

A Hybrid Approach to Data Mining from IoT and WSN Systems for Precision Agriculture Decision Support

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Abstract

Precision agriculture integrates advanced technologies to optimize crop production, resource management, and sustainability. Wireless Sensor Networks (WSNs) and IoT continuously collect large-scale agricultural data, but extracting actionable insights from this data poses significant challenges. This research proposes a hybrid data mining framework combining machine learning, statistical analysis, and pattern recognition to process real-time data from IoT-enabled WSNs. The system addresses key issues such as energy-efficient data collection, noise reduction, feature selection, and predictive analytics for yield estimation, disease detection, and irrigation management. By merging centralized and edge-based data mining, the model ensures real-time, adaptive decision support while minimizing communication and energy overhead. Experimental results on real-world datasets show enhanced accuracy in crop monitoring, resource optimization, and yield prediction, contributing to a sustainable and intelligent precision agriculture system.

Index Terms – Agricultural Analytics, Crop Monitoring, Data Mining, Decision Support System, Edge Computing, Energy-Efficient Data Processing, IoT, Machine Learning, Precision Agriculture, Smart Farming, Wireless Sensor Networks, Yield Prediction.

I INTRODUCTION

Agriculture is a critical sector that sustains global food security and economic growth. However, traditional farming methods often face challenges such as unpredictable climate conditions, inefficient resource utilization, and inconsistent crop yields. Precision agriculture has emerged as a solution to these challenges by integrating advanced technologies to monitor and optimize farming practices. The goal is to improve crop productivity while ensuring environmental sustainability and efficient resource management.

Among the key enablers of precision agriculture are Wireless Sensor Networks (WSNs) and the Internet of Things (IoT). These technologies facilitate the real-time collection of diverse agricultural data, including soil moisture, temperature, humidity, plant health, and climatic variations. Despite the availability of large volumes of sensor-generated data, extracting meaningful and actionable insights remains a significant research problem due to issues like data heterogeneity, noise, and energy constraints in sensor nodes.

Data mining plays a pivotal role in addressing these challenges by transforming raw data into valuable knowledge for decision-making. However, traditional data mining approaches may not be fully suitable for resource-constrained IoT and WSN environments due to high computational and energy demands. Therefore, developing an efficient and adaptive data mining framework is essential.

This research proposes a hybrid data mining approach that combines machine learning, statistical methods, and pattern recognition techniques to analyze real-time data from IoT-enabled WSNs. The proposed system integrates centralized and edge computing strategies to ensure energy-efficient data processing, real-time analysis, and accurate predictions for agricultural decision support.

II Literature Survey

In recent years, the combination of IoT, Wireless Sensor Networks (WSNs), and Data Mining has revolutionized the agricultural sector, driving the advancement of Precision Agriculture (PA). Several studies have contributed to the development of smart farming systems, but challenges in data analysis, energy efficiency, and real-time decision-making persist.

IoT and WSNs play a crucial role in collecting agricultural data from fields through sensors that monitor soil moisture, temperature, humidity, and plant health.

Mekala and Viswanathan (2017) presented an IoT-based precision farming model for real-time monitoring of agricultural parameters but highlighted limitations in data processing scalability.

Jawad et al. (2017) focused on energy-efficient WSN protocols for agricultural monitoring, proposing communication strategies to prolong sensor node lifetime. However, their work lacked advanced data analytics for decision support.

Data mining techniques, including clustering, classification, and regression, have been applied to analyze agricultural datasets to support predictive analytics.

Patil and Kumaraswamy (2018) used classification algorithms for crop yield prediction, but their approach was limited to static datasets, making it unsuitable for real-time IoT data streams.

