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INTACT INDUSTRIAL INTERNET OF THINGS COMMUNICATION SOLUTION

Dumitru-Cristian TRANCĂ[1], Eugen BUZILĂ[2], Daniel ROSNER[3], George Cristian PĂTRU[4], Răzvan Victor RUGHINIȘ[5]

In the past decades, the internet revolution has expanded in numerous application areas and has redefined both B2C (business-to-consumer) and B2B (business-to-business) industries, with the industrial environment adapting to the fast-changing technologies. IIoT (Industrial Internet of Things) based solutions are increasingly employed to address several limitations of previous generations of technologies, with multiple applications in areas such as energy, agriculture, industrial facilities. One specific area of high impact for IIoT is communication equipment interconnection in industrial scenarios. Most industries rely on wired interconnections - with several benefits, but also specific limitations and costs. This article proposes a wireless communication solution for this specific area, based on the LoRaWAN protocol, complete with a solution for centralizing information and offering a high-level overview of active infrastructure. We proposed a general module, that can be attached to any industrial equipment, collecting and transferring data through LoRaWAN protocol, introducing new opportunities but also new risks related to data security and integrity.

Keywords: communication, IIoT, industrial, long distance, LoRaWAN, wireless

1. Introduction

Industrial Internet of Things is the latest trend in industrial applications. It offers new opportunities as it combines the major advantages of the Internet with the ability of direct control of the physical world, including applications in factories, industrial machines, and other specialized equipment. This integration can be considered successful if it manages to adequately address the following key challenges:

[1] Faculty of Automatic Control and Computer Science, University POLITEHNICA of Bucharest, e-mail: dumitru.tranca@cs.pub.ro, Romania

[2] Faculty of Automatic Control and Computer Science, University POLITEHNICA of Bucharest, Romania

[3] Faculty of Automatic Control and Computer Science, University POLITEHNICA of Bucharest, Romania

[4] Faculty of Automatic Control and Computer Science, University POLITEHNICA of Bucharest, Romania

[5] Faculty of Automatic Control and Computer Science, University POLITEHNICA of Bucharest, Romania

- the impact in terms of integration and required modifications on the hardware and software architecture that are already in place;
- the impact on the workforce;
- the impact on the security requirements corresponding to each industry.

Industrial wireless communication must respect different requirements: shared wireless bandwidth, low-cost operation, long durability and a high distance radio propagation through the environment [1].

There are several methods of remote data transmission that have been used over time, including Wi-Fi, radio, Bluetooth, infrared, ultrasonic. All of them made different equipment interconnection possible without the need for a wired environment. Based on those methods, several protocols have been proposed, each of them providing new methods of data transmission, payload encryption and messages exchange between the communicating devices.

This article provides a method of interconnecting industrial devices using a radio data transmission based on LoRaWAN protocol. We propose a general module that is suitable to the communication port of any industrial device that employs the RS232 or RS485 communication protocols, making it a simple and efficient method for long distance data transmission. The proposed demonstrator module achieves long transmission distance, long battery life and secure exchange of information.

The proposed module is suitable to the industrial environment, for applications that require small amounts of data to be transmitted in a set of pre-determined time slots. Data acquisition is performed periodically at fixed time intervals (the interval can be set by the user, but considering legislative and protocol communications, specific for products operating in the 868 MHz band – the transmission is restricted to 36 second per hour).

The implemented solution is based on the LoRaWAN protocol, capable of sending information via radio. In terms of scalability, LoRaWAN can support millions of endpoints transmitting several bytes of data, on a restricted time slot [2]. Also, depending on the distance between the endpoint and the gateway, the number of successfully relayed data packets can vary.

Within 2 km from the base station, the signal exceeds -100 dBm [3]. The maximum number of packets lost for this range does not exceed 12%, which usually occurs due to line of sight blockade or other radio interferences. Juha et al. also mention that, in the 2-5 km range, the limit of failed packets stayed below 15%, while in the 10-15 km range the limit grows to 74% [4].

Possible use cases for the module include: data collection from wind power generators (consumption, status, temperature etc.); data collection from solar panels (data regarding production and operating conditions); data collection from security systems inside industrial facilities; data collection from industrial sensors situated remotely from the command center; statistics generation on consumption and energy production in power plants.

In the next section we will discuss the recent published similar solutions, available technologies and limitations. The next chapters will present the overall system architecture and its components, from data acquisition to information provision for the users.

