A study on energy efficiency in IoT communication with wireless interface redundancy

Robert Cabral de A., F. Helder C. Santos F., A. Joel Ramiro de C., Thiago W. B. da Silva, Alisson V. Brito

***Abstract*— With the increase in technological innovations that have occurred in recent years, the Internet of Things (IoT) is increasingly present in our daily lives. More and more devices are connecting to the Internet, using different communication methods to carry out this intermediation. However, many devices do not have the necessary adaptation to work with low power consumption without losing connectivity. The present work aims to conduct a comparative study between the Wi-Fi, General Packet Radio Services (GPRS), and Long Range (LoRa) networks, seeking to find out the best network for a given device. A reliability study was carried out using packet duplication diversities with the same networks. As a result, it is possible to state that GPRS and Wi-Fi is not a suitable type of communication when one values energy efficiency, while LoRa presents better results. These results were obtained by using more than one type of communication at a time, in which all packets sent were received at the same time, even if one communication was used at a time. In addition, packet losses were perceived.**

***Keywords*— IoT, GPRS, Wi-Fi, LoRa, low power, energy, network.**

I. Introduction

Embedded systems are devices with data processing capability that have been gaining market share, mainly with the different embedded items connected to the Internet of Things (IoT), allowing data collection and exchange. IoT is a concept in which things connect globally, from vehicles and appliances to even animal husbandry [1]. There are embedded systems connected to the Internet, doing tasks that often go unnoticed. Still, with the increase in devices, there are some concerns, such as the energy efficiency of these devices.

The connectivity of embedded systems with the Internet has grown in recent decades, and several communication protocols can perform this intermediation. Many devices are not adapted to work with devices that require low power consumption without losing connectivity. The consumption of energy in IoT devices does not only cause losses for the manufacturer, and the environment, generating more and more electronic waste and releasing CO_2 into the atmosphere.

Most of the time, the communication used in IoT devices is wireless, using different communication protocols and frequency ranges. In the case of thousands of sensors, the significant number of nodes connected to a base station causes many problems packet loss.

Problems like these motivated the present study on energy efficiency when using communication protocols. This work proposes to analyze the energy efficiency in the Wi-Fi, GPRS, and LoRa protocols, in addition to a study on the technique of packet duplication. In the analysis of the experiments, a comparison is made between the protocols, analyzing their energy characteristics. Contributes to the community of developers and hardware/software device designers, providing the best choice in projects with a low need for maintenance of the energy source. Likewise, the packet duplication technique allows effective testbeds in the different communication categories.

This work is organized as follows: the section II describes the pros and cons of the related works; the section III addresses a discussion of the networks used in the study of IoT and packet duplication; the IV section details the methodology used to carry out the study; the V section analyzes the results obtained; and, finally, the section VI discusses the conclusions of this work.

II. Related works

In [2], the authors deal with the energy consumption rate in different types of communications on Low Power Wide Area (LPWA) networks, focusing on the daily consumption of the device transmitting a maximum of 10kB of data per day. The authors use the Long Range-Wide Area Network (LoRaWAN), Sigfox, Narrowband IoT (NB-IoT), and Extended coverage GSM IoT (EC-GSM-IoT) to carry out the work; however, the authors use simulators and datasheets of the components for data collection.

In the work of [3], an analysis of energy consumption in short-range devices for low-energy industrial applications, focusing on the IEEE 802.11b/g and IEEE 802.15.4 protocols. The article presents a comparison between the protocols, which seek the lowest possible power without losing the transmission speed, coming to transmit up to 250 kbps in the case of IEEE 802.15.4 and 54,000 kbps in the case of IEEE 802.11b/g, however the range of 10 to 140 meters, which makes a huge difference when compared to LPWA networks.