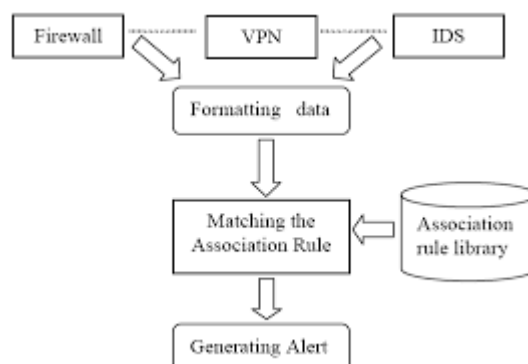
Kamilaris and Prenafeta-Boldú (2018) reviewed the application of machine learning in agriculture, emphasizing the need for robust models that can handle large, heterogeneous data sources from IoT and WSNs.

Hybrid approaches that combine multiple data mining techniques with IoT systems are emerging to enhance precision agriculture capabilities.

Singh et al. (2019) proposed a hybrid system integrating IoT with cloud-based analytics for smart irrigation, achieving efficient water management but facing latency issues due to centralized processing.

Bhagat et al. (2020) developed a system using edge computing and machine learning for crop disease detection, reducing the need for cloud computation but focusing only on plant health without considering holistic

1. Data Mining in Precision agriculture



Data Mining in Agriculture remains a valuable, well-structured introduction to classic data mining techniques applied to the agri-environmental domain. It's particularly suited for educational use and for those beginning their journey in agricultural data analysis.

The agri-environmental domain refers to the intersection of agriculture and the environment, focusing on how farming practices impact ecosystems and natural resources, and vice versa. It covers policies, research, and practices aimed at achieving sustainable agriculture while protecting the environment.

Agri-Environmental Domain

1. Soil conservation
2. Water management
3. Biodiversity protection
4. Organic and regenerative farming

1.1. Precision agriculture

Precision agriculture is a modern farming technique that uses technology to monitor and manage agricultural activities more accurately and efficiently. It involves the use of sensors, GPS, drones, and data analytics to collect real-time information about soil conditions, crop health, weather, and resource usage. This data helps farmers make informed decisions about where, when, and how much to plant, water, fertilize, or treat crops. The main goals of precision agriculture are to: Increase crop yield and quality, Reduce waste of resources like water, fertilizer, and pesticides, Lower production costs, Promote sustainable farming, By applying inputs only where needed, precision agriculture improves productivity while minimizing environmental impact. It is a key part of smart farming and the future of agriculture.[1]. (PA) ensures both the profitability of farming operations and the sustainable management of agricultural land. It relies heavily on software and information technology to access real-time data related to crop growth, soil conditions, weather patterns, and air quality. Using this data, the system can provide valuable insights such as optimal planting and harvesting times, suitable crop rotation schedules, and effective soil management strategies. A key technology enabling this is the Wireless Sensor Network (WSN), which is widely used for data collection and environmental monitoring. WSNs play a crucial role in supporting data-driven decision-making for efficient and intelligent farm management..[2].

1.1. Internet of Things (IoT) in Agriculture

The **Internet of Things (IoT)** plays a vital role in transforming traditional farming into smart agriculture. IoT refers to the network of interconnected devices and sensors that collect and exchange data over the internet without the need for direct human involvement. In agriculture, IoT devices are used to continuously monitor various parameters such as soil moisture, temperature, humidity, light intensity, and crop health. These smart devices send real-time information to centralized systems where it can be analyzed for making timely and accurate decisions. IoT enables farmers to: Automate irrigation and fertilization processes, Detect pests or diseases early, Monitor livestock remotely, Optimize resource usage and minimize waste, By integrating IoT into agriculture, farmers can achieve better productivity, reduce operational costs, and enhance sustainability. The ability to remotely control and manage farming operations makes IoT an essential component of modern agricultural practices.

IoT is a key element of modern agriculture, enabling farmers to increase crop yields while reducing costs. By using wireless sensors and software tools, IoT helps improve farm productivity, profitability, and sustainability. A survey conducted in 2020 reported that IoT applications in agriculture could reach up to 75 million devices, highlighting its growing adoption in the sector[3]. IoT farming enables remote monitoring of fields using sensors for temperature, soil moisture, light, and crop health. It helps farmers reduce resource waste—such as water and electricity—by automating processes like irrigation, improving efficiency and sustainability.

