An Energy-efficient Wireless Sensor Network Applied to Greenhouse Cultivation

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Keywords

Wireless Sensor Networks, Bluetooth Low Energy, ESP32, Precision Agriculture

ABSTRACT

1. RESEARCH PROBLEM AND MOTIVATION

Wireless sensors have already been used for a long time in military, health, and agricultural environments [6]. Despite the advances in precision agriculture, wireless sensor networks remain a distant reality for small farmers, mainly greenhouse farmers, in developing nations. Fungi and bacteria cause damage to the cultures and tend to spread quickly, limiting its production. Therefore, their early detection is essential for the food production market.

Precision agriculture [5, 2] is based on the principle of soil and climate variability. Using specific data from geographically referenced areas, the agricultural automation process is implemented by dosing fertilizers and pesticides. Through the acquisition and analysis of data from sensors, a management policy is capable of reducing the use of pesticides, favoring the conservation of cultivated land, limiting environmental degradation and increasing productivity.

One of the main challenges implementing precision agriculture is to optimize the expenditure of the device's battery. In this context, it is important to evaluate the consumption of wireless protocols to increase energy efficiency.

2. BACKGROUND AND RELATED WORK

BLE (Bluetooth Low Energy), Zigbee and other wireless communication protocols were studied and several consumption measurements are being carried out using BLE in order to implement a reliable infrastructure for small farmers [1]. In [3], the authors highlight the opportunities for monitoring temperature and humidity systems using Wireless Sensor Network. [4] brings automation ideas using IoT concepts and ESP32.

The main difference between the related works to the work developed is the use only of off-the-shelf components (easy access to the general public and low cost) for the composition of the system, and the combination of low cost items with components and software focused on low energy consumption.

3. APPROACH AND UNIQUENESS

Various types of sensors for humidity, temperature, atmospheric pressure, CO2 and soil pH were studied. But the selected one, BME/BMP280, joins low cost and good accuracy; Microcontrollers such as ESP8266, ESP32, Arduino boards and Raspberry Pi Zero W; SOCs such as BeagleBone Black and power banks available on the market were evaluated in order to identify whether their specifications meet the characteristics and goals of the target application.

The selection of components considers fundamental points such as low energy consumption, affordable price and accuracy in reading. For this purpose, a prototype made of fully connected sensors using the BLE protocol was constructed aiming low energy consumption experiments.

This prototype has a microcontroller (supplied by a power bank) which receives the data collected by the sensors at different locations in the greenhouse and transmits them to a single SOC or microcontroller who will analyze the measurements. Therefore, the farmer can monitor, in real time, useful data from its cultivation using a smartphone connected to a low cost system. The power bank is exchanged every month.

The ESP32 was selected due to its native energy saving modes. These states select specific parts of the hardware to sleep and reduce the power consumption. The BME/BMP280 sensor is also used to collect temperature, humidity and atmospheric pressure data. The WSN designed for the prototype operates in both Broadcaster and Observer modes. This configuration, which is depicted in figure 1, enables communication not only between the subordinate nodes and the main node but also allows the subordinate nodes to communicate with each other. This functionality facilitates the retransmission of messages from nodes located at greater distances.

*This work received financial support through research grants provided by FAPERJ (Brazil).

SRC SIGMETRICS '23 Orlando, Florida USA

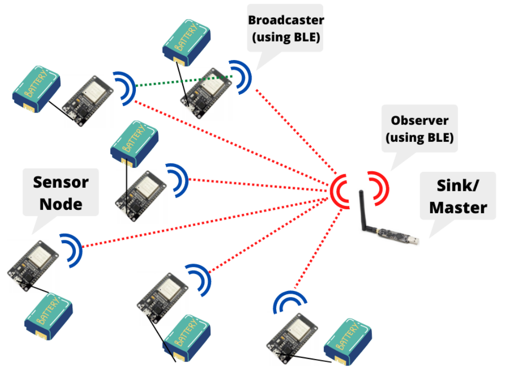

Figure 1: Wireless Sensor Network Prototype.

4. PARTIAL RESULTS AND CONTRIBUTIONS

The figures show some results of energy consumption, recorded at the time of data collection, reading and storage by the microcontroller and during data transmission to the main microcontroller. For consumption and loss tests the sensor INA219 and the Arduino UNO were used, plus the Ubertooth One tool to detect packet loss.

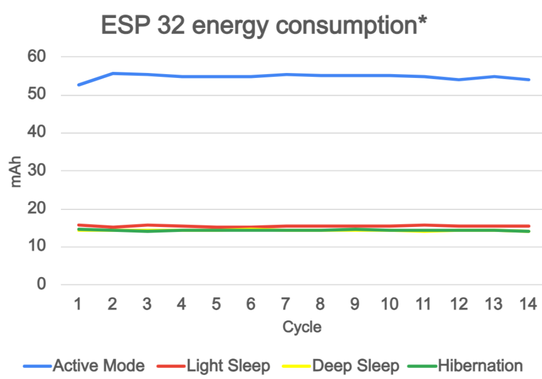

Figure 2: ESP32 Consumption.

