CubeSat Remote Data Collection & Communicaton

by Shawez shaikh

Submission date: 15-May-2025 05:33PM (UTC+0530)
Submission ID: 2676547618
File name: major_project__Copy__karan-3.pdf (6.07M)
Word count: 4353
Character count: 27131

Main Project Stage - I
VI^{th} **Semester**
Report

CubeSat Remote Data Collection & Communicaton

Submitted in partial fulfillment of
the requirements of the term work for subject Main Project Stage -I

Submitted by

Enrollment No.	Names of Students
2021200082	Mr. Karan Panikatti
2022200104	Mr. Shawez Shaikh

Under the guidance of
Dr. Inderkumar M. Kochar and Prof Govind Haldankar

Department of Electronics and Telecommunication Engineering
Bharatiya Vidya Bhavan's
Sardar Patel Institute of Technology
Munshi Nagar, Andheri(W), Mumbai-400058
University of Mumbai

Academic Year 2025 - 26

CERTIFICATE

This is to certify that the dissertation entitled **"CubeSat Remote Data Collection & Communicaton "** has been partially completed successfully by **Mr. Shawez Shaikh and Mr. Karan Panikatti** under the guidance of **Dr. Inderkumar M. Kochar and Govind Haldankar** for the award of Degree of **Bachelor of Technology** in **Electronics & Telecommunication Engineering** from **University of Mumbai**.

Certified by

Dr. Inderkumar M. Kochar	**Prof Govind Haldankar**
Project Guide	**Project Co-Guide**

Dr. Reena Sonkusare
Head of Department

Department of Electronics & Telecommunication Engineering
Sardar Patel Institute of Technology
Munshi Nagar, Andheri(W), Mumbai-400058
UNIVERSITY OF MUMBAI
2025-2026

CERTIFICATE

This is to certify that this is a true record of the project presented by the students whose names are given below during Semester VI in partial fulfillment of the requirements of the Bachelor of Engineering degree in Electronics and Telecommunication Engineering.

Roll No	Names of Students
2022200104	Shawez Shaikh
2021200082	Karan Panikatti

External Examiner | **Internal Examiner**

(signature) | **(signature)**

Name: | **Name:**

Date: | **Date:**

Seal of the Institute

Abstract

This project explores the use of CubeSat technology for remote data collection and communication. CubeSats are small, low-cost satellites that can be launched into low Earth orbit to perform various space-based tasks. Their compact size and modular design make them ideal for research, environmental monitoring, and communication in areas where traditional infrastructure is unavailable.

The system developed in this project is designed to collect data from remote sensors and transmit it to a ground station using wireless communication. Key components include power systems, onboard processors, sensors, and communication modules that work together to ensure reliable data acquisition and transmission. The project also considers the use of UHF/VHF or S-band frequencies for effective communication with the ground station.

This CubeSat-based approach offers a scalable and efficient solution for accessing data from hard-to-reach locations. It has potential applications in disaster management, climate monitoring, and scientific research. By demonstrating a working model, the project highlights the growing role of small satellites in advancing remote sensing and communication technologies.

Acknowledgement

We would like to express our sincere gratitude to all those who supported and contributed to the successful completion of our project titled *"CubeSat Remote Data Collection & Communication."*

First and foremost, we are deeply grateful to our project guides, **Dr. Inderkumar M. Kochar** and **Prof. Govind Haldankar** for their invaluable guidance, insightful suggestions, and constant encouragement throughout this journey. His expertise and mentorship have played a crucial role in shaping the direction and execution of our project, and we are truly grateful for his unwavering support.

We also extend our heartfelt thanks to the faculty members of the **Sardar Patel Institute of Technology**, whose teachings and support have laid a solid academic foundation for our work. Their commitment to excellence in education has greatly enriched our understanding of satellite communication systems and space-based data collection technologies.

The authors express sincere appreciation to the researchers and authors whose work formed the basis of our review of the literature. Their pioneering studies in CubeSat technology, remote sensing, and satellite-based communication provided essential insights that guided the development of our project.

We also thank all those who contributed during the testing and evaluation phases of the project. Their feedback and practical inputs helped us refine the system for better performance and real-world applicability.

Lastly, we thank all the individuals, friends, peers and family, who supported us directly or indirectly throughout the course of this project. Your encouragement and assistance have been instrumental in helping us achieve our goals.

Thank you for being part of this journey.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Remote data collection and communication are essential for monitoring environmental conditions, supporting disaster response, and enabling scientific research in areas where traditional infrastructure is limited or non-existent. Conventional ground-based systems and manned missions often face challenges such as high costs, limited coverage, and operational risks in remote or inaccessible regions. The emergence of CubeSat technology offers a compact, cost-effective, and scalable solution to overcome these limitations, opening new possibilities for global data acquisition and low-latency communication.