The work of [4] presents packet duplication as a promising solution to meet the requirements of 5G networks, as suggested by 3rd Generation Partnership Project (3GPP) adopted the packet duplication technique. The author focuses a lot on reliability and latency as problems, so the reliability of a wireless system can increase by transmitting the same packet through several redundant means, such as the types of communications used in this study, thus increasing the reliability of each of them. However, this duplication of packages directly affects energy efficiency, mentioned by the author but has not been studied further.

Even with studies on energy efficiency and packet duplication presented above, no studies in the literature propose testbeds on communications comparing these networks on IoT devices using reliable metrics to measure the power required by communication. In addition, works like the one of [4] present solutions for reliability without showing the behavior of duplicating packages since the energy consumption increases with this.

The comparison of the networks proposed in this work and the study using packet duplication with real communication modules uses a current sensor to collect the data, aiming at greater reliability in the data collected for the work.

In [5], it investigates austere industrial and energy harvesting environments to study the performance of the LoRa for indus-

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trial automation. Initially, a model for LoRaWAN, and then, the potential of the energy harvest available in an Industry 4.0, analyzing the impact of the energy harvested on the battery life and the detection interval with LoRa implanted in a production facility. The authors obtain as the main result an analysis of cost compensation between the replacement of the battery and the penalty for damages over different detection intervals.

III. Theoretical foundation

A. Internet of Things (IoT)

In recent decades, technology has been gaining more and more space daily. With that, new concepts emerge to facilitate human life. The term Internet of Things (IoT) appeared in 1999 and is linked to RFID in the organization of pallets in the product supply chain [6].

The authors in [7] define technologies and protocols that enable objects to connect to the internet and be identified and controlled through the network. Already [8] defines the term "things" in the internet of things as devices that have, to some degree, computing, communication, and control capabilities, simultaneously.

Since the emergence of the IoT, simple tasks have been automated, making people's lives easier, such as turning on the air conditioning even when you are not in the room or even programming the coffee maker so that the coffee is ready when you get home. In 2019 there were 26.66 billion devices connected to the internet. The forecast for 2025 is that we will have approximately 75 billion devices connected to the internet, generating an increase of approximately 182% in six years.

B. Energy Efficiency

Discussions usually take place on energy efficiency in embedded systems [9]. Thus, designers must think about improving this type of system so that it does not become something that requires a long time for maintenance [10].

According to [11], the term "efficiency" describes the effectiveness of devices that operate in cycles or processes to produce the expected results. According to [12] energy efficiency comprises the analysis of energy consumption, intending to reduce costs and greater savings, combined with new technologies, materials, and equipment. The concept of energy efficiency has been formulated for some years; as described by the authors, energy efficiency focuses on reducing the amount of energy spent to do some activity to increase energy efficiency.

An energy-efficient embedded system consumes the least amount of current possible, using sensors and low-power communications in a way that does not lose performance in the tasks performed. In the case of IoT devices that mostly use wireless technologies, a case study with the variables that cause energy problems becomes more than necessary for the further development of the system.

C. Wi-Fi Technology

Wi-Fi is present in most places of our daily lives, allowing wireless connections and connecting devices to the network. Wi-Fi is the name for the IEEE 802.11 technology, which is the original name for this technology.

There are several 802.11 standards for wireless networks, all of which transmit data at a much higher rate than all other communications used for this job. However, because it transmits data very quickly, the Wi-Fi network has a high energy consumption, which is a severe problem in IoT devices [13].

The IoT came up with devices likely to use Wi-Fi, as it is an easily accessible and wireless network. Still, over the years, several protocols have been implemented to achieve higher data transmission speed. As a result, this type of IoT communication became unviable. However, in 2017 IEEE 802.11ah technology appeared, intending to cover a sufficient area to serve a residence and use a smaller amount of energy working in frequencies of approximately 900MHz [14].

