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Evaluation Of Radiated Electromagnetic Immunity Of The IoT LoRa Protocol

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Abstract:
Background: *With the advancement of Industry 4.0, the automation of industrial processes has shifted from wired communication technologies to wireless networks, enabling greater flexibility, efficiency, and scalability. Technologies such as LoRaWAN and NB-IoT have been widely adopted due to their low energy consumption and long-range communication capabilities, which are essential for industrial applications. However, the increasing density of connected devices has introduced new challenges, particularly related to electromagnetic interference (EMI), which can degrade network performance, cause packet loss, and delay communication.*

EMI, caused by various sources such as electronic devices and natural phenomena, is a critical issue in industrial environments. EMI simulations and analyses allow for network parameter adjustments and the implementation of mitigation techniques, ensuring robust communications. This study's primary objective is to test the radiated electromagnetic immunity of the LoRa protocol, assessing its ability to operate in environments subject to electromagnetic interference. The research emphasizes the importance of understanding EMI impacts to preserve data accuracy, improve communication performance, and ensure regulatory compliance, fostering a safe, reliable, and efficient industrial environment.

Materials and Methods: *The study evaluates the radiated electromagnetic immunity of Heltec LoRa ESP32 V2 boards, essential for IoT applications, in compliance with the IEC 61000-4-3 standard, which establishes methods for testing immunity to high-frequency electromagnetic fields. The boards were tested in an anechoic chamber to analyze the impact of radiated fields on LoRa communication. During the tests, conducted at frequencies from 80 MHz to 6 GHz and with a field intensity of 10 V/m, a transmitting board continuously sent LoRa packets while the receiving board recorded RSSI values and packet reception rates.*

The results demonstrated the sensitivity of the LoRa protocol to electromagnetic interference, evidenced by RSSI variations and packet losses under certain conditions. The tests highlighted the importance of robust configurations to maintain data integrity and device functionality in challenging industrial environments. The study provides valuable insights for improving electromagnetic compatibility in Industry 4.0 and IoT applications, meeting the criteria established by the IEC 61000-4-3 standard.

Results: *The study identified critical communication disruptions in the LoRa system at specific frequencies (305 MHz and 730 MHz) under radiated electromagnetic fields with a power of 1.5 dBm, characterized by packet loss and performance degradation. At 3 dBm, total communication failure occurred, attributed to internal resonances in the RF components and insufficient shielding or filtering of the modules. The interference likely overlapped with harmonics of the LoRa signal, reducing its ability to distinguish useful signals from noise. These findings highlight the system's vulnerability to specific EMI conditions, emphasizing the need for improved filtering, shielding, and protocol adjustments to enhance robustness in industrial environments.*

Conclusion: *The study finds LoRa unstable at 305 MHz and 705 MHz with 1.5 dBm, causing packet loss and potential communication failure, highlighting the need for mitigation in high-interference environments.*

Key Word: *Electromagnetic interference, Lora, Heltec, IoT*

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I. Introduction

For years, the industry has been automating its processes using wired communication technologies[1]. However, logistical evolution and the increase in connected devices have driven the adoption of wireless technologies, especially with the advent of Industry 4.0[2]. This new industrial architecture has highlighted the limitations of wired networks, both technologically and economically, and in some cases even functionally, where distance is the main factor prompting the shift to a different physical communication medium. Wireless communication technologies are fundamental to the implementation of Industry 4.0, providing the foundation for the interconnection of devices and systems in an intelligent production environment. The integration of sensors, actuators, and control systems via wireless networks enables real-time collection and analysis of critical data, facilitating automation and optimization of industrial processes[3]. Industry 4.0, characterized by the integration of advanced technologies to create smart factories and highly automated production systems, has been significantly driven by innovations in wireless communication technologies. Wireless communication plays a crucial role in connectivity and data exchange between devices and systems in modern industrial environments, enabling more efficient, flexible, and scalable operations. However, the increasing complexity and density of technological systems also brings new challenges, with electromagnetic interference (EMI) being one of the main issues to be addressed.

Electromagnetic interference (EMI) is a phenomenon that occurs when unwanted electromagnetic signals disrupt the operation of electronic devices, causing performance degradation or failures[4]. This phenomenon is a growing concern in various engineering fields due to the increasing density and complexity of electronic systems. EMI sources are varied and may include electronic devices such as computers, cell phones, industrial equipment, power transmission lines, electric motors, and even natural phenomena such as solar storms. The increasing use of Internet of Things (IoT) devices and the deployment of 5G networks have significantly increased potential EMI sources, creating new challenges for the effective management of this phenomenon[5]. Long-range, low-power network technologies such as LoRaWAN and NB-IoT are widely used in Industry 4.0 for applications requiring long-distance communication with low energy consumption[6].