This project focuses on the design, development, and evaluation of a **CubeSat-based system for remote data collection and communication**. The proposed system utilizes a CubeSat deployed in low Earth orbit (LEO) to collect data from remote sensors placed on Earthâs surface and transmit it back to a designated ground station. The CubeSat is equipped with onboard computing, storage, a power system, and a communication module designed to handle data packets efficiently in resource-constrained environments.

The project explores three key architectural components critical to system performance:

1. **Sensor Integration & Uplink Protocols**, for collecting environmental or situational data and transmitting it to the CubeSat in orbit.
2. **Onboard Processing & Storage**, enabling real-time data handling, compression, and temporary storage during orbit cycles.
3. **Downlink Communication Systems**, using UHF/VHF or S-band frequencies to relay collected data to the ground station reliably.

Each subsystem is evaluated in terms of efficiency, accuracy, power consumption, and communication latency. A significant focus is also placed on optimizing orbital parameters and ground station alignment to ensure reliable data transmission and maximum coverage for remote regions.

The system developed through this project offers a range of benefits, including cost-effective deployment, scalability across various monitoring applications, and the ability to operate in harsh or inaccessible conditions. By demonstrating the practicality of CubeSat-based remote communication, this project contributes to the growing field of space-based IoT systems and provides a foundation for future innovations in Earth observation, environmental monitoring, and emergency response.

Through this work, we aim to validate the potential of CubeSats as a robust platform for autonomous, global-scale data collection and to illustrate their transformative impact on communication infrastructure in the age of space-based technologies.

Chapter 2

Literature Review

The table shown below is the literature survey of the research papers to which we have referred during our research.

Table 2.1: Summary of Research Papers on Directional Antennas

Paper Title & Year	**Literature Review (Findings)**	**Identified Research Gap**
A Wideband Directional Antenna Based on Hybrid Mode Dipole (2023)	Proposes a hybrid mode dipole design for wideband applications; improved radiation efficiency	Limited real-world testing of hybrid mode dipole antennas for different applications
Directional Antenna Systems for Through-Wall Human Activity Recognition (2023)	Examines 2.4 GHz directional antennas for long-range human activity recognition through walls	Need for optimization of directional antennas for improved accuracy in human activity recognition
Directional Antennas Modeling and Coverage Analysis of UAV Networks (2022)	Studies UAV network coverage using directional antennas; reduces interference and improves connectivity	Lack of standardization in UAV network antenna design for scalability
Compact Planar Yagi-Uda Antenna with Improved Characteristics (2017)	Traditional Yagi-Uda antennas were bulky; planar versions improved weight and integration. Various feed structures enhanced bandwidth but increased size or complexity. Compact designs often sacrificed gain, bandwidth, or F/B ratio	Need for a compact Yagi-Uda design with optimized bandwidth, gain, and F/B ratio. Existing solutions either require large ground planes or suffer from trade-offs in performance

2.1 Technical Gap

Although CubeSats have proven valuable for low-cost space missions, their use in real-time remote data collection and communication remains underdeveloped. Most current systems focus on Earth observation rather than integrating with ground-based sensor networks for continuous data exchange.

2.1.1 Communication Challenges

Challenges such as limited bandwidth, high communication latency, and restricted onboard processing capabilities hinder efficient and reliable data transmission. The bandwidth restrictions of CubeSat downlinks, typically ranging from 9.6 kbps to 1 Mbps, severely restrict real-time data applications, especially when handling multiple sensor inputs simultaneously. This limitation becomes particularly pronounced during critical monitoring scenarios that require immediate response.

Additionally, transmission latency, which can range from seconds to minutes depending on orbital parameters and ground station availability, creates significant obstacles for time-sensitive applications such as disaster monitoring or emergency response systems. The miniaturized hardware constraints of CubeSats further complicate these issues, as their limited power budgets (typically 1-10W) and computational resources cannot support sophisticated data processing algorithms that would otherwise mitigate these communication bottlenecks.

2.1.2 Protocol and Standardization Issues

The lack of standardized communication protocols between CubeSats and terrestrial sensors further limits their potential in autonomous, large-scale monitoring applications. While terrestrial IoT networks have established standards such as LoRaWAN, Zigbee, and NB-IoT, CubeSat compatibility with these protocols remains fragmented and poorly defined. This incompatibility creates integration difficulties when attempting to create unified space-ground sensor networks and often requires custom-designed interface solutions that increase system complexity and development costs.

2.1.3 Operational Synchronization Problems

Moreover, synchronization between CubeSat passes and ground station availability is not always optimal, often resulting in data delays or losses. Low Earth Orbit (LEO) CubeSats typically provide only 5-15 minutes of coverage per pass over a given location, with revisit times ranging from 12-24 hours depending on constellation design. This intermittent visibility creates fundamental challenges in maintaining continuous data flows, particularly for applications requiring regular monitoring intervals.

