DOI: https://doi.org/10.54966/jreen.v1i1.1264

Journal of Renewable Energies

Revue des Energies Renouvelables

journal home page: https://revue.cder.dz/index.php/rer

Conference paper

IoT Weather Station Optimized for Energy Efficiency

Ahmed Rennane [a,*], **Fateh Benmahmoud** [b], **Abdelhak Djoudi** [a], **Ali Dali** [a], **Abderrahmene Tayeb Cherif** [c]

[a] *Centre de Développement des Energies Renouvelables, CDER, BP 62 Route de l'Observatoire, Bouzaréah, 16340, Algiers, Algeria.*

[b] *Antennas and Microwave Devices Laboratory, Polytechnic Military School, Bordj El Bahri, 16111 Algiers, Algeria.*

[c] *Ecole Nationale Supérieure d'Informatique of Algiers (ESI), BP 68M, 16270 Oued Smar, Algiers, Algeria.*

ARTICLE INFO

Article history:

Received August 6, 2024

Accepted September 9, 2024

Keywords:

Automatic weather station,
IoT,
Low power consumption,
WSN,
Energy harvesting,
WPT.

ABSTRACT

This work presents an economical IoT weather station with energy-efficient capabilities. It offers a multi-sensor platform, with balanced functionality and power optimization that ensures an extended- wireless range. The developed system features diverse sensors measuring temperature, humidity, pressure and light intensity. Employing power-saving techniques like sleep/wake cycles and controlled sampling rates makes the station economical and power-efficient. This setup allows distant observation via a web browser interface, addressing the challenge of low power and extended-range deployments of embedded systems. The adopted energy optimization strategy enabled autonomous long-range functioning, with real-time data collection and visualization. The recoded peak power consumption is only 2022 µA for all the embedded operations.

1. INTRODUCTION

In recent years, IoT has revolutionized environmental monitoring. Traditional weather stations, known for their power-intensive and limited communication range, have been replaced by energy-efficient and autonomous solutions enabled by LoRaWAN and IoT technologies (Rennane et al. 2021). Various communication technologies are employed in modern IoT weather stations (Santos et al. 2020). Wi-Fi and LoRa are commonly utilized for data transmission, offering distinct advantages. Wi-Fi provides high bandwidth over short distances, while LoRa ensures robust communication over long ranges. In (Radhi & Al-Naima, 2022), researchers explore the comparative performance of Wi-Fi and LoRa for rainfall monitoring, employing sensors to collect real-time data. Additionally, low-cost wireless weather stations based on Arduino Uno microcontrollers can transmit data to a web server via Wi-Fi. In (Faudzi

[*] *Corresponding author, E-mail address: a.rennane@cder.dz*
Tel : + 213 771698517

ISSN: 1112-2242 / EISSN: 2716-8247

et al. 2023), researchers focus on an ESP8266-based Wi-Fi module NodeMCU for local weather monitoring. Another efficient solution utilizes GPRS for real-time rainfall data transmission (Wang et al. 2021). NB-IoT is pivotal in modern weather stations, facilitating wireless data transmission to the Internet for real-time monitoring (Migabo et al. 2020). Its integration with IoT technologies enhances weather systems, supported by major industry players like Ericsson and Huawei (Joris et al. (2019). Similarly, Sigfox technology enables long-range, energy-efficient data transmission for environmental monitoring applications (Maudet et al. 2021). LoRa and LoRaWAN are popular for IoT due to their long-range capability and low power usage. Researchers demonstrate their viability in weather monitoring systems with multiple sensor nodes (Wang et al. 2019). Another system focuses on long-range outdoor air quality monitoring with low energy consumption (Jabbar et al. 2022).

In this work, we present the design and implementation of a new low-power autonomous weather station prototype that collects meteorological data from dedicated sensors. The acquired data is subsequently transmitted to a central server via the internet to enable real-time display through a web interface. Furthermore, we detail the adopted energy optimization strategy that allowed us to meet the requirements of energy efficiency, data reliability, and information accessibility.

The paper is organized as follows, in section two, we present our LoRa IoT architecture, in section 3, we show the power management strategy, followed by results discussion in section four and finally, conclusions are drawn in the last section.