LoRaWAN technology is designed to provide long-range communication with low power consumption, characteristics that make it ideal for industrial applications[7]. However, EMI can impair network performance, leading to packet loss and communication delays. Recent studies indicate that EMI analysis is crucial for optimizing network configuration and enhancing communication robustness, ensuring system efficiency under adverse conditions. Simulating EMI in industrial environments allows for testing and adjusting network parameters to mitigate the effects of interference[8].Continuous research into advanced EMI mitigation techniques and the development of new materials and technologies are crucial to addressing interference challenges in Industry 4.0[9]. The integration of artificial intelligence-based solutions for EMI monitoring and management is emerging as a promising area, offering the ability to quickly detect and respond to interference issues.

The analysis of electromagnetic interference is vital to ensure the efficient operation of sensors in IoT LoRaWAN networks in industrial environments. EMI simulation provides an in-depth understanding of interference impacts, enabling the implementation of solutions to preserve data accuracy, improve communication performance, and ensure regulatory compliance. This study highlights the importance of a thorough analysis aimed at optimizing the performance of IoT systems, with the objective of promoting a safe, reliable, and efficient industrial environment. To achieve this, the work focuses on evaluating the radiated electromagnetic immunity of the LoRa protocol, considering its ability to operate in environments with electromagnetic interference.

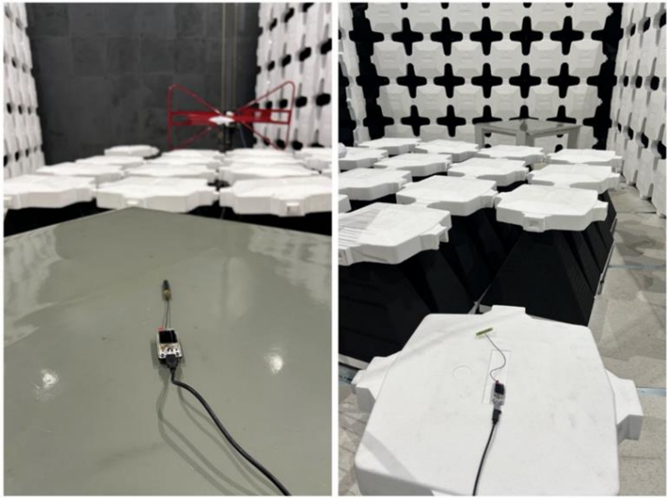
II. Material And Methods

Hardware for test

The Heltec LoRa ESP32 V2 is a compact and versatile development board designed for IoT applications that integrate LoRa, Wi-Fi, and Bluetooth communication[10]. Based on the ESP32 microcontroller, it offers dual-core processing (Tensilica Xtensa LX6) with a clock speed of up to 240 MHz, 4 MB of flash memory, and 520 KB of SRAM. This board supports multiple communication protocols, including Wi-Fi IEEE 802.11 b/g/n, Bluetooth v4.2 (BLE and classic), and LoRa, with the SX1276 modem from Semtech. The LoRa communication operates at frequencies of 433 MHz, 868 MHz, and 915 MHz (depending on the version), with a sensitivity of up to -148 dBm and adjustable transmission power up to +20 dBm. The Heltec V2 also features an integrated OLED display with a resolution of 128x64 pixels, controlled via I²C, facilitating real-time information display. Its power circuit supports 5 V via micro-USB or 3.3 V on GPIO pins, with an efficient voltage regulator and an integrated circuit for Li-Po battery charging.

For the experiments, two identical boards were used, presented in figure no 1, with specific configurations to ensure the evaluation of LoRa communication. One board was configured as a transmitter and powered exclusively by a direct current power supply, ensuring the device's energy stability during the experiment. The other board was configured as a receiver and connected to a computer via a serial interface. This connection enabled continuous and real-time monitoring of the transmitted data, allowing the analysis of the communication's stability and efficiency between the devices. Both boards operated at a frequency of 915 MHz, as specified for LoRa applications in ISM bands. The spreading factor was set to 7, a commonly used value to balance transmission rate and robustness against interference. The transmission power was adjusted to 5 dBm, allowing for moderate range while minimizing energy consumption. The preamble was configured with a length of 8, aligned with recommendations for efficient packet synchronization. Additionally, the buffer was set to a size of 30 bytes, suitable for sending short and consistent messages in communication tests. These configurations were chosen to replicate a realistic scenario of LoRa protocol usage, aiming at analyzing the stability, range, and robustness of communication under controlled conditions.

