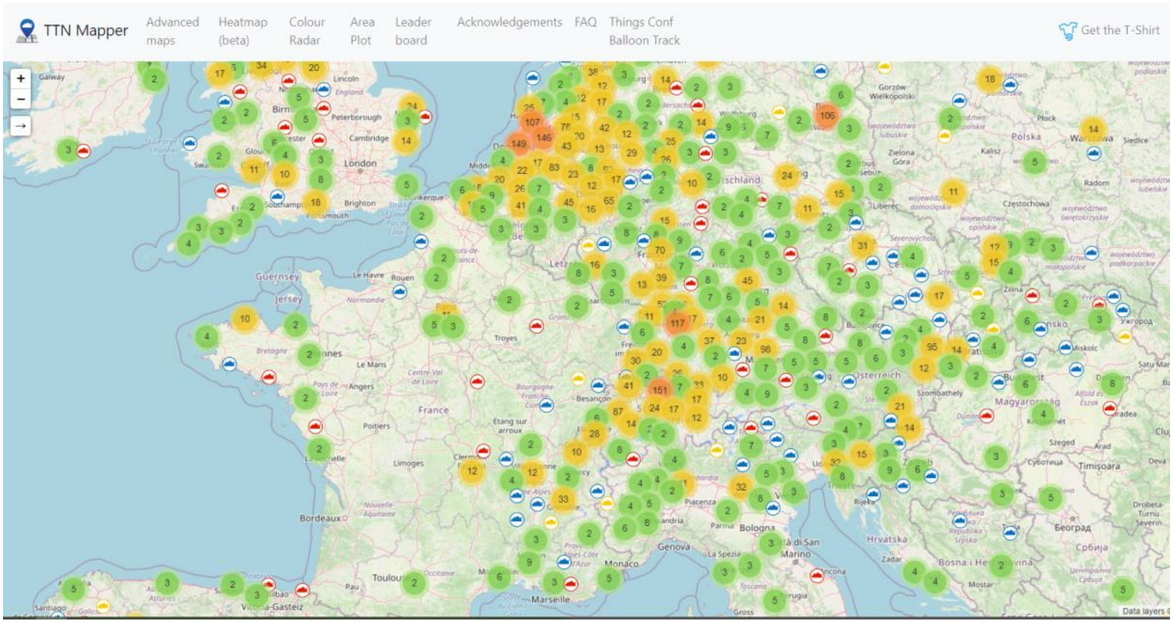


Figure 4.10*: LoRaWAN gateways in France and a part of Euro on TTN Mapper*

The structure for carrying out this test is as follows, TTN Mapper will collect the GSP information from the smart phone which is placed in the same position as end device when a LoRaWAN packet is sent from that end device. Its geo-tag is uploaded to TTN Mapper. From that, we can have the information about geographical location as well as the LoRa's parameters (RSSI, SNR, DR…).

The following figure is the result of the LoRa coverage measurement and the distribution of gateways in Grenoble. The longest distance in the measurements is 18.3 Km.

