



Performance Analysis of IoT-Based Wireless Sensor Networks for Smart Agriculture using Optimized Network Engineering Tools (OPNET 14.5)

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Introduction

Agriculture received a transformation through IoT and WSN integration because it enabled instantaneous environmental surveillance combined with improved resource management systems. The research examines how ZigBee and Wi-Fi and LoRa perform as wireless communication standards inside intelligent agricultural systems. These three communication standards have different characteristics which influence the combination of power use and data speed and scalability capabilities. The main benefits of ZigBee include energy-efficient communications within short distances alongside Wi-Fi capabilities for rapid data transfer except for its high-power requirements and LoRa's extended range capabilities and minimal power requirements that work well for agricultural large areas. The research relies on Optimized Network Engineering Tools (OPNET) 14.5 software for performing field-based simulations and assessing the performance comparison of these protocols. The main objectives focus on assessing performance through throughput and delay along with energy consumption and packet delivery ratio and network lifetime for developing affordable and scalable IoT solutions for precision farming.

Methodology

The research used OPNET Modeler 14.5 to construct WSN models which contained ZigBee, Wi-Fi, and LoRa communication protocols. The simulation models reproduced agricultural scenarios by representing actual distribution of nodes together with environmental factors and data processing infrastructure. The simulation generated networks containing 30 sensor nodes which transmitted information to a central server through gateways by following standard agricultural use parameters. System performance analytics consisted of evaluating energy usage together with data processing capabilities and message delivery rates and system delays and device lifetime at different communication and node population levels.

Results

Performance evaluations through simulation techniques demonstrated different operational features in these three technologies. The wireless technology demonstrated the best transfer speed (~150,000 kbps) together with an optimal packet delivery rate (~90%) yet used excessive power so it is not suitable for mobile remote applications. The network longevity of LoRa technology reached ten years while its energy usage remained at the lowest level of 0.5 normalized units which made it suitable for extended-range energy-efficient monitoring across extensive agricultural landscapes. Protocol LoRa introduces prolonged delay of ~450 ms together with reduced throughput that stands at ~1,000 kbps limiting its suitability to real-time applications. The ZigBee protocol offered an optimal performance set with moderate data rates up to 20,000 kbps alongside both fast data transfers under 10 ms delay and adequate power economy reaching one normalized unit which made it well-suited for medium-size operations.

Conclusion

The study demonstrates that Wi-Fi provides peak performance for data-intensive real-time video monitoring which prevents its use as a widespread tactical solution because of high energy needs. ZigBee provides an appropriate solution for agricultural settings that requires medium-scale operations with power efficiency and fast response times. LoRa takes the lead as the most appropriate protocol because it delivers both high energy efficiency and extended operational duration for vast smart farming deployments.

Keywords

Crop Management Systems, Farming, Internet of Things (IoT), OPNET, Smart Agriculture