D. GPRS Technology

GPRS is a type of communication on GSM networks. Before data transmissions happened with GPRS technology, data transmission was done by GSM technology. GPRS is a cellular data service used in 2G networks and improved for 3G technology. It uses a specific channel for data, making communication faster. As it is a technology that uses telephony, it is a type of communication that requires a data usage plan, costing a monthly fee. This technology has advantages that allow for higher throughput, and it also allows for increased network capacity when multiple users share the same resources. GPRS, unlike other technologies, allows the telephone company to charge for the amount of data used in IoT.

E. LoRaWAN Technology

LoRaWAN is a long-range, low-power protocol and an open standard based on LoRa that is gaining more and more market. It is maintained by LoRa, AllianceTM ™.

The LoRaWAN specification is an LPWA network protocol designed to connect battery-operated wireless "things" to the Internet on regional, national or global networks. It targets the main requirements of the Internet of Things (IoT). LoRaWAN operates at low frequencies with a transmission rate of up to 50 kbps, transmitting unlimited messages during one day. Being an LPWA network, LoRaWAN promises low energy costs with good coverage, covering an area of up to 15km [15], regional, national or global, and targets the main requirements of the IoT. LoRaWAN operates at low frequencies with a transmission rate of up to 50 kbps, transmitting unlimited messages during one day. Being an LPWA network, LoRaWAN promises low energy cost with good coverage, covering an area of up to 15km [15].

F. Duplication of Packages

Packet duplication is a technique that increases system reliability by sending redundant data over more than one communication interface. Figure 1 shows the infrastructure used in

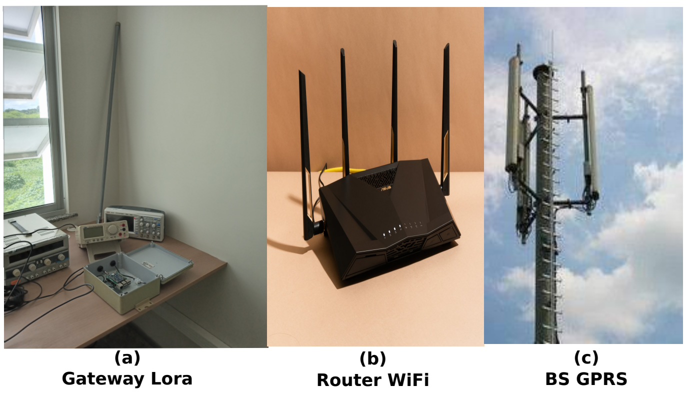

Fig. 1. The Base station used in the testbed

the test, where the raspberry PI board collects the data from the DHT22 sensor and sends it to the cloud server via the following communication interface: (a) LoRa, (b) Wi-Fi, and (b) GPRS.

IV. Methodology

The necessary steps for the execution of the work, from the communication modules to the way of carrying out the testbeds. The steps are as follows:

- Implementation of the Communication Drivers.
- Communications validation.
- Data collection.
- Analysis of collected data.

Each communication has its way of exchanging data, so the drivers for each type of communication were implemented in this step, configuring the modules for the possible sending of packets. With the three communication interfaces working, then the data collected by the sensor is sent by only one interface or by pairs of interfaces[1].

A. Data collection

Data were collected, such as current (mA) and voltage (V) for each type of communication. Ohm's law is used to calculate the power, explained in Equation 1, where V is the voltage applied in the system, and i is the current required for the system to function.

$$P = v \cdot i \tag{1}$$

It was necessary to use an auxiliary plate to collect voltage and current data, together with the current and voltage sensor INA219. Figure 2 illustrates how to connect the current sensor to the modules of the respective types of communication.