1.2. Intelligent Farming Domain Systems

In agriculture, the major causes of loss are due to production and revenue loss. [4] identify the crop disease as early-stage helps farmers to reduce the production loss. IoT-based monitoring is done to monitor the crops by using sensors. The sensors are placed along with the farm to monitor the crops for any changes in light, humidity, temperature. Sensor devices are sensitive to anomalies. If any anomaly is detected by the sensors the farmer gets notified. Thus the sensors can help in the growth of the crop as well as prevent the diseases it spreads. Automation disease detection is precise and less expensive to the farmer than physical detection.

Based on weather conditions

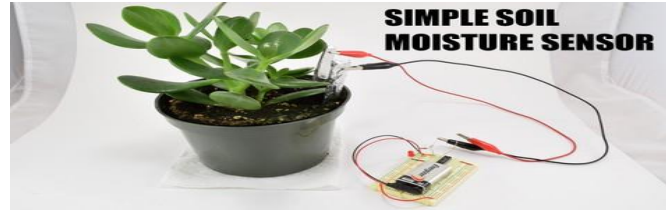
In agriculture productivity, the climate is one of the important factors [5]. Climate change lets to influence the crop and live production, hydro-logic balance, input supplies, and another agriculture system. And it also reflects in frequencies and intensities of the crop and pests, determining the water supplies and severity of the soil erosion.[6]. The parameter that is used to collect the data are temperature, soil, humidity, moisture precipitation, wind direction, and air pressure. The data are used by the sensors to determine the weather in farms and new insights are provided to farmers to improve agricultural productivity. A wireless sensor network is used in IoT technology to monitor the weather by using a sensor and some device that can monitor the weather.

Soil quality

Soil moisture is an important factor in both local and large-scale agriculture; crops depend on the amount of moisture in the soil at the root level. [7]. In farm productivity determining the soil moisture and its availability is the major factor for farm growth. If the farm consists of little moisture then it results to yield loss, and if it's more moisture causes root diseases. Soil quality determination helps determine the best value and barren places in the plot, helping farmers adjust the water usage based on the condition so that wastage can be reduced.

Soil quality is a key parameter in precision agriculture as it directly affects crop yield, irrigation planning, and fertilizer application. Monitoring soil parameters such as:

1.5.1 Soil Moisture



1.5.1 soil Moniture sensor

Soil moisture sensors are electronic devices that measure the water content in soil. They help farmers determine when and how much to irrigate, preventing both overwriting and under watering. Using soil moisture sensors for irrigation scheduling is one of the simplest and most effective methods to enhance irrigation efficiency, leading to better crop yields, improved grain quality, water and energy conservation, and reduced nutrient leaching.

Type	Working Principle	Usage in Agriculture
Capacitive Sensors	Measure the dielectric constant of the soil, which changes with moisture levels.	Low power, good for IoT & WSN systems, durable for long-term monitoring
Resistive Sensors	Measure electrical resistance between two probes; resistance changes with soil moisture.	Affordable but prone to corrosion, useful for short-term monitoring
Tensiometers	Measure the tension (suction) plants need to extract water from the soil.	Good for irrigation management but require maintenance
Time Domain Refractometer (TDR)	Sends electromagnetic pulses to measure moisture based on	Highly accurate but expensive, used in research
Gypsum Blocks	Use conductivity change in gypsum to estimate soil moisture.	Low-cost but less precise

1.5.2 Soil Temperature

Soil temperature refers to the heat level within the soil at different depths. It is a critical environmental factor affecting plant growth, seed germination, root development, microbial activity, and nutrient availability.

1.5.2.1 Plant Growth and Germination: Each crop has an optimal soil temperature range for seed germination and root function.

Example: Wheat: 12–25°C, Maize: 15–30°C, Rice: 20–35°C,

1.5.2.2 Nutrient Availability: Soil temperature affects chemical and biological processes like decomposition

and nutrient mineralization.