Current data handling approaches rely heavily on store-and-forward mechanisms that accumulate data between passes, often leading to information bottlenecks and increased risk of data loss due to onboard storage limitations (typically 1-4 GB on standard CubeSat platforms). During peak data collection periods, these limitations can result in prioritization challenges where critical information may be delayed or displaced by lower-priority data.

2.1.4 Needed Improvements

These limitations highlight the need for improved system design that ensures timely, secure, and energy-efficient communication between CubeSats and distributed ground sensors. Future architectures must address these constraints through innovative approaches such as:

- Adaptive communication protocols that dynamically adjust to available bandwidth and connection quality.
- Edge computing capabilities that reduce transmission volume through onboard data processing.
- Cross-platform standardization efforts to ensure seamless integration between space and terrestrial systems.
- Enhanced security mechanisms designed specifically for the unique constraints of CubeSat-ground communications.
- Optimized power management systems that maximize communication windows while ensuring mission longevity.

Addressing these technical gaps would significantly enhance the utility of CubeSats as integral components of global sensing infrastructures, enabling new applications in environmental monitoring, disaster response, agricultural management, and remote infrastructure supervision.

Table 2.2: Summary of Research Papers on LoRa Modules

Paper Title & Year	**Literature Review (Findings)**	**Identified Research Gap**
Performance Analysis of LoRa Modulation for IoT Applications (2022)	Demonstrates LoRa's superior range (up to 15km) and low power consumption compared to other LPWAN technologies. Chirp spread spectrum modulation provides resilience against interference and multipath fading	Limited evaluation in dense urban environments where signal obstacles affect performance. Need for optimized parameters based on specific deployment scenarios
Energy-Efficient LoRa Network Planning for IoT Applications (2023)	Proposes optimization algorithms for LoRa gateway placement, reducing power consumption by 35% while maintaining coverage. Adaptive data rate mechanisms extend battery life of end devices	Lack of real-world validation across diverse geographic and climate conditions. Insufficient testing of energy efficiency during peak network loads
Security Vulnerabilities in LoRaWAN Implementations (2021)	Identifies critical security weaknesses in LoRaWAN protocol implementations including key management vulnerabilities, potential replay attacks, and join procedure weaknesses	Need for standardized security testing frameworks specific to LoRa deployments. Gaps in lightweight encryption solutions suitable for constrained LoRa devices
Integration of LoRa Technology for Smart Agriculture Systems (2023)	Demonstrates successful deployment of LoRa networks for crop monitoring, irrigation control, and livestock tracking. Shows 30% reduction in water usage and improved crop yields through precise sensor data	Limited investigation of LoRa's reliability under extreme weather conditions. Need for specialized antenna designs to enhance signal propagation in dense vegetation environments

2.2 Problem Statement

Monitoring temperature and humidity in crowded areas is essential for public health and safety. Traditional fixed sensor systems are often limited in coverage and flexibility, making them inefficient for dynamic, densely populated environments, especially during events or in rapidly changing conditions.

A mobile solution, such as a drone-based monitoring system, can overcome these limitations by providing real-time data collection across large or congested areas. However, current UAV systems often face challenges in continuous monitoring and data transmission due to power and communication constraints.

This project aims to develop a drone-based system using an ESP32 microcontroller and environmental sensors to monitor temperature and humidity. The data will be transmitted via LoRA communication to a ground station for real-time analysis, offering a more flexible and scalable solution for environmental monitoring in crowded, dynamic environments.

2.3 Project Objectives

Real-time monitoring of environmental conditions like temperature and humidity in crowded areas is essential for public safety and comfort. Traditional fixed sensor systems are often inadequate for large or dynamic environments. This project aims to develop a **drone-based monitoring system** using an ESP32 microcontroller and environmental sensors, coupled with LoRA communication for real-time data transmission to a ground station. The system will provide a flexible, scalable solution for monitoring environmental conditions in urban and densely populated areas.

1. **Design and Develop a Drone-based Monitoring System**: To design a drone equipped with an ESP32 microcontroller and sensors for monitoring temperature and humidity in crowded, dynamic environments.

2. **Integrate LoRA Communication for Data Transmission**: To incorporate a LoRA communication module for reliable, low-power, real-time data transmission from the drone to a ground station.

3. **Develop Real-Time Data Processing at Ground Station**: To build a ground station capable of receiving, processing, and visualizing real-time data on temperature and humidity from the drone.

4. **Optimize Power Consumption and Efficiency**: To ensure that the drone system operates efficiently by minimizing power usage while maintaining stable sensor performance and communication.

