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# Enhancing energy management in IoT networks

João Mota<sup>a,\*</sup>, Carlos Coutinho<sup>a,\*</sup>

<sup>a</sup>*Instituto Universitário de Lisboa (ISCTE-IUL), ISTAR, Lisbon, Portugal*

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## Abstract

The Internet of Things is nowadays available everywhere, collecting data that can be used for different purposes. These end-devices are available in different formats, and depending on the use case, they need different features in order to function properly. Due to their specific requirements, some of these devices need to be portable, so a battery is an important component. Additionally, choosing the right communication protocol for these particular use cases is essential for establishing a network connection while minimising energy consumption. This will ensure that the collected data is transmitted for further analysis. This paper aims to provide an overview of LoRa, LoRaWAN, and Duty Cycling, along with their advantages and disadvantages in terms of energy efficiency on Internet of Things devices. Lastly, a suggested architectural design is proposed based on an energy-efficiency strategy, and some scenarios are assessed and compared in order to determine which could be preferred when it comes to an energy efficient solution.

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*Keywords:* LoRa;LoRaWAN;Duty Cycling;Energy Efficiency

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## 1. Introduction

The Internet of Things (IoT) has arisen as a disruptive technology that has grown through time, reshaping the way we interact with the world around us. The IoT ecosystem has generated multiple advantages, such as collecting but also providing data for further analysis and making decisions based on that shared data [1]. IoT devices are available in a variety of forms and types, and depending on the use case, they need different features in order to function properly. These devices need requirements such as a battery or a direct power supply, can be stationary or portable, and have attached different types of components to gather information. Also, having a network connection is a critical feature in order to communicate all the data they collect [2].

There are some challenges, one of which is that in order to run an IoT device and exchange data, power supply efficiency must be maximised, especially in places where there is no possibility of having a direct source of energy.

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\* Corresponding authors.

*E-mail address:* [jlma@iscte-iul.pt](mailto:jlma@iscte-iul.pt) (João Mota), [carlos.eduardo.coutinho@iscte-iul.pt](mailto:carlos.eduardo.coutinho@iscte-iul.pt) (Carlos Coutinho)

One particularly valid use case is the role of IoT in waste management, which may improve trash collection systems in areas where obtaining a direct power source is difficult and requires optimisation [3].

Energy management is an interesting area because charging the batteries frequently is not a productive task and can increase maintenance costs. There is also a potential gain from an economic perspective, where energy costs are a significant factor in households or in company budgets. Improving the energy efficiency of IoT solutions can result in substantial cost savings, making them economically viable and increasing interest in implementing further IoT projects.

Although several studies have been conducted regarding this subject [4], this paper aims to revisit and analyse this topic for potential opportunities to improve the current state of the art to address power efficiency challenges in IoT.

This research will be structured into the following chapters. Chapter 1 includes a brief overview of the topic and the goal of this research. Chapter 2 provides a detailed description of the methodological approach that was selected, outlining each step that was taken in compliance with the chosen methodology for this study. The chapter 3 assesses the relevant content that has already been published in the field of IoT energy efficiency research and shares the main findings. Next, in chapter 4 the current state is presented and compared with the proposed solution in order to assess if energy efficiency is improved on IoT devices. Finally, chapter 5, outlines the main findings, limitations of the work, and suggested future work for further investigation.

## 2. Methodology

This research follows the Design Science Research (DSR) Methodology commonly used in fields such as Information Systems (IS), which aims to produce and present solutions to identified organisational problems [5]. The authors define six steps that should be taken into consideration.

**Identification of the problem**, describing the research issue, and demonstrating the worth of a potential solution.

**Define Objectives of a Solution**, based on the nature of the problem, defines the objectives of a solution.

**Design and Development of Artefacts**, activity in which a research contribution is embedded and the product is made (constructs, models, methods). Additionally, a Systematic Literature Review (SLR) will be used in this step, where it will be possible to collect data related to the purpose of this research. After gathering and resuming all the information, it can be used to compare with the outputs of this work. The extracted outputs may add knowledge to the current studies, progress must be built on prior existing work [6].

