LoRA based, low power remote monitoring and control solution for Industry 4.0 factories and facilities

George-Cristian Pătru
Computer Science and Engineering Department
University POLITEHNICA of Bucharest
Bucharest, Romania
cristi.patru@cs.pub.ro

Dumitru-Cristian Trancă
Computer Science and Engineering Department
University POLITEHNICA of Bucharest
Bucharest, Romania
dumitru.tranca@cs.pub.ro

Ciprian-Marian Costea
Faculty of Automatic Control and Computers Science
University POLITEHNICA of Bucharest
Bucharest, Romania
costea.ciprian.marian@gmail.com

Daniel Rosner
Computer Science and Engineering Department
University POLITEHNICA of Bucharest
Bucharest, Romania
daniel.rosner@cs.pub.ro

Răzvan-Victor Rughiniș
Computer Science and Engineering Department
University POLITEHNICA of Bucharest
Bucharest, Romania
razvan.rughinis@cs.pub.ro

***Abstract*— Over the years, industrial automation has repeatedly been impacted by the continuous and tremendous evolution in the fields of computer systems, electronics and data transmission. Industry 4.0, the current wave of the industrial revolution – dubbed *the data revolution* -, integrates these advances in communication and computational systems with the Internet, resulting in a paradigm shift towards the (Industrial) Internet of Things. Automation systems and remote data acquisition systems evolved over the last years from classic solutions based on wired infrastructure to modern, flexible solutions bringing together wireless communications, battery powered devices and wireless sensors networks. In this paper we first define the main problems encountered in modern wireless automation systems - small distance limitations of wireless communication solutions, weak security or complete lack of security in data transmission, and high energy consumption of battery powered remote data acquisition systems. In order to address these limitations, we propose, implement, trial-run and benchmark a novel low power LoRa-based flexible hardware architecture for use in industrial remote monitoring and control. We obtain a LoS capability above 3km and a calculated autonomy of about 10 years, exceeding the capabilities of current State of the Art solutions.**

Keywords*— *LoRaWAN, low power, monitoring, Industry 4.0

I. Introduction

In the automation and industrial control domain, companies direct their efforts at process optimization, power consumption reduction, and accurate information collection about device malfunctions. Ideally, prediction regarding when machinery will need to be shut down for regular maintenance should also be obtained. Retrieving such information (especially for machinery) is done through continuous motorization of essential parameters such as - but not limited to - vibration, current consumption and temperature. Current monitoring solutions include wired sensors and wired equipment, methods that present the disadvantage of expensive initial installation, and the need of periodic maintenance of the system. Due to this, companies and factories rarely implement condition monitoring systems [1]. With the latest developments in wireless sensor networks, available equipment has become cheaper and less energy hungry, thus making WSN more feasible and easier to employ at large scale. Wireless systems offer the following advantages compared to the wired solutions [2]:

- low cost,
- suitable for monitoring hazardous locations,
- greater flexibility and adaptability,
- smoother system expansion.

All the benefits brought by wireless networks lead to a new paradigm in industry, called Industry 4.0. Some of the advantages brought by Industry 4.0 and the use of wireless technology in industrial control systems are: enhanced flexibility, high data processing rates, increased productivity in factories, better quality of finished products with less scrap and wasted material [3].

Some researchers state that Industry 4.0 is strongly related to the IoT (Internet of Things) paradigm, that emphasizes the importance of interconnecting all devices, allowing a better bond between IT (Internet Technology) and OT (Operations Technology), as stated in [4] and [5].

Naturally, in order to maximize the benefits without incurring other penalties, there are several hardware and software requirements for wireless monitoring systems, that need to be respected when adopting such technologies in industrial environments [6]:

- robust radio technology,
- reduced cost,

978-1-7281-5344-5/19/$31.00 ©2019 IEEE

- low-power central processing unit,
- extended capabilities for sensors interfacing,
- extended battery life,
- reduced dimensions,
- enhanced modularity.

This article will present a solution that brings forward all the advantages of an IoT (Industrial Internet of Things) system, while minimizing some possible drawbacks through careful design and implementation.

In Section II we will present the current State of The Art, regarding both wireless transmission technologies and also current marketed devices with similar capabilities. In Section III we will describe the general system architecture, important schematics, algorithms and details regarding the construction of the controller itself, while in Section IV we will show and analyze the results of the benchmarks regarding power consumption and data transmission. In Section V we will conclude the advantages of our work compared to the current state of the art and state the future development directions in this project.