5. **Enhance Data Accuracy and Reliability**: To ensure that the environmental data collected by the sensors is accurate, reliable, and transmitted without errors, even in challenging environments.

6. **Evaluate System Performance in Real-World Conditions**: To assess the drone systemâs effectiveness in different real-world environments, including urban and crowded areas, measuring data accuracy, communication stability, and overall functionality.

7. **Test and Improve System Scalability**: To test the scalability of the system, ensuring that the drone-based monitoring solution can handle multiple drones or expanded sensor coverage if needed for larger or more complex environments.

Chapter 3

Cansat Telemetry

3.1 CubeSats in Remote Data Collection

CubeSats are small, cost-effective satellites that are used for Earth observation, communication, and scientific research. Their compact size allows for large-scale deployment, making them ideal for remote data collection in areas where traditional satellites are impractical. CubeSats provide continuous monitoring, high-resolution data, and access to difficult to reach environments, making them suitable for applications in climate research, agriculture, and disaster management. With advanced sensors and communication modules, they can efficiently capture and transmit vital data for analysis.

3.1.1 Key Features of CubeSat Remote Data Collection Systems

- **Autonomous Operation**: CubeSats operate autonomously, managing their systems without constant human intervention. This ensures continuous data collection and transmission, even when ground control is unavailable.

- **Miniaturization and Cost-Effectiveness**: The compact, modular design of CubeSats makes them affordable compared to traditional satellites, offering tailored solutions for specific tasks and reducing development and operational costs.

- **Scalability**: CubeSats can be deployed in constellations, providing broader coverage, redundancy, and enhanced communication, making them ideal for large-scale monitoring like weather observation or disaster management.

3.2 Control Models for CubeSats in Remote Data Collection

Efficient management of drone operations and environmental data is essential for the reliability of the system. The drone uses an ESP32 microcontroller to handle sensor input and ensure that only relevant temperature and humidity data is processed and transmitted. This minimizes bandwidth usage and allows for faster, more efficient communication.

- **Onboard Processing**: The ESP32 performs preliminary analysis and filters out sensor noise, sending only useful data to the ground station. This reduces communication load and supports quicker decision-making.

- **LoRA Communication**: LoRA enables low-power, long-range communication between the drone and the ground station. Itâs well-suited for crowded areas, providing stable data transfer despite potential interference.
- **Ground Station Integration**: The ground station collects and processes incoming data in real time, helping operators monitor environmental conditions, generate reports, and make informed decisions. Advanced software tools can be used for trend detection and early warnings.

3.2.1 Applications of Temperature and Humidity Monitoring

This system offers wide-ranging benefits across various fields:

- **Urban Monitoring**: Helps track microclimate conditions for pollution control and smart city planning.
- **Disaster Response**: Rapid environmental assessments improve emergency coordination and safety.
- **Agriculture**: Enables farmers to monitor conditions and optimize irrigation and crop yield.
- **Event Management**: Enhances safety at large public gatherings by monitoring heat and humidity levels.

3.2.2 Challenges and Considerations

- **Communication Reliability**: LoRA performs well in long ranges, but interference in crowded environments may still affect data transmission.
- **Power Efficiency**: Battery life is a limiting factor; efficient energy use is vital for extended operations.
- **Sensor Accuracy**: Calibration is necessary to maintain data precision under changing environmental conditions.
- **Crowded Navigation**: Safe drone operation in populated areas requires robust obstacle detection and controlled flight paths.

3.3 Methedology

The block diagram illustrates a wireless communication system consisting of two interconnected nodes based on ARM Cortex M4 microcontrollers. Node 1 integrates sensors, a monopole antenna, and the ARM Cortex M4 processor. The sensors collect environmental or physical data, which is processed by the microcontroller. The processed data is then transmitted to Node 2 either through radio waves using the monopole antenna or via a serial USB connection. Node 2 also includes an ARM Cortex M4, a monopole antenna for wireless reception, and a USB interface that connects to a laptop. The microcontroller in Node 2 processes the received data and forwards it to the laptop for visualization, logging, or further analysis. This block diagram represents a typical IoT or wireless sensor network (WSN) setup, where low-power microcontrollers and flexible communication methods are used for efficient remote data acquisition and monitoring.