**Demonstration**, consists of using the artefact capacity to solve the problem.

**Evaluation**, evaluate the solution, comparing the objectives and the actual observed results from the use of the artifact.

**Communication**, communicating the problem, the artefact, its utility, and its effectiveness to other researchers and practicing professionals.

### 2.1. Research Question

As previously referred, Design and Development of Artefacts will be carried out an SLR. This will gather relevant information about the research questions and help into the next sections of this research.

**RQ1:** How can communication protocols in IoT be leveraged to optimise energy efficiency?

**RQ2:** How can the lifetime of batteries in IoT devices be extended?

### 2.2. Hypotheses

The hypotheses proposed to be tested for this research are the following.

**H1-RQ1:** Energy efficiency on IoT devices can be increased by taking advantage of LoRaWAN communication.

**H2-RQ1:** Reduced energy consumption during data transmission.

**H1-RQ2:** Dynamically optimising IoT device behaviours based on the current state of the equipment will extend his battery life.

**H2-RQ2:** Implement duty cycling techniques, where IoT devices periodically wake up, perform tasks, and then switch to a low-power sleep mode in order to save energy.

### 3. State of the Art

This section reviews the relevant content that has already been published in the field of IoT energy efficiency and shares the main findings. An SLR was conducted to find and select articles discussing about IoT energy efficiency LoRa, LoRaWAN and duty cycle. Below there is a list of the the main benefits and challenges of LoRa and LoRaWAN. Moreover, there is also a summary of the main benefits and challenges of using Duty Cycling approach on IoT devices.

LoRa and LoRaWAN technology offer some benefits, such as long-range communication, low power consumption, scalability, and flexible deployment. The modulation scheme of LoRa enables communication over extended distances, making it ideal for connecting remote sensors and devices[7, 8, 9, 10]. LoRaWAN energy-efficient protocols and duty cycling mechanisms ensure minimal power consumption, facilitating long-term deployments without frequent battery replacements. The scalability and flexibility of LoRaWAN allow for seamless integration of multiple devices within a single network, enabling diverse IoT implementations across different contexts and businesses [7, 11, 12, 8, 9, 10, 13]. Although LoRa and LoRaWAN provide many benefits, applications that require transmitting large amounts of data may not work properly due to limited bandwidth, which can limit data rates and throughput. In industrial or dense areas, communication reliability may be affected by interference and noise from multiple devices trying to communicate simultaneously or from external factors. Also, installing several devices in a small area may result in a congested network, which will have an impact on data loss and increased latency[8, 14, 15, 12].

Lastly, because LoRaWAN has a limited capacity for bidirectional communication, applications that require frequent data interaction may experience complications. Challenges such as limited bandwidth, interference and noise, network congestion, and limited bi-directional communication must be taken into consideration, depending on the use case requirements.

Regarding duty cycling, it offers benefits such as extended battery lifespan, reduced radio activity, and mitigation of network congestion. It allows devices to save energy during idle times by controlling the timing when a device is allowed to transmit, this extends the battery life and reduces the maintenance of the equipment. Also, duty cycling, by controlling radio activity, contributes to mitigating network congestion and reducing radio interference by coordinating communication schedules and preventing simultaneous device transmissions. Despite its benefits, duty cycling also have several challenges that need to be considered. Because transmission schedules are cyclical, latency could be added into the network, which could lead into real-time or time-sensitive applications issues. Another scenario would be that if multiple devices need to transfer data simultaneously and duty cycling is not somehow under control, throughput limitations may also arise, leading to high traffic demand and consequently latency. Moreover, devices that are in sleep mode during important events may also miss events, which could result in delays or data loss. Duty cycling puts energy efficiency ahead of throughput, therefore, it might not be appropriate for applications that need continuous or high-rate data transmission[16, 17].