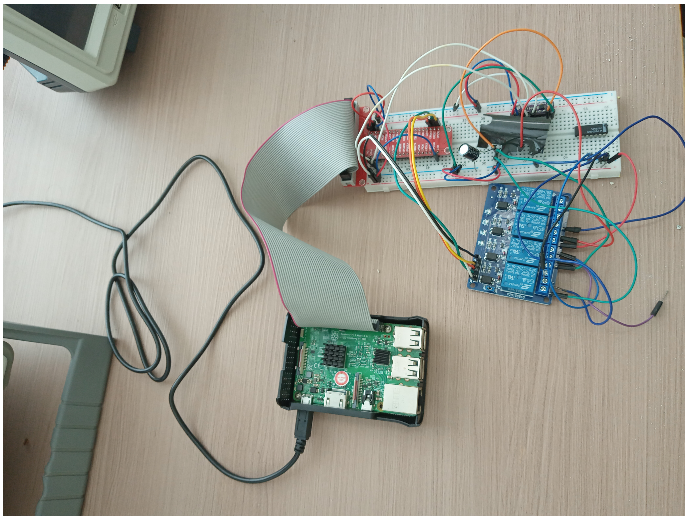

Fig. 2. Voltage and current reading circuit

V. Numerical Results and Discussion

The results obtained from the experiments at work. Each type of communication sent 1000 packets to the cloud containing a tracking number.

During the entire sending of the packets, the current sensor captured information on the consumption of the types of communications.

The graph in Figure 3 shows the consumption of the system using only LoRa. Unlike other types of communications, the LoRa module wakes up only to send the packet, causing the graph to have constant peaks.

[1]It was impossible to send simultaneously through the three communications interfaces as the hardware did not support it.

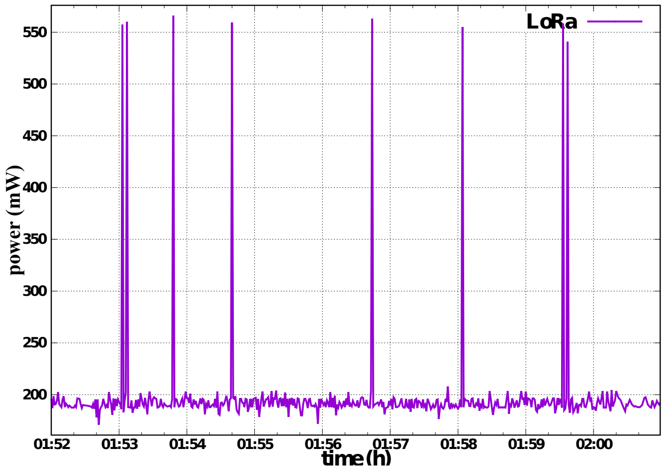

Fig. 3. LoRa consumption graph

The system consumes an average of approximately 194.60 mW, while the median is around 189.51 mW. The median is also crucial because of the spikes throughout the experiments, making the mean disproportionate. An important observation is the difference between the mean and the median, as it has a more significant number of values above the mean. Finally, it notes that LoRa obtained a very satisfactory result regarding packet loss; out of a total of 1000 packets, only two were lost, with a success rate of 99.8%.

In Figure 4 shows the behavior of the system when sending data using only Wi-Fi.

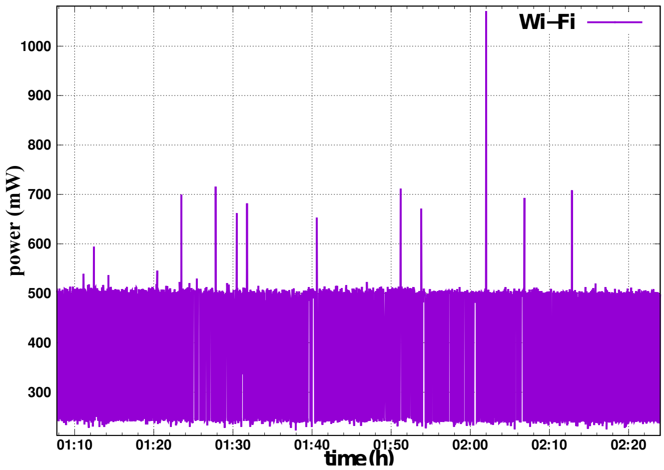

Fig. 4. Wi-Fi consumption graph

The variations between the idle system and the sending of packets, which sends the so-called beacon frames transmitted periodically and renew the concession on the network. The beacon frames raise the power level at any given moment, which shows a considerable variation between the mean and median. Wi-Fi correctly sent 987 packets out of 1000, a percentage with a 98.7% success rate. The system consumes an average of approximately 383.99 mW, while the median is around 490.48 mW.