Chapter 4

System Design

4.1 Block Diagram

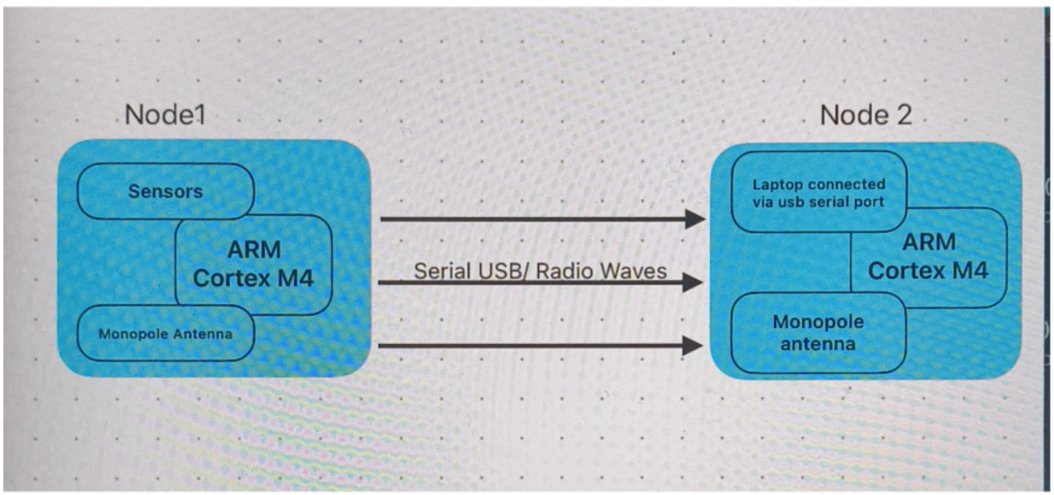

Figure 4.1: Block diagram of Experimental setup using Arm M4 core and communication between nodes using RF signals

- The Block Diagram illustrates a wireless sensor communication system involving two nodes, each built around an ARM Cortex M4 microcontroller. Node 1 serves as the transmitting unit and is equipped with sensors to collect environmental or physical data. This data is processed by the ARM Cortex M4, which is well-suited for real-time embedded processing tasks. The processed information is then transmitted either through a monopole antenna using radio waves or via a serial USB connection, offering flexibility in communication methods.
  Node 2 functions as the receiving unit and also houses an ARM Cortex M4 microcontroller, along with a monopole antenna to receive the radio signals sent from Node 1. Additionally, Node 2 is connected to a laptop through a USB serial port, enabling the visualization, logging, or further processing of the received sensor data. The entire setup demonstrates a typical architecture used in wireless sensor networks (WSNs) or IoT-based data acquisition systems,

where low-power microcontrollers and wireless modules are used to gather and transmit data from remote locations to a central system.
This system can be utilized in various real-world applications such as environmental monitoring, industrial automation, or smart agriculture, where sensor data needs to be collected from different locations and transmitted wirelessly to a control center or database. The use of monopole antennas makes the hardware simple and cost-effective, while the inclusion of USB connectivity ensures easy debugging and development during the prototyping phase. Overall, the design showcases a balanced approach between wireless communication and embedded data processing.