2. PROPOSED LORA IOT ARCHITECTURE FOR METEOROLOGICAL STATION

The automated meteorological stations autonomously can collect environmental data using various sensors, process it, and transmit it to a server (figure 1). Users can real-time access to meteorological conditions through a user-friendly interface, enabling easy monitoring.

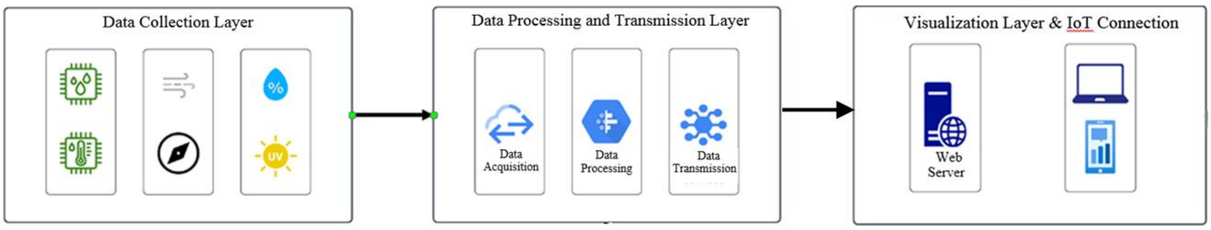


Fig 1. Functional architecture of the developed LoRaWAN-based meteorological station

The weather station prototype, built on the P-NUCLEO-LRWAN2 board, employs a low-power STM32L073RZ microcontroller and a SX1272 LoRa radio module integrating long-range spread spectrum technology with interference immunity and low power consumption. Featuring sensitivity exceeding -137dBm and an integrated +20dBm power amplifier, it offers an optimal link budget for extended range and robust applications. Sensors are integrated into the STEVAL-IDI003V2 development board, facilitating data collection and transmission via SPI to the LoRa module (figure 2). Data is then sent to Laird's Sentrius RG186 gateway and forwarded to the ChirpStack Network Server v3. An energy recovery module ensures continuous power supply using a 3.7V, 1000mAh rechargeable lithium-ion battery.

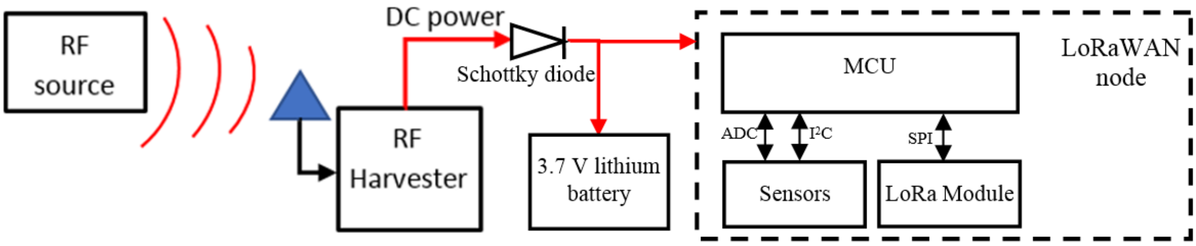


Fig 2. Modular architecture of the based-LoRaWAN node implemented for the weather station

3. POWER MANAGEMENT OF THE IMPLEMENTED LORAWAN NODE

To optimize power management, a P1110-EVB Power Management Integrated Circuit (PMIC) with a 3.7 V, 1000 mAh lithium-ion battery, and a 915MHz 6.1 dBi planar antenna were utilized for the LoRaWAN node. A Schottky diode prevents battery backflow, ensuring a stable power supply to the node's components: four low power MEMS sensors, MCU, and LoRa module. The PMIC regulates battery charging and energy distribution, which enhances the energy efficiency. The MCU employs a power-saving STOP mode for deep power conservation during recharge cycles. It also manages energy storage based on sensor data. A LoRaWAN communication control feature adjusts transmission frequency and duration, optimizing energy usage. Pressure sensor interrupts trigger data transmission on significant pressure changes, further enhancing efficiency. Sensor data is compressed and transmitted to the ChirpStack server for processing.

