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Cloud Controlled LoRaWAN Communication Smart Agriculture Gateway Load Regulation

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ABSTRACT

Agriculture remains the primary source of livelihood for a significant proportion of the population in developing countries, making the adoption of advanced technologies essential for achieving sustainable and productive farming practices. The integration of engineering innovations with Sustainable Development Goals (SDGs) supports precision agriculture through intelligent soil preparation, automated irrigation, crop nutrient monitoring, smart fertilizer application, and efficient multi-cropping strategies. This study proposes a low-power communication framework for smart agriculture by modelling distributed sensor nodes as a weighted network topology. Two routing approaches are evaluated: the conventional Flooding protocol and a LoRaWAN-based shortest-path routing mechanism implemented using Dijkstra’s algorithm. The comparative analysis focuses on key performance metrics, including communication latency, data accuracy, false alarm rate, and gateway load regulation. Experimental results demonstrate that the Flooding protocol suffers from excessive packet duplication, network congestion, increased hop count, and reduced communication efficiency. In contrast, the proposed LoRaWAN-based routing strategy identifies optimal transmission paths, minimizes communication distance, reduces latency, improves data delivery accuracy, and lowers the false alarm rate while maintaining balanced gateway utilization. The framework is implemented using Python, Flask for web-based interaction, NetworkX for network topology modelling, TinyDB for lightweight data storage, and Matplotlib for performance visualization. The findings confirm that intelligent shortest-path routing enhances communication reliability, scalability, and energy efficiency, providing a robust foundation for sustainable precision agriculture and next-generation smart farming applications.

Keywords: LoRaWAN, Smart Agriculture, Precision Agriculture, Internet of Things (IoT), Dijkstra's Algorithm, Wireless Sensor Networks.

1. INTRODUCTION

Agriculture continues to serve as one of the primary pillars of economic development in many developing countries, contributing substantially to Gross Domestic Product (GDP), employment generation, food security, and foreign exchange earnings despite the rapid expansion of industrial and manufacturing sectors [1]. A significant proportion of the global population relies directly or indirectly on agriculture for its livelihood, making the adoption of advanced technologies essential for improving productivity, sustainability, and efficient resource utilization. In recent years, the Internet of Things (IoT) has emerged as a transformative technology that enables seamless communication among interconnected devices through the internet. IoT-based solutions have been successfully deployed across various domains, including healthcare, industrial automation, smart homes, transportation, and precision agriculture, providing real-time monitoring, intelligent decision-making, and automated control. Within agriculture, IoT technologies enable continuous monitoring of critical

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environmental parameters such as soil moisture, temperature, humidity, soil pH, light intensity, and nutrient levels, allowing farmers to make timely and informed decisions that improve crop productivity and overall farm management.

Despite these technological advancements, farmers in many developing regions continue to face significant challenges in monitoring soil and environmental conditions due to the limited availability of laboratory facilities, high testing costs, long travel distances, and inadequate technical infrastructure [2]. Conventional methods of soil analysis and crop monitoring are often time-consuming, labor-intensive, and incapable of providing continuous field observations required for precision farming. IoT-enabled sensing systems overcome these limitations by integrating embedded sensors, intelligent controllers, and automated monitoring platforms that continuously collect, process, and transmit environmental data without requiring constant human intervention. These real-time monitoring capabilities support predictive analysis, early identification of unfavorable crop conditions, efficient resource allocation, and data-driven agricultural decision-making while remaining affordable and practical for small and medium-scale farmers.

Efficient irrigation management remains one of the most critical components of sustainable agriculture, as water is among the most valuable natural resources required for crop production [3]. Traditional irrigation practices frequently result in excessive water consumption due to inefficient distribution systems, leakage, seepage, and poor scheduling, particularly in developing countries where irrigation infrastructure remains outdated [4]. IoT-based automated irrigation systems address these challenges by utilizing intelligent sensors, Decision Support Systems (DSS), and automated controllers to continuously monitor field conditions and regulate water distribution according to real-time crop requirements. Although many existing smart agriculture solutions have demonstrated promising results, several rely on short-range communication technologies such as Wi-Fi and Bluetooth, which suffer from limited communication range, higher power consumption, and reduced reliability in large agricultural fields. These limitations become more pronounced in rural and geographically dispersed farming regions where internet connectivity is often unreliable. Therefore, the adoption of long-range, low-power communication technologies is becoming increasingly important for developing scalable, energy-efficient, and reliable smart agriculture systems capable of supporting continuous monitoring and precision farming applications [5].