4.2 Flowchart

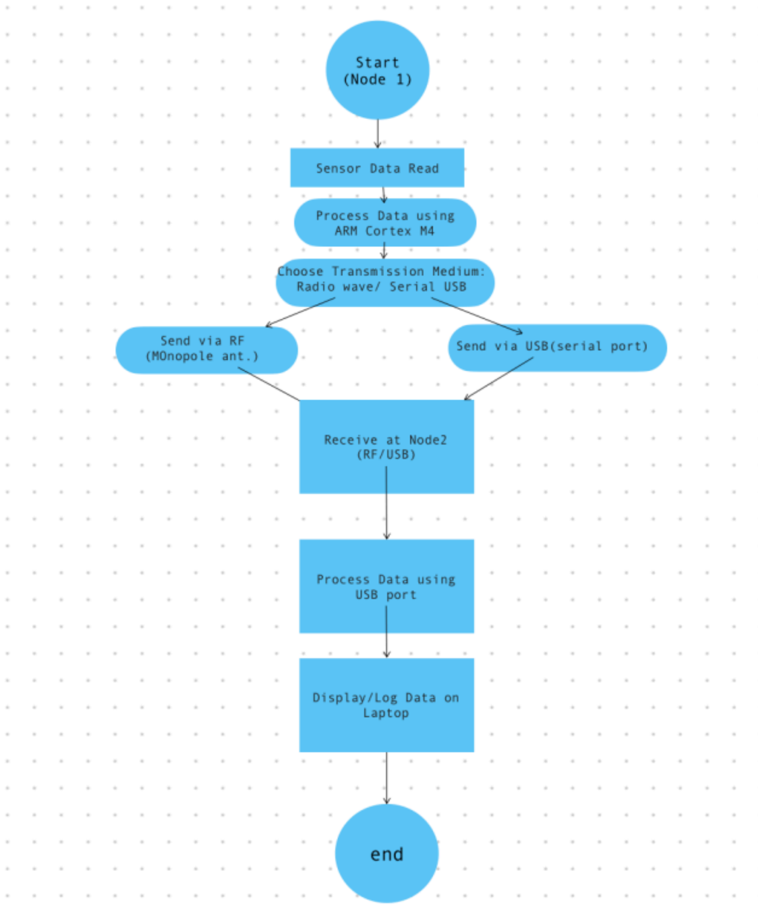

Figure 4.2: Flow Diagram telemetry using LoRa- Protocol

The block diagram illustrates a wireless communication system consisting of two interconnected nodes based on ARM Cortex M4 microcontrollers. Node 1 integrates sensors, a monopole antenna, and the ARM Cortex M4 processor. The sensors collect environmental or physical data, which is processed by the microcontroller. The processed data is then transmitted to Node 2 either through radio waves using the monopole antenna or via a serial USB connection. Node 2 also includes an ARM Cortex M4, a monopole antenna for wireless reception, and a USB interface that connects to a laptop. The microcontroller in Node 2 processes the received data and forwards it to the laptop for visualization, logging, or further analysis. This block diagram represents a typical IoT or wireless sensor network (WSN) setup, where low-power microcontrollers and flexible communication methods are used for efficient remote data acquisition and monitoring.

