Smart Waste Monitoring System in Hospitals Using LoRa-Based Self-Healing Mesh Network

Project Proposal

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1 Introduction

Hospitals generate diverse waste that requires efficient monitoring and management to ensure cleanliness, hygiene, and regulatory compliance. Manual waste bin monitoring is labor-intensive and prone to inefficiencies, potentially leading to overflow, cross-contamination, and increased infection risks. With the rise of smart infrastructure and IoT, automating waste monitoring using low-power, wireless technologies offers a sustainable solution. This project proposes a Smart Waste Monitoring System leveraging ESP32 microcontrollers, ultrasonic sensors, and LoRa-based mesh networking to create an energy-efficient, self-healing, real-time monitoring system tailored for hospital environments.

2 Aim

The aim of this project is to develop a LoRa-based, self-healing mesh network for hospital waste bins that:

- Accurately detects waste levels using ultrasonic sensors with a moving average algorithm.
- Minimizes energy usage via ESP32s deep sleep functionality and wake-up on IR-based external interrupts.
- Transmits data wirelessly to a central master node using a LoRa-based mesh network.
- Displays waste status centrally using an OLED interface.

3 Objectives

- Design end nodes using ESP32, ultrasonic sensors, and IR modules.
- Implement a moving average algorithm to improve waste detection accuracy.
- Establish a LoRa mesh network with star topology for data transmission.

- Enable self-healing communication for reliable data delivery even if nodes fail.
- Build a central master node to aggregate and display waste bin status on an OLED screen.
- Optimize the system for low power consumption, enabling battery-powered deployments.
- Lay the foundation for future updates like waste segregation detection, alert systems, or real-time dashboards.

4 Version Scope

4.1 Version 1.0 Scope

- Waste level detection via ultrasonic sensors.
- ESP32 as the primary controller for each dustbin node.
- Basic star topology LoRa mesh communication with master node.
- Data visualization on OLED display at the master.
- Initial deployment and testing with multiple dustbins in a controlled environment.

4.2 Version 2.0 Scope

Version 2 enhances the system to support multi-hop communication, better power optimization, and intelligent alerting. Key additions include:

- **True LoRa Mesh Topology**: Implement multi-hop routing where nodes relay data, enabling communication over larger hospital areas or low-signal zones.
- **Fault Tolerance & Self-Healing**: Nodes dynamically reroute data if intermediate nodes fail, with health status monitoring.
- **Smart Alert System**: Bins send alerts when 80% full, shown on OLED.
- **Basic Data Logging**: Master node stores recent data (e.g., last 10 readings per bin) with optional SD card or EEPROM integration.
- **Improved Power Management**: Adaptive wake-up based on historical fill patterns and dynamic LoRa transmission power optimization.
- **System Settings via Master**: Master node sends remote configuration commands (e.g., wake-up intervals, alert thresholds).

4.3 Final Version Scope (Production-Ready)

The final version is designed for real-world hospital deployment with cloud integration and analytics. Key features include:

- **Full-Scale LoRa Mesh with OTA Updates**: All nodes support over-the-air firmware updates and complete mesh routing with node discovery.
- **Cloud Integration**: Master node connects to Wi-Fi/Ethernet gateway for cloud data push (Firebase, AWS IoT, Blynk, or ThingsBoard).
- **Web & Mobile Dashboards**: Live bin location and fill status map, with admin panel for node management.
- **Smart Waste Pattern Analysis**: Optional ML models to forecast bin fill times and recommend collection schedules.
- **Security & Compliance**: Encrypted communication and audit logs for regulatory compliance.
- **Power Optimization**: Smart power profiling using temperature, usage, and day/night cycles, with solar or supercapacitor options.
- **Multimodal Alerts**: Email, SMS, and app notifications for critical conditions.
- **Maintenance Dashboard**: Predictive maintenance alerts and QR code scanning for manual inspection.

5 System Architecture

5.1 Hardware Components

- ESP32 (low-power microcontroller)
- HC-SR04 Ultrasonic Sensor (waste level detection)
- IR Proximity Sensor (external interrupt trigger)
- LoRa SX1278 Module (long-range wireless communication)
- OLED Display (data visualization at master node)
- Li-ion Battery (power source for nodes)
- Voltage Regulator Circuitry & Sleep Circuit

5.2 Software and Algorithms

- Firmware in Arduino/C++ for ESP32
- Moving Average Algorithm for smoothing sensor data
- Custom LoRa Mesh Stack with self-healing features
- Display UI logic for OLED using I2C

6 Methodology

1. **Node Initialization**: ESP32 remains in deep sleep to conserve energy, with IR sensor triggering wake-up on motion or periodic intervals.
2. **Waste Detection**: Ultrasonic sensor measures waste level, processed through a moving average filter for noise reduction.
3. **Data Transmission**: Waste level data sent via LoRa to the master node in star topology, with self-healing logic for future versions.
4. **Data Display**: Master node receives data and updates OLED screen with bin statuses.
5. **Power Management**: ESP32 returns to deep sleep after transmission.

7 Applications

- Waste management in hospitals, clinics, and pharmaceutical labs.
- Smart bins in airports, railways, or industrial areas.
- Any location requiring cleanliness, automation, and low-power IoT deployment.

8 Benefits

- **Energy Efficient**: Optimized for battery-powered environments using ESP32 deep sleep and selective wake-up.
- **Low Maintenance**: Automated monitoring reduces human intervention.
- **Scalable**: Extendable with more bins or integration into building management systems.
- **Reliable**: Mesh topology ensures data delivery despite node failures.
- **Cost-Effective**: Utilizes open-source hardware and protocols.

9 Future Enhancements

- Implement multi-hop mesh routing for improved network resilience.
- Add cloud integration for real-time dashboards and analytics.
- Introduce waste categorization (biomedical, recyclable, general).
- Include alert systems for overflow or full-bin conditions.
- Develop mobile app interface for remote monitoring.

10 Conclusion

This project proposes an intelligent, energy-efficient system for hospital waste monitoring using modern IoT technologies. With its self-healing mesh network, smart wake-up logic, and low-power design, the system is well-suited for real-world deployment. Version 1.0 lays the groundwork for a scalable, modular solution that can evolve with advanced features in future iterations.