Both hardware and software implementations will be discussed in the next sections. Finally, an assessment of the performance obtained by the hardware and software demonstrator will be presented.

2. State of the art

In the following we will consider the main wireless solutions that have recently been consider for industrial applications, with both main advantages and limitations.

ZigBee defines specifications for low-rate WPAN (Wireless Personal Area Network) and it is used for transmitting data from devices with a simple architecture, usually operating in ranges between 10 and 100 meters [5]. It implements a mesh multi-hop topology. This protocol can emit in two bands: 2.4 GHz and 868 MHz [5, 6]. Data transmission in the 2.4 GHz band can be an advantage, because this is a free band in Europe, and it does not need any license. LoRa, by comparison, can emit in 433 MHz and 868 MHz bands, which are restricted in this area. For implementation, in Europe, the 868 MHz band is preferred. This implies respecting a restriction regarding air transmission: the limit of transmission is only 1% from duty cycle (36 second per hour). This implies a limitation regarding the amount of data transmitted and a very well-defined transmission system. Even with this limitation, LoRa is a more efficient protocol, in terms of distance and battery life. LoRa can emit up to 5 km in urban environment and up to 15 km in open field, covering a larger area. In this way, the number of nodes is minimized, and the cost for implementing the solution is reduced. Also, the endpoints from the LoRa network can be configured, so that the energy consumption will be suitable to the application context.

In LoRaWAN topology, only the gateway needs to be connected to the internet, for communication with a cloud server or network server, usually for data upload and storage into a cloud solution, while the endpoints are independent.

While LoRa is widely recognized as a viable solution for open spaces, there are also several studies that consider the usage in city space / buildings. Tests on LoRa based sensors in scenarios involving different reinforced concrete layouts assessed the worst-case signal propagation deterioration scenario and found communication to be reliable [6]. A recent study [7] also supports the viability of using LoRaWAN in urban scenarios.

Several LWPA (Low Power Wide Area Networks) technologies and standardization activities were analyzed by Raza et al. [8] and noted that LWPA technologies adopt similar approaches with similar limitations and challenges. The authors expand researching challenges and try to identify potential solutions.

Haxhibeqiri et al. [9] tested and concluded that they can cover an industrial area with a surface of 34,000 m^2, with an average RSSI values of above -100dBm at all measuring locations. The authors showed that wrong CRC for the received packets were uncommon (0.5-0.8% for indoor measuring points and 6% at the most distant measuring points).

Penkov et al. present a concept of industrial network design using LPWAN that can be used for industrial monitoring and control applications [10]. Their main goal is to combine low energy protocols and transmission methods and to discuss the advantages of using MQTT (Message Queuing Telemetry Transport, ISO Standard) with LoRa networks.

In [11], the authors focus their attention to the concept of Industry 4.0, on cost-effective sensing and computing elements and on ad-hoc communication protocols that are making production process monitoring possible. They analyze and show advantages and possibilities of using LoRa and Low Power wide Range Area Network protocols in industrial scenarios.

Lavric and Popa [12] focus their work on studying LoRa networks and their behavior. The authors analyze Time on Air, Bitrate and Spreading Factor on the performance of LoRa networks. They conclude that increasing the bandwidth can lead to decreases in the specific Time of Arrival.

In a recent study, Rizzi et al. [13] analyze the viability of using LoRa in industrial wireless sensors and demonstrate that LoRa based sensors can meet the strict operating requirements typical for industrial environments.

LoRa is considered the defacto state of the art low power protocol, while there are proposals to further improve this. Aoudia et al. present a low power architecture [14], based on the need in industrial environment of a predictability of the communication they propose an improved architecture based on one transceiver used for both waking up the nodes and for data communication.

While the current available work in the filed is focused on assessing the radio capabilities or the brute packet capabilities for general data transmission, we found that a specific implementation with appropriate test for applying LoRaWAN in common industrial scenarios is missing. Thus, the following will address this both in a general proposed approach, and with a hardware and software solution for validating the viability of using LoRaWAN in replacing wired infrastructure for two of the most common industrial communication protocols.

3. Architecture

Fig. 1 highlights the overall architecture of the proposed system. The LoRa transceiver module retrieves data from the industrial device to which it is attached and redirects it, via LoRaWAN protocol, to a central gateway. The gateway retrieves the information and stores it to LoRa Cloud, making it visible to the user through specific Web Services. As the cloud stores the information for a specific period of time, another server was used to act as a copy for the LoRa Cloud, but on which the data is stored permanently in the database. Also, this server contains information about every user, about the modules that they manage and about the data sent by every module individually. The information is then made visible in an Android Mobile Application, which can generate daily statistics, making it possible to observe the state and activity of the industrial device.