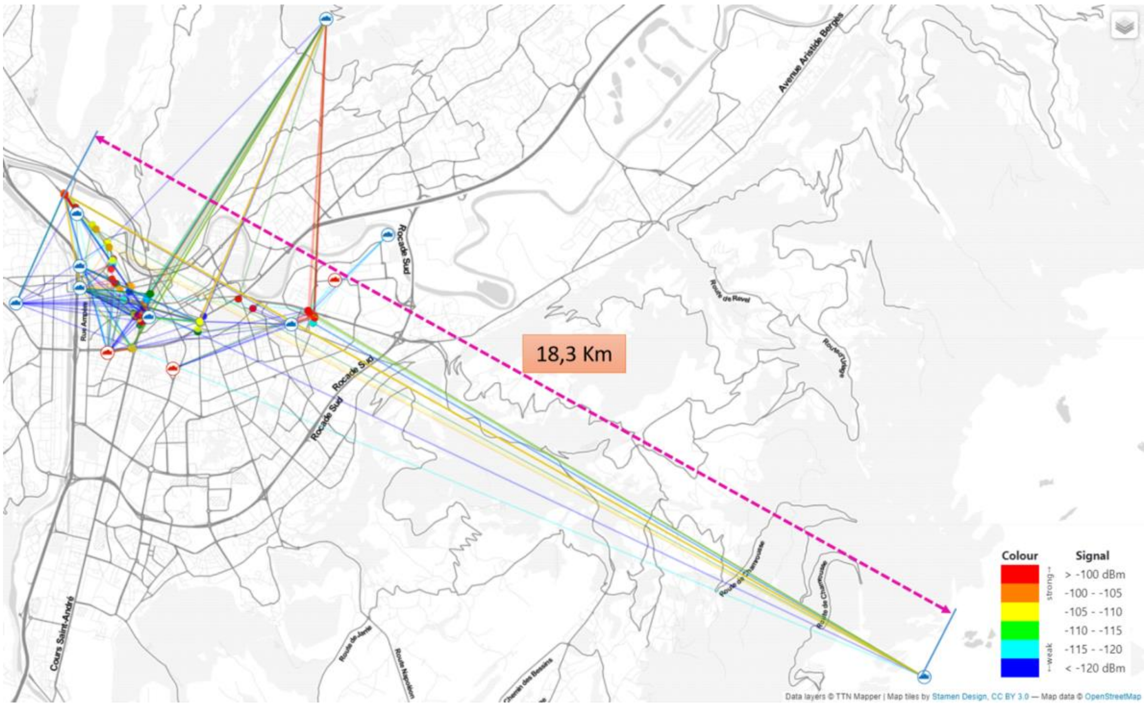


Figure 4.11: *The longest distance transmited by GeeLink at SF7 (18,3 Km)*

4.6. Payload Decoder on TTN:

The data sent from GeeLink is encrypted to ensure the confidentiality of the information, so we need to decode these data from TTN to retrieve those information.

Payload

00 00 01 4A 01 01 00 56 02 02 00 94 70 03 03 00 07 5B CD 15   20 bytes

Figure 4.12: *A payload transmitted by GeeLink to TTN*

To decode this kind of payload, I built a custom payload decoder using JavaScript on TTN console. The format is based on the indexes we collected from Linky meter: IINS, PAPP, BASE and VccTIC.

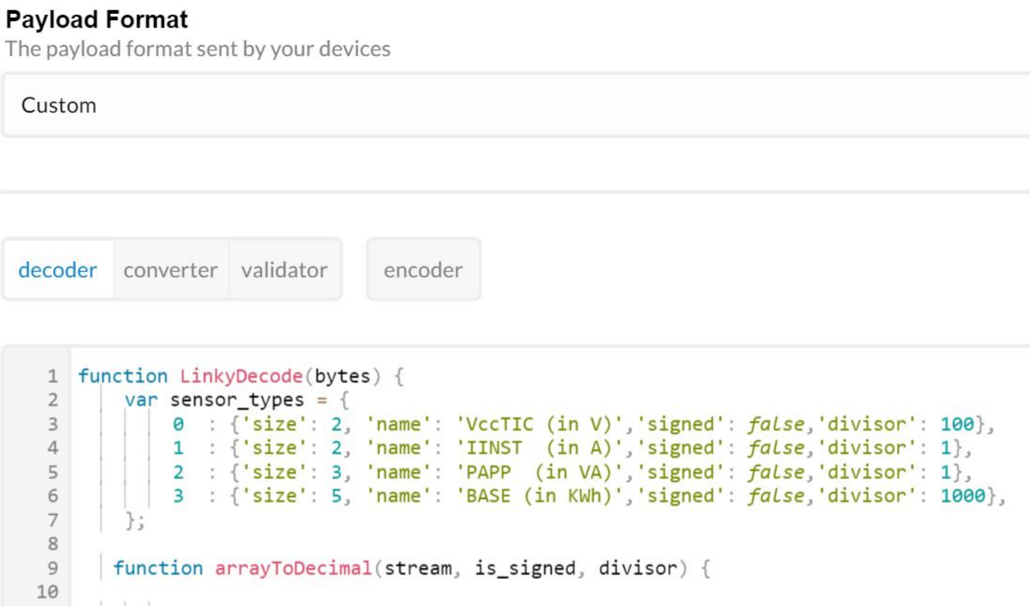


Figure 4.13: *Format the payload decoder on TTN*

And the payload result on TTN after decoding is in this format:

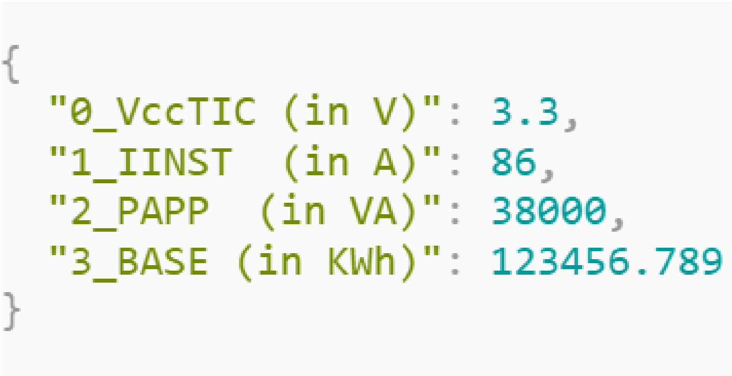


Figure 4.14: *Payload format for GeeLink*

I can also process the data from GeeLink sent to TTN through this payload decoder. The general index – BASE – read from GeeLink is in Wh but its unit on TTN is KWh.

4.7. Application server

The application server including 2 versions: Personal-server and University-server of datacenter in Grenoble. Personal-server is built on a VPS (Virtual Private Server) running Ubuntu operating system.