II. STATE OF THE ART

Taking into account limitations imposed by wireless sensor networks such as long distances, high speed, low power consumption, current technology developments entail the introduction of new protocols and long-distance communication architectures in order to obtain low power consumption for M2M (machine to machine) applications [3].

In industry there are both ready-made network nodes and wireless modules that can be incorporated into own architecture. In the following we will describe separately the solutions existing in these two categories:

A. Data Transmission Modules

There are different types of wireless technologies relevant and related to the IoT domain that have different coverage areas, from a few centimeters to tens of kilometers. Depending on the transmission distance you can use, for short and medium distances, technologies such as Bluetooth, Wi-Fi, ZigBee and 6LowPAN, and for long-distance technologies such as: LoRA, Sigfox or GSM [7].

In [8] the authors compare multiple low power long range transmission protocols, showing in a comparative figure the distance coverage of different data transmission solutions. From the presented solutions, LoRaWAN stands out through the following characteristics: high interference immunity, up to 45km line of sight communication range, mesh topology, lowest power consumption (calculated autonomy of up to 10 years), multiple frequency compatibility and data rates up to 50 kbps (data rate comparable and sufficient for most industrial equipment.).

In terms of transmission power, in [7], the authors compare transmission modules dedicated for the LoRaWAN protocol. The solutions are provided by Microchip, Multiteh and Nemerus. One can see that compared to the modules provided by the other companies, the one produced by Microchip has the most power at transmission and reception, but it also provides the widest range of communication. A disadvantage of the LoRaWAN protocol is that the maximum size of the message is smaller than for other protocols in the same category: ZigBee - 102Byte [9], 6LoWPAN - 102byte [10], Low Power Wi-Fi - 2312byte [11], LoRaWAN - 64byte [12].

Various methods have been addressed to reduce power consumption: hardware optimization, implementation of adaptive algorithms for data rate, duty cycle, and transmission power. In [13], various adaptive algorithms are also tested to re-transmit data to determine the effect on power consumption. The tests were carried out at different sizes of the transmitted data packet and at different time intervals between two consecutive transmissions. The analysis of the results revealed that the sensor nodes can have at least 5 years of autonomy in monitoring applications. Another analysis of the power consumption of a sensor node with LoRaWAN was done in [14]. Here, a 1-year autonomy has been achieved for a 2400mAh battery with a 5-minute transmission rate between two consecutive packets. However, they have come to the conclusion that the hardware technology on which LoRaWAN is currently implemented is not as well optimized as that of other low-power technologies.

B. Low Power commercial solutions

Out on the industrial equipment market there are different solutions integrating LoRaWAN and industrial graded protocols. For example, Cascademic Solution [15] offers an IP66 graded monitoring node, with autonomy of about 1 year, powered by a 3.7 2600mAh rechargeable battery, that can withstand temperatures from 0 up to 55 C. Another example is provided by SOLVERA LYNX [16], the COMBOX.L offering remote sensing and control solution. Their product allows connecting multiple sensor types to one gateway, allowing either monitoring or remote control. Besides the ones briefly previously mentioned, we can find many other similar solutions from companies such as [17], [18], [19].

The current marketed products use specialized modules (sensors, end devices) that are used either for direct sensor reading (data acquisition board), or for remote control. In contrast with commercial solutions, the solution that we present in this paper is designed to have digital outputs, in addition to multiple digital and analog inputs, such as an RS485 connection that allows it to query and control industrial devices. Our solution is designed to empower the user to perform remote monitoring of analog sensors, digital sensors and industrial RS485 enabled devices and, at the same time, to directly remotely command actuators (motors, lights, fans) using either the Digital Outputs, or the RS485 communication line. Furthermore, the proposed flexible architecture allows reprogramming the device as a LoRaWAN-connected real-time control unit (while losing the low-power characteristics).

III. ARCHITECTURE AND IMPLEMENTATION

This platform is a hardware and software solution which was built for operating in any environment, both for monitoring environmental parameters and for acquiring data from various industrial installations. The platform allows the connection of sensors through various digital (I2C, SPI, UART) or analog (4-20mA) interfaces. In addition to these types of connection, the current platform is equipped with a hardware interface for the RS485, over which it can communicate through the ModBus protocol and with a USB hardware interface. These interfaces are present on most local industrial procurement facilities.

