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Hardware Evaluation of Cluster-Based Agricultural IoT Network

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Abstract- Agricultural Internet of Things (Agri-IoT) networks combine distributed sensors, wireless communication and data-processing devices to monitor field conditions and support timely farm decisions. A cluster-based architecture organizes sensor nodes into groups and assigns a cluster head to collect and forward measurements. This paper presents a hardware-oriented evaluation framework for such a network, focusing on practical factors that influence deployment in agricultural environments. The proposed framework considers sensing accuracy, communication reliability, energy consumption, transmission range, response time, scalability and environmental suitability. A representative prototype may use soil-moisture and temperature-humidity sensors, low-power microcontrollers, Bluetooth Low Energy (BLE) or LoRa communication, a gateway and a cloud or local monitoring interface. The paper explains the roles of the hardware components, the flow of sensed data and a repeatable procedure for evaluating node and network performance. Rather than reporting fabricated measurements, it defines the parameters and test conditions required for a valid field evaluation. The discussion highlights how clustering can reduce redundant transmissions and simplify network management, while also introducing the need to manage cluster-head energy and communication overhead. The framework can guide the development of affordable, maintainable and scalable monitoring systems for precision agriculture.

Keywords— Agricultural IoT, Cluster-Based Network, Wireless Sensor Network, Hardware Evaluation, Soil Moisture Monitoring, BLE, LoRa.

I. INTRODUCTION

Agriculture depends on timely information about soil and environmental conditions. Traditional field inspection provides useful observations, but it can be labour-intensive and may not capture rapid changes across a large field. Internet of Things (IoT) technology supports continuous or scheduled monitoring by connecting sensors, processing units and communication devices. Measurements such as soil moisture, temperature and relative humidity can help farmers understand field conditions and plan irrigation more efficiently.

An agricultural wireless sensor network (WSN) contains multiple sensor nodes distributed across a field. In a simple architecture, every node may communicate directly with a central gateway. As the number of nodes or the distance from the gateway increases, direct communication can increase energy use and network-management complexity. A cluster-based architecture addresses this issue by grouping nearby nodes. Member nodes send their measurements to a selected cluster head (CH), which aggregates the information and forwards it to a gateway or another cluster.

Recent hardware studies have demonstrated the feasibility of cluster-based agricultural IoT using commercially available controllers and low-power wireless technologies. Effah, Thiare and Wyglinski describe a real-world cluster-based agricultural IoT testbed based on Bluetooth Low Energy and Raspberry Pi hardware [1]. A later multihop study combines BLE and LoRa to support communication between distant clusters [2].

These studies emphasize that field conditions, power supply, ease of deployment and communication reliability must be considered alongside the theoretical network design.

The objective of this paper is to organize the main hardware elements and define a practical evaluation method for a cluster-based agricultural IoT network. The focus is on measurable evaluation criteria and deployment considerations, not on claiming experimental results that have not been collected.

II. SYSTEM ARCHITECTURE

1. Sensor Nodes

A sensor node is the field-level unit responsible for collecting environmental information. A typical node contains a microcontroller, one or more sensors, a wireless communication interface and a power source.

A soil-moisture sensor estimates the water content of soil, while a temperature-humidity sensor records surrounding atmospheric conditions. The microcontroller reads the sensor outputs, adds a node identifier and timestamp, and prepares a data packet for transmission.

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2. Cluster Head
A cluster head coordinates communication within its cluster. It receives readings from member nodes, checks packet information and may aggregate multiple readings before forwarding them. Aggregation can reduce repeated transmissions and help conserve energy. Since the cluster head performs additional work, its processing load and battery condition should be monitored. Cluster-head rotation may be considered to distribute this workload among suitable nodes.

3. Gateway and Monitoring Layer
The gateway receives data from cluster heads and transfers it to a local computer, server or cloud platform. A monitoring application can display sensor values, node status and alert conditions. If irrigation automation is included, a control unit can use verified moisture thresholds to request pump operation. The control stage should remain separate from sensor acquisition so that a communication or software fault does not produce an unintended actuation.

III. HARDWARE COMPONENTS

- **Microcontroller:** A low-power microcontroller is suitable for sensor acquisition and packet handling. The selection should consider input/output pins, memory, wireless support, operating voltage, programming support and availability.
- **Soil-Moisture Sensor:** This sensor provides an indication of soil water condition. Its output should be calibrated for the soil type and installation depth. Sensor placement, corrosion resistance and long-term stability influence the quality of readings.
- **Temperature and Humidity Sensor:** This component measures local air conditions. It should be installed in a ventilated, shaded enclosure to reduce direct solar heating and moisture exposure.
- **Wireless Module:** BLE can support short-range, low-energy communication between nearby devices. LoRa can be considered where longer-range, low-data-rate communication is required. The choice depends on field size, obstacles, data rate, power budget and regional radio regulations.
- **Gateway:** A single-board computer or suitable embedded gateway collects cluster data and provides an interface to local storage or an internet connection. The gateway should support the selected radio technology and provide sufficient power and environmental protection.
- **Power Unit and Enclosure:** Battery capacity, regulator efficiency and expected duty cycle determine node operating time. Solar charging may be considered for outdoor deployments. Enclosures should protect electronics from dust, rain, insects and accidental contact while allowing sensors to measure the environment correctly.