Utilizing the P1110-EVB for efficient power management, coupled with MCU-programmed energy and communication control, and pressure sensor interrupts, an optimal power solution was achieved for LoRaWAN nodes with MEMS sensors. The energy strategy, illustrated in Fig. 3, involves activating only necessary peripherals, resulting in significant energy savings.

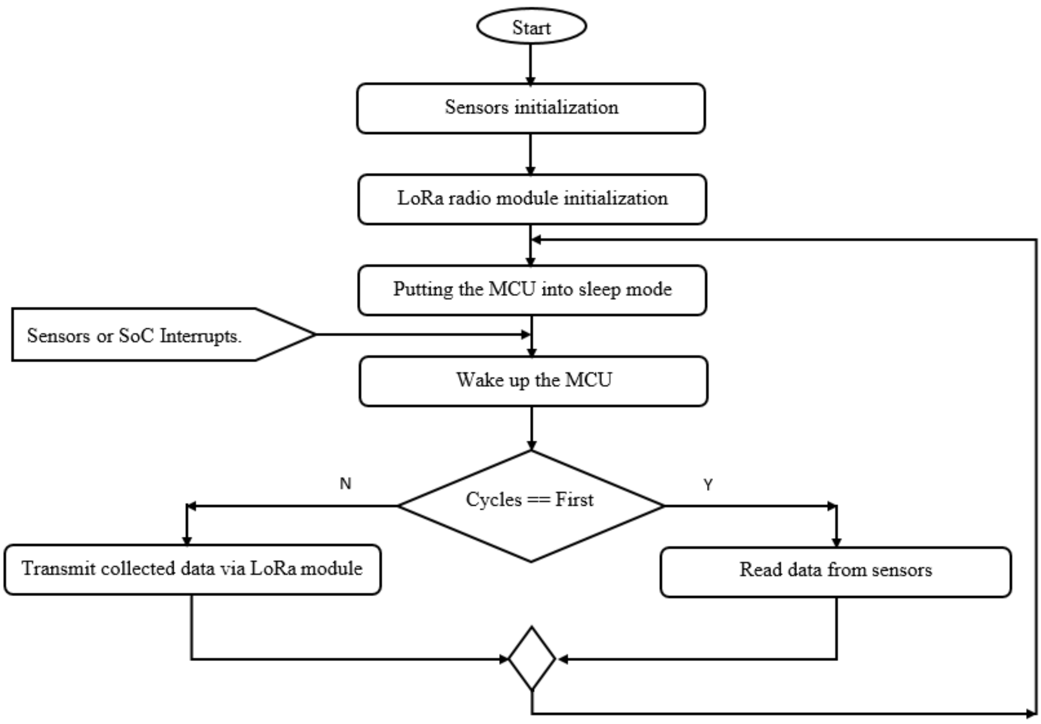


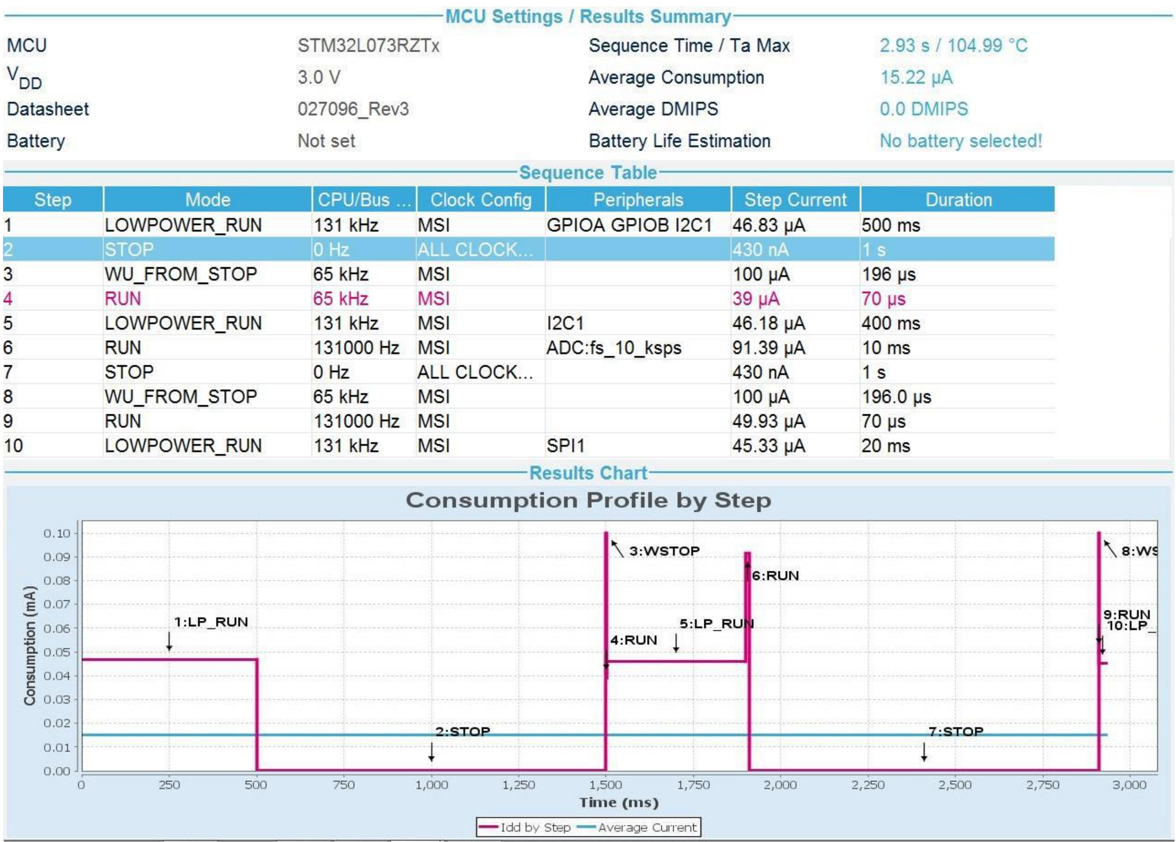
Fig 3. Activity Diagram of the overall system operation

4. RESULTS AND DISCUSSION

The following section can be divided into three main aspects. First, we target the energy Consumption estimation, where we delve into understanding and predicting energy demands to ensure optimal resource management. Then our focus extends to the Optimization and IoT Integration of the LoRaWAN Node, where the goal is the enhancement of the node functionality and connectivity. Finally, a prototype is built and tested to ensure the reliability and effectiveness of our solutions.

4.1. Energy Consumption Estimation

With the energy management strategy and the utilized peripherals, we estimated the power consumption of our system using the Power Consumption Calculator (PCC) feature in CubeMX software. By specifying the microcontroller, battery model, and user-defined power sequence, the PCC provides an estimation of the average power consumption and average DMIPS. The PCC relies on an accurate power model that considers the microcontroller's operating modes, peripherals, clock configurations, and voltage regulator settings. It simulates the system's behavior based on the defined power sequence, comprising periods of activity, sleep modes, and peripheral usage patterns. We defined a representative power sequence encompassing the sensor node's operational phases, including initialization, data acquisition from MEMS sensors (Rennane et al. 2017; 2018), LoRa transmission, and low-power modes. This sequence incorporates the appropriate peripheral activations, such as the LoRa module, MEMS sensors, and microcontroller units. The estimated power consumption for the STM32L073RZ microcontroller is shown in Figure 4.


MCU Settings / Results Summary

MCU	STM32L073RZTx	Sequence Time / Ta Max	2.93 s / 104.99 °C
V_{DD}	3.0 V	Average Consumption	15.22 µA
Datasheet	027096_Rev3	Average DMIPS	0.0 DMIPS
Battery	Not set	Battery Life Estimation	No battery selected!