Warm soil enhances nutrient uptake; cold soil slows down plant metabolism.

3. Soil Moisture Interaction: Temperature directly impacts soil moisture readings because warmer soil evaporates moisture faster.

Accurate monitoring of both soil temperature and moisture is essential for precision irrigation.

4. Microbial and Biological Activity: Soil microorganisms responsible for nitrogen fixation and organic matter breakdown are temperature-sensitive.

5. Optimal temperatures promote soil fertility.

6. Frost and Heat Stress Management: Monitoring soil temperature helps prevent frost damage in winters and heat stress in summers by adjusting irrigation and planting schedules.

1.5.3. Soil pH : Soil pH is a measure of the acidity or alkalinity of soil, expressed on a scale from 0 to 14:

pH < 7: Acidic Soil, **pH = 7:** Neutral Soil, **pH > 7:** Alkaline (Basic) Soil.

1. Nutrient Availability: Soil pH controls the availability of essential nutrients like nitrogen, phosphorus, potassium, calcium, and magnesium.

Extreme pH levels cause **nutrient lock-up**, making nutrients inaccessible to plants.

Acidic soil (pH < 5.5): Limits availability of phosphorus and calcium; may increase toxic metals like aluminum.

Alkaline soil (pH > 8): Reduces micro nutrients like iron, zinc, and manganese.

1.5.4. Soil Nutrient Levels (NPK: Nitrogen, Phosphorus, Potassium)

NPK stands for the three primary macro nutrients essential for plant growth:

Nutrient	Role in Plant Growth
Nitrogen (N)	Promotes leafy growth, photosynthesis, and chlorophyll production.
Phosphorus (P)	Supports root development, flower and fruit production, and energy transfer.
Potassium (K)	Enhances overall plant health, disease resistance, and water regulation.

1. Balanced Plant Nutrition: Proper NPK balance ensures healthy crop growth. Deficiencies or excesses can lead to: Nitrogen deficiency: Yellowing leaves (chlorosis), poor growth.

Phosphorus deficiency: Poor root development, stunted plants.

Potassium deficiency: Weak stems, leaf curling, poor fruit quality.

2. Efficient Fertilizer Management:

Over-fertilization leads to nutrient runoff, water pollution, and soil degradation.

Under-fertilization reduces crop yield and quality.

3. Sustainable Farming: Real-time NPK monitoring enables site-specific nutrient management (SSNM).

Supports **precision agriculture**, minimizing environmental impact.

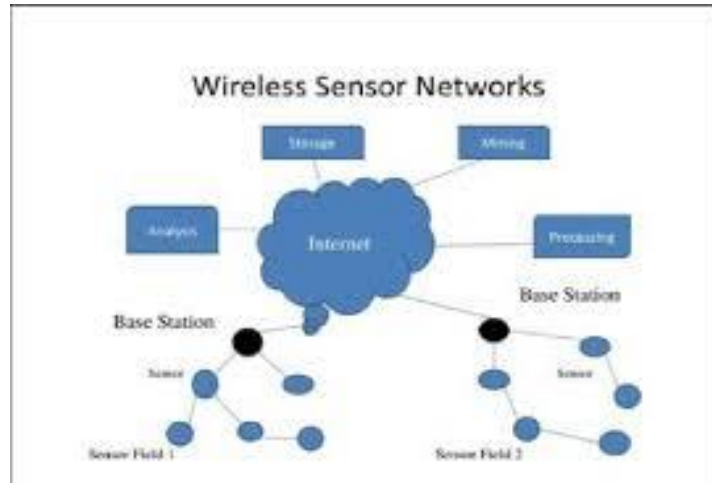
1.5.5. Soil Salinity

1.3. Drones

Camera and Sensors are used in a drones to monitor farms land. Drones can be controlled remotely or can be programmed to fly automatically using special software. Unmanned aerial vehicles (UAVs) and unmanned aircraft systems (UASes) are known as drones it also refers to flying robots, respectively. The data collect by the drone are crop health, soil, and field, yield prediction irrigation, spraying and planting. Drones are mostly used in a large farm since monitoring are need to do continuously because it consists of more bacterial and fangs which are difficult to handle.