Figure no 1: Emitter and receiver Heltec Wi-Fi Lora V2

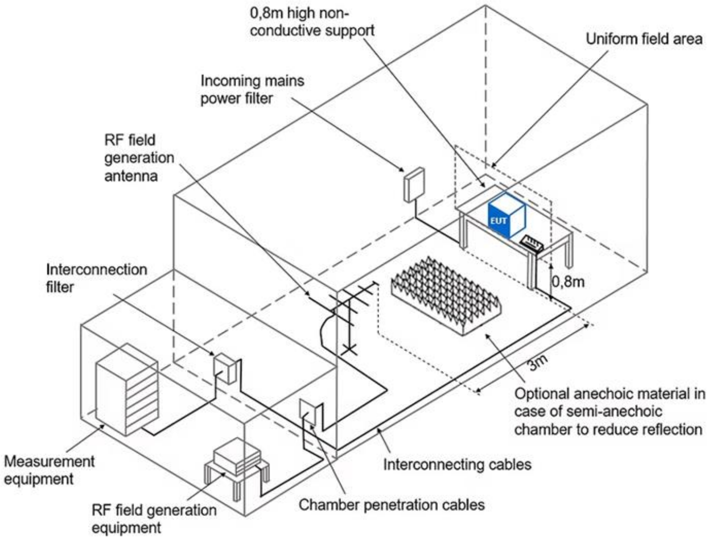


Electromagnetic compatibility (EMC) - Part 4-3: Testing and measurement techniques - Radiated, radiofrequency, electromagnetic field immunity test

The IEC 61000-4-3 standard establishes the methods for conducting immunity tests on electronic equipment to high frequency radiated electromagnetic fields. These tests aim to evaluate the ability of equipment to operate correctly even when exposed to interference from radiofrequency (RF) sources, such as radio transmitters, telecommunications, and industrial devices. The methodology for performing the test is structured in specific steps to ensure reproducibility and reliability of results[11].

The test must be conducted in a controlled environment, such as an anechoic or semi-anechoic chamber, to minimize reflections and external interference. In this environment, an RF signal generator connected to an amplifier is used to produce the required electromagnetic fields, a transmission antenna to radiate the field onto the equipment under test (EUT), and a measurement system to monitor the applied field using probes and receivers. The figure no 2 show the setup configuration for the test.

Figure no 2: IEC 61000-4-3 Setup of tests



The equipment under test must be installed according to its normal operating conditions, including power and communication connections, and positioned on a non-conductive table, typically 0.8 meters above the ground. If the equipment has different operating configurations, all of them must be evaluated. During the test, predefined parameters are used, such as the frequency range, which typically varies from 80 MHz to 1 GHz and can be extended to 6 GHz, the electric field intensity, usually between 1 V/m and 10 V/m, and in some critical applications, up to 30 V/m. The field can be modulated by a continuous wave (CW) or by a 1 kHz amplitude-modulated (AM) signal at 80%. The antenna must radiate the field in both horizontal and vertical polarizations, with a sweep across the entire frequency range at a specified rate, typically 1.5×10^{-3} decades per second.