Sequence Table

Step	Mode	CPU/Bus ...	Clock Config	Peripherals	Step Current	Duration
1	LOWPOWER_RUN	131 kHz	MSI	GPIOA GPIOB I2C1	46.83 µA	500 ms
2	STOP	0 Hz	ALL CLOCK...		430 nA	1 s
3	WU_FROM_STOP	65 kHz	MSI		100 µA	196 µs
4	RUN	65 kHz	MSI		39 µA	70 µs
5	LOWPOWER_RUN	131 kHz	MSI	I2C1	46.18 µA	400 ms
6	RUN	131000 Hz	MSI	ADC:fs_10_ksps	91.39 µA	10 ms
7	STOP	0 Hz	ALL CLOCK...		430 nA	1 s
8	WU_FROM_STOP	65 kHz	MSI		100 µA	196.0 µs
9	RUN	131000 Hz	MSI		49.93 µA	70 µs
10	LOWPOWER_RUN	131 kHz	MSI	SPI1	45.33 µA	20 ms

Fig 4. Energy consumption estimation for the STM32L073RZ

The estimated average power consumption is 12.22 µA for our LoRaWAN prototype. We simulated the system's three states: initialization cycle, data acquisition cycle, and the transmission cycle. It is observed that the average consumption of each cycle remains stable at around 37 µA. The consumption peaks at steps (3, 6, 8) are attributable to transitions between the microcontroller's operating modes, which require intermediate states to be executed.

4.2. Optimization and IoT Integration of the LoRaWAN Node

As the development process progresses, the code size naturally increases, making energy efficiency optimization a more challenging task. We needed to ensure optimal program size and execution speed during the development process to achieve the lowest possible energy consumption. The communication with LoRa module is facilitated by the LDL library, implemented in C language. It provides minimal interfaces that conform to the LoRaWAN specifications. By leveraging this library, we could efficiently implement the LoRaWAN protocol stack and integrate our LoRaWAN node into the IoT ecosystem, enabling seamless communication and data exchange with the network server and cloud platforms. The LDL library enabled seamless integration with the ChirpStack server and real-time data visualization through Grafana. Offering flexibility via the LDL_ENABLE_SX1272 configuration, it ensures reliable and secure LoRaWAN data transmission with encryption and key management support.

4.3. Experimental validation and prototyping

The establishment of a private LoRaWAN network was undertaken by utilizing the ChirpStack project alongside MQTT and gRPC. Deployment involved configuring the Laird Sentrius RG186 gateway with RF antennas for LoRa (863-870 MHz European frequency). Compatibility challenges with ChirpStack Network Server v3 prompted the selection of the Semtech packet forwarder over the MQTT broker, ensuring successful communication on port 1700. We were able to power the designed prototype solely via an RF energy harvesting source in view of its extremely low consumption level, as shown in Fig.5. It has been recoded that the consumption peak (200µA) occurs during the radio transmission.

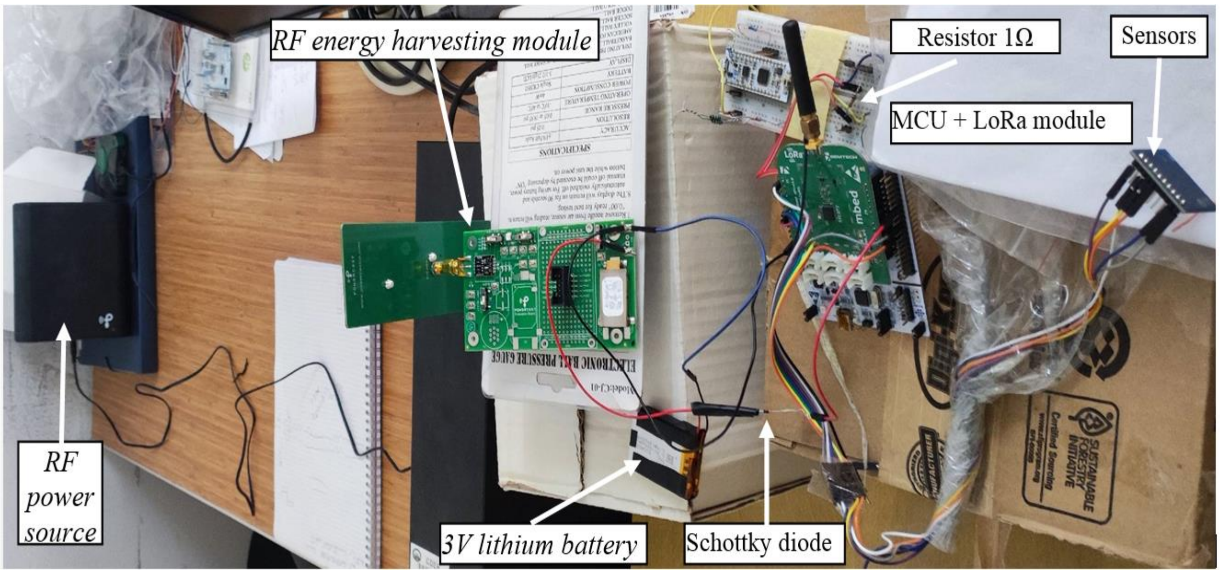


Fig 5. Prototype operates solely on RF energy harvesting and a 3V lithium battery