The graph in Figure 5 shows the system's energy consumption data when only GPRS is used as communication. A significant variation in power can be seen in the graph because GPRS must keep the connection active with the network, so several packets are sent over time.

In addition, peaks are noticed when the system collects data from the sensor or sends it to the cloud, keeping the data on average between 300 mW and 400 mW. GPRS correctly sent

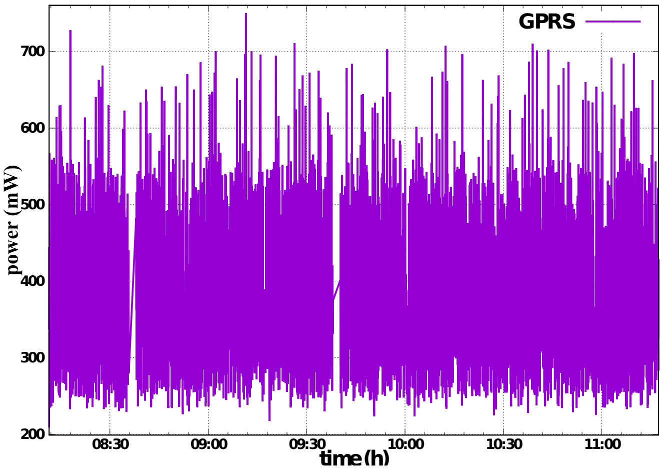

Fig. 5. GPRS consumption graph

937 packages of 1000, a percentage with a 98.7% success rate. The system consumes an average of approximately 374.18 mW, while the median is around 355 mW.

After obtaining the data using a single communication, testbeds were started using more than one communication at a time, seeking more excellent reliability. The graph in Figure 6 shows the system consumption when combining LoRa and GPRS.

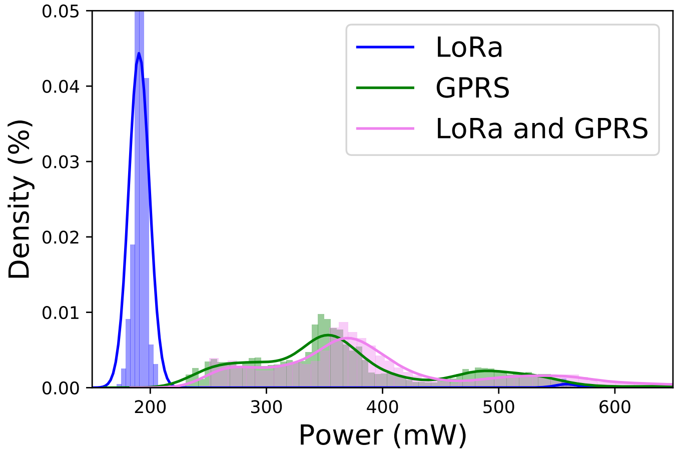

Fig. 6. LoRa and GPRS consumption graph

We can see in the graph a variation very similar to the graph in Figure 5; however, the peaks are more prominent because sending the LoRa increases consumption for a constant period. The average of 404.28 mW and the median of 375.48 mW closely approximated the results obtained using only GPRS. However, the experiment shows a leap in confidence, which went from just over 90% to 100%.

Figure 7 shows the consumption graph when using GPRS and Wi-Fi simultaneously. The graph is similar to GPRS, but with higher consumption values, with peak consumption. The values obtained in the testbed show a higher consumption when analyzing the testbeds with GPRS and Wi-Fi.