Chapter 5

Results & Discussion

5.1 Results of Simulation

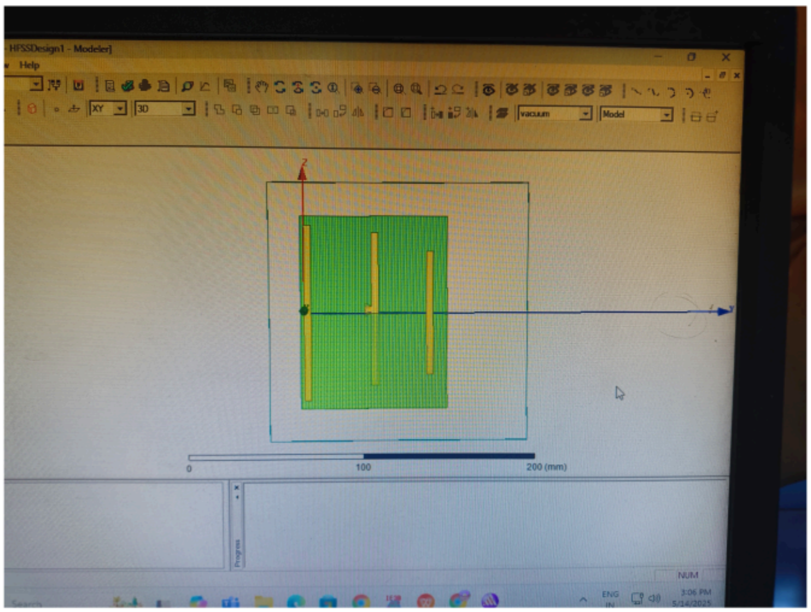

Figure 5.1: Dual Compact Yagi-Huda antenna model

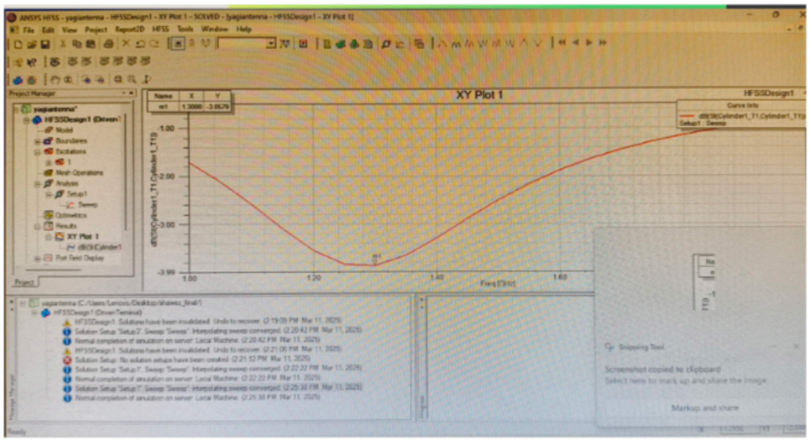

Figure 5.2: S11 of designed Antenna model

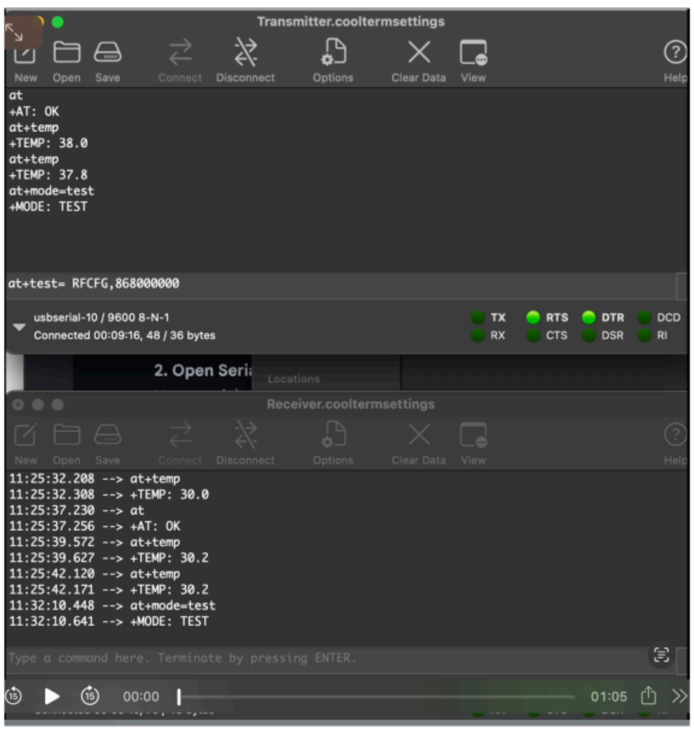

Figure 5.3: AT command running on terminal sensing temperature

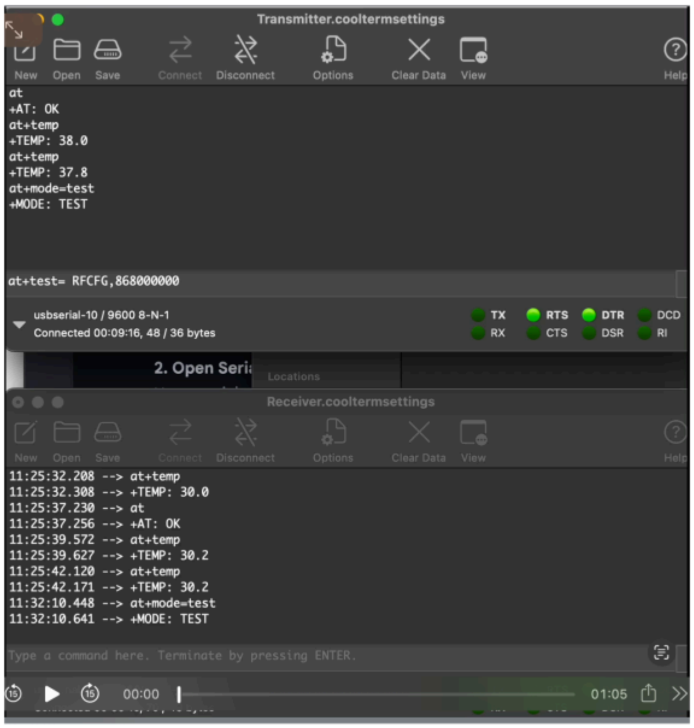

Figure 5.4: AT command running on terminal sensing temperature

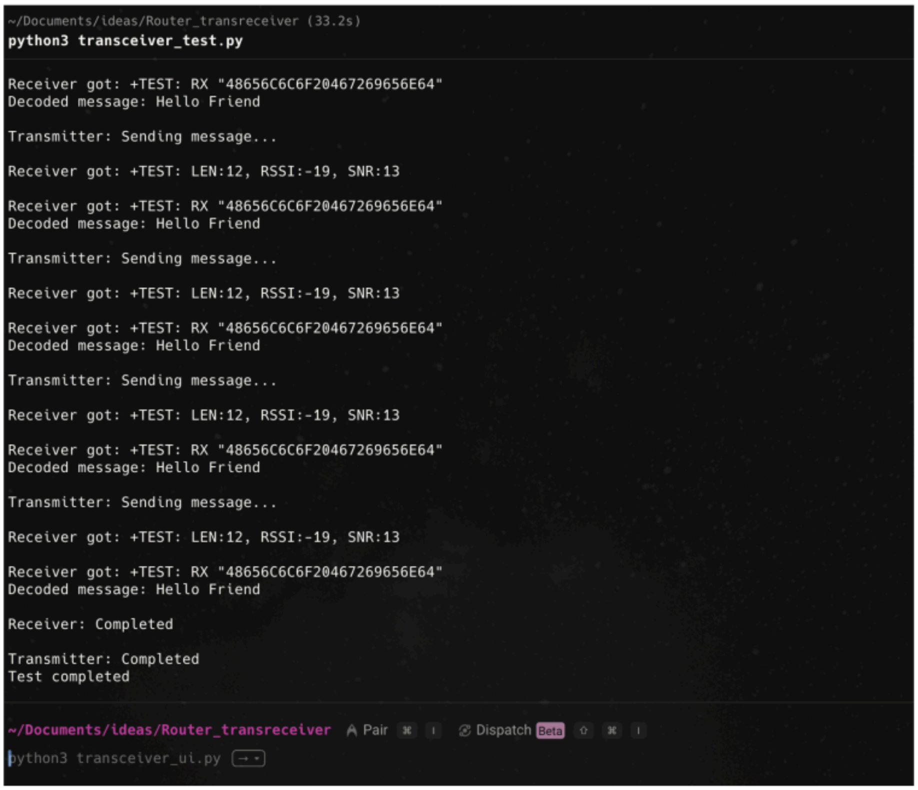

Figure 5.5: Flow Diagram telemetry using LoRa- Protocol

Chapter 6

Conclusions

The project successfully established a basic LoRa-based wireless communication link between two Wio-E5 modules using AT commands, demonstrating reliable telemetry for sending and receiving text data. We also implemented temperature sensing and message reception using AT command-based control. Initially, we designed a compact dual Yagi-Uda antenna for 1.33â¯GHz operation intended for ground station use; however, due to practical considerations, a monopole antenna was later adopted. While the current setup validates fundamental communication and sensing capabilities, key objectives such as implementing STM32 CLI for truly wireless control and designing a structured payload format remain as future development goals..

Chapter 7

Future Scope

To make it truly wireless communication setup. Our future goals focus on advancing the current LoRa-based communication system by integrating more sophisticated and autonomous features. We aim to establish truly wireless communication by utilizing the STM32 Command Line Interface (CLI), removing the dependency on serial terminal applications. Another key objective is to leverage the inbuilt sensors of the development boards to automatically collect and transmit data via the LoRa protocol. Additionally, we plan to optimize transmission and reception by improving parameters such as latency, Received Signal Strength Indicator (RSSI), and Signal-to-Noise Ratio (SNR). We also intend to further explore the capabilities of the Wio-E5 development kit to support more complex telemetry functions. Finally, we will design a structured and efficient payload format to ensure reliable and scalable data communication.

Bibliography