LoRa, LoRaWAN and Duty Cycling have benefits and challenges, choosing these technologies will always depend on the use case requirements.

It is important to acknowledge that this SLR may have limitations, including data extraction flaws and classification errors. While the study offers valuable insights, further research is needed to confirm the findings. Expanding the research with additional keywords and related investigations would provide a more comprehensive understanding of the subject.

In the meantime, the recommendations for future work should concentrate on overcoming on the challenges identified in this work. To get started, this study found that Limited Bandwidth & Interference and Noise were the two main challenges of LoRa and LoRaWAN. Also, looking at the second challenge interference and noise, one possibility could be finding ways to reduce interference and noise by exploring the adaptive frequency and how to shift when issues are found, this could enhance communication reliability in areas with radio frequency issues.

The study identified Latency & Missed Events as the main challenges in duty cycling. To address latency, optimizing duty cycle parameters based on external sensor data and prioritization could reduce delays. For missed events, implementing event buffering and developing algorithms to dynamically adjust transmission schedules based on conditions and application requirements.

These are merely a few recommendations for future research that can be investigated to evaluate whether it could improve some of the challenges associated with the technologies mentioned in this work. Nevertheless, this falls out of the scope of this research but will be addressed as a future work lead.

## 4. Current State vs. Proposed Solution

The proposed solution focuses on reducing the energy consumption of IoT devices that gather sensor information without compromising the loss of critical data. This will involve integrating optimised wireless and software technologies to reduce power consumption. To achieve this proposal, it combines different types of technology, such as duty cycling, LoRaWAN and LoRa communications. Also, other technologies, such as The Things Network (TTN) and Node Red are used to receive and integrate the data that comes from the IoT sensors.

Duty cycling is used to switch between active and sleep modes to save energy. It is optimised with an algorithm that was designed to avoid the transmission of unnecessary data, which lowers the number of communications and contributes to reducing energy consumption. LoRa is a physical layer technology that defines the modulation technique used for transmitting and receiving data, is focused on long-range, low-power communication using chirp spread spectrum modulation. LoRaWAN is a network protocol that uses LoRa to create a wide-area network, managing communication between end devices and gateway, with features for scalability, security, and bi-directional communication. This proposed solution aims for use cases that need long-term operation, reduced maintenance, and the ability to scale multiple IoT devices gathering a large amount of sensor data.

### 4.1. Solution Architecture

The figure 1 shows the proposed architecture design, the Micro Controller Unit (MCU) and sensor layer is where all relevant data is gathered by the sensors and the MCU determines if data is relevant or not to be sent. Next, the LoRa wireless gateway is used in the communication layer to receive the data that comes from the sensors. Positioned within the middleware layer, the gateway establishes an internet connection, enabling data flow towards the application layer. Finally, the application layer is where the data is received, used, and visualised to support business decisions.

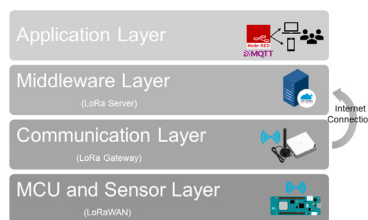


Fig. 1. Proposed Architecture.

The proposed architecture makes use of a variety of hardware and software, such as in the sensor layer, an arduino MK1310 [18] with three sensors attached is used. The sensors are a temperature and humidity sensor DHT22 Velleman VMA345 [19], a light sensor version 1.2 [20], and a distance sensor ultrasonic ranger version 2.0 [21] both from grove manufacturing. On the communication layer, the gateway is configured to use the frequency 868 MHz [6], and the model used is a SenseCAP M2 SX1302 [22]. The middleware allows to connect the gateway to the internet and sent the data to TTN, that it is received at the application layer via Message Queuing Telemetry Transport (MQTT) and then integrated into the Node Red programming tool, where it can be used according to the business requirements.

Lastly, the device is powered by an external battery, and a USB UM25C multimeter is used to measure the amperage (A) and voltage (V), it supports measures from 4V to 24V and 0A to 5A with a minimum measurement of 0.001V and 0.0001A [23].