The system with the two communications consumes above 600 mW. Compared to the median value of Wi-Fi, it presents a higher consumption because it is shifting the distribution. In addition, a change in the average indicates a more significant deviation or the associated error function. Finally, the success rate obtained is 100 %.

The graph in Figure 8 shows the results of the frequency distribution testbeds when using LoRa and Wi-Fi to send packets. Wi-FI alone has a value of about 500 mW; when sending occurs with LoRa, it can be analyzed that the consumption power of the system on average increases because the distribution shift is occurring. Finally, the success rate obtained is 100 %.

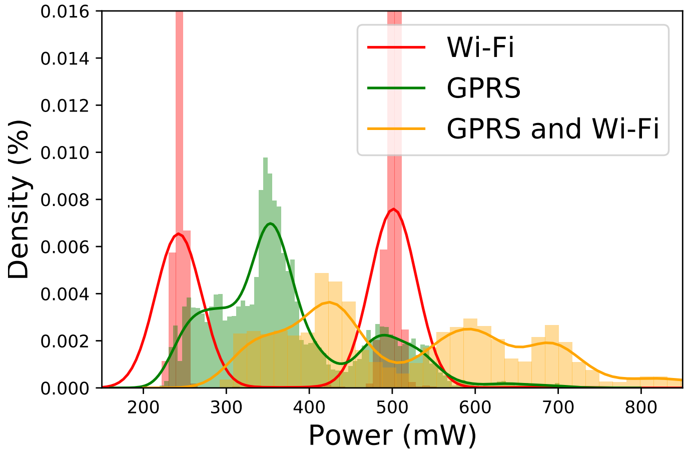

Fig. 7. GPRS-Wi-Fi consumption graph

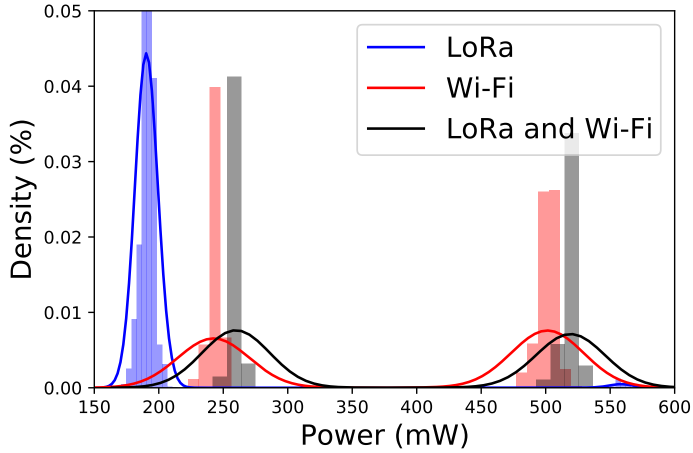

Fig. 8. LoRa-Wi-Fi consumption graph

The graph in Figure 9 shows the averages of the frequency distributions. Duplicate packets send the same packet over more than one link. Thus, GPRS and Wi-Fi transmission distribution obtained the highest consumption power above 700 mW. When LoRa and Wi-Fi were used for sending, consumption was above 500 mW, and below 600 mW, while using GPRS and LoRa, consumption was lower when using GPRS and Wi-Fi.

The averages were calculated using the frequency distribution method. The equation 2 shows the formula used to obtain the averages, where X_i is the average of the power intervals (mW) and f_i are their absolute frequencies.

$$\frac{\Sigma X_i \cdot f_i}{\Sigma f_i} \tag{2}$$

The graph in Figure 10 shows the testbed values related to reliability. During the simulation, 1000 packets were sent to the testbeds. Initially, communications were tested in isolation, without duplicating packets, sending data through only one interface. When sending via GPRS, 937 packages were delivered, while when sending with LoRaWAN, 998 packages