The current proposed solution does not entail a real-time data transmission, due to the radio band transmission limit. The purpose of this application is to provide a method of remote data transmission and generation of statistics, for non-time critical applications (usually, monitoring applications, with no critical reaction time constrains). In implementing the solution, we propose a star topology network. Thus, endpoints are connected directly to a central gateway, which deals with acquisition of data, integrity, and cloud storage.

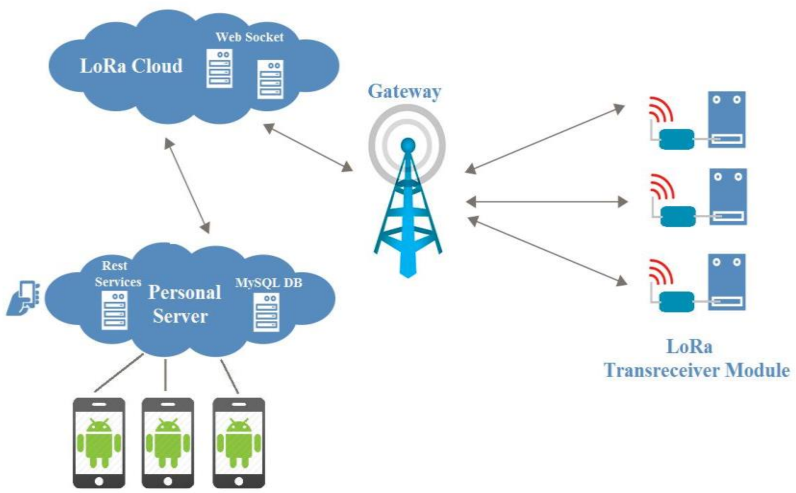

Fig. 1. General Architecture

All data is transmitted first to the gateway node which will redirect it to the source destination – either a server in the cloud either a different LoRa node (Transceiver Module). This ensures continuous functionality of the system, even if one node fails. The gateway node consists of a dedicated gateway with a high degree of reliability. The information is transmitted more easily than with a mesh topology because it eliminates the strain caused by relaying data packets from one node to another.

In terms of distance, for a industrial scenario with mixed building and partial open filed, we consider a minimum range of 2km as required.

4. Hardware implementation

The hardware module has been implemented to comply with the project requirements, as described in chapter 3, and industrial standard temperatures operating conditions (-40 to 85 deg. Celsius).

A general organization at functional level is showed in Fig. 2. There are 4 basic components: command, data acquisition, data processing and transmission. All of them create a compact and general module, for getting data and redirect it through LoRaWAN protocol. In terms of data acquisition, we have chosen two protocols: RS232 and RS485. We introduce both protocols in order to cover a broad selection of industrial devices. The module does not require a change in the already built architecture of the industrial equipment, but it provides a light method for increasing the flexibility of the device. Both protocols are often used in industrial environment.

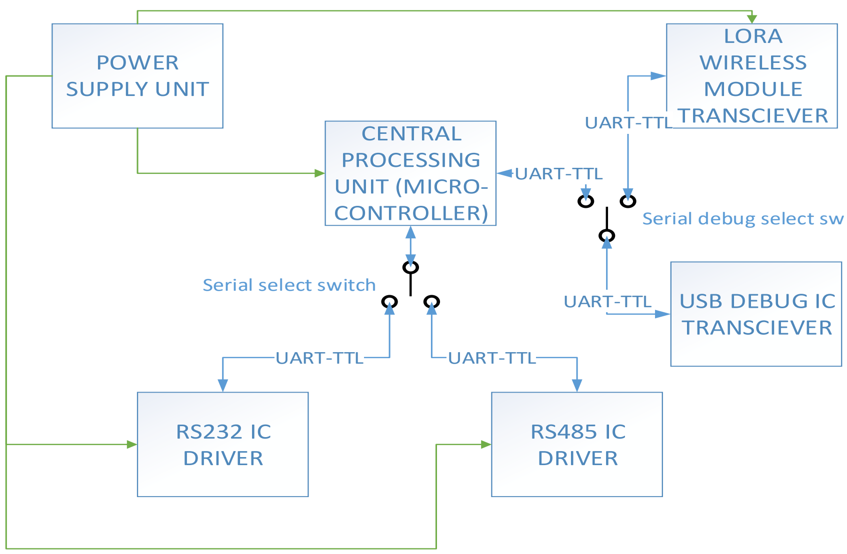

Fig. 2. General Module Diagram

RS232 it is used especially for short distance transmission, with low baud requirements. The maximum distance for data transmission between devices equipped with RS232 capabilities is of about 300m [15]. RS485 is a differential 2-

line protocol, based on a drop-down network topology that allows for interconnecting of multiple devices. An advantage of this protocol is that it can allow up to 32 devices with distances of up to 1.2 km [16].