2. WSN (wireless sensor network)

A wireless sensor network is made up of several sensor nodes that are tiny in size they help to collect the data surrounded by it, the communication takes place wireless. As shown in Fig 1 Nodes are typically deployed in an ad-hoc form, in a decentralized fashion, and in a low-power mode. [8] nodes consist of data processing, communication protocols, and sensing[9]. And sensor position need not be predetermined. Sensors are almost used in all fields due to their size complicity and the technology used. WSN is mostly used in monitoring the agriculture fields.



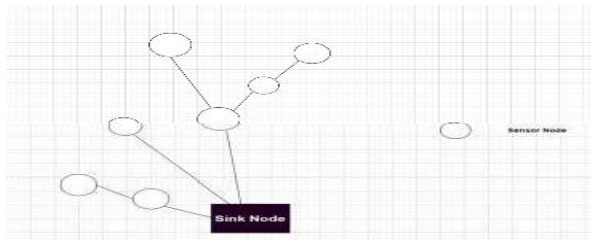
2.1. Star Topology:

Star topology consists of one of the central nodes that could be a switch or a hub. The node in a network is connected to a central hub. As shown in Fig 2 The data flow from the central hub to all the nodes, hence the intelligent hub is necessary. Star topology is easy to implement and design hence it is the most commonly used topology. if any hub in the network tends to fail then it leads to the failure of the entire network. [10] proposed the protocols that help to recover when there is a connectivity loss. the link between the sensors and the access point (AP) is cluttered suddenly due to temporary obstruction. Neighbor-Assisted Connectivity Recovery Protocol (NACRP), helps in the selection of sensor nodes that act as a relay when there is a loss of connectivity in the AP. A stochastic geometry tool has been used to characterize the scattered sensors. The trade-off points and the usage of the power that the sensor needed to spend to transmits and the star topology alter into local mesh networks are identified. [11].The star topology performance was examined using random node deployment, and the smallest number f nodes that could be deployed for confident surveillance was determined. Because the WSN is a sensitive network, create the node and WSN availability using the Poisson process information. And also discussed the three questions in the work.

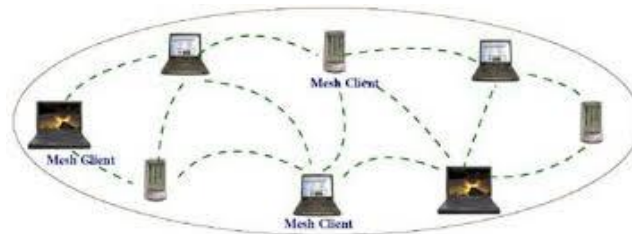


2.2. Mesh Topology

Mesh topology is a network configuration in which each computer is linked to the network device. this topology allows to transmit the data even when there is disconnection happens. This is a self-healing network since the data can be routed to a different path if any node fails, There are 2 different types of mesh topology I,e, partially connected mesh and fully connected mesh [12] proposed the architecture of a hybrid mesh sensor network, based on mesh routers and sensors nodes.



This helps in the reduction of network load leading to data WSNs in determining encryption and authentication.[13] proposed EMRP energy-Aware Mesh Routing protocols its multiple path solutions for event-based cluster-based routing. The main features of these protocols are data transmission, load balance, and energy efficiency. These protocols can also be used for routing in the virtualization of WSN.