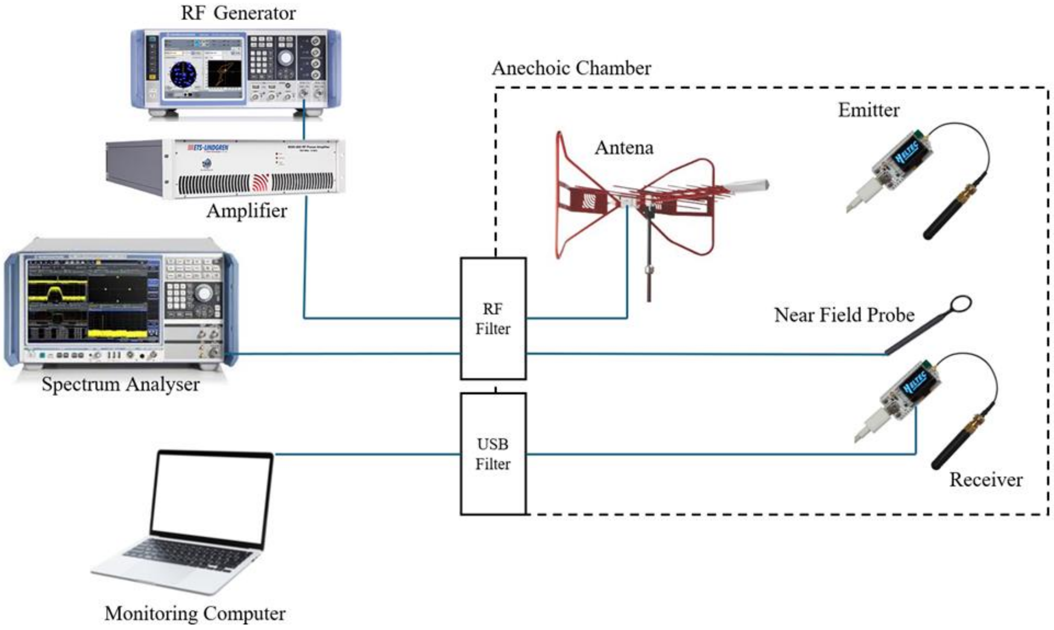
The test execution begins with the calibration of the electric field. A field sensor is positioned in the test area to measure and adjust the intensity of the field generated by the antenna, ensuring it meets the standard's requirements. Next, the EUT is exposed to the electromagnetic field at different frequencies and polarizations, being continuously monitored to identify possible failures, interruptions, or performance degradations. During the test, all exposure conditions, such as frequency, field intensity, and EUT configuration, are recorded, and any observed failures are documented for analysis.

The acceptance criteria defined by the standard include three classifications. Criterion A requires the EUT to continue operating without any loss of performance or functionality. Criterion B allows temporary degradations during the test, provided that the EUT recovers its functionality after the field is removed. Criterion C permits functionality loss during the test, as long as it can be restored through simple actions, such as restarting[12].

Setup of Lora immunity tests

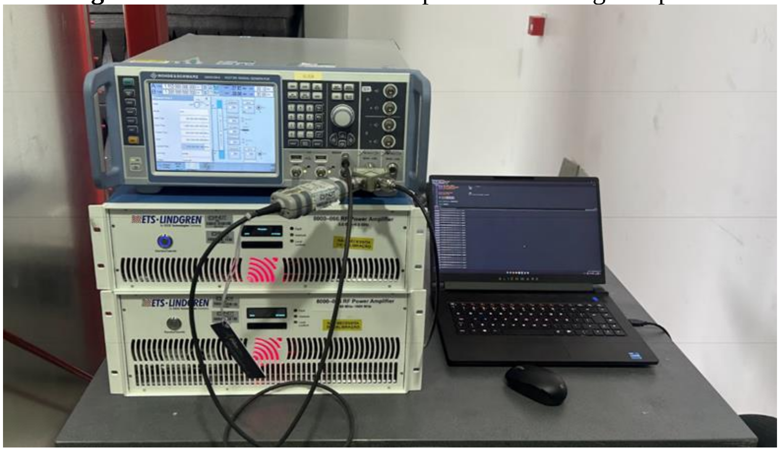
For the experiments, two Heltec boards were placed at a fixed distance of 2 meters inside the anechoic chamber, see the schematic in figure no 3, ensuring a controlled environment for the analyses. Prior to the tests, the communication via the LoRa protocol was pre-tested, ensuring the proper functioning of the devices and the integrity of the transmitted data. The monitoring of transmissions was performed using an FSW67 spectrum analyzer from Rohde & Schwarz. Inside the chamber, an electromagnetic field generator antenna was used to create a field with an intensity of 10 V/m, as required by the standard. The antenna was connected to a signal amplifier, which was powered by a signal generator responsible for performing a frequency sweep in the range of 80 MHz to 6 GHz, covering the band specified for the test. The field was calibrated beforehand to ensure uniformity in the test area, guaranteeing that the equipment under test was exposed to the exact conditions stipulated by the standard.

Figure no 3: Assembly diagram of the Lora protocol radiated electromagnetic immunity tests



During the test, the transmitter continuously sent LoRa messages, while the receiver recorded the RSSI values and packet reception rates. The exposure to the radiated electromagnetic field was performed for frequencies within the specified range, with the antenna in both horizontal and vertical polarizations. The receiver was connected to a monitoring system that recorded, in real-time, RSSI variations and possible packet losses during exposure. The figure no 4 showed the setup of standard and the monitoring computer to register the RSSI data.