### 4.2. Pre-Solution State

#### 4.2.1. State

The objective of this research is to enhance the energy efficiency of IoT devices by making use of communication protocols such as LoRa, LoRaWAN and improved duty cycling. A few metrics and key performance indicators (KPIs) are proposed below to compare the outcomes and determine whether the objectives were fulfilled.

### Battery Lifetime:

- Measure the duration of time an IoT device can operate on a 1000 mAh battery.
- KPI: Increase battery lifetime by 30%, measure in hours.

Equation 1 is used to determine the battery lifespan KPI value, where  $Bl$  be battery lifetime in hours,  $Bc$  be the battery capacity in mAh, and  $Ah$  be Ah converted to mAh once being multiplied by 1000.

$$Bl = Bc \div (Ah \times 1000) \quad (1)$$

### Total Energy Consumption:

- Quantify the amount of total energy consumed by the IoT device for each different approach.
- KPI: Decrease energy consumption by 30%, measure in watt-hour (Wh).

This KPI will be obtained by using the equation 2 where  $Wh$  be Wh,  $V$  as V and  $Ah$  as Ah.

$$Wh = V \times Ah \quad (2)$$

### Duty Cycle Efficiency:

- Evaluate how effectively duty cycling is to conserve energy.
- KPI: Duty cycling optimised to balance energy savings and communication needs.

This qualitative KPI is obtained by observing the first two KPIs checking if both are improved. Also, all significant data collected by the sensors continues to be sent to the gateway.

#### 4.2.2. Current State

To assess the possible enhancements proposed in this research, the IoT device consumption will first be recorded when data is collected but is not being communicated to the gateway, the device will continuously collect data from all three sensors once every minute. Also, a second benchmark will consist of gathering every minute all the data from the three sensors in the same way as previously detailed, but the collected data is sent to the gateway.

All test scenarios that were previously detailed were carried out in the same office and distance from the gateway for about 5 hours, starting at 9:00 and finishing around 14:00.

#### 4.2.3. Current State Results

The results of the scenarios one and two are shown in figure 2.

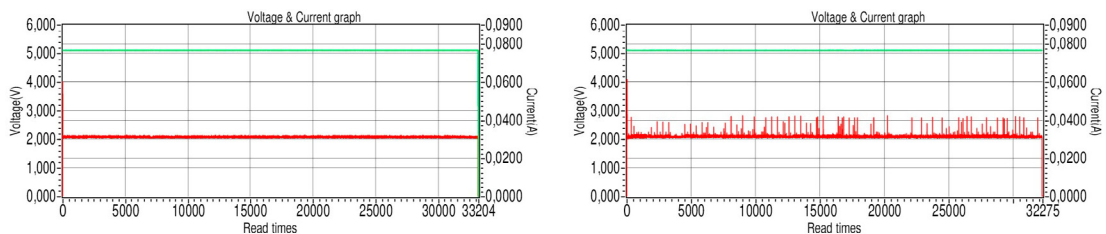


Fig. 2. Scenario one without communications (left) and scenario two with communications (right), readings of V (green) and A (red).

On scenario one it can be observed that there are no peaks, and the energy consumption is stable on both V and A. In scenario two, where data collection and transmission are taking place, it shows that there are some peaks because of the additional energy required to transmit the data.

Despite the additional energy required to transmit the data, comparing with scenario one, table 1, reveals that the average (AVG) results of V and A collected are similar. This outcome of low energy transmission consumption might be the result of the IoT device being near the gateway and inside the office where weather conditions do not have any interference or negative impact, it is under optimal test conditions, as also referred in previous studies [12].

### 4.3. Proposal Solution

Similar with the previous scenarios, the proposed solution will gather data once every minute, however, it will only send the data if there is a significant predetermined change in the data gathered from the sensors. All changes in temperature, humidity, and light with a difference of 2 or more units were considered relevant. For distance, changes with a difference of 5 or more units were taken into account. By doing this, it may decrease the number of transmissions to the gateway, but it continues to provide information by comparing it with the latest measured data that was saved and sent.