2.3. Cluster tree Topology

Cluster tree topology can refer to a parent-child relationship, it forms a tree-like structure The communication router in the network is a central hub called the root node. As shown in Fig 3 A root node is a top node and below that is the central hub. A router helps in extending the network coverage. For the star and peer-to-peer typologies, this cluster tree network appears to be hybrid. The cluster tree network helps in the usage of energy consumption in the WSN. Thus this cluster tree topology is mainly used.[14] proposed the clustering- tree protocols are showed better result on network lifetime, packet drop, delay, and throughput in comparison with LEACH and another existing clustering tree algorithm. Performance analyses are done for the node densities of 30 to 150. This clustering tree protocol helps in controlling the network When the nodes in a cluster are grouped together, and also maintaining close relation between the cluster.[15]

The cluster-tree- based energy-efficient data gathering (CTEEDG) protocol was suggested to extend the lifetime and throughput of wireless sensor networks. The protocol for selecting cluster heads was developed

DL-LEACH. And also the proposed protocols help in getting a better result in the implementation of industrial automation.

3. Protocols in WSN

In agriculture, a variety of IoT protocols are used for smart farming. These protocols assist farmers in achieving better agricultural growth performance. thus this protocol helps in taking an efficient decision. Some of the wireless protocols are mentioned below are Zig-Bee, IEEE 802.11, RFID WiMAX

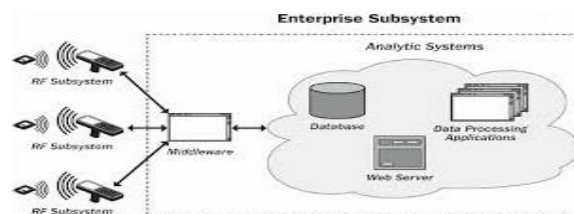
3.1. ZigBee

ZigBee is an IEEE 802 standard created for wireless networking. It requires low cost, low power, low data rate, scalability, and high reliability ZigBee is a low-cost wireless sensor network that can collect, store, and exchange data with other nodes. It's the most convenient standard. ZigBee is used in low data rate that leads to longer battery life and secure network.[16] proposed an interference mediator schema based on the features of ZigBee. This is used for scan reports and Connecting to the different networks for communication to the server.[17] proposed a new model using the neural network and ZigBee wireless sensor network, to identify indoor location tracking.

3.2. IEEE 802.11 WIFI

IEEE 802.11 standard popularly knows as WiFi, which lays the architecture and specification of wireless LANs, uses radio waves frequency for connecting the node. There are different standards of IEEE 802.11 such as 802.11, 802.11a, 802.11b, 802.11g, 802.11n, 802.11p. the data rate provided by the IEEE 802.11 could be 1Mbps or 2 Mbps. [18] the tune IEEE 802.15.4, was proposed to enhance the sample frequency for sensor nodes for precision agriculture. [19] In the Internet of Things, WiFi-based networks are utilized to efficiently connect agriculture and farming.

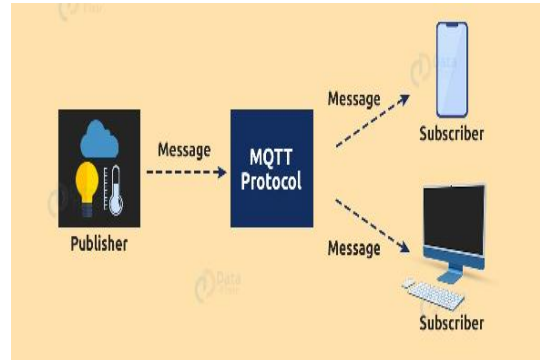
3.3. RFID



RFID (Radio Frequency Identification), also known as a wireless system, is made up of two parts: tags and readers. The reader could be an antenna-ed device that emits radio waves and the signals are received from RFID tags. RFID is divided into two categories: active RFID and passive RFID. The battery is used to power active RFID tags. The reader, rather than a battery, power passive RFID tags. Tags could be active or passive that use radio waves to communicate the information to nearby readers.[20] tags consists of unique number

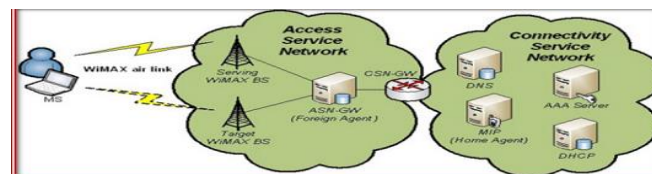
could refer as ID and tags stores environment information such as humidity, temperature condition, moisture level.

3.4. MQTT



MQTT stands for MQ Telemetry Transport, and it's a low-bandwidth communications protocol used in the Internet of Things. MQTT is mainly used for analysis and deployment in the smart agriculture sector. MQTT uses very little battery power. [21] MQTT has been used and tested on the IBM wireless sensor network. [22] MQTT protocol was developed for smart city model. It employs a publish/subscribe approach to decrease packet size, making it ideal for IoT.

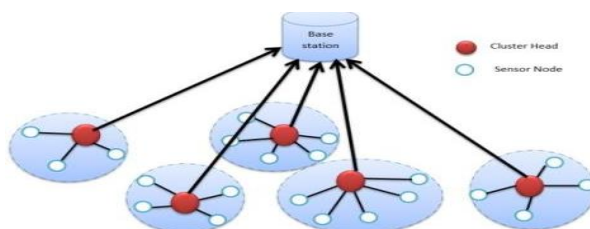
3.5. WiMAX



WiMAX is one of the wireless technology. WiMAX operates similar to WiFi, but it gives a high speed for a greater number of users. It is able to provide the service even in a place that uses wired infrastructure and overcome the limitation of the physical wired infrastructure. [23] The Ghanaian Ministry of Food and Agriculture uses WiMAX technology. WiMAX and WiFi are deployed in the network to provide the connection in the MOFA buildings for efficiency and cost. [24] proposed a system for innovative smart farming, developed by a sensor WiMAX. The proposed system increasing agriculture productivity by monitoring wide areas and diverse data. And also helps the farmer to decide the time for harvesting. And deciding the type of fertilization and pesticides that can be used.

4. Energy Efficient protocols in WSN

4.1. LEACH



LEACH is the routing protocol, the amount of energy is shared between the sensor nodes. Clusters are created using LEACH routing protocols, and one sensor node is designated as the cluster heads (CH), which serves as the routing node for all other nodes in the cluster [25] proposed an energy-efficient LEACH protocol to reduce sensor node energy consumption, resulting in a longer wireless sensor network lifetime and energy savings.. [26] described the LEACH-based protocols briefly since protocols can enhance the lifetime of the WSN and save energy consumption. and comparison of the LEACH and its descended protocols are done.

4.2. EE-MRP(Energy-Efficient Multistage Routing Protocol)

To maximize the WSN's life-time and use energy efficiently, an efficient algorithm is required. [27] EE-MRP protocols are used to get a better result in the performance and energy consumption of the sensors, efficient usage of the resource availability. A comparison between existing protocols and LEACH And MOD-LEACH has been done and proved that existing protocols can perform well better than the existing protocols.

4.3. EE-RP Energy Efficient Routing Protocol

[28] Using A-star algorithm, The energy-efficient routing protocol has been proposed. .These protocols help in improving the lifetime of the networks. The A-star algorithm is used for better efficiency, and it can increase the life-time when compared with other protocols.

Conclusion

Energy-efficient IoT and Wireless Sensor Network (WSN) protocols play a pivotal role in enabling **real-time agricultural monitoring**. Agriculture requires continuous data collection from diverse environmental conditions—such as soil moisture, temperature, humidity, and crop health—which imposes a significant

demand on sensor nodes that often operate on limited power sources like batteries or energy harvesting systems.

By integrating optimized communication protocols, low-power hardware, and adaptive data transmission strategies, energy-efficient systems significantly extend network lifetime while maintaining reliable and accurate data delivery. Techniques such as clustering, data aggregation, duty cycling, and adaptive routing minimize redundant transmissions and reduce energy consumption, making large-scale, real-time agricultural monitoring feasible and sustainable.

These energy-aware approaches not only lower operational costs but also support **precision agriculture**, improving crop yields, conserving water, and reducing environmental impacts. As a result, energy-efficient IoT and WSN protocols are not just technological innovations—they are key enablers of **smart, sustainable farming practices** in the face of global food security challenges.

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