2. LITERATURE SURVEY

Balaji, et al. [6] proposed a fuzzy logic-based smart agriculture framework for optimal crop selection by considering multiple environmental and agricultural parameters such as soil properties, climatic conditions, and resource availability. The proposed system effectively handled uncertain and imprecise agricultural data, enabling accurate crop recommendation while maximizing productivity and minimizing the utilization of land, water, and other farming resources. The study demonstrated that fuzzy logic significantly improves decision-making compared to conventional farming approaches by supporting efficient resource management and sustainable agricultural practices. Bockstaller, et al. [7] investigated various agricultural constraints and field parameters that directly influence crop productivity and farm performance. The study emphasized that continuous evaluation of soil conditions, environmental variables, and cultivation practices enables farmers to make informed decisions regarding crop management.

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Furthermore, the research highlighted the importance of Wireless Sensor Networks (WSNs) in smart agriculture, where distributed sensors continuously monitor field conditions and provide real-time information for precision farming. Sakthipriya, et al. [8] developed a smart farming system by integrating Internet of Things (IoT) technologies with automation and intelligent control mechanisms. The proposed framework incorporated sensors, controllers, actuators, Global Positioning System (GPS), and autonomous agricultural robots capable of performing farming operations such as seeding, irrigation, spraying, weed control, soil moisture monitoring, human detection, and remote field surveillance. The system demonstrated significant improvements in farming efficiency, precision, and reduction of manual labor.

Jawad, et al. [9] proposed a cloud-enabled smart agriculture framework that integrated sensing devices, cloud computing infrastructure, and GPS-based positioning systems to support intelligent farm management. The proposed architecture collected environmental information from field sensors and agricultural images, processed the data through cloud computing platforms, and delivered location-aware recommendations to farmers for effective crop management. The framework also incorporated an automated irrigation system based on real-time sensing information, thereby improving water utilization and operational efficiency. Rehman, et al. [10] developed an intelligent irrigation management system that minimized unnecessary water consumption by replacing conventional irrigation practices with automated water distribution techniques. The proposed system supplied irrigation only when environmental conditions required it, thereby conserving water resources, reducing wastage, and promoting sustainable farming practices. Gutiérrez, et al. [11] proposed a low-cost Wireless Sensor Network (WSN) for continuous monitoring of soil temperature and moisture across multiple agricultural locations. The system enabled real-time collection of environmental data, allowing farmers to optimize irrigation scheduling, improve crop management decisions, and reduce operational costs through automated monitoring. Sarmadian, et al. [12] investigated the application of remote sensing technologies for crop estimation and cropland mapping. The study demonstrated that satellite imagery and remote sensing techniques provide accurate monitoring of agricultural fields, enabling efficient crop yield estimation, environmental monitoring, and precision farming through continuous observation of farmland conditions.

Sonka, et al. [13] emphasized the critical role of remote sensing technologies in agricultural monitoring by explaining that crop productivity depends on highly dynamic factors including soil characteristics, climatic conditions, environmental changes, and agricultural management practices. The study highlighted that accurate and timely monitoring is essential because crop conditions can change rapidly due to unfavorable weather conditions, making continuous observation necessary for effective agricultural planning and decision-making. Kim, et al. [14] reported that agricultural productivity has gradually declined due to environmental changes and increasing farming challenges. The study demonstrated that adopting intelligent agricultural technologies and modern farming innovations significantly improves crop production while reducing manual labor, operational costs, and human effort. Furthermore, the research emphasized that integrating advanced sensing technologies, automated monitoring systems, and data-driven decision support mechanisms provides practical solutions for enhancing

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agricultural productivity, supporting farmers, and promoting sustainable precision agriculture.

3. PROPOSED SYSTEM

The proposed system as shown in Figure 1, introduces a Cloud-Controlled LoRaWAN Communication Smart Agriculture Gateway Load Regulation framework designed to enable efficient, low-latency, and reliable communication between distributed agricultural IoT sensors and a centralized cloud platform. Unlike traditional manual or flooding-based systems, this approach uses optimized shortest-path routing to reduce network congestion, improve data accuracy, and regulate gateway load effectively. The system ensures scalable, energy-efficient, and real-time monitoring suitable for large-scale smart farming environments.

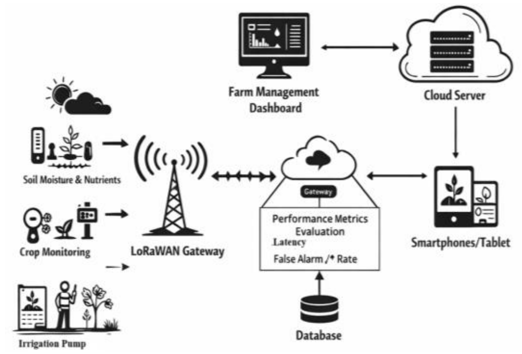

Figure 1: Proposed system architecture smart agriculture gateway load regulation.