Additionally, this enhanced duty cycling algorithm will manage the microprocessor and all the sensors energy, for better visualisation, the figure 3 illustrates a flowchart with the implemented algorithm.

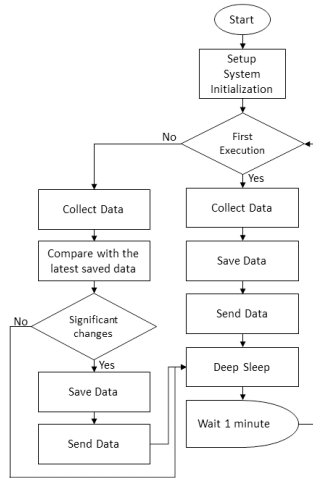


Fig. 3. Duty Cycling flowchart to improve energy efficiency.

### 4.4. Results

This proposed solution was tested on the same conditions of the current state scenarios previously detailed. Figure 4 illustrates the proposed solution that only transmits data when there is a significant difference from the last collected information and also implements additional duty cycling code focused on energy efficiency. There is a noticeable oscillation in the energy consumption when data is being collected, and when the IoT device is in deep sleep, this has a positive impact on the total energy consumption of the IoT device.

There are also a few visible high peaks that can be observed, this could be due to the need for extra energy when the device is sending data to the gateway. This observation does not have a significant impact on energy consumption, it can also be observed from the previous scenarios, which showed that sending data to the gateway has a reduced impact on energy consumption.

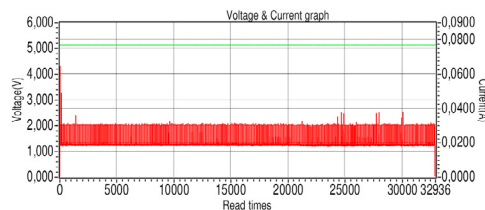


Fig. 4. Measures data obtained from the proposed solution, enhanced duty cycling.

With all the data collected from the three scenarios, the proposed KPIs can now be evaluated and visualised on table 1. Looking at the AVG values, the current state scenarios do not have any significant variations. This suggests

that in this test scenario, having an IoT device collect and send the data to the gateway once a minute does not have a significant impact on energy consumption in comparison to when it just collects data without sending it. But, as expected, the proposed solution scenario with enhanced duty cycling has noticeably decreased energy consumption where we can also determine if the last KPI regarding duty cycling efficiency is achieved.

Table 1. Measures and KPIs analysis from the two scenarios and the proposed solution.

Scenario	Measures	Battery Lifetime (hours)	Total Energy Consumption (Wh)	Duty Cycle Efficiency
Once a minute without communication (AVG)	5.111V - 0.0313A	31.97	0.1599	Baseline
Once a minute with communication (AVG)	5.111V - 0.0316A	31.69	0.1613	Baseline
Enhanced duty cycling with communication (AVG)	5.115V - 0.0191A	52.45	0.0975	Improved

Based on AVG values of the conducted tests, the proposed solution scenario with enhanced duty cycling managed to increase energy efficiency without missing any significant changed events from the data collected by the sensors. The battery lifetime was increased by almost 62% when comparing the enhanced duty cycle scenario to the current state testing scenarios.

Furthermore, as compared to the current scenarios, enhanced duty cycling was able to reduce the overall energy consumption by 39%. Depending on how many daily data readings the particular use case scenario requires, this improvement might be greater.