4.7.1. Node-RED and MQTT

The application server is connected with TTN by MQTT protocol throught a Node-RED palette: node-red-contrib-ttn

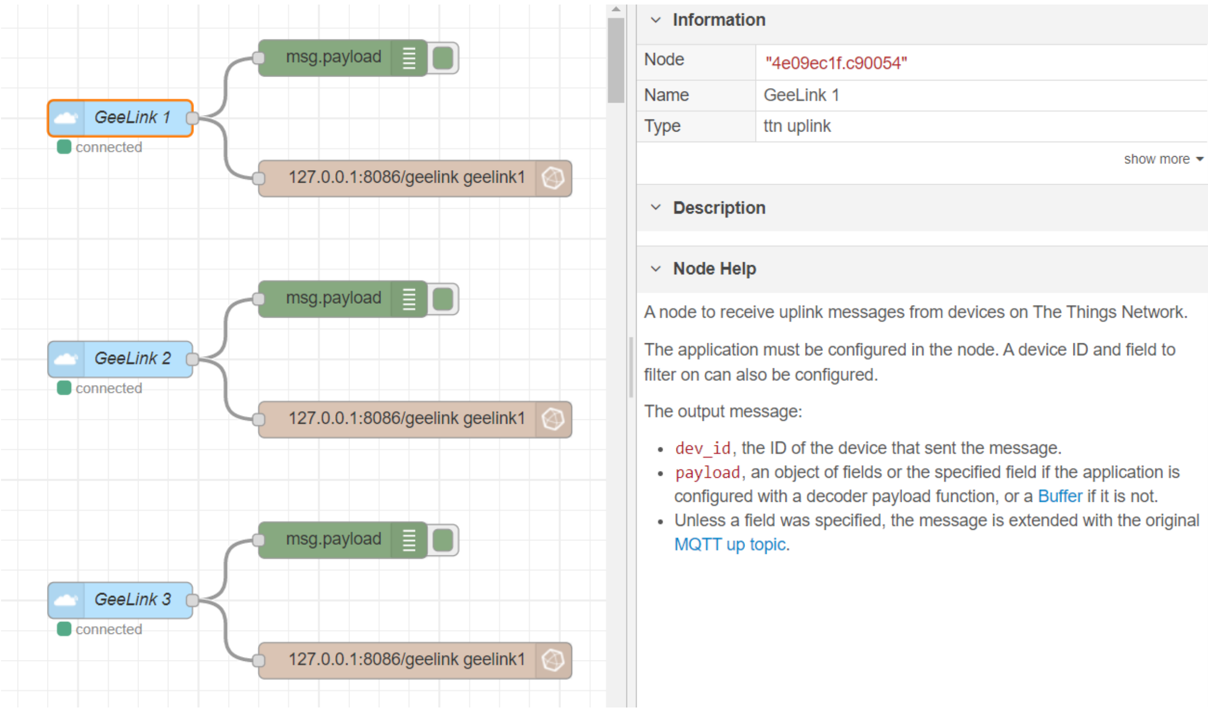


Figure 4.15: *Node-RED on personal-server*

A device of GeeLink application in TTN will be configure MQTT like the following figure:

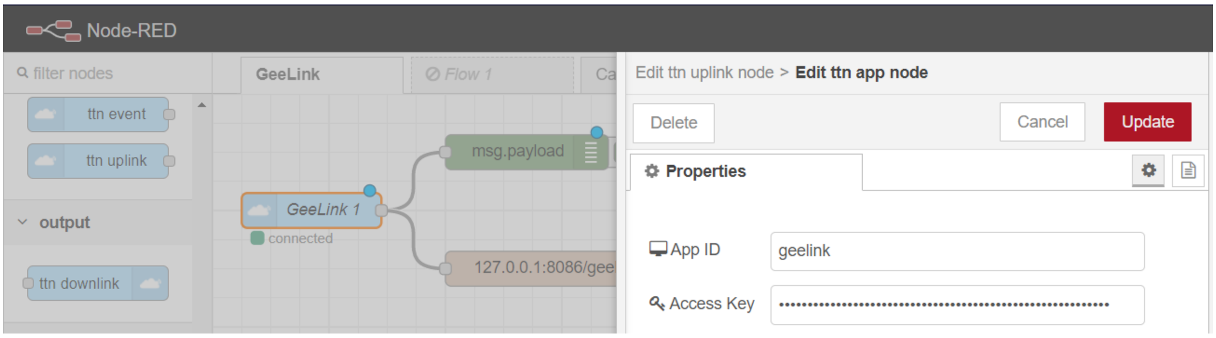


Figure 4.16: *Configuration an TTN uplink*

When the configuration of MQTT is completed, we can debug a packet from TTN from Node-RED debug from server as follows:

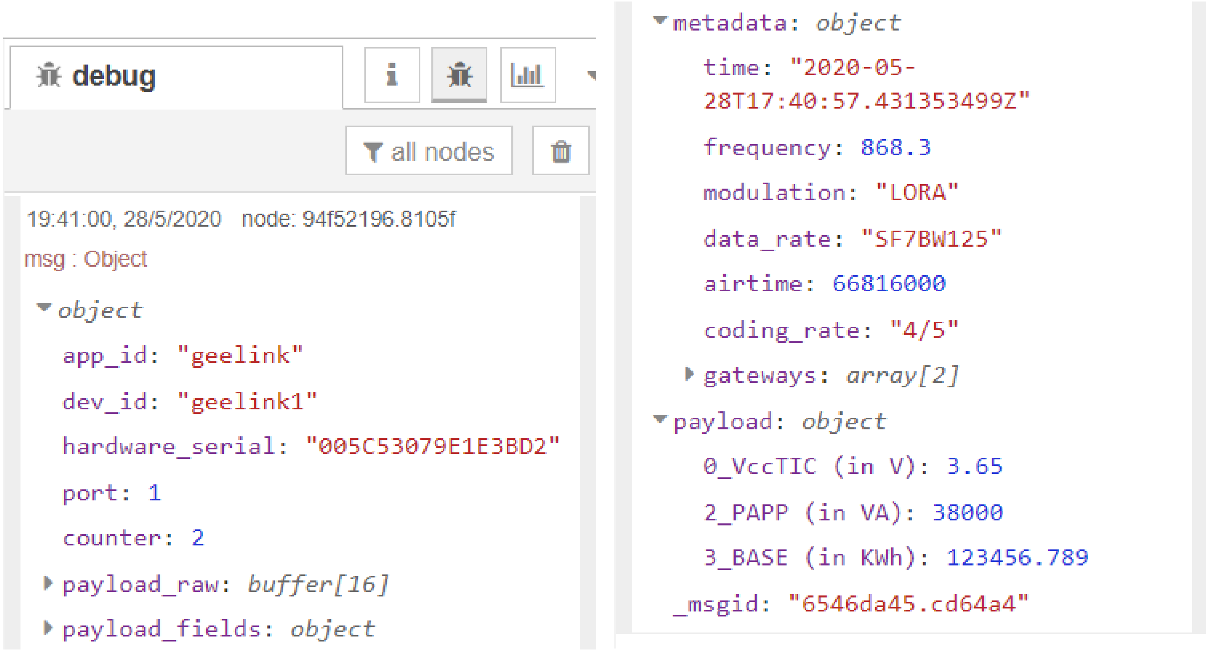


***Figure 4.17**: Information of a packet on Node-RED debug*

4.7.2. InfluxDB

The information of the packet decrypted from TTN will be saved in the database of the application server. Node-RED is also used for this process by the palette: **node-red-contrib-influxdb**

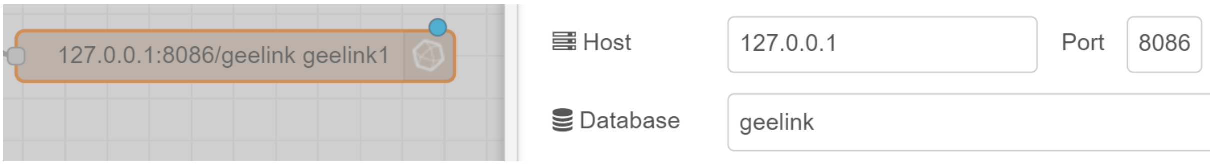


***Figure 4.18**: Configuration InfluxDB on Node-RED*

We can manage the databases on the server:

```
Connected to http://localhost:8086 version 1.8.0
InfluxDB shell version: 1.8.0
> show databases
name: databases
name
----
_internal
geelink
Sensor_IOT
```

***Figure 4.19**: Databases on application server*

4.7.3. Querying data and Visualization by Grafana

First of all, we have to link the database with Grafana by adding data sources from InfluxDB with port 8086.