For the command and processing part, we use an ATMEGA 324PA microcontroller with two serial ports. As we integrated several communication interfaces in the module designed, we tried to make maximum use of the microcontroller resources, by implementing a management and access approach to its serial ports. One of the serial ports is used to receive data from RS232 and RS485 ports (9600 baud rate), and the second one to make the connection between USB and microcontroller, or RN2483 and microcontroller (57600 baud rate).

For integrating the LoRaWAN protocol, we rely on RN2483 circuit from Microchip. This module complies with LoRaWAN protocol features, meeting all specifications of a class A module. It ensures a spread spectrum communication with high immunity to EM interference. This way, it can achieve a receiver sensitivity of around -146dBm. As pointed out by Sánchez [17], industrial environment is very often affected by noise, which can affect data transmission. RN2483 solves this problem, being able to demodulate 20 dB below the noise level [18].

The management of serial access in case of conflict is achieved through intermediate switches, that alternate the connection between the communication interface and microcontroller.

Fig.3 outlines the main hardware components:
1) RN2483 Microchip Module, 2) RS232 port, 3) RS485 port, 4) Atmega 324PA microcontroller, 5) USB mini connector, 6) radio-frequency connector, 7) step-down convertor, 8) MAX3232, 9) programmer adapter, 10) USB to serial convertor, 11) 8 MHz crystal, 12) programmable LED, 13) transmission signaling LED 14) microcontroller pins 15) reset.

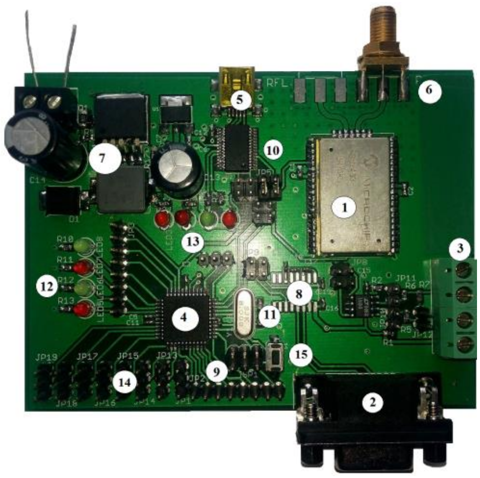

Fig. 3. Hardware Module

5. Software implementation

The software is composed of three individual parts, providing support for data acquisition and information retrieval. The three software components work seamlessly together as depicted in the architectural diagram in Fig 4.

The main software components are:

- data acquisition from the industrial device, redirection via LoRaWAN protocol and storage on LoRa Cloud. From the cloud, the information is accessible through web socket services.

- storage of user details, including the modules that they have access to and data associated to every module. All this information is stored on the server, in a MySQL database and made accessible through RESTful Web Services.

- displaying of the information specific to the user in an Android Mobile Application (as shown in Fig. 5). The application aids in performing a number of tasks, such as adding new modules to the system or supervising current modules. The user can view all the information that has been sent by the industrial device to which the module is attached, and they have access to statistics generated from this information. Also, via a custom made mobile service, it is possible to notify the user in case some of the values received fall outside of a manually pre-set range.