Figure no 4: IEC 61000-4-3 setup and monitoring computer



The test aimed to evaluate the immunity of Heltec V2 boards in LoRa systems against radiated high-frequency electromagnetic fields, simulating conditions found in industrial environments. The data collected, such as RSSI variations and packet loss rates, enabled the determination of the communication's robustness and reliability in scenarios with high electromagnetic interference, providing insights for improving electromagnetic compatibility in IoT and Industry 4.0 applications.

III. Result

During the electromagnetic compatibility test, it was observed that communication between the devices experienced critical disruptions at two specific frequency levels: 305 MHz and 730 MHz, with a radiated signal power of 1.5 dBm. At these frequencies, the LoRa protocol demonstrated irregularities in communication, characterized by intermittent packet loss and degradation in transmission performance. When the radiated signal power was increased to 3 dBm, total communication failure occurred, indicating that the system was unable to maintain connectivity under these conditions. The loss of communication at these frequencies can be explained by several factors related to electromagnetic interference and the intrinsic susceptibility of the LoRa system. First, these frequencies may coincide with specific resonances in the internal circuits of the modules used, such as in RF amplifiers or filters, which could amplify the impact of the interference generated by the radiated electromagnetic field. Such resonance can cause saturation of the reception circuits or distortion of the received signals, rendering them unreadable by the protocol. Additionally, LoRa uses chirp spread spectrum modulation, designed to be robust against interference. However, interference at specific frequencies may align with harmonics of the LoRa signal or with the spectrum used for communication, reducing the receiver’s ability to distinguish the useful signal from background noise. In particular, the frequencies 305 MHz and 730 MHz might fall within the passband of the LoRa module’s internal components, resulting in greater coupling of interference with the useful signal.