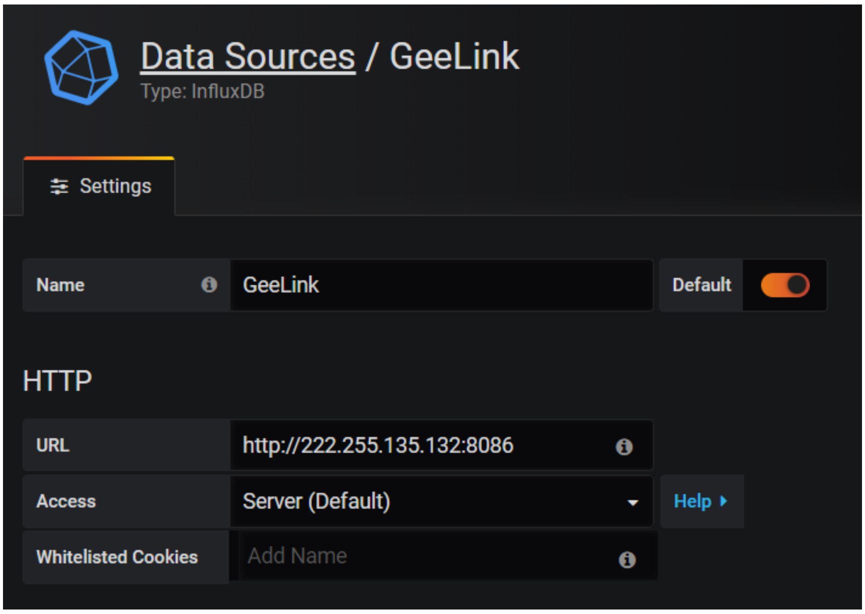


***Figure 4.20**: Adding InfulxDB to Grafana*

After that, we can use Grafana to query the data from the InfluxDB data source by using the graph or gauge or bar gauge,… on Grafana to visualize the information.

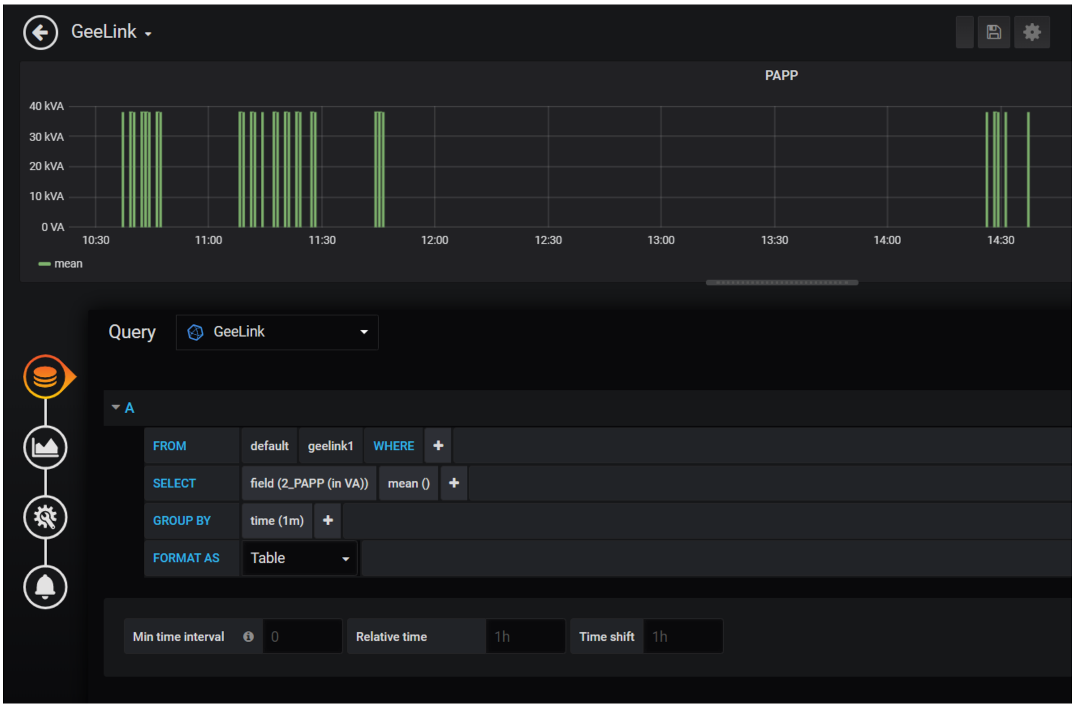


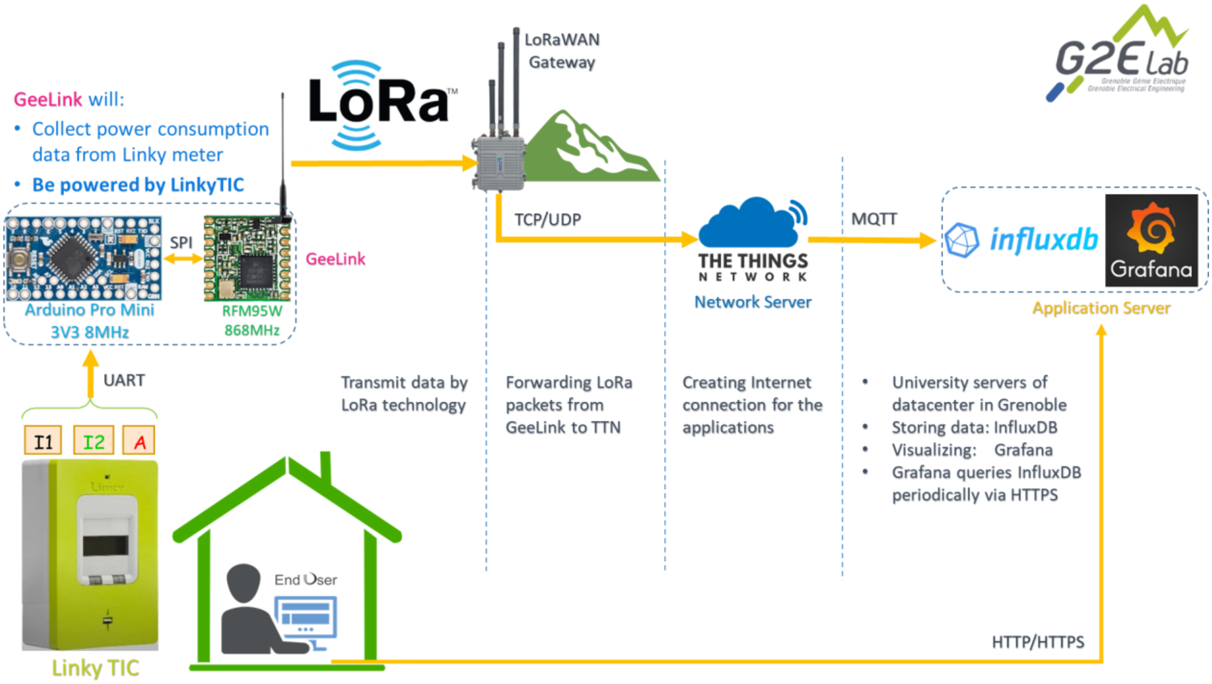
***Figure 4.21**: Configure a visualization on Grafana*