Network Initialization and Node Deployment: The system initializes a scalable IoT network where multiple sensor nodes are deployed across agricultural fields. These nodes represent soil, temperature, humidity, and crop monitoring sensors arranged in a structured topology. A graph-based model is generated to simulate connectivity and communication paths.

Link Formation and Distance Calculation: Each node establishes connections with neighboring nodes based on predefined topology rules. The system calculates the physical distance between nodes, assigning weights to communication links. This weighted graph structure enables intelligent routing decisions.

Data Transmission Request Generation: When a source node needs to transmit agricultural data to a destination (gateway/cloud node), the system triggers a routing request. The communication process begins with identifying possible paths within the network.

LoRaWAN-Based Shortest Path Routing: Using Dijkstra's algorithm, the system determines the most optimal path between source and destination. This ensures minimum hop count, reduced travel distance, and controlled packet forwarding, thereby minimizing latency and network congestion.

Performance Metric Evaluation: After routing, the system calculates key performance metrics including latency, accuracy, and false alarm rate. These metrics simulate real-world communication efficiency and reliability under the LoRaWAN protocol.

Gateway Load Regulation and Cloud Synchronization: Optimized routing reduces unnecessary traffic at the gateway, preventing overload conditions. The gateway forwards structured and reliable data to the cloud server for storage, analysis, and monitoring.

Visualization and Result Analysis: The system generates comparative performance graphs and stores simulation results in a database. This enables historical analysis, performance evaluation, and validation of LoRaWAN's superiority over traditional flooding mechanisms.

4. RESULT ANALYSIS

The implementation of the Cloud Controlled LoRaWAN Communication Smart Agriculture Gateway Load Regulation system is carried out using a Flask-based web framework integrated with graph modeling through NetworkX. The system generates a scalable IoT network topology, implements both LoRaWAN (shortest-path routing using Dijkstra's algorithm) and Flooding protocol

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(broadcast-based traversal) for communication simulation, and computes performance metrics such as latency, accuracy, and false alarm rate. Results are stored using TinyDB and visualized through Matplotlib-generated comparison charts, enabling efficient protocol analysis within a structured and modular application environment.

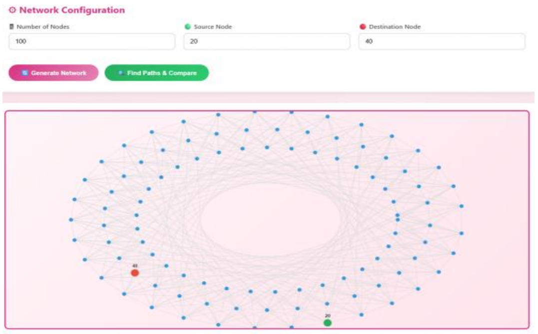

Figure 2: Network generation using 100 Nodes

The figure 2 represents the generated smart agriculture IoT network topology consisting of 100 nodes arranged in a structured circular multi-layer layout. Each blue dot indicates an individual sensor node deployed across the agricultural field, while the grey connecting lines represent communication links established between neighboring nodes based on distance-weighted edges. The green node (20) denotes the selected source node and the red node (40) represents the destination node for routing simulation. This visualization demonstrates the scalable graph-based network structure used for implementing and comparing LoRaWAN (shortest-path routing) and Flooding (broadcast-based routing) protocols within the simulation environment.

Figure 3: Paths obtained using both the protocols

The figure 3 visualizes the routing comparison between the LoRaWAN protocol (proposed) and the Flooding protocol (legacy) after clicking "Find Paths & Compare." The green path represents the LoRaWAN shortest path from source node 20 to destination node 40, consisting of 7 hops, demonstrating optimized routing with minimal traversal distance and controlled forwarding. In contrast, the red path shows the Flooding protocol route with 11 hops, where multiple intermediate nodes and extended detours increase the path length. The visualization clearly highlights how LoRaWAN selects an efficient weighted shortest path using Dijkstra's algorithm, while the Flooding protocol explores longer broadcast-based routes, resulting in higher distance and network overhead.