5. CONCLUSION

We developed a scalable sensor node system that collects meteorological data from dedicated sensors, and transmits it via a LoRaWAN network. We used the Chirpstack server as a private LoRaWAN server. We adopted an effective energy consumption optimization strategy at the weather station level, allowing it to operate in an autonomous or automatic mode while harvesting RF energy from an RF 3Watts Effective Isotropic Radiated Power (EIRP) source and a 3Volts 1000mAh lithium battery. For data visualization in the dashboard, we employed a tool called GRAFANA to monitor environmental parameters in real-time. For future perspective, we plan to incorporate additional sensor types and leverage ThingsBoard as an IoT platform, enabling the integration of real-time data forecasting and vigilant settings.

REFERENCES

Faudzi, A. A. M., Raslan, M. M., Alias, N. E. (2023). IoT based real-time monitoring system of rainfall and water level for flood prediction using LSTM Network. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing, p. 012015.

Jabbar, W.A., Subramaniam, T., Ong, A.E., et al. (2022). LoRaWAN-based IoT system implementation for long-range outdoor air quality monitoring. Internet of Things, 19, p. 100540.

Joris, L., Dupont, F., Laurent, P., et al. (2019). An autonomous Sigfox wireless sensor node for environmental monitoring. IEEE Sensors Letters, 3(7), p. 01-04.

Maudet, S., Andrieux, G., Chevillon, R., et al. (2021). Refined node energy consumption modeling in a LoRaWAN network. Sensors, 21(19), p. 6398.

Migabo, E.M., Djouani, K.D., Kurien, A.M. (2020). The narrowband Internet of Things (NB-IoT) resources management performance state of art, challenges, and opportunities. IEEE Access, 8, p. 97658-97675.

Radhi, A. A., et Al-Naima, F. M. (2022). Design of a Prototype Local Smart Weather Station Based on Wi-Fi. In: 2022 International Conference on Innovation and Intelligence for Informatics, Computing, and Technologies. IEEE. p. 559-565.

Rennane, A. et al., (2018). Passive UHF RFID Sensor Tag for Pressure and Temperature Conditions Monitoring, 2018 2nd URSI Atlantic Radio Science Meeting (AT-RASC), Gran Canaria, Spain, pp. 1-3, doi: 10.23919/URSI-AT-RASC.2018.8471459.

Rennane, A., Benmahmoud, F., Abdelnour, A., Fonseca, N., Kaddour, D., Touhami, R., & Tedjini, S. (2017). Passive UHF RFID bending and absolute force strain gauge-based sensors. In 2017 Mediterranean Microwave Symposium (MMS) (pp. 1-4). IEEE.

Rennane, A., Benmahmoud, F., Cherif, A. T., Touhami, R., & Tedjini, S. (2021). Design of autonomous multi-sensing passive UHF RFID tag for greenhouse monitoring. *Sensors and Actuators A: Physical*, 331, 112922.

Santos, S. C., Firmino, R. M., Mattos, D. M., et al. (2020). An IoT rainfall monitoring application based on wireless communication technologies. In: 2020 4th Conference on Cloud and Internet of Things (CIoT). IEEE. p. 53-56.

Wang, Y., Huang, Y., Song, C. (2019). A New Smart Sensing System Using LoRaWAN for Environmental Monitoring, IEEE Internet of Things Journal.

Wang, Z., Deng, Z., Xu, K., et al. (2021). Based on Internet of Things Platform Using NB-IoT Communication Low-Power Weather Station System. In: International Conference On Wireless Communications, Networking And Applications. Singapore: Springer Nature Singapore, p. 633-643.