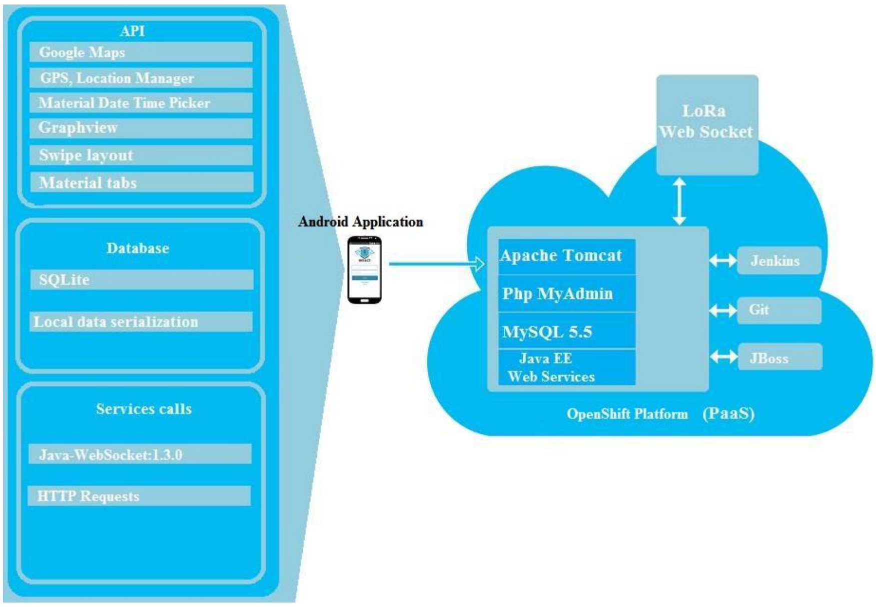

Fig. 4. Software Architecture

The server side is managed through the OpenShift Platform. This is an online platform responsible with server administration and management. This is a PaaS (Platform as a Service) and provides many functionalities, from which we have chosen an Apache Tomcat server, a MySQL database for storing all the information, PhpMyAdmin for the management of the database and Java EE Web Services for exposing the services needed in the mobile application. OpenShift provides a great method for scaling applications: it provides the ability to react to changes in traffic caused by an increase in the number of users accessing resources. OpenShift's infrastructure is monitoring traffic and automatically allocates containers, to fill the necessary resources to ensure proper functionality of the system. When traffic drops, the platform deallocates additional resources. It is an ideal way for managing the requests and for protecting from DoS attacks.

The Android application is based on two types of request: REST and WebSocket. They involve a different functionality, requiring a different treatment. The RESTful requests are used for accessing the information from the server, while the WebSocket requests are meant for cases in which saving the information in to the LoRa Cloud is required.

For better management and location tracking for all the modules that a given user administrates, we have chosen to integrate in the application the Google Maps Service. Thus, at the enrollment of a module in the system, the user is prompted to either manually enter the coordinates where the module is located or to use the GPS functionality from the mobile phone, in order to automatically position the module exactly in the place where he makes the enrollment. Also, the user can have a brief overview of the entire system that he manages, making it possible to easily locate every module.

As Pathan states [19], the security of the wireless data transmission is paramount. We managed to reduce the security threats by using two encryption methods: one at module level (after the data received from the industrial device is transmitted via LoRaWAN protocol) and another at the gateway side. We also ensure a secured data transmission. The encryption is made by using AES128, on Counter mode. Two keys are employed: NwkSKey (used if FPort is 0) and AppSKey. The counters are never repeated and are managed only by the nodes or by the network server. Another increase in security is achieved by using the UUID to send the information to the gateway and to receive it in the application. The UUID (Universally Inique IDentifier) is stored on the RN2483 module and cannot be changed.

Fig. 5. Mobile Application

6. Tests

We conducted a series of tests in order to determine the optimal and the maximum distance for data transmission that can be achieved. The first test was for endpoint-to-endpoint transmission (Fig.6) and the second test for node-to-gateway transmission (Fig.7).

Fig.6 presents the endpoint-to-endpoint transmission test result. The blue pinpoint represents the emitter, which was placed in the campus of University Politehnica of Bucharest. The red pinpoints represent the places where data acquisition was performed. The data acquisition test have been carried out over a suitably large area, with a maximum test distance of 1.09km.

Within the same test, we measured transmission latency from one node to another. The average delay obtained for this test was 40ms, confirming a reduced transmission time. The darker area represents an area where the obtained transmission time was between 37 and 40 milliseconds, while the lighter area reveals a transmission time between 40 and 45 milliseconds. The reason for this discrepancy is based on the additional effort for penetrating different obstacles.