The final result after configured all the graphs is the main dashboard on the port 3000 of personal-server:

***Figure 4.22**: Main Dashboard of Grafana*

Until now, I have not had the opportunity to collect actual data from the Linky meter. I have built the initial basis for this data collection. The results obtained above are all assumptions. The University-server of datacenter in Grenoble is going to integrated after all the tests on personal-server are completed.

This is the platform of my entire project from the Linky meter to the application server



* *All my works and programs are totally pubished on my Github:*
https://github.com/hovuduybao/GeeLink

Chapter 5 - CONCLUSION

First of all, I can say that I was very lucky to be an intern at G2Elab. It brought me personal experiences and thus knowledge inevitably that I had not yet had the opportunity to apprehend, those who will help me a lot in the future. I was also able to have an overall view of the life of a company, relations between employees, difficulties related to working conditions, aspects and importance of safety. Thanks to the internship here, I have learned more about the role of an engineer as managing his project and also take responsibility for his work.

As stated in the context, the decentralized management of power generation will be solved, this project will be a stepping stone to develop IoT for Smart Grid and Smart Buildings in the future.

The knowledge and experience acquired from this Capstone project will be a valuable tool to help me become a professional engineer later.

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Appendices

Désignation	Étiquette	Nombre de caractères	Unité	Compteur Linky monophasé	
				Contrat historique	Contrat non historique
Adresse du compteur	*ADCO*	12		ADS	
Option tarifaire choisie	*OPTARIF*	4		Selon contrat	"BASE"
Intensité souscrite	*ISOUSC*	2	A	PREF (en VA)/200 V	
Index option Base	*BASE*	9	Wh	Index fournisseur 1	Index Totalisateur
Index option Heures Creuses					NON TRANSMIS
Heures Creuses	*HCHC*	9	Wh	Index fournisseur 1	
Heures Pleines	*HCHP*	9	Wh	Index fournisseur 2	
Index option EJP					NON TRANSMIS
Heures Normales	*EJPHN*	9	Wh	Index fournisseur 1	
Heures de Pointe Mobile	*EJPHPM*	9	Wh	Index fournisseur 2	
Index option Tempo					NON TRANSMIS
Heures Creuses Jours Bleus	*BBRHCJB*	9	Wh	Index fournisseur 1	
Heures Pleines Jours Bleus	*BBRHPJB*	9	Wh	Index fournisseur 2	
Heures Creuses Jours Blancs	*BBRHCJW*	9	Wh	Index fournisseur 3	
Heures Pleines Jours Blancs	*BBRHPJW*	9	Wh	Index fournisseur 4	
Heures Creuses Jours Rouges	*BBRHCJR*	9	Wh	Index fournisseur 5	
Heures Pleines Jours Rouges	*BBRHPJR*	9	Wh	Index fournisseur 6	
Préavis Début EJP (30 min)	*PEJP*	2	min	"30", en préavis EJP	NON TRANSMIS
Période Tarifaire en cours	*PTEC*	4		Selon contrat et tarif	"TH.."
Couleur du lendemain	*DEMAIN*	4		Selon annonce, en Tempo	NON TRANSMIS
Intensité Instantanée	*IINST*	3	A	Courant efficace (en A)	
Avertissement de Dépassement De Puissance Souscrite	*ADPS*	3	A	Courant efficace, si IInst > IR	
Intensité maximale appelée	*IMAX*	3	A	90 (en A)	
Puissance apparente	*PAPP*	5	VA	S (en VA), arrondi à la dizaine la plus proche	
Horaire Heures Pleines Heures Creuses	*HHPHC*	1		"A"	
Mot d'état du compteur	*MOTDETAT*	6		"000000"	

L'intensité maximale « IMAX » est toujours égale à 90 A dans le cas de ce compteur monophasé.
Le contrôle de dépassement de puissance souscrite (ADPS) est effectué en comparant l'intensité efficace instantanée à l'intensité de référence (déduite de la puissance de référence). L'intensité de référence est calculée de la façon suivante : IR = P Référence en VA/200 V.