Figure no 5: LoRa RSSI Variation During Radiated Electromagnetic Immunity Test

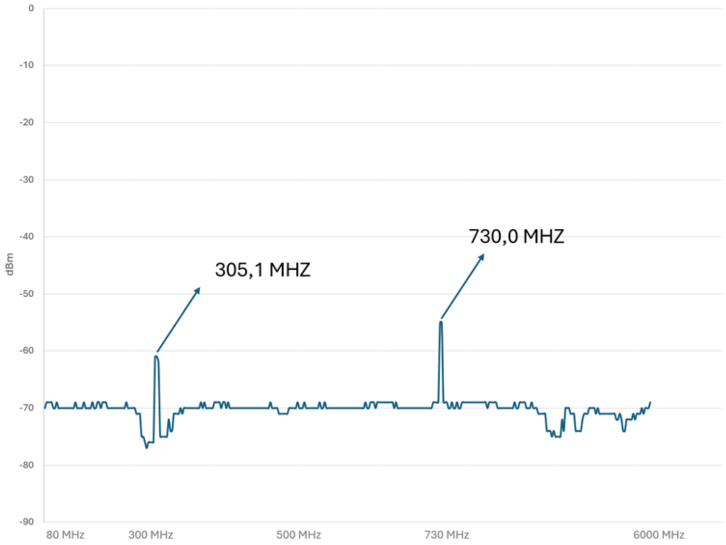


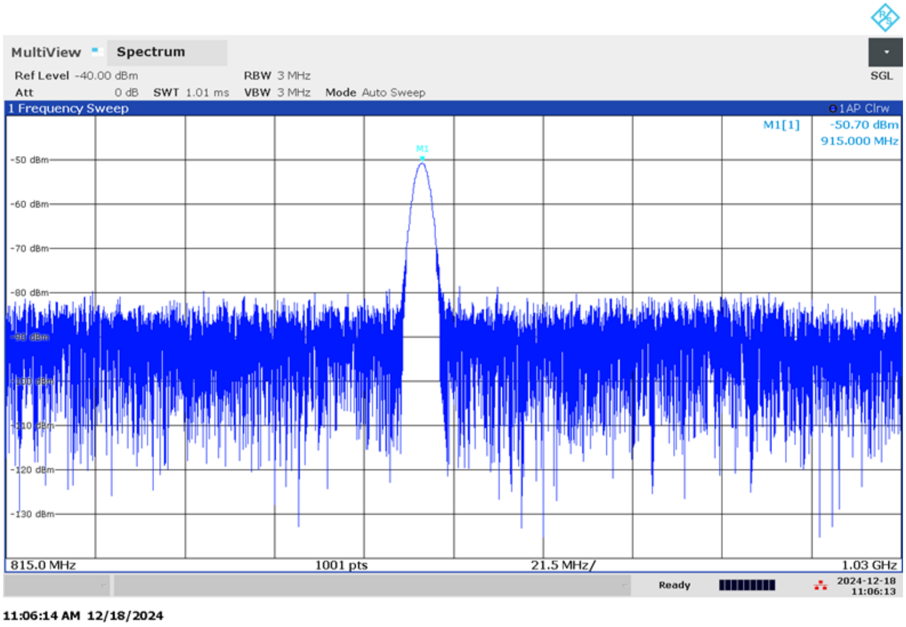
Figure 5 presents the variation in RSSI values observed during the radiated electromagnetic immunity test, conducted across the frequency range of 80 MHz to 6 GHz. The fluctuations in RSSI values reflect the impact of electromagnetic interference signals introduced at different frequencies and field strengths during the test. These variations provide insights into the susceptibility of the LoRa communication system to external electromagnetic disturbances, highlighting specific frequency ranges where the signal strength was most affected. Such data is crucial for evaluating the robustness and reliability of LoRa-based systems in environments prone to high levels of electromagnetic interference. Another relevant factor is the impact of the intensity of the radiated field. At 1.5 dBm, the system experienced partial degradation, possibly because the receiver could still process some of the useful signals despite the increased noise. However, at 3 dBm, the electromagnetic field became sufficiently intense to saturate the receiver's input circuits, leading to complete signal loss. This behavior indicates that the filtering or shielding of the LoRa module against external interference is inadequate under extreme conditions.

These results highlight the vulnerability of the LoRa system when subjected to radiated electromagnetic fields at specific frequencies and power levels above certain thresholds. This susceptibility underscores the need for mitigation strategies, such as the use of more efficient filters, enhanced electromagnetic shielding of the modules, and adjustments to the protocol's error correction algorithm. Additionally, the analysis emphasizes the importance of understanding the behavior of internal resonances and system harmonics to improve its robustness in critical applications, such as in industrial environments exposed to high levels of electromagnetic interference.

IV. Discussion

During the test, it was observed that when communication between the devices was interrupted, the transmission signal at 915 MHz remained consistent, indicating that the transmitter continued to send packets at regular intervals. However, upon monitoring the receiver, it was noted that no messages were successfully received during the communication exchange between the transmitter and the receiver. The monitoring was conducted using an FSW67, in figure 6, spectrum analyzer equipped with a near-field probe, providing detailed insights into the transmitted signal and its stability during the interruption.

Figure no 6: Static LoRa signal at 915 MHz during communication interruption


Ref Level -40.00 dBm
Att 0 dB
SWT 1.01 ms
RBW 3 MHz
VBW 3 MHz
Mode Auto Sweep
M1[1] -50.70 dBm 915.000 MHz
815.0 MHz
1001 pts
21.5 MHz/
1.03 GHz
Ready
2024-12-18 11:06:13
11:06:14 AM 12/18/2024

This behavior suggests that the communication disruption did not occur during the signal transmission process but likely at the reception or processing stage of the receiver. This may have been caused by the saturation of the receiver's input circuits due to the radiated electromagnetic field, resulting in its inability to decode the transmitted packets. Additionally, the LoRa protocol, although robust against interference, may have been directly impacted by the interference frequencies at 305 MHz and 730 MHz, which could have generated significant noise or distortion in the received spectrum. This phenomenon also points to a potential failure in the receiver's electromagnetic shielding or filtering, unable to isolate useful signals from the noise generated by the radiated field. The continuity of the static signal at 915 MHz reinforces that the issue lies not in the interruption of transmission but in the degradation of the reception and processing conditions of the receiver, leading to total communication loss.

V. Conclusion

Therefore, this study concludes that when subjected to radiated electromagnetic fields at frequencies of 305 MHz and 705 MHz, with a power of 1.5 dBm, the LoRa protocol exhibits instability, evidenced by packet loss and degradation in communication performance. Under these conditions, communication between two devices may fail, compromising the system's reliability. These results highlight the protocol's vulnerability to specific interference frequencies and emphasize the importance of mitigation strategies to ensure robustness in environments exposed to high levels of electromagnetic interference.

In the industrial context, these findings are particularly relevant, as systems based on the LoRa protocol are widely used in critical applications such as remote monitoring, predictive maintenance, and process automation. Ensuring communication reliability in these scenarios is essential to prevent operational failures, service disruptions, and potential financial losses. Thus, this study contributes to the development of more robust solutions adapted to challenging industrial environments, promoting greater safety and efficiency in industrial processes.

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