Hardware Architecture

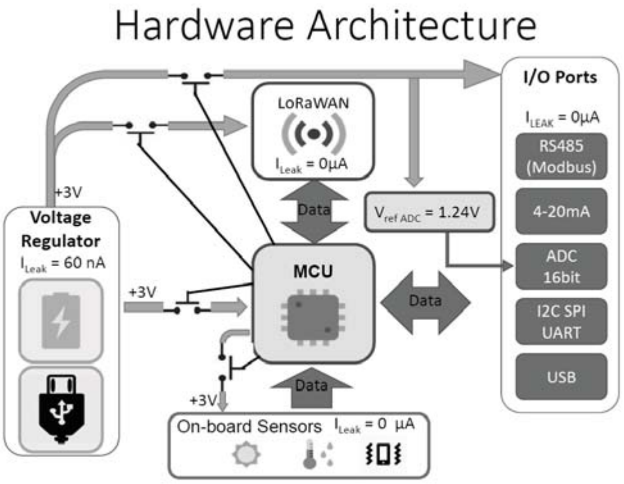

Figure 1: Hardware Architecture

The hardware architecture is based on a Kinetis family microcontroller, KL25Z with 32-bit Arm Cortex-M0 + core, from NXP. We chose this microcontroller especially for: low power consumption, integrated USB interface and high-resolution ADC, up to 16 bits. On the same board we place some sensors which are connected via I2C, like: integrated environmental sensor, BME280 from Bosch, accelerometer, LIS2DW12, from ST.

To collect data from industrial equipment we include on this platform a RS485 interface, over which we implement ModBus protocol. We use a dedicated integrated circuit, ISL83485, which is a Half-Duplex interface with up to 10Mbps data rate.

Data are transmitted to network server through LoRaWAN protocol. We implemented this protocol over a Microchip module, RN2483. Its advantages are as follows: low power and low cost, data rate up to 50kbps, downlink, range up to 15km and it has FCC (Federal Communications Commission) and IC (Industry Canada) certification.

The main problem in terms of working temperature was on batteries because most of them were only capable of supplying energy at temperatures of 0 □ and above. We have solved this problem by using the following chemistry battery: Lithium Thionyl Chloride (LI-SOCL2) [20]. This is a lithium battery that has a working voltage of 3.6V and a capacity of 2600mAh at ambient temperature of 25˚C. This battery can generate energy without degrading it as long as the temperature is in the range of [-40˚C:+85˚C], but as the temperature approaches the extremes, the storage capacity decreases [21].

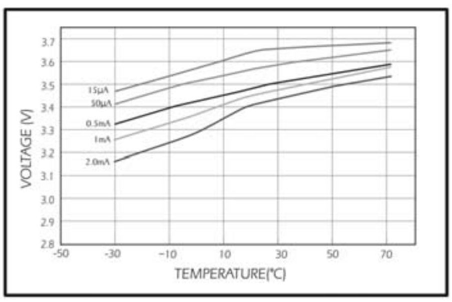

Figure 2: Battery Characteristics [20]

Also this device can be powered from the USB charger. It is capable of self-selecting between being powered by battery or USB. In Figure 3 is the circuit which select the power supply.

All electronics are mounted in an IP65 polycarbonate housing, resistant to temperatures between -40˚C and 120˚C, and to solar radiation. One thing that was particularly important in choosing the enclosure was the possibility of

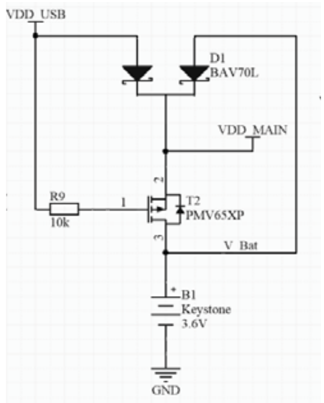

Figure 3: Power Circuit

mounting it on any surface. As one can observe from Figure 4 the case has side holes to be fastened with both dowels on a wall and metal or plastic necklaces on the pillars. The connection between the electronics inside the enclosure and the outside sensor is made by means of a pressure gauge to keep the water and dust resistant. Also for this, the micro-USB connector has been chosen to the IP67 standard. A very important element that prevents condensation inside the casing is the pressure equalizer, which allows air exchange from the inside to the outside air [22].