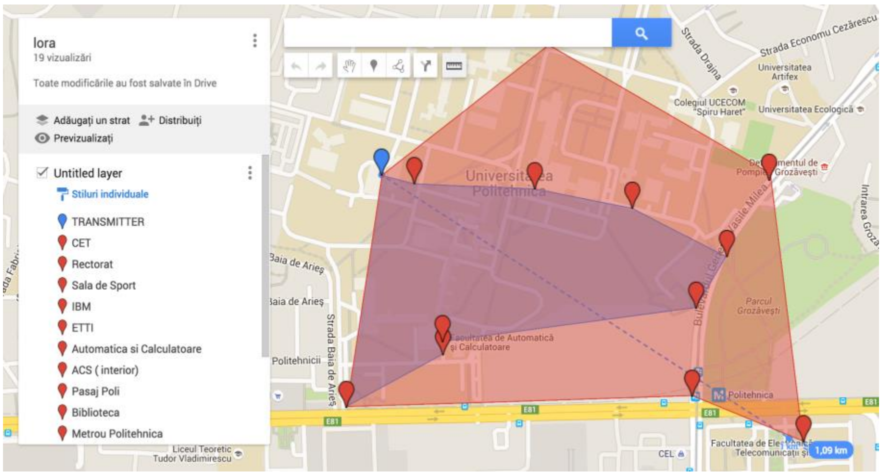

Fig. 6. Endpoint-to-endpoint transmission

After analyzing these results, we concluded that, using an endpoint-to-endpoint transmission via LoRa, the maximum transmission distance has increased tenfold compared with the use of a Wi-Fi connection. However, this does not meet the needs of the proposed application. Thus, we also made measurements for an endpoint-to-gateway transmission. Results are in Fig.7.

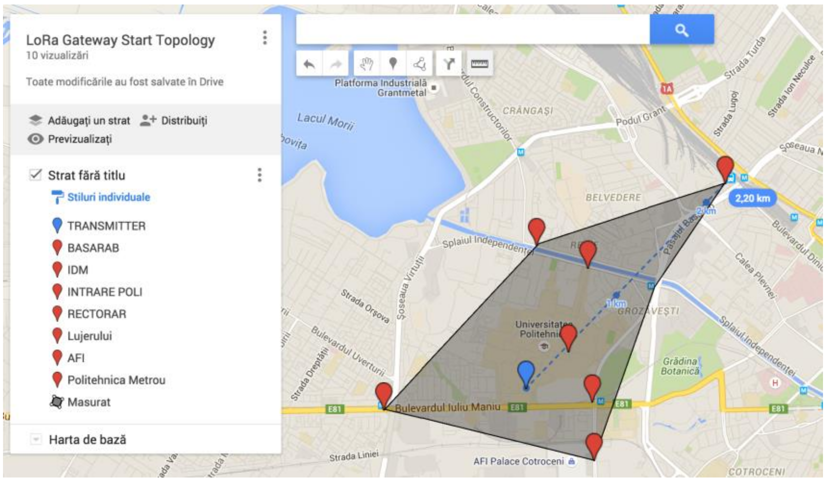

Fig. 7. Endpoint-to-gateway transmission

We achieved a maximum transmission distance of about 2.20 km, above the required range.

7. Conclusions and further work

The current paper presents an industrial Internet of Things communication solution, integrating LoRaWAN protocol for wireless data transmission. The data transmission is performed on long distances, reaching values between 2 to 5 km in urban areas and maximum 15 km in open field.

The current work is focused on creating a hardware module that collects the information sent by the industrial device to which is attached, analyzes it, encrypts it and redirects it through the LoRaWAN protocol, to a central gateway. The gateway is responsible for collecting all the information sent by all the modules under its coverage. Next, the data is decrypted and stored on a Cloud solution, in order to be accessible to the user through web services. The information will be displayed in an Android mobile application, capable of making daily statistics based on data received and inform the user, via push notifications, if the values received are not in a preset range. Another issue covered by our research is reducing energy consumption, thus prolonging battery life. This was achieved through the implementation of the architecture with a LoRa module of class A, which uses data transmission at fixed time intervals. When not transmitting the module kept in sleep state, thereby reducing power consumption: in transmission mode the power consumption is about 40mA, in idle mode is 2.8 mA and in sleep mode is 1μA.

Double encryption ensures data security: both on the module side and on the gateway side. Future improvements can include sensor co-management support to enable the monitoring of several parameters that characterize the sensor network [20], such as load, link quality, processor and radio usage on the nodes. The module also allows the execution of tasks such as enabling sensing or actuation, changing the sampling rate.

To sum up, the proposed solution achieves the set goals, and provides an adequate solution for replacing wired communication with a dedicated wireless system, in specific industrial scenarios – specially for sensor systems used for monitoring and statistics, with low bandwidth requirements, and no real time constrains. The solution allows for a high degree of security, long term autonomy when operating on batteries and a low installation overhead.

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