[1] S. H. P. Peesapaty, A. Mallik, A. Naik, R. Bhadade and S. Jadhav, "Zigbee Communication Protocol for Cansat Telemetry and Control," 2024 Second International Conference on Emerging Trends in Information Technology and Engineering (ICETITE), Vellore, India, 2024, pp. 1-6, doi: 10.1109/ic-ETITE58242.2024.10493250. keywords: Wireless communication;Wireless sensor networks;Protocols;Microcontrollers;Transmitters;Zigbee;Small satellites;Wireless Sensor Network;Zigbee Protocol;Wireless Communication;Small Scale Applications;Xbee,

[2] Z. Yuping, Y. Xiaoling and L. Chen, "Research of the Emergency Communication System in Coal Mine Based on ZigBee Technology," 2015 Seventh International Conference on Advanced Communication and Networking (ACN), Kota Kinabalu, Malaysia, 2015, pp. 60-63, doi: 10.1109/ACN.2015.20. keywords: Zigbee;Wireless communication;Coal mining;Wireless sensor networks;Fuel processing industries;Ad hoc networks;wireless communication in coal mine;emergency communication system;ZigBee technology,

[3] A. Zeedan and T. Khattab, "CubeSat Communication Subsystems: A Review of On-Board Transceiver Architectures, Protocols, and Performance," in IEEE Access, vol. 11, pp. 88161-88183, 2023, doi: 10.1109/ACCESS.2023.3304419. keywords: CubeSat;Transceivers;Baseband;Satellites;Costs;Field programmable gate arrays;Protocols;Low-power electronics;Small satellites;Baseband architectures;RF transceivers;communication protocols;low-power communications;SDR;FPGA;CubeSat;nanosatellites;low Earth orbit (LEO) satellites,

[4] T. Alam, M. Javed, A. R. Qureshi and A. A. M. Anik, "CanSat: Design, Development, and Deployment of Open-Source Weather Monitoring Nano-Satellite," 2024 4th International Conference on Digital Futures and Transformative Technologies (ICoDT2), Islamabad, Pakistan, 2024, pp. 1-8, doi: 10.1109/ICoDT262145.2024.10740189. keywords: Wireless communication;Radio frequency;Nanosensors;Satellite broadcasting;LoRa;Data visualization;Web pages;Streaming media;Reliability engineering;Real-time systems;LoRa (Long Range);CanSat;Nanosensors;Radio Frequency;Wireless Communication;Nano-Satellite Technology,

[5] R. M. Colombo, A. Mahmood, E. Sisinni, P. Ferrari, and M. Gidlund, "Low-cost SDR-based tool for evaluating LoRa satellite communications," in *Proceedings of the 2022 IEEE International Symposium on Measurements Networking (MN)*, Padua, Italy, Oct. 2022, pp. 20â26, doi: 10.1109/MN55117.2022.9887761.