A. Software Description

The architecture of the platform was designed to increase energy efficiency. The platform has two main states

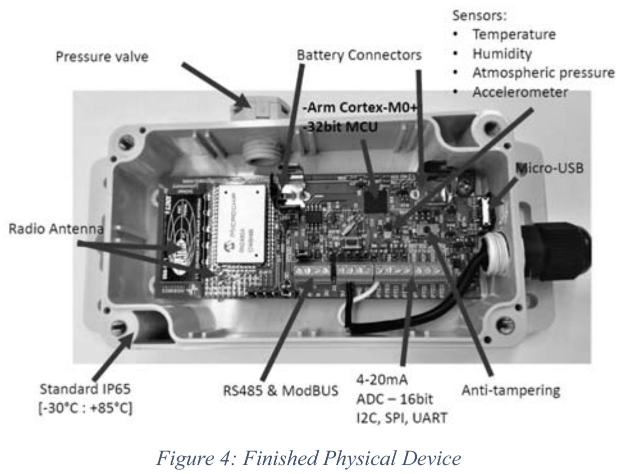

Figure 4: Finished Physical Device

of operation, a “Sleep” state and an “Active” status. In Sleep state, power consumption is reduced by operating the microcontroller in low power consumption mode, and all peripheral power is turned off using the circuit described previously. In the “Active” state, the microcontroller interrogates all peripherals, both externally connected and those on the motherboard (temperature, relative humidity, atmospheric pressure, acceleration). Then the data is preprocessed, packaged and transmitted via LoRaWAN to the network server. At the time of data pre-processing, the data is analyzed to determine whether certain decisions are being made, such as:

- Based on data received from the accelerometer, it will be determined when the module is moved from its position, at which point the module will make an alarm transmission to notify the user. This is useful to prevent tampering with the platform. Another use of the accelerometer data is determination of mechanical defects of the equipment when it vibrates at a higher intensity than the nominal one.
- The tampering button is intended to alert the user via an alarm message that the platform has been opened by a person. This alarm is a hardware security method.
- The battery voltage level is monitored periodically, and if it is under working voltage, a new alarm is generated.
- Alarms are also generated at times when the temperature, humidity or atmospheric pressure inside the enclosure exceeds certain thresholds.

The data acquisition solution taken from the acquisition platforms is an online dashboard provided by Cayenne (www.cayenne.mydevices.com) [23]. It takes the data from the acquisition platforms via a gateway connected to the TheThingsNetwork network server (www.thethingsnetwork.org) [24]. You can also view the real-time position of the modules on the online platform. The tests were conducted around the Polytechnic University of Bucharest.

In order to make the interaction between the user and the platform easier, the functionality of updating the microcontroller's firmware has been added. This can be done via the micro-USB connector and the Windows application that was done in Visual Studio and written in C# code. In addition to being able to update the microcontroller's firmware, the application also allows the platform to be configured to establish the LoRaWAN addresses and to determine from which sensors the data is being downloaded.

Also via this connector, in addition to the update, there exists the possibility to connect the module to another computing unit to retrieve data from it, in order to further transmit it over the radio network.

IV. TESTING & RESULTS

A. Case Study

The data acquisition platform for industrial applications was tested in the laboratory on a test facility with the following elements found in the industrial environment:

- IEM3150 Power Meter Station [25]
- Single Phase Engine
- Engine temperature sensor
- Relay for starting and stopping the engine
- Three electrical outlets for external consumers.

In Figure 5 we present the test-bench used to cross-check the functionalities of our device in a simulated environment. With the help of the power station we can request data regarding the following parameters:

- Active energy for each phase
- electric current
- voltage
- frequency
- active power.

All of this data is retrieved via the RS485 interface, transmitted via LoRaWAN and graphically displayed in a web interface. In addition to measuring the various parameters, the acquisition platform may command to start and stop the engine via a relay.

To prevent damage to the electric motor due to a blockage or incorrect cooling, the motor has a temperature sensor attached. Thus, when the temperature exceeds a certain threshold, it is possible to command the engine to stop and to alert the user by radio about the problem.

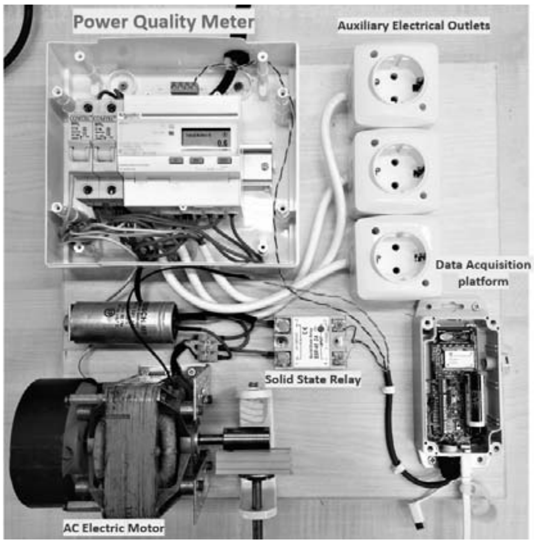

Figure 5: Case Study Laboratory Test-bench

B. Power Consumption

During the development phase of our device we ran through multiple iterations. In this platform the current consumed in "Sleep" mode was significantly reduced. If at the previous version we achieved an average consumption of 36µA, now the current consumption is 2.7µA. The average current consumption of the transmission period is approximately 11.69mA. The variation in consumption during a transmission can be seen in Figure 6.