## 5. Conclusions

Finding ways to improve energy efficiency on IoT solutions was the main goal of this paper. With all the information gathered from previous studies, it was possible to work on an architecture solution and also develop a duty cycling algorithm that combined was able to enhance the energy efficiency of an IoT device with several sensors gathering and sending the data for further analysis. Based on the provided current state scenarios and the proposed solution, there were some interesting findings, such as on the technology used for communication, LoRa and LoRaWAN, it was observed that under optimal conditions, the energy consumption was minimal. By comparing both current state tests, the results revealed that there was no significant difference between sending and not sending data in terms of total overall energy consumption. This observation is beneficial when it comes to choosing the technology for devices that have limited energy resources that still needs to send data, but, the technology has also some drawbacks such as limited bandwidth and daily data transmission restrictions per device depending on the country that is operating.

Another identified IoT energy optimisation based on the results of the current scenarios, and the proposed solution was enhanced duty cycling. It makes use of the deep sleep state to switch the IoT device to low power mode. Although this output is a relevant contribution to lowering the power consumption of the IoT device, it should be carefully evaluated where missed events are critical. Additionally, it was also observed that the duty cycling algorithm could reduce the number of data transmissions, and it may be adjusted depending on the use case. It can determine whether there have been significant changes from earlier gathered data and decide if the data should be transmitted or not. Although communication has a low impact on energy consumption due to the optimal test conditions, it minimises potential data transfer restrictions due to specific country legislation and the transmission of unnecessary data, reducing radio activity and network congestion if used in environments where a high density of IoT devices are connected. The proposed solution focuses on energy efficiency that may be implemented in several use cases, such as agricultural environments, smart cities solutions, and many other scenarios where energy efficiency is critical, and it could result in additional positive impacts such as operational efficiency, cost savings, and environmental sustainability.

Despite all the knowledge that was previously acquired on this subject from the SLR that was conducted and the tests that were carried out to gather and evaluate the results, it may still have certain limitations. To increase confidence in the findings of this research, it would need more testing involving several IoT devices connected simultaneously

and including tests outside the office. As a proposal for future work, the shared limitations may serve as a starting point for further investigation to strengthen this specific area of energy efficiency on IoT technology.

