Implementation of Heed Routing Protocol in Lora-Based Wireless Sensor Network

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***Abstract*— Wireless Sensor Networks have become a major subject in the development of efficient and wide-ranging monitoring systems. There are several things that need to be considered in the running of WSN, especially in energy consumption. Without energy- efficient techniques, the battery energy source in the nodes will be depleted in a short time. This causes the lifetime of WSN to be very short and cannot meet the needs of the system. Effective routing protocols are key in improving the performance of these sensor networks. One protocol that has attracted attention is HEED (Hybrid Energy-Efficient Distributed), which has been shown to minimize energy consumption and increase network lifetime. The application of HEED to LoRa-based sensor networks can extend the communication range and efficiency in data transmission. The results of this study show the effectiveness of implementing the HEED routing protocol system to measure energy consumption on LoRa devices. In testing 4 LoRa networks in experiments every 10 minutes to 1 hour using the HEED Routing Protocol shows that battery usage is more efficient and on average reduced by 3% compared to without the protocol it is more wasteful and the average usage is reduced by 5%.**

Keywords*— *Energy Efficiency, HEED Routing Protocol, IoT, LoRa, WSN.

I. INTRODUCTION

Wireless Sensor Network (WSN) is a network that has many low-power sensor nodes placed in a certain area with at least one base station [1]. In WSN, the position of the nodes is not predetermined which allows the formation of an autonomous network organization. There are several things that need to be considered in the running of WSN, especially on energy consumption. Without energy-efficient techniques, the battery energy source of the nodes will be depleted in a short time [2]. This causes the lifetime of WSN to be very short and may not meet the needs of the WSN system when placed in remote areas [3].

Long Range (LoRa) is one of the wireless-based communication media that provides long-distance and low-power communication [4]. LoRa has resistance to unwanted signal interference that is always present in the process of sending data on LoRa which can later interfere with the process of receiving data or sending data [5]. One of the first clustering protocols discovered and very popular is LEACH (Low Energy Adaptive Clustering Hierarchy). LEACH forms clusters with a distribution algorithm where each node has an equal opportunity to become a Cluster Head without centralized control [6]. LEACH has inspired various developments of hierarchical-based routing protocols in WSN, one of which is the HEED (Hybrid Energy Efficient Distribute) protocol. Hybrid Energy-Efficient Distributed (HEED) protocol is a cluster-based routing with multi-hop communication at the cluster head [7].

This research proposes the implementation of the HEED routing protocol in LoRa-based WSN. Based on research that analyzes the comparison of power consumption in the HEED and LEACH routing protocols, the HEED Protocol requires less energy consumption than the LEACH Protocol so that the network lifetime is higher and has an impact on the maximum amount of data sent [8]. This system is implemented with the aim of improving network performance and efficiency on each WSN node with LoRa module devices.

The HEED (Hybrid Energy-Efficient Distributed) algorithm is an algorithm for energy management in wireless sensor networks (WSNs). In this algorithm, the cluster head is adaptively selected based on the node's energy level and the probability of selection [9]. In the HEED (Hybrid Energy-Efficient Distributed) algorithm, CHprob and Cprob are probabilities used to determine whether a node will become a Cluster Head (CH) or become a member of an existing cluster (Cluster Member) [10]. The formula used in the HEED algorithm is as follows:

1. CHprob (Cluster Head Probability) :

To determine the CHprob value in the HEED algorithm, we can use the following Equation (1):

$$CHprob = P \times (1 - (r \bmod p)) \quad (1)$$

Where :
P is the initial CHprob value
r is the number of neighboring nodes that are not yet CHs

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p is the total number of nodes in the network.

2. Cprob (Cluster Member Probability) :

To determine the Cprob value in the HEED algorithm, it is necessary to understand that Cprob is the probability that a sensor node will join a particular cluster. Using the following Equation (2):

$$\text{Cprob} = (1 - \text{CHprob}) \times (r/p) \quad (2)$$

Where :

CHprob is the probability value that the sensor node will become a cluster head

r is the number of neighboring nodes that have not yet become CH

p is the total number of nodes in the network.

Wireless Sensor Network (WSN) is a very popular network in various fields such as the defense field, health service field, smart city field, etc. In the Wireless Sensor Network there are base stations and nodes to collect data that has been obtained from nodes and analyze these results, while nodes are used to capture various information [11]. Wireless Sensor Network (WSN) technology is often used in terms of monitoring an object such as monitoring traffic control, pipeline monitoring, active volcano, underground mining [12]. LoRa is a wireless technology used to establish a remote communication link. LoRa's communication range is so far that it reaches several tens of kilometers. So communication between a station and its gateway can be done with only one range [13].