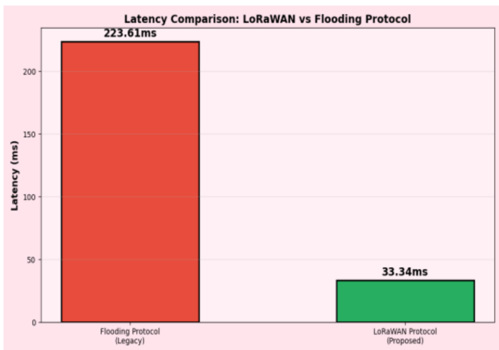

Figure 4: Latency comparison graph of both protocols

The figure 4 presents the latency comparison between the Flooding protocol (legacy) and the LoRaWAN protocol (proposed). The Flooding protocol shows a significantly higher latency of 223.61 ms, which is due to

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redundant packet broadcasting, increased hop count, and extended routing paths. In contrast, the LoRaWAN protocol achieves a much lower latency of 33.34 ms by utilizing Dijkstra's shortest-path algorithm to select the most efficient route between source and destination. This visualization clearly demonstrates that optimized routing in LoRaWAN drastically reduces communication delay, making it more suitable for real-time smart agriculture monitoring and gateway load regulation.

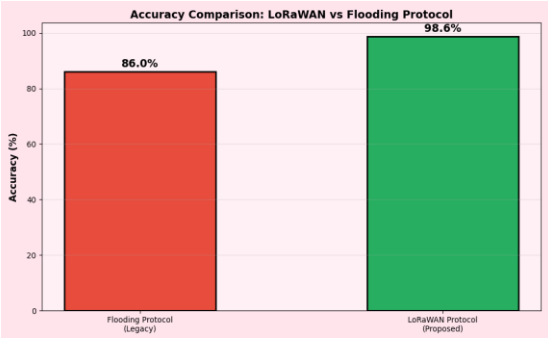

Figure 5: Accuracy comparison graph for both protocols

The figure 5 illustrates the accuracy comparison between the Flooding protocol (legacy) and the LoRaWAN protocol (proposed). The Flooding protocol achieves an accuracy of 86.0%, which is lower due to redundant transmissions, increased hop count, and higher chances of packet interference or data degradation. In contrast, the LoRaWAN protocol reaches a significantly higher accuracy of 98.6%, as it utilizes optimized shortest-path routing that minimizes transmission errors and reduces network congestion. This result clearly demonstrates that controlled and intelligent routing in LoRaWAN improves data reliability and ensures more precise communication in smart agriculture networks.

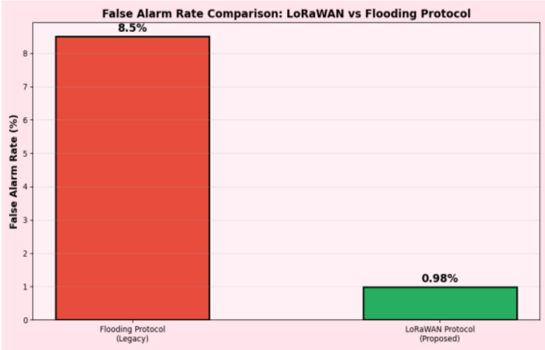

Figure 6: False alarm rate comparison graph

The figure 6 presents the False Alarm Rate comparison between the Flooding protocol (legacy) and the LoRaWAN protocol (proposed). The Flooding protocol exhibits a significantly higher false alarm rate of 8.5%, primarily due to redundant packet transmissions, multiple broadcast paths, and increased chances of duplicated or corrupted data reaching the destination. In contrast, the LoRaWAN protocol maintains a very low false alarm rate of 0.98%, as it follows an optimized shortest-path routing mechanism that minimizes unnecessary transmissions and reduces network interference. This comparison clearly demonstrates that LoRaWAN provides more reliable and stable communication, making it highly suitable for precision-based smart agriculture monitoring systems.

5. CONCLUSION

This research successfully demonstrates the effectiveness of optimized routing in large-scale agricultural IoT networks through a structured graph-based simulation approach. By modeling sensor nodes as a weighted network and implementing both the legacy Flooding protocol and the proposed LoRaWAN-based shortest path routing using Dijkstra's algorithm, the research provides a clear comparative performance evaluation. The results conclusively show that LoRaWAN significantly outperforms Flooding in terms of reduced latency, higher communication accuracy, and substantially lower false alarm rate. The flooding mechanism, due to its

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broadcast-based transmission and redundant path exploration, leads to increased hop count, greater network congestion, higher gateway load, and degraded communication reliability. In contrast, the LoRaWAN protocol ensures controlled packet forwarding, minimal transmission distance, and efficient load regulation at the gateway level, making it highly suitable for real-time smart agriculture applications. The integration of Flask-based APIs, NetworkX graph modeling, TinyDB storage, and Matplotlib-based visualization further enhances the system by providing interactive simulation, performance tracking, and scalable experimentation up to 500 nodes.

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