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## References

- [1] S. Kumar, P. Tiwari, and M. Zymbler, "Internet of Things is a revolutionary approach for future technology enhancement: a review," *Journal of Big Data*, vol. 6, p. 111, Dec. 2019.
- [2] J. C. Talwana and H. J. Hua, "Smart World of Internet of Things (IoT) and Its Security Concerns," in *2016 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData)*, pp. 240–245, Dec. 2016.
- [3] M. S. Pal and M. Bhatia, "Lifetime Maximization of Bin Level IoT Sensor and Route Optimization for Smart Waste Management in Hilly City Shimla, India: A Comparative Analysis," in *2022 Second International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT)*, pp. 1–6, Apr. 2022.
- [4] I. Lvovich, Y. Lvovich, and A. Preobrazhenskiy, "Modeling the Processes of Increasing the Efficiency of the Internet of Things System," in *2022 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*, pp. 1030–1034, May 2022.
- [5] K. Peffers, T. Tuunanen, M. A. Rothenberger, and S. Chatterjee, "A Design Science Research Methodology for Information Systems Research," *Journal of Management Information Systems*, vol. 24, pp. 45–77, Dec. 2007.
- [6] Y. Xiao and M. Watson, "Guidance on Conducting a Systematic Literature Review," *Journal of Planning Education and Research*, vol. 39, pp. 93–112, Mar. 2019.
- [7] A. Lavric and V. Popa, "Internet of Things and LoRa™ Low-Power Wide-Area Networks: A survey," in *2017 International Symposium on Signals, Circuits and Systems (ISSCS)*, (Iasi, Romania), pp. 1–5, IEEE, July 2017.
- [8] Z. Qian, D. R. Thinesh, B. Sivaneasan, K. T. Tan, K. J. Tseng, and P. Chakrabarti, "Advancing Low-Power Self-Sustaining IoT Sensors Through CdTe PV-Driven LoRa Communication," in *IECON 2023- 49th Annual Conference of the IEEE Industrial Electronics Society*, (Singapore, Singapore), pp. 1–6, IEEE, Oct. 2023.
- [9] P. Mayer, M. Magno, A. Berger, and L. Benini, "RTK-LoRa: High-Precision, Long-Range, and Energy-Efficient Localization for Mobile IoT Devices," *IEEE Transactions on Instrumentation and Measurement*, vol. 70, pp. 1–11, 2021.
- [10] X. Zhang, M. Zhang, F. Meng, Y. Qiao, S. Xu, and S. Hour, "A Low-Power Wide-Area Network Information Monitoring System by Combining NB-IoT and LoRa," *IEEE Internet of Things Journal*, vol. 6, pp. 590–598, Feb. 2019.
- [11] V. Vatskel, A. Biloshchytskyi, A. Neftissov, O. Kuchanskyi, Y. Andrashko, and I. Sachenko, "Energy-efficient Internet of Things using LoRa Network and modular universal programmable controller in bee apiary management," *Procedia Computer Science*, vol. 231, pp. 715–720, 2024.
- [12] O. H. Kombo, S. Kumaran, and A. Bovim, "Design and Application of a Low-Cost, Low- Power, LoRa-GSM, IoT Enabled System for Monitoring of Groundwater Resources With Energy Harvesting Integration," *IEEE Access*, vol. 9, pp. 128417–128433, 2021.
- [13] S. Lee, J. Lee, H.-S. Park, and J. K. Choi, "A Novel Fair and Scalable Relay Control Scheme for Internet of Things in LoRa-Based Low-Power Wide-Area Networks," *IEEE Internet of Things Journal*, vol. 8, pp. 5985–6001, Apr. 2021.
- [14] S. Khriji, O. K. Gunyeli, D. El Houssaini, and O. Kanoun, "Energy-Efficient Short-Long Range Communication Network Combining LoRa and Low-Power Radio for Large-Scale IoT Applications," in *2022 IEEE 9th International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications (CIVEMSA)*, (Chemnitz, Germany), pp. 1–6, IEEE, June 2022.
- [15] P. D. P. Adi and A. Kitagawa, "Performance Evaluation of Low Power Wide Area (LPWA) LoRa 920 MHz Sensor Node to Medical Monitoring IoT Based," in *2020 10th Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS)*, (Malang, Indonesia), pp. 278–283, IEEE, Aug. 2020.
- [16] R. Piyare, A. Murphy, M. Magno, and L. Benini, "On-Demand LoRa: Asynchronous TDMA for Energy Efficient and Low Latency Communication in IoT," *Sensors*, vol. 18, p. 3718, Nov. 2018.
- [17] A. Augustin, J. Yi, T. Clausen, and W. Townsley, "A Study of LoRa: Long Range & Low Power Networks for the Internet of Things," *Sensors*, vol. 16, p. 1466, Sept. 2016.
- [18] "MKR WAN 1310 | Arduino Documentation." <https://docs.arduino.cc/hardware/mkr-wan-1310/>. Accessed: 2024-03-14.
- [19] "Cm2302 / dht22 temperature and humidity sensor module." <https://www.velleman.eu/products/view/?id=455464&country=be&lang=en>. Accessed: 2024-03-14.
- [20] "Grove - Light Sensor | Seeed Studio Wiki." [\\$https://wiki.seeedstudio.com/Grove-Light\\_Sensor/\\$](https://wiki.seeedstudio.com/Grove-Light_Sensor/). Accessed: 2024-03-14.
- [21] "Grove - Ultrasonic Ranger | Seeed Studio Wiki." [\\$https://wiki.seeedstudio.com/Grove-Ultrasonic\\_Ranger/\\$](https://wiki.seeedstudio.com/Grove-Ultrasonic_Ranger/). Accessed: 2024-03-14.
- [22] "SenseCAP M2 Gateway(SX1302)." <https://www.sensecapmx.com/docs/sensecap-m2-data-only/overview-m2do/>. Accessed: 2024-03-14.
- [23] "Joy-IT JT-UM25C." <https://joy-it.net/en/products/JT-UM25C>. Accessed: 2024-03-23.