II. METHOD

A. System Design

The type of research conducted uses methods with a quantitative approach. Quantitative methods are used for the measurement of network parameters such as the number of nodes, battery power level, node density, and node movement patterns to understand their effect on protocol performance. The results of this study can provide insight into the effectiveness and efficiency of HEED in various network conditions. This research starts from the formulation of the problem to the conclusion which forms a systematic flow. Hybrid Energy- Efficient Distributed Routing Protocol is a multi-hop cluster-based routing protocol that aims to create well-distributed clusters that lead to evenly distributed energy consumption making the network lifetime longer [14].

In addition, the system design defines the structure of the wireless sensor network and the communication mechanism between sensor nodes and the base station. Each node operates autonomously while exchanging information with neighbouring nodes to support the cluster formation process based on residual energy and communication cost. This design allows the network to perform data transmission efficiently through cluster heads, ensuring balanced energy usage and improved network performance.

The stages of research are made to detail the stages of making tool devices to the tests carried out so that sequential results are obtained. Literature study as a reference and comparison material in making the application of the HEED routing protocol for energy efficiency in wireless sensor networks. Then, making the system by implementing the system in accordance with the system design that has been made by implementing the HEED routing protocol for energy saving and network efficiency. Before performing these steps, it is necessary to make a system design as shown in Figure 1.

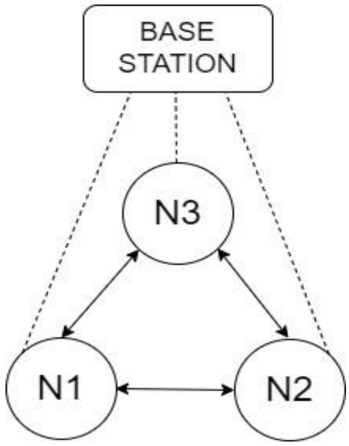

Figure 1. System design

In the system design, there are 3 sensor nodes connected to each other to exchange information and 1 other node as a base station for receiving data. The three nodes will take turns as the CH. Then, each sensor node will communicate with the Cluster Head to send the data they collect. The HEED protocol will be used to select the Cluster Head in the network. Then, each sensor node will consider its own energy level and the energy level of its surrounding neighbours. Sensor nodes with higher energy levels have a greater possibility of becoming the Cluster Head. In this topology, the CH node of the Cluster Head selected by the HEED protocol then transmits directly to the base station.

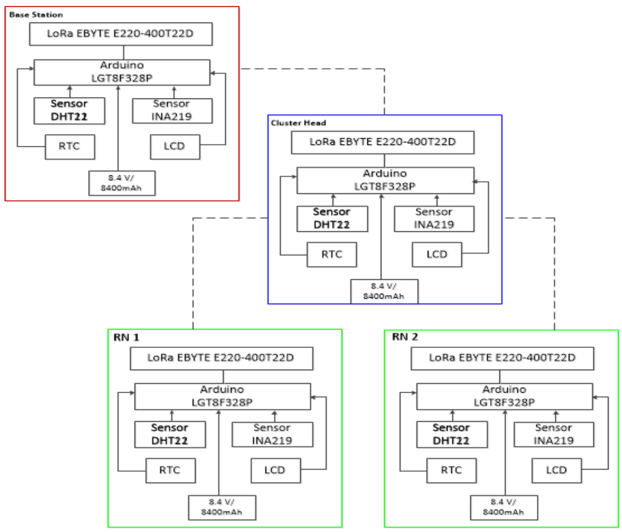

Figure 2. Block diagram

In the system block diagram as shown in Figure 2, the sensor node functions to perform sensing or measurement on the battery using the INA219 sensor and the DHT22 sensor functions to detect temperature and humidity data on each node. Then all the data collected on the node will be sent to the CH using LoRa communication. CH receives data sent by sensor nodes via LoRa. In addition to transmitting data from sensor nodes, the CH also sends data from sensor readings to the base station. The Figure shows that all sensor nodes can take turns being CH according to the energy conditions of each node.

The block diagram illustrates the hierarchical communication structure consisting of the base station, cluster head (CH), and regular nodes (RN). Each node is equipped with a microcontroller, sensing modules, and a LoRa EBYTE E220-400T22D transceiver, enabling low-power long-range communication. The base station functions as the central data collection point, where data forwarded by the CH are received for monitoring and analysis purposes. This architecture supports efficient data aggregation and transmission while reducing energy consumption at individual nodes, thereby extending the overall network lifetime.