DIODES INCORPORATED

1N4148 / 1N4448

FAST SWITCHING DIODE

Please click here to visit our online spice models database.

Features

- Fast Switching Speed
- General Purpose Rectification
- Silicon Epitaxial Planar Construction
- **Lead Free Finish, RoHS Compliant (Note 2)**

Mechanical Data

- Case: DO-35
- Case Material: Glass
- Moisture Sensitivity: Level 1 per J-STD-020D
- Leads: Solderable per MIL-STD-202, Method 208
- Terminals: Finish — Sn96.5Ag3.5. Solderable per MIL-STD-202, Method 208
- Polarity: Cathode Band
- Marking: Type Number
- Ordering Information: See Page 2
- Weight: 0.13 grams (approximate)

Maximum Ratings @T_A = 25°C unless otherwise specified

Characteristic	Symbol	1N4148	1N4448	Unit
Non-Repetitive Peak Reverse Voltage	V_{RM}	100		V
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	75		V
RMS Reverse Voltage	$V_{R(RMS)}$	53		V
Forward Continuous Current (Note 1)	I_{FM}	300	500	mA
Average Rectified Output Current (Note 1)	I_O	150		mA
Non-Repetitive Peak Forward Surge Current @ t = 1.0s @ t = 1.0μs	I_{FSM}	1.0 2.0		A

Thermal Characteristics

Characteristic	Symbol	Value	Unit
Power Dissipation (Note 1) Derate Above 25°C	P_D	500 1.68	mW mW/°C
Thermal Resistance, Junction to Ambient Air (Note 1)	$R_{\theta JA}$	300	°C/W
Operating and Storage Temperature Range	T_J, T_{STG}	-65 to +175	°C

Electrical Characteristics @T_A = 25°C unless otherwise specified

Characteristic	Symbol	Min	Max	Unit	Test Condition
Maximum Forward Voltage 1N4148 1N4448 1N4448	V_{FM}	— 0.62 —	1.0 0.72 1.0	V	I_F = 10mA I_F = 5.0mA I_F = 100mA
Maximum Peak Reverse Current	I_{RM}	—	5.0 50 30 25	μA μA μA nA	V_R = 75V V_R = 70V, T_J = 150°C V_R = 20V, T_J = 150°C V_R = 20V
Total Capacitance	C_T	—	4.0	pF	V_R = 0, f = 1.0MHz
Reverse Recovery Time	t_{rr}	—	4.0	ns	I_F = 10mA to I_R =1.0mA V_R = 6.0V, R_L = 100Ω

6.5 Electrical Characteristics

over recommended ranges of operating virtual junction temperature (unless otherwise noted)

PARAMETER	TEST CONDITIONS[1]			MIN	TYP	MAX	UNIT
Line regulation[2]	$V_I - V_O$ = 3 V to 40 V		T_J = 25°C		0.01	0.04	%/V
			T_J = 0°C to 125°C		0.02	0.07	
Load regulation	I_O = 10 mA to 1500 mA	C_{ADJ}[3] = 10 µF, T_J = 25°C	$V_O \le 5$ V			25	mV
			$V_O \ge 5$ V		0.1	0.5	$\%V_O$
		T_J = 0°C to 125°C	$V_O \le 5$ V		20	70	mV
			$V_O \ge 5$ V		0.3	1.5	$\%V_O$
Thermal regulation	20-ms pulse,	T_J = 25°C			0.03	0.07	$\%V_O$/W
ADJUST terminal current					50	100	µA
Change in ADJUST terminal current	$V_I - V_O$ = 2.5 V to 40 V, $P_D \le 20$ W, I_O = 10 mA to 1500 mA				0.2	5	µA
Reference voltage	$V_I - V_O$ = 3 V to 40 V, $P_D \le 20$ W, I_O = 10 mA to 1500 mA			1.2	1.25	1.3	V
Output-voltage temperature stability	T_J = 0°C to 125°C				0.7		$\%V_O$
Minimum load current to maintain regulation	$V_I - V_O$ = 40 V				3.5	10	mA
Maximum output current	$V_I - V_O \le 15$ V,	$P_D < P_{MAX}$[4]		1.5	2.2		A
	$V_I - V_O \le 40$ V,	$P_D < P_{MAX}$[4],	T_J = 25°C	0.15	0.4		
RMS output noise voltage (% of V_O)	f = 10 Hz to 10 kHz,	T_J = 25°C			0.003		$\%V_O$
Ripple rejection	V_O = 10 V,	f = 120 Hz	C_{ADJ} = 0 µF[3]		57		dB
			C_{ADJ} = 10 µF[3]	62	64		
Long-term stability	T_J = 25°C				0.3	1	%/1k hr