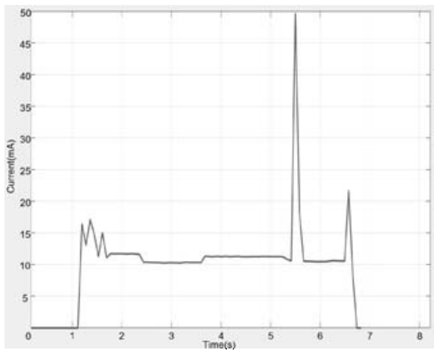

Figure 6: Power consumption during data transmission

To determine battery life, we measured and transmitted data to the cloud every hour (sample rate of 60 minutes). In this case, the average current consumed in one hour is 20µAh. Considering the same battery capacity of 2700mAh, we have gained a 13-year autonomy. In computing this autonomy, we accounted for a battery capacity drop of 15% due to leakage current inside the battery.

$$Current_{24h} = Current_{1h} * 24hours =$$

$$= 20\mu Ah * 24hours = 480\mu Ah$$

$$Autonomy = \frac{2700mAh * 85\%}{480\mu Ah} = 4781days = 13\ years$$

In Figure 7 we illustrated graphically the dependence of battery life versus sample rate for two cases: with an ideal battery and a real battery.

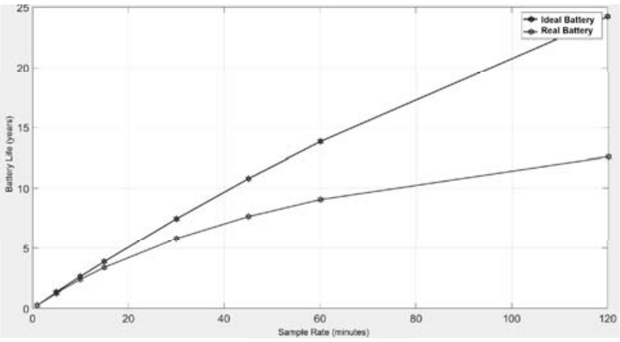

Figure 7: Sample rate vs Battery life

C. Communication Distance Coverage

The maximum distance from which data was transmitted was 3km. The results can be seen in Figure 8. The green pin represents the gateway, and the blue pairs are the nodes.

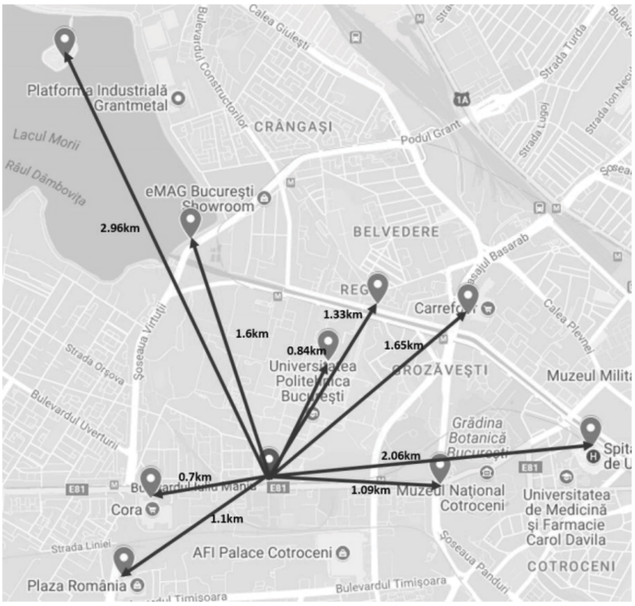

Figure 8: Communication Distance Benchmark

V. CONCLUSIONS

The use of sensor wireless networks developed over the last few years offers countless advantages to companies, such as: they can be deployed on a large scale at low cost, can increase productivity, reduce power consumption, or save equipment from mechanical damage.