There is a noticeable in figure 2 a significant drop in power consumption of the ESP32 during its sleep modes, with Hibernate mode demonstrating the most favorable results, since it turns off most components, such as the radio, core, memory, ULP co-processor, and any peripherals. Making it ideal for situations where the prototype will remain in a suspended state for extended periods of time, thereby optimizing its performance.

Indoor and outdoor tests results (figures 5 to 8) demonstrate the performance of the BLE protocol, considering the cited metrics. These tests were performed at 15, 20, 25 and 30 meters environments (indoor and outdoor). The term "cycle" refers to a 20-minute testing period, wherein the ESP32 was active for 5 minutes, sending 30 packets, and remained in its Hibernate mode for the remaining 15 minutes. Three ESP32 devices equipped with BME280 sensors and power banks were employed for these tests.

Figures 3 and 4 illustrate the testing locations for indoor and outdoor environments, respectively. The yellow lines indicate the maximum testing distance of 30 meters.

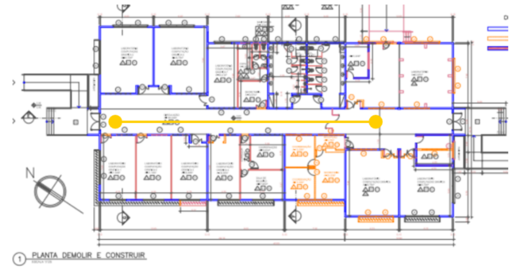

Figure 3: Indoor tests site. (Practical Classes Building (PAP) for Information Systems, UFRRJ, Seropédica Campus.)

Figure 4: Google Earth image of the location (22º46'21"S 43º41'09"W) where the outdoor tests were conducted.

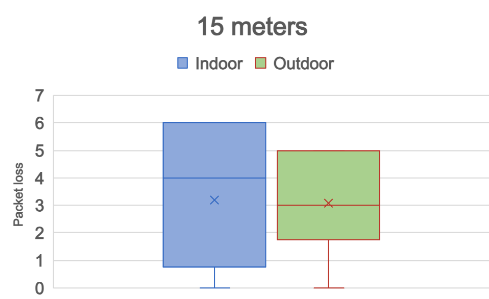

Figure 5: Packet loss per cycle at a distance of 15 meters.

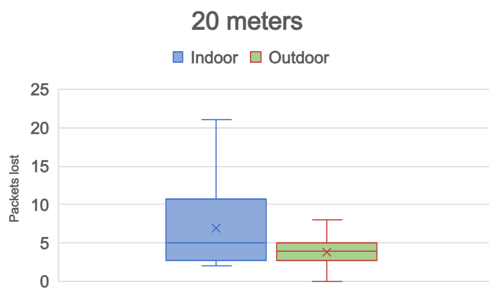

Figure 6: Packet loss per cycle at a distance of 20 meters.

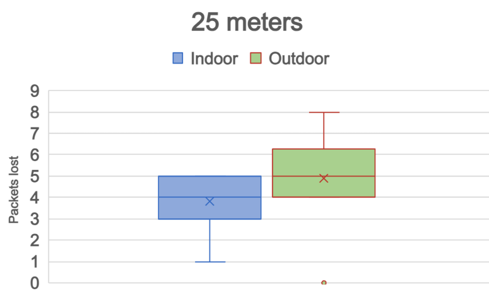

Figure 7: Packet loss per cycle at a distance of 25 meters.

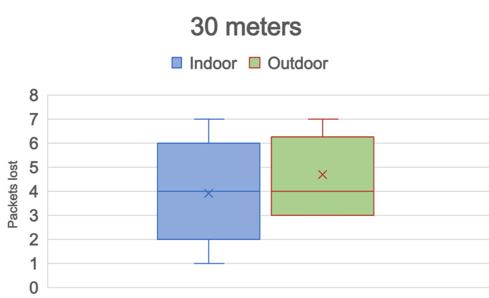

Figure 8: Packet loss per cycle at a distance of 30 meters.

The variation in packet loss, especially during peak times, indicates that indoor environments are more susceptible to packet loss and collisions. This can be attributed to the higher number of physical barriers and the presence of individuals with BLE devices within the building.

5. ONGOING WORK

Currently, experiments are underway in actual greenhouses (9). Preliminary results indicate that due to the remote location and the absence of constant presence of individuals with BLE devices, among other factors, the packet collision and loss rate is considerably lower. It averages around 2 to 3 losses per 30 packet transmissions. This allows for a reduction in the number of packets sent, consequently reducing the active mode duration of the ESP32 and enabling significant energy savings.

An initiative is currently underway to develop a mechanism for transmitting metadata on the current status of the prototype's external batteries. The primary objective of this effort is to enhance the precision in determining the optimal timing for their replacement, thereby improving our overall capability in this aspect.

Figure 9: Tomato greenhouse utilized as the testing ground for the prototype's new experiments.

6. ACKNOWLEDGEMENT

I would like to express my gratitude to my laboratory colleague, Isabelle Santiago Cardoso Rizzo, for the months of research, study, and dedicated testing we have undertaken together.

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