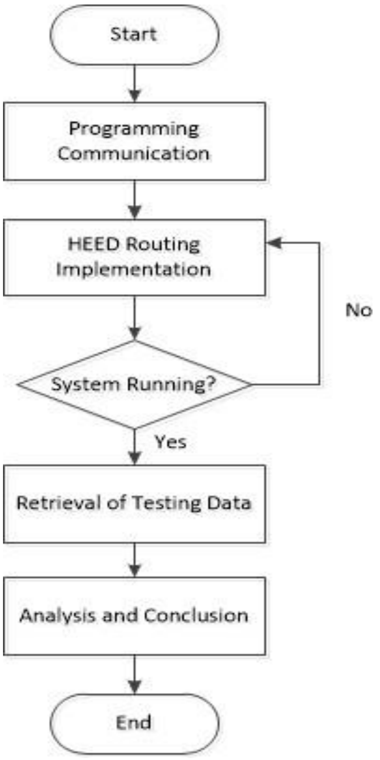

Figure 3. Flowchart system

The flowchart as shown in Figure 3 that to start working on the system, first the design and application for the system is built, in addition to the system, node programming is carried out which functions as a place to store packet delivery routes in the system. After designing and implementing the system built, then make an implementation for the HEED route. Furthermore, verification is carried out whether the system made is running correctly or not. This is done by checking the results obtained whether the system can communicate well with each other according to the routing used. After the test is carried out, the data obtained is taken and analysed and the conclusion is drawn.

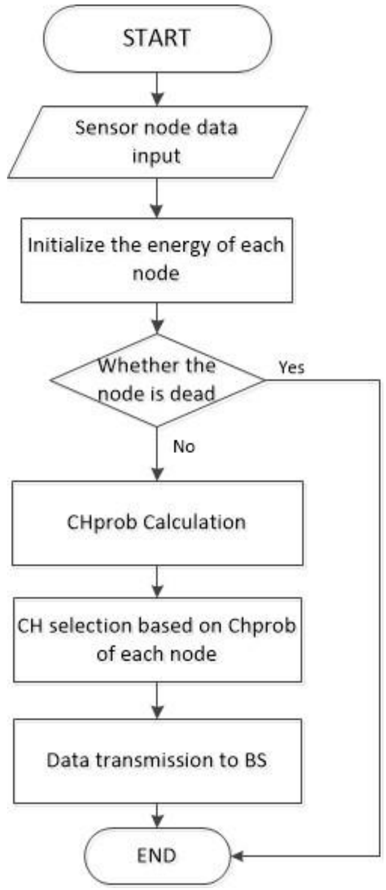

Figure 4. Implementation flowchart

Based on the flowchart stages as shown in Figure 4, it starts with inputting data from sensor nodes. Then, initialize the energy of each node. After that, each node calculates CHprob before determining the Cluster Head. Each node decides whether to become a Cluster Head or not during that session. If yes, then that CH node will receive data information from each node. Then, the CH node will transmit the data to the Base. If a node is dead, data will not be automatically transmitted and will wait for the next CH replacement session for the next data transmission. The CH selection itself is also based on the energy level and CHprob of each node.

III. RESULTS AND DISCUSSION

A. System Prototype Design Results

The results of the hardware implementation in this study are 4 nodes consisting of Node 1, Node 2, Node CH, and Node Base. In each Node there are several components such as Arduino LGT8F328P which is used as a data processing place and will be sent to the LoRa EBYTE E220-400T22D device, then the DHT22 sensor as a temperature sensor used as data to be sent, INA219 sensor as a sensor used to measure current and voltage on the battery, RTC as a tool to store and calculate the time of sending data accurately and there is an LCD in each node as a data display or serial monitor. Then, at the Node Base there is no DHT22 sensor and INA219 sensor because it only functions as a receiver. It showed at Figure 5 and 6.