IV. WORKING METHODOLOGY

The proposed network follows a sequence of sensing, local processing, cluster communication and gateway delivery. First, each sensor node samples the connected sensors at a defined interval. The controller checks whether the readings are within the sensor's valid output range and forms a packet containing the node ID, time and measured values. The packet is sent to the assigned cluster head using the selected short-range wireless link.

The cluster head receives packets from its member nodes and checks packet integrity. It may calculate a summary, such as the average value for a sampling period, while retaining individual readings when detailed analysis is required. The aggregated packet is then sent to the gateway. If clusters are beyond direct gateway range, a relay or multihop path may be evaluated. The gateway stores the received data and makes it available to a dashboard or analysis application.

A repeatable evaluation should record the same parameters under defined conditions. Indoor tests can be used for initial functional checks, but outdoor tests are necessary to assess the effects of distance, vegetation, weather and physical obstructions. Each test should document node placement, antenna orientation, sampling interval, packet size, battery condition and radio settings.

V. HARDWARE EVALUATION PARAMETERS

1. Sensor Accuracy and Stability
Sensor readings should be compared with a suitable reference instrument or a calibrated measurement method. The difference between the sensor output and reference value can be recorded as absolute error. Repeated readings help identify fluctuations, drift and inconsistent sensor behaviour. Calibration should be performed before interpreting field data.

2. Packet Delivery and Communication Range
Packet delivery ratio (PDR) is the number of packets successfully received divided by the number of packets transmitted, multiplied by 100. Tests should be repeated at different distances and with representative obstructions. Received signal strength, packet loss and reconnection behaviour provide additional information about link quality.

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3. Energy Consumption
Current should be observed during sensing, processing, transmission, reception and sleep modes. Average current depends on the duration and frequency of each operating state. Battery runtime can then be estimated using measured average current and usable battery capacity, while allowing for regulator losses, battery ageing and temperature effects.

4. Latency and Throughput
Latency is the time between a measurement being generated and its arrival at the gateway or monitoring application. Throughput represents the amount of useful data delivered per unit time. Both values should be measured under different node counts and traffic conditions because packet aggregation and multihop forwarding can change delivery delay.

5. Scalability and Reliability
Scalability can be examined by increasing the number of sensor nodes and observing packet delivery, delay, gateway load and energy use. Reliability tests should include temporary link interruption, node restart and gateway unavailability. The network should recover in a controlled manner and clearly identify missing or stale measurements.

VI. DISCUSSION

Cluster-based communication offers a practical way to organize sensor nodes in agricultural fields. Member nodes can use short-range links to reach a nearby cluster head, while cluster heads handle forwarding toward the gateway. This arrangement can reduce the number of long-distance transmissions made by individual nodes. However, the cluster head may consume more energy because it receives, processes and forwards data. A fair evaluation must therefore compare member-node and cluster-head energy use separately.

The selection of BLE or LoRa should be based on the application rather than on range alone. BLE is suitable for low-power communication within a cluster, whereas LoRa may be useful for links between distant clusters or a gateway. A combined architecture can provide flexibility, but it also increases integration and testing requirements. Interference, antenna placement, vegetation, moisture and terrain can affect outdoor communication.

Hardware evaluation should distinguish laboratory functionality from field performance. A sensor may work correctly on a bench but produce unstable readings after prolonged exposure to soil and weather. Similarly, a radio link that works across an open indoor space may behave differently when crops, buildings or uneven terrain obstruct the path. Long-duration tests across different weather conditions are therefore important before drawing conclusions about deployment lifetime or commercial suitability.

VII. CONCLUSION

This paper presented a hardware-oriented framework for evaluating a cluster-based agricultural IoT network. It described the main hardware units, including sensor nodes, cluster heads, wireless modules, a gateway and the power system. It also identified key evaluation parameters such as sensor accuracy, packet delivery ratio, communication range, energy consumption, latency, throughput, scalability and reliability. Clustering can support organized data collection and reduce redundant communication, but the additional workload placed on cluster heads must be considered. BLE and LoRa provide possible communication options for different network distances and data requirements. The proposed framework is intended to support systematic prototype development and field testing. Future work should implement the network with selected hardware, collect repeatable indoor and outdoor measurements, and report results for different node counts, weather conditions and power configurations.

REFERENCES

1. E. Effah, O. Thiare, and A. M. Wyglinski, “Hardware Evaluation of Cluster-based Agricultural IoT Network,” IEEE Access, vol. 12, pp. 33628–33651, 2024, doi: 10.1109/ACCESS.2024.3370230.
2. E. Effah, G. Ghartey, J. K. Aidoo, and O. Thiare, “Hardware Development and Evaluation of Multihop Cluster-Based Agricultural IoT Based on Bluetooth Low-Energy and LoRa Communication Technologies,” Sensors, vol. 24, no. 18, article 6113, 2024, doi: 10.3390/s24186113.

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