(1) Unless otherwise noted, the following test conditions apply: $|V_I - V_O|$ = 5 V and I_{OMAX} = 1.5 A, T_J = 0°C to 125°C. Pulse testing techniques are used to maintain the junction temperature as close to the ambient temperature as possible.
(2) Line regulation is expressed here as the percentage change in output voltage per 1-V change at the input.
(3) C_{ADJ} is connected between the ADJUST terminal and GND.
(4) Maximum power dissipation is a function of T_J(max), θ_{JA}, and T_A. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(max) - T_A) / \theta_{JA}$. Operating at the absolute maximum T_J of 150°C can affect reliability.

■ Absolute Maximum Ratings

(Ta= 25˚C)

Parameter		Symbol	Rating	Unit
Input	Forward current	I_F	± 50	mA
	*1Peak forward current	I_{FM}	± 1	A
	Power dissipation	P	70	mW
Output	Collector-emitter voltage	V_{CEO}	35	V
	Emitter-collector voltage	V_{ECO}	6	V
	Collector current	I_C	50	mA
	Collector power dissipation	P_C	150	mW
Total power dissipation		P_{tot}	200	mW
*2Isolation voltage		V_{iso}	5 000	V_{rms}
Operating temperature		T_{opr}	- 30 to + 100	˚C
Storage temperature		T_{stg}	- 55 to + 125	˚C
*3Soldering temperature		T_{sol}	260	˚C

*1 Pulse width<=100µs, Duty ratio : 0.001
*2 40 to 60% RH, AC for 1 minute
*3 For 10 seconds

■ Electro-optical Characteristics

(Ta= 25˚C)

Parameter			Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Input	Forward voltage		V_F	$I_F = \pm$ 20mA	-	1.2	1.4	V
	Peak forward voltage		V_{FM}	$I_{FM} = \pm$ 0.5V	-	-	3.0	V
	Terminal capacitance		C_t	V= 0, f= 1kHz	-	50	250	pF
Output	Collector dark current		I_{CEO}	V_{CE}= 20V, I_F = 0	-	-	10^{-7}	A
Transfer charac-teristics	*4Current transfer ratio		CTR	$I_F = \pm$ 1mA, V_{CE} = 5V	20	-	300	%
	Collector-emitter saturation voltage		$V_{CE(sat)}$	$I_F = \pm$ 20mA, I_C = 1mA	-	0.1	0.2	V
	Isolation resistance		R_{ISO}	DC500V, 40 to 60% RH	5 x 10^{10}	10^{11}	-	Ω
	Floating capacitance		C_f	V= 0, f= 1MHz	-	0.6	1.0	pF
	Cut-off frequency		f_c	V_{CE} = 5V, I_C = 2mA, R_L = 100Ω, - 3dB	15	80	-	kHz
	Response time	Rise time	t_r	V_{CE}= 2V, I_C= 2mA, R_L = 100Ω	-	4	18	µ s
		Fall time	t_f		-	3	18	µ s

PRODUCT SPECIFICATION / APPROVAL SHEET

1. General Specification

Item		Specification/Condition
01	Part №	SE-5R5-D105VY
02	Rate discharge capacitance (F 25℃ΔV = 3V-2.5V I = 0.01A)	1.0
03	Capacitance tolerance	-20%～+80%
04	Rated Voltage U_0 (V)	5.5
05	Operating temperature range	-25℃~70℃
06	MAX.ESR(Ω 1KHz)	15
07	Dimension(mm ΦD×L) ±0.5	20.5×7.5
08	Down-lead diameter(mm p)	5.0±0.5
09	Cycle life Expectancy	After nominal voltage,100,000 times charge-discharge circle ∣ΔC/C∣≤30% of the initial value ,ESR≤4 times of the specified value(25℃).

2. Environmental Specification

Item		Specification/Condition
01	Temperature characteristics	+70℃,∣ΔC/C∣≤30% of the initial value，ESR≤specified value (25℃) -25℃,∣ΔC/C∣≤50% of the initial value，ESR≤4 times of specified value (25℃)
02	High temperature load characteristics	After +70℃±2,nominal voltage，1000h，∣ΔC/C∣≤30% of the initial value，ESR≤4 times of specified value (25℃)。
03	High temperature without load characteristics	+70˚C±2, 1000h±4, ∣ΔC/C∣≤30% of the initial value, ESR≤2times of specified value（25˚C）
04	Humidity Resistance	After +40℃±2, 90--95%RH，240h,∣ΔC/C∣≤30% of the initial measured value, IL≤2 times of specified value (25℃) ,ESR≤4 times of specified value (25℃)。