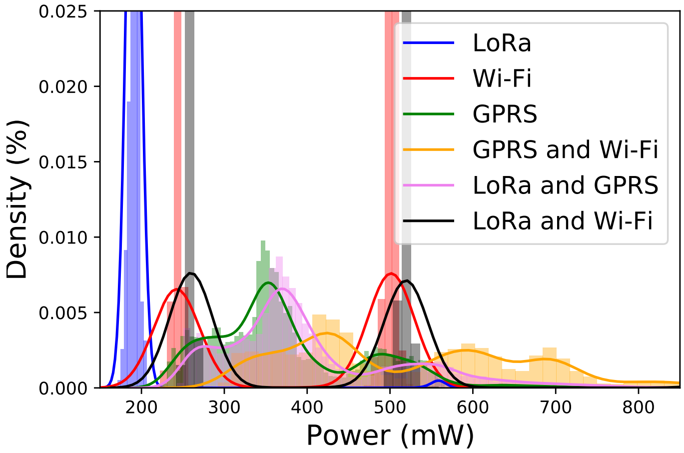

Fig. 9. Graph of energy consumption of devices

were delivered, and when Wi-Fi was used, 987 packages arrived at the destination.

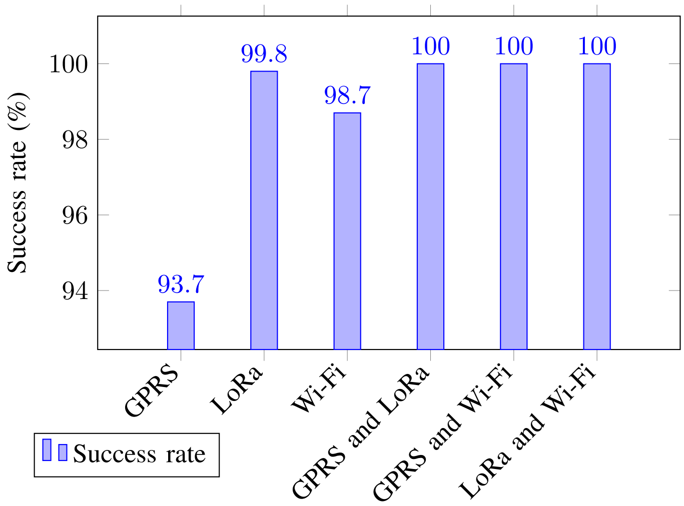

Fig. 10. Performance comparasion for one/two communication interfaces.

When using more than one link for the transmission of the packages, in all testbeds, 100% of packages were delivered; whenever any communication failed, the other link used for sending managed to get the package to the destination the right way.

VI. Conclusions

This work aimed to study and analyze the energy consumption in IoT devices and compare specific types of communication, in addition to using packet duplication to study the feasibility of using more than one type of communication about consumption compared to the reliability of the package delivery.

It is concluded that it is preferable to use GPRS with another type of interface in the transmission because GPRS presents a significant loss of packets. When using packet duplication, packet loss drops to no lost packages. With the gain in reliability and a not very large increase in power consumption, it is feasible to use more than one type of communication.

Still, based on the test results, it is possible to say that it is not worth using packet duplication when using LoRa with few nodes because the consumption is deficient compared to other communication types.

Low consumption linked to a success rate of almost 100% shows that LoRa achieved the best test results. However, in massive networks, the number of nodes increases considerably, which may cause more interference using the same frequency range. In this case, the use of packet duplication decreases this packet loss and increases reliability.

Wi-Fi had the worst results in terms of power consumption, as it remained above other types of communications in the testbeds carried out. Still, it had a pretty success rate, losing a few packages.

LoRa, together with GPRS, proved to be the best package duplication option, having comprehensive coverage. Wi-Fi, in conjunction with other technology, had the worst results, being quite limited and restricted to a few meters. GPRS is a good choice in systems that do not require high reliability but need to communicate without distance limits.

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