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The LEACH Protocol to Improve Energy Efficiency of Wireless Sensor Networks in Smart Agriculture

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ABSTRACT

Smart agriculture is the application of technology to improve efficiency, productivity, and sustainability in agricultural practices. However, smart agriculture systems face major challenges related to connectivity and energy management. To address connectivity issues, the Wireless Sensor Network (WSN) architecture is utilized, consisting of sensor nodes to collect and transmit sensor data wirelessly. Despite the implementation of WSN, there are still issues related to high power consumption in smart agriculture systems. This can lead to reduced battery life for each sensor node in the WSN architecture. Therefore, increasing energy efficiency is crucial to optimizing the performance of smart agriculture systems. This study proposes the use of the LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol in smart agriculture to manage clusters within the WSN and reduce energy consumption in each sensor node. Experimental methods were conducted by building the WSN using the nRF24L01 as the sensor data transmitter and Arduino / Node MCU as the microcontroller. The use of the LEACH protocol aims to address energy issues. Additionally, data from each sensor is collected using the Message Queuing Telemetry Transport (MQTT) protocol to facilitate monitoring of sensor data transmission and battery power information. Test results show that the integration of the LEACH protocol into the WSN can be carried out at each stage, from Discovery-State to Steady-State, to Setup-State. These steps are aimed at significantly reducing energy consumption in sensor nodes by 13% over a 12-hour testing period. Furthermore, it can extend battery life and improve the overall system efficiency.

Keywords : *Smart Agriculture, Wireless Sensor Networks, LEACH, Internet of Things, Energy Saving*

ABSTRAK

Smart agriculture merupakan penerapan teknologi untuk meningkatkan efisiensi, produktivitas, dan keberlanjutan dalam praktik pertanian. Namun, sistem smart agriculture menghadapi tantangan utama terkait konektivitas dan manajemen energi. Untuk mengatasi masalah konektivitas, digunakan arsitektur Jaringan Sensor Nirkabel (JSN) yang terdiri dari node-node sensor untuk mengumpulkan dan mengirim data sensor secara nirkabel. Meskipun JSN telah diimplementasikan, masih ada permasalahan terkait konsumsi daya yang tinggi pada sistem smart agriculture. Hal ini dapat mengakibatkan pengurangan masa pakai baterai pada setiap node sensor pada arsitektur JSN. Oleh karena itu, peningkatan efisiensi energi menjadi sangat penting untuk mengoptimalkan kinerja sistem smart agriculture. Studi ini mengusulkan penggunaan protokol LEACH (Low-Energy Adaptive Clustering Hierarchy) pada smart agriculture untuk mengelola klaster dalam JSN dan mengurangi konsumsi energi pada setiap node sensor. Metode eksperimental dilakukan dengan membangun JSN menggunakan nRF24L01 sebagai pengirim data sensor dan Arduino / Node MCU sebagai mikrokontroler. Penggunaan protokol LEACH bertujuan untuk mengatasi permasalahan energi. Selain itu, data dari setiap sensor dikumpulkan menggunakan protokol Message Queuing Telemetry Transport (MQTT) untuk memudahkan pemantauan pengiriman data sensor dan informasi daya baterai. Hasil pengujian menunjukkan bahwa integrasi protokol LEACH pada JSN dapat dilakukan pada setiap tahapnya, mulai dari Discovery-State, Steady-state, hingga Setup-State. Langkah-langkah ini bertujuan untuk secara signifikan mengurangi konsumsi energi pada node sensor sebesar 13% selama 12 jam pengujian. Selain itu dapat memperpanjang masa pakai baterai, dan juga meningkatkan efisiensi keseluruhan sistem.

Kata Kunci : *Smart Agriculture, Jaringan Sensor Nirkabel, LEACH, Internet of Things, Penghematan Energi*

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1. Introduction

The widespread adoption of various Internet of Things (IoT) technologies has significantly improved people's lives. IoT has been implemented in various fields, including government, healthcare, livestock, and notably, agriculture (Dwiyatno, et al., 2022). One example of IoT application in agriculture is the implementation of Smart Agriculture systems. These systems can monitor the conditions of crops and transmit data directly via the internet (Sulistiyo, 2019). In a study conducted by Dwiyatno, et al. (2022), they developed a smart agriculture system for monitoring and irrigating plants based on IoT. In their research, the smart agriculture system created could perform remote monitoring via the internet and automate plant irrigation. However, the system had a limitation regarding connectivity. IoT devices require reliable and stable network connections to transmit and receive data. Connectivity becomes limited when the size of the farm is extensive. Thus, it becomes challenging to access and transmit data from sensors on IoT devices due to limited internet coverage.

The connectivity issues in IoT can be addressed by building a Wireless Sensor Network (WSN) architecture. WSN can be utilized in environments that demand data collection from sensors and wireless data transmission to central nodes or gateways. This network architecture can help overcome connectivity challenges by extending communication beyond the reach of traditional communication technologies, such as Wi-Fi or cellular networks. Additionally, this system can be used to create a mesh network. Each sensor node communicates with the nearest node to provide data to the central node or gateway. This way, the system can provide a robust communication path and ensure data delivery (Gulati, et al., 2022).

One of the main challenges faced in using WSN in agriculture is high power consumption, which can reduce the battery life of devices. The LEACH (Low-Energy Adaptive Clustering Hierarchy) protocol has been recognized as an efficient method for managing wireless sensor networks to conserve energy (Dhawan & Waraich, 2014). Previous research has shown the significant potential of using the LEACH protocol to optimize energy usage in WSNs. However, implementing the LEACH protocol in the domain of Smart Agriculture systems also poses substantial issues related to power consumption in WSN devices, which require the proper algorithmic flow to ensure optimal energy utilization (Berlianto, et al., 2021).

Furthermore, the IoT protocol used is the Message Queuing Telemetry Transport (MQTT) protocol. This protocol is utilized to activate devices and facilitate data transmission/reception. MQTT is highly suitable for IoT applications due to its lightweight and efficient design, with small code footprint and minimal network bandwidth requirements. It also simplifies IoT technology development by facilitating sensor module installation (on the client side) and supporting multi-platform capabilities on the publisher side (Vijayaraghavan, 2020).

The implementation of the Wireless Sensor Network (WSN) architecture with the integration of the LEACH protocol within the scope of Smart Agriculture systems is a crucial step in addressing connectivity and energy consumption challenges in IoT networks. Through this strategy, it is expected that the recurring issues related to connectivity difficulties and high power usage in sensors can be more effectively resolved. The development of the LEACH protocol, particularly in the context of Smart Agriculture, is anticipated to deliver significant energy savings for each sensor device utilized. With this optimization, energy usage in sensors can be minimized, battery life extended, and overall system efficiency enhanced. This innovation represents a vital step in building the technological foundation that supports smart and sustainable agriculture, enabling more effective management, accurate monitoring, and informed decision-making to support sustainable agricultural productivity.

2. Discussion

This research method takes the form of an experimental approach utilizing quantitative methods, as depicted in Figure 1. The initial step involves identifying issues through a literature review to uncover field and technological aspects that have not been explored to address existing problems. In the Design and Implementation phase, an analysis of the proposed system's requirements is conducted to address the identified issues. Additionally, the design and development of a prototype are undertaken. The final phase emphasizes Testing, which involves unit testing techniques, examining the performance of each unit or component within the system separately.

Figure 1. Research Method

2.1. Problem Identification

Smart Agriculture is a directed and automated information technology application using Internet of Things (IoT) technology. This solution emerges as a response to challenges such as water wastage, lack of soil fertility monitoring, excessive fertilizer misuse, as well as climate change or other plant diseases. The utilization of IoT technology integrated with wireless sensor networks provides an effective solution to transform conventional agriculture into smart agriculture. This system will provide information on irrigation and intelligent decision-making services based on real-time data from the field (Sulistiyo, 2019) (Nasution, et al., 2019).

Wireless sensor networks are a wireless network using sensors that work together to monitor specific conditions such as temperature, sound, light, pressure,

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and others. A wireless sensor network is a sensor network consisting of sensor nodes deployed at various points and capable of communicating wirelessly. So, the simple concept of a wireless sensor network is based on the functions of sensing, CPU, and Radio (Gulati, et al., 2022).

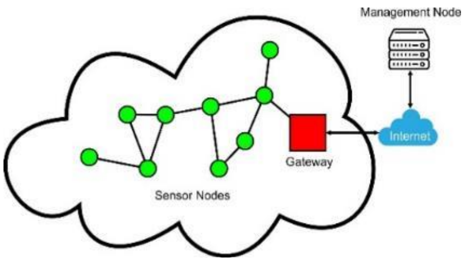

Figure 2. Wireless Sensor Network Structure

As illustrated in Figure 2, wireless sensor networks generally consist of several sensor nodes and a central coordinator node. All information is sent to the coordinator node directly from one sensor node through other nodes as relays within the network. Sensor nodes are the most crucial components in a wireless sensor network because it is from these nodes that sensor data information is collected, converted into digital information, processed, and then transmitted as processed data (Bajaj, et al., 2020).

WSNs involve sensors that typically work continuously to collect data and transmit it to a central node or gateway. This process requires significant power, primarily because the sensors often need to be active continuously or periodically to gather information from their surrounding environment. In the context of agriculture, where WSNs are used to monitor crops or the agricultural environment, this high energy demand can be a constraint as it may reduce the battery life of the sensors or require additional energy sources (Chen, et al., 2012). Strategies such as the use of energy-efficient protocols like LEACH are ways to address the issue of high energy consumption in WSNs (Dhawan & Waraich, 2014) (Al Tahtawi, et al., 2021).

Low Energy Adaptive Clustering Hierarchy (LEACH) is a popular and widely used protocol in Wireless Sensor Networks (WSNs). This protocol is designed to reduce energy consumption in sensor nodes in the network, thus extending its operational lifespan. As illustrated in Figure 3, WSNs typically consist of a number of small sensor nodes with limited resources deployed to collect and transmit data from the monitored area (Urdiain, 2012).

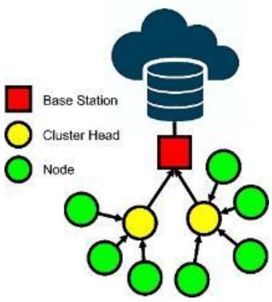

Figure 3. LEACH Protocol

LEACH is effective in extending the lifespan of Wireless Sensor Network (WSN) by minimizing the energy expenditure of sensor nodes. By rotating the cluster head roles, energy consumption is distributed more evenly, preventing certain nodes from quickly draining their batteries. Additionally, the use of data aggregation reduces the amount of data transmitted, thereby focusing node energy solely on communication (Anzola, 2018).

The Wireless Sensor Network (WSN) system to be implemented in the context of Smart Agriculture consists of various sensors, such as temperature and air humidity sensors, as well as soil moisture sensors. To improve energy efficiency in this system, the LEACH protocol will be implemented on the deployed sensors. Through this protocol, sensors can manage communication more efficiently, optimize energy usage, and enable energy-efficient data transmission to the base station. The WSN will act as a publisher that sends data from the base station to the MQTT Broker and stores the data. The stored data can be accessed via an Android device by subscribers. With the integration of the LEACH protocol, it is expected that energy usage in the sensors can be optimized, battery life extended, and overall energy consumption reduced in the WSN system for Smart Agriculture (Vijayaraghavan, 2020).

2.2. Design & Implementation

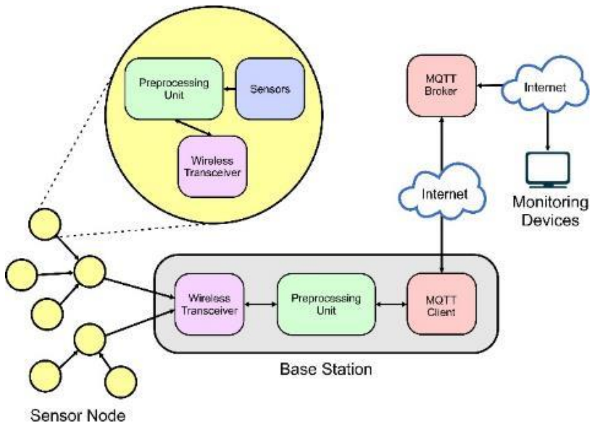

Figure 4. Smart Agriculture Architecture

The designed Smart Agriculture system consists of three important components. As seen in Figure 4, these essential components include the Sensor Node, Base Station, and MQTT Protocol. The role of the sensor node is to collect data from its surrounding environment through the deployed sensors, such as temperature, humidity, or other relevant parameters. After gathering data, the sensor node performs initial processing for data preprocessing before transmitting it to the base station. The processed data is then wirelessly transmitted to the base station or central node, where further analysis is conducted. Additionally, the sensor node is responsible for managing power usage efficiently, crucial for maintaining the limited battery life. The addition of the LEACH protocol to the sensor node is essential as it can

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help optimize energy usage, regulate sensor node sleep modes, and organize sensor clustering to significantly reduce power consumption, thus contributing to extending the battery life of the sensor node.

Base station within WSN architecture serves as a pivotal hub for data collection from interconnected sensors. Its primary tasks include aggregating data from multiple sensors, conducting initial processing and analysis, managing network activities, and facilitating external communication with other systems or devices. Acting as a central control point, the base station enables the exchange of processed information, regulates data collection schedules, and coordinates responses to environmental changes, playing a critical role in orchestrating the flow of information within the sensor network.

The data collected at the Base Station will be transmitted to the database via the MQTT Protocol. The MQTT Client on the Base Station will send the processed data through the MQTT Broker to store it in the cloud. There, we can also perform monitoring through other devices/platforms.

a. Base Station Architecture

Table 1. Base Station Component

No	Name	Type
1	NodeMCU ESP8266	Microcontroller
2	nRF24L01	Transceiver
3	5V Single-Channel Relay Module	Actuator
4	Water Solenoid Valve	Actuator

The Base Station consists of two main devices: the Node MCU and the nRF24L0. The Node MCU is responsible for transmitting data from the node to the MQTT Broker. Meanwhile, the nRF24L0 is responsible for communication between each JSN node (Shobrina, et al., 2018). Figure 5 illustrates the design of the Base Station using the Node MCU. Additionally, the Base Station will also have a relay connected to a solenoid valve. Its function is used to control the opening/closing of water flow. The schematic overview of the base station can be seen in Figure 5, and the equipment details are provided in Table 1.

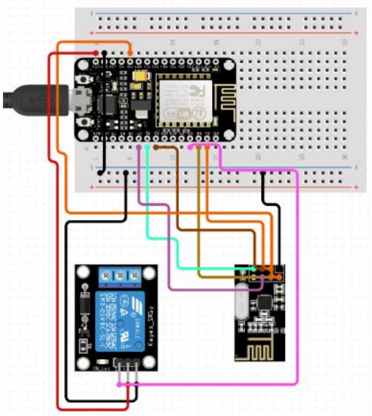

Figure 5. Base Station Schematic

b. Sensor Node Architecture

Table 2. Sensor Node Component

No	Name	Type
1	Arduino Mini Pro	Microcontroller
2	nRF24L01	Transceiver
3	DHT11	Sensor
4	Hygrometer YL-69	Sensor
5	INA219 or Voltage Divider	Sensor
6	LED	Actuator
7	Buzzer	Actuator
8	Battery 18650 1200 mAh	Battery

The sensor node will be equipped with several sensors, including temperature sensor, air humidity sensor, and soil moisture sensor. Additionally, a power detection sensor will be added to detect the power consumption of each node, allowing periodic monitoring of device power. This power sensor is used to determine which node will be designated as the Cluster Head. Furthermore, an LED will be provided as an indicator to identify which node is selected as the Cluster Head. The schematic overview of the sensor node can be seen in Figure 6, and the equipment details are provided in Table 2.

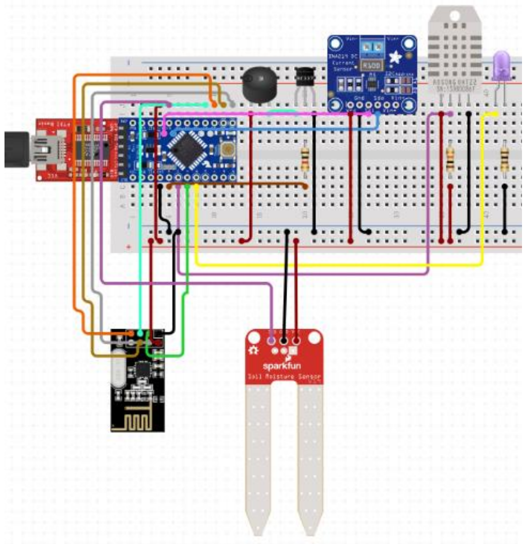

Figure 6. Sensor Node Schematic

c. Sensor Node Protocol Network Architecture

According to the research conducted by Berlianto et al. (2021), the phases in the LEACH protocol can be divided into three main phases:

1) Discovery Phase: This phase marks the beginning of the LEACH protocol operational cycle. During this stage, each sensor node determines whether it will become a cluster head or not by considering the probability based on its energy level. These nodes send advertisement messages to other nodes in the network to announce their capability as cluster heads. Nodes receiving these messages consider this information in deciding their roles within the network.

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2) Steady-State: After the Discovery Phase, the network enters the Steady-State phase. In this phase, cluster heads and other nodes have been determined. Cluster heads are responsible for gathering data from nodes within their cluster and forwarding it to the base station. Other nodes function as data transmitters or receivers, collecting environmental data and communicating with cluster heads.
3) Setup-State: This phase occurs when the LEACH operational cycle restarts. Nodes in the network recalculate their probabilities of becoming cluster heads and decide their roles for the next operational cycle. This phase provides opportunities for new nodes that may have sufficient energy to become cluster heads in the next cycle.

Each phase plays a specific role in the operation of the LEACH protocol. The Discovery phase enables the initial determination of cluster heads, the Steady-State phase is the main operational phase where data collection and communication occur, while the Setup phase prepares the network for the next operational cycle. This process repeats in the operational cycle of wireless sensor networks using the LEACH protocol to organize and manage clusters within the network with high energy efficiency.

d. System Implementation

As seen in Figure 7, the Sensor nodes are constructed according to the schematic shown in Figure 6, with an emphasis on the design allowing communication between nodes. In our implementation, we created 10 sensor nodes capable of wireless communication with each other. On the other hand, our base station is designed using the nRF24L01 module equipped with a transceiver antenna. The selection of this module was made considering enhancing signal range, allowing broader and more effective communication between the base station and sensor nodes. Thus, the base station acts as a communication hub that receives and transmits data between the sensor nodes and the wider system.

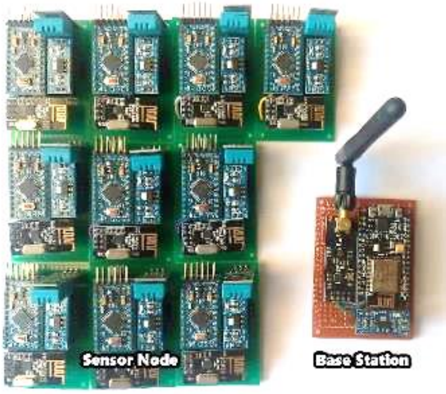

Figure 7. Sensor Node & Base Station Implementation

2.3. Testing

The testing conducted included the functionality of the Wireless Sensor Network (WSN) in sending data to the Base Station (as shown in Figure 8). Additionally, the implementation of the LEACH protocol was assessed for its proper functioning. A total of 10 sensor nodes were tested, which were designated as cluster nodes and sensor nodes. The results of the testing are summarized in Table 3 below.

Figure 8. Testing Process

Table 3. Functional Testing Results

No	Testing	Expected Results	Status
1	Determination of initial node (Discovery-State)	All nodes are given an initial address	Success
2	Sending data to Base Station (Steady-State)	All data on each cluster node is received at the Base Station	Success
3	Performing Cluster Head setup (Setup-State)	Determine the Cluster Head	Success
4	Changing Cluster Head (Setup-State)	Cluster Head changes to another cluster	Success
5	Sending data back after the Cluster Head is different (Steady-State)	All data on each cluster node is received at the Base Station	Success
6	Sending (Publish) data from Base Station to MQTT broker	Data can be received at the Broker	Success

The LEACH protocol implementation on the Wireless Sensor Network (WSN) has been successful. Changes in cluster nodes are indicated by the LED indicators on the devices, as seen in Figure 9. If the LED indicator on the device is lit, then that device functions as a Cluster Head. Due to the maximum connection limit of the nRF24L0 module being 5 child nodes, there are 2 Cluster Heads on this device. Data transmission on each node operates smoothly. Additionally, data transmission from the base station to the MQTT Broker can be achieved, allowing data to be monitored through the MQTT Dashboard or other platforms.

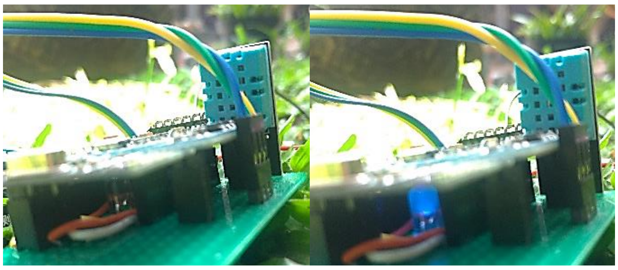

Figure 9. LED Light Indicator

An issue arises when nodes considered as candidates for becoming cluster heads cannot be reached by the signal from the base station, as depicted in Figure 10. Only nodes within the reach of the base station have the opportunity to become cluster heads. This constraint hinders the process of selecting cluster heads because nodes outside the base station's range cannot participate in this role. Consequently, the formation of clusters within the network becomes limited, involving only a small portion of nodes, while nodes beyond the base station's range will never become cluster heads. This situation can reduce the efficiency and overall performance of the wireless sensor network. Therefore, a solution to consider is expanding the signal range of the base station or exploring alternative strategies for assigning cluster heads, as done in the research by Dhawan & Waraich (2014), to ensure the availability of a sufficient number of nodes for this critical role in the network.