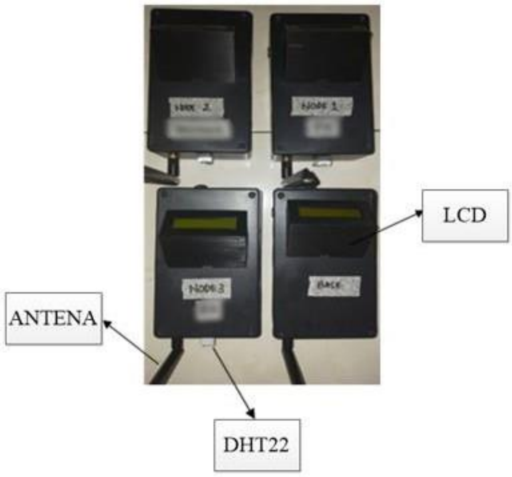

Figure 5. Results of overall node implementation

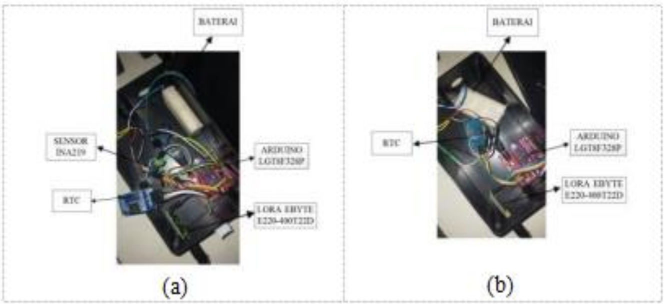

Figure 6. Inner node implementation results inside view

B. System Testing Results

a. Testing Nodes without HEED Routing Protocol

Functional testing conducted on nodes operating without the HEED (Hybrid Energy-Efficient Distributed) routing protocol is intended to verify that each node or device can operate correctly and reliably in the absence of any routing-based optimization mechanism. This testing scenario is essential to establish a baseline performance, ensuring that the fundamental communication functions of the nodes are not inherently dependent on the HEED routing protocol for successful data transmission.

During this testing phase, the embedded program was executed simultaneously on all participating nodes, specifically Nodes 1, 2, and 3. Each node was configured to transmit data packets directly to the destination node, referred to as the Base Node, without utilizing intermediate nodes or routing decisions provided by the HEED protocol. This direct communication approach allows for an objective assessment of the network's basic operational capability, including node responsiveness, transmission reliability, and baseline energy consumption.

The results obtained from this testing process provide valuable insights into the overall effectiveness of the network topology when routing intelligence is excluded. Furthermore, the observed transmission behaviour enables an evaluation of energy usage patterns associated with direct data delivery, which serves as a critical reference point for subsequent comparisons with HEED-based routing implementations. The detailed outcomes of this functional testing are illustrated in Figures 7, 8, and 9, which present the communication performance and energy utilization characteristics observed during the experiment.

```
21:45:20.327 -> NODE 1 READY!
21:45:39.381 -> ===== BATT CHECK =====
21:45:39.381 -> Bus Voltage:   6.10 V
21:45:39.414 -> Battery Status:   17%
21:45:39.446 -> =====================
21:45:39.446 -> Shunt Voltage: 0.19 mV
21:45:39.480 -> Load Voltage:  6.10 V
21:45:39.531 -> Current:       2.00 mA
21:45:39.545 -> Power:         11.00 mW
21:45:39.545 -> =====================
21:45:39.604 -> =============================================
21:45:39.670 -> DHT: 77% | 28 C
21:45:39.670 -> Send message! ==> 200:1:28:77:000 ==> BASE NODE   ==>  Success
```

Figure 7. Node 1 Sends to base node

```
21:45:37.921 -> NODE 2 READY!
21:45:56.941 -> ===== BATT CHECK =====
21:45:56.941 -> Bus Voltage:   7.68 V
21:45:57.021 -> Battery Status:   74%
21:45:57.022 -> =====================
21:45:57.022 -> Shunt Voltage: 6.23 mV
21:45:57.038 -> Load Voltage:  7.69 V
21:45:57.070 -> Current:       65.10 mA
21:45:57.102 -> Power:         501.00 mW
21:45:57.134 -> =====================
21:45:57.134 -> =============================================
21:45:57.198 -> DHT: 79% | 28 C
21:45:57.198 -> Send message! ==> 200:2:28:79:000 ==> BASE NODE   ==>  Success
```

Figure 8. Node 2 send to base node

```
21:50:59.477 -> NODE 3 READY!
21:51:18.594 -> ===== BATT CHECK =====
21:51:18.594 -> Bus Voltage:   7.40 V
21:51:18.627 -> Battery Status:   64%
21:51:18.659 -> =====================
21:51:18.659 -> Shunt Voltage: 6.52 mV
21:51:18.692 -> Load Voltage:  7.41 V
21:51:18.725 -> Current:       67.50 mA
21:51:18.757 -> Power:         505.00 mW
21:51:18.789 -> =====================
21:51:18.789 -> =============================================
21:51:18.854 -> DHT: 75% | 29 C
21:51:18.854 -> Send message! ==> 200:3:0:0:000 ==> BASE NODE   ==> Success
```

Figure 9. Node 3 send to base node

The results of the functional testing conducted on Nodes N1, N2, and N3 indicate successful operational performance, as illustrated in the corresponding figure. The visualization demonstrates that all nodes were in a ready state prior to transmission, confirming that each node was properly initialized and capable of executing the assigned communication tasks. In addition, the system successfully recorded information related to power and energy consumption for each node during the data transmission process.