Although the environments in which our platform should work are highly corrosive and very noisy from an electrical point of view, they function according to the parameters set at the beginning of the development. The main advantages of these platforms are:

- High autonomy (over 10 years) compared to other industrial products (5-10 years)
- Robust system
- No interference
- Large coverage (over 3 km in urban environment)
- Modularity and rapid access to data
- Cost reduction due to:
  - Lack of expensive cables
  - Large area covered by a single gateway
  - Easy assembly and moving of the entire system

REFERENCES

[1] G. P. H. Vehbi C. Gungor, Industrial Wireless Sensor Networks: Challenges, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 56, NO. 10, p. 8, 2009.

[2] N. Z. M. W. Ning Wang, Wireless sensors in agriculture and food industry-Recent, Computers and Electronics in Agriculture 50 , p.14, 2006.

[3] A. T. R. S. L. M. A. T. Francesco Bonavolonta, Enabling wireless technologies for Industry 4.0, IEEE International Workshop on Measurement and Networking (M and N), p. 5, 2017.

[4] J. Y. T. C. W. M. T. Alo¨ys Augustin1, A Study of LoRa: Long Range and Low Power Networks for the Internet of Things, Sensors, p. 18, 2016

[5] IT and OT convergence - two worlds converging in Industrial IoT. [Online]. Available: https://www.i-scoop.eu/internet-of-thingsguide/industrial-internetthings-it-ot/., accessed 07.2018

[6] S. M. G. P. H. Vehbi C. Gungor, Opportunities and Challenges of Wireless Sensor, IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 57, NO. 10, p. 8, 2010.

[7] A. A. H. M. Mahmoud Shuker Mahmoud, A Study of Efficient Power Consumption Wireless Communication Techniques/Modules for Internet of Things (IoT) Applications, Advances in Internet of Things, p. 11, 2016.

[8] J. J. P. C. R. A. M. A. P. S. A. L. L. A. Jonathan de Carvalho Silva, LoRaWAN - A Low Power WAN Protocol, 2nd International Multidisciplinary Conference on Computer and Energy Science (SpliTech), p. 6, 2017.

[9] T. V. S. a. W. D. Burchfield, Maximizing Throughput in ZigBee Wireless Networks through Analysis, Simulations and Implementations, Proceedings of the International Workshop on Localized Algorithms and, pp. 18-20, 2007.

[10] G. K. N. H. J. a. C. D. Montenegro, Transmission of IPv6 Packets over IEEE 802.15.4 Networks. Network Working Group, Copyright (C) IETF Trust, 2007.

[11] J.-S. S. Y.-W. a. S. C.-C. Lee, Comparative Study of Wireless Protocols: Bluetooth, UWB, ZigBee, and Wi-Fi, 33rd Annual Conference of the IEEE Industrial Electronics Society (IECON), pp. 46-51, 2007.

[12] N. L. M. E. T. K. T. a. H. O. Sornin, LoRaWAN Specifications, LoRa Alliance, 2015.

[13] A. S. P. P. R. A. I. Samarth Mathur, Energy Analysis of LoRaWAN Technology for Traffic Sensing Applications, ITS World Congress 2017 Montreal, p. 12, 2017.

[14] B. M. R. V. C. G. Lluis Casals, Modeling the Energy Performance of LoRaWAN, Sensors, p. 30, 2017.

[15] http://cascademic.com/products/modbus-to-lora-converter/ [accessed 01.2019]

[16] https://www.solvera-lynx.com/en/ [accessed 01.2019]

[17] https://www.adeunis.com/en/ [accessed 01.2019]

[18] https://www.comtac.ch/#1 [accessed 01.2019]

[19] https://www.lobaro.com/ [accessed 01.2019]

[20] EVE ENERGY CO., LTD, ER14505V.pdf, [Interactiv]. Available: https://www.powertechsystems.eu/wpcontent/uploads/2013/07/ER14505V.pdf. [accessed 01.2019]

[21] R. N. S. K. G. A. M. J. M. I. Haider Mahmood Jawad, Energy-Efficient Wireless SensorNetworks for Precision Agriculture: A Review, Sensors 2017, 2017.

[22] Multicomp, www.farnell.com,[Interactiv]. Available: http://www.farnell.com/datasheets/2052882.pdf [accessed 01.2019]

[23] https://mydevices.com/cayenne/features/ [accessed 01.2019]

[24] https://www.thethingsnetwork.org/ [accessed 01.2019]

[25] IEM3150 Official Site https://www.schneider-electric.com/en/product/A9MEM3150/iem3150-energy-meter---63-a---modbus/ [accessed 01.2019]