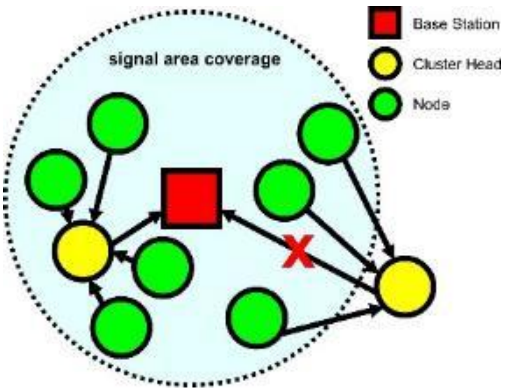

Figure 10. Cluster Head Candidate Beyond Base Station Reach

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The performance of the LEACH protocol is evaluated by comparing it with conventional hierarchical protocols, which use static clustering. The system will run for the same duration, which is 12 hours, and the power consumption difference for each protocol will be measured. The test results, as shown in Figure 11, indicate that the Cluster Head tends to degrade faster, resulting in the depletion of the Cluster Head node's battery life sooner. The battery reduction in the Cluster Head is 27%. Unlike the LEACH protocol, there is no node exchange in the conventional protocol. Consequently, when the Cluster Head's power is depleted, the system will not operate optimally.

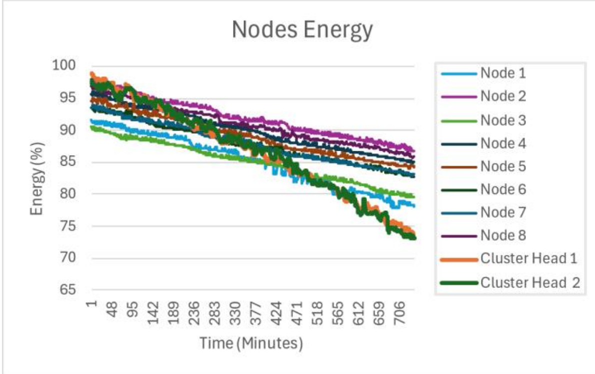

Figure 11. Energy Consumption Using Static Clustering

As seen in Figure 12, the graph shows a cone-shaped line depicting the dynamic change of Cluster Head nodes. The node change process will be scheduled every 15 minutes by selecting the node with the highest energy. The average energy consumption of the LEACH protocol is 13%. Compared to the results in Figure 11, the LEACH protocol can save power consumption by 14% over a 12-hour system operation. This is because the LEACH protocol allows the rotation of the Cluster Head, thus distributing the energy more efficiently among the devices. These results may vary depending on the number of nodes implemented and the type of hardware used in the system. Therefore, the use of the LEACH protocol in WSN can significantly improve energy efficiency, extend battery life, and enhance the overall system efficiency.

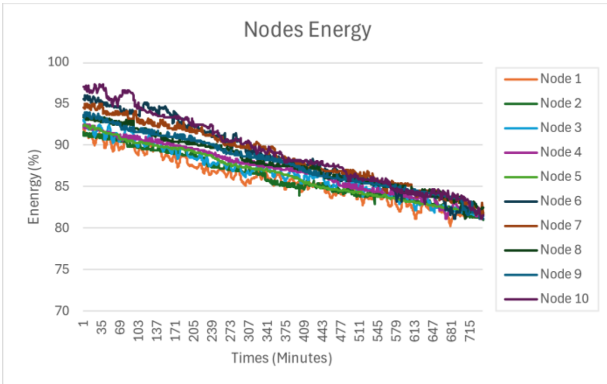

Figure 12. Energy Consumption Using LEACH

3. Conclusion

Efficient energy usage in sensor devices is a crucial aspect of the overall smart farming system. The implementation of the LEACH protocol, which can reduce the power consumption of these sensors, not only enables energy savings but also extends the device lifespan, reduces maintenance costs, and enhances the availability of necessary data for farmers to make more informed decisions. Integrating LEACH into Smart

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Agriculture Systems could be a significant milestone in improving energy efficiency in wireless sensor networks on a broader scale in modern agriculture.

Although LEACH has proven to significantly reduce energy consumption in various sensor applications, adaptation to the ever-changing agricultural environment poses challenges. Weather conditions, variations in plant types, land topography, and other environmental fluctuations influence the power requirements of these sensors. Therefore, further research is needed to optimize both the devices and the LEACH protocol to adapt to dynamic agricultural environmental conditions.

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