Furthermore, the testing results show that data packets generated by Nodes N1, N2, and N3 were transmitted successfully and received by the Base Node without any transmission failure. This confirms the reliability of direct node-to-base communication under the tested conditions. The availability of energy usage data for each transmission also provides important insight into the energy characteristics of the network when routing protocols are not applied. The detailed output of this testing process, including node readiness, energy measurements, and successful data delivery to the Base Node, is presented in Figure 10.

```
21:59:44.983 -> Node Base . . .Ready !
21:59:53.964 -> RSSI: -48
21:59:53.964 -> ================================================
21:59:54.074 -> Message:
21:59:54.079 -> Node                ==> 3
21:59:54.080 -> Temperature         ==> 29 C
21:59:54.080 -> Humidity            ==> 75 %
21:59:54.093 -> ================================================
21:59:58.316 -> RSSI: -52
21:59:58.316 -> ================================================
21:59:58.348 -> Message:
21:59:58.380 -> Node                ==> 2
21:59:58.411 -> Temperature         ==> 28 C
21:59:58.444 -> Humidity            ==> 78 %
21:59:58.444 -> ================================================
22:00:12.048 -> RSSI: -57
22:00:12.048 -> ================================================
22:00:12.081 -> Message:
22:00:12.113 -> Node                ==> 1
22:00:12.145 -> Temperature         ==> 28 C
22:00:12.178 -> Humidity            ==> 77 %
```

Figure 10. Base node successfully receives message

The results of the Base Node testing are presented in the corresponding figure, which demonstrates that the Base Node successfully received data transmitted directly from the sensor nodes without the implementation of the HEED routing protocol. This outcome confirms that the communication system can support direct data transmission and reception under non-routing conditions, thereby validating the fundamental functionality of the network architecture.

The serial monitor output on the Base Node displays the received sensor data obtained from the DHT22 module, including temperature and humidity measurements, along with the associated signal strength recorded during the transmission process. The availability of signal strength information provides additional insight into the quality and reliability of the wireless communication link between the transmitting nodes and the Base Node. Moreover, the LCD display on the Base Node visually confirms successful message reception by indicating that the transmitted data from each node has been correctly received and processed. Collectively, these observations verify the operational readiness of the Base Node and its ability to accurately acquire, display, and interpret sensor data in a network configuration that operates without HEED-based routing mechanisms.

b. Testing Cluster Head Determination in the HEED Routing Protocol

The testing process for determining the Cluster Head (CH) is carried out based on the test scenarios that have been previously designed and explained in the test scenarios sub-chapter. This test aims to evaluate how effectively the HEED routing protocol selects a Cluster Head by considering the residual energy (E_residual) of each node in the network. During this process, the HEED routing mechanism is initiated by broadcasting information related to the residual energy from all participating nodes. Based on this information, the value of CH probability (CHprob) is calculated to determine which node is most eligible to become the Cluster Head.

Cluster testing is performed by executing the embedded program on all sensor nodes, excluding the base node. Each node broadcasts its residual energy data using a message type 255 so that all nodes in the cluster can receive and process the same information. After all residual energy data have been successfully received, each node independently calculates the CHprob value according to the HEED algorithm. The node with the highest eligibility based on this calculation is then selected as the Cluster Head. Once the CH is determined, it sends a type 200 message to the destination node, indicating a forward message. This process occurs after all sensor data have been collected at the CH node, since the Cluster Head functions as an intermediary that aggregates data from member nodes before forwarding the complete data set to the Base Node.

```
16:22:56.531 -> ===== BATT CHECK =====
16:22:56.531 -> Bus Voltage:   6.51 V
16:22:56.562 -> Battery Status:   32%
16:22:56.596 -> ======================
16:22:56.596 -> Shunt Voltage: 5.04 mV
16:22:56.636 -> Load Voltage:  6.52 V
16:22:56.676 -> Current:       51.10 mA
16:22:56.710 -> Power:         333.00 mW
16:22:56.745 -> ======================
16:22:56.745 -> Broadcast Message ==> 255:1:32:000 ==> Success
```

Figure 11. Node 1 Successfully broadcasts message

```
16:22:58.004 -> Calculate & Save CHProb
16:22:58.004 -> CHProb        ==> -0.1000
16:22:58.004 -> CProb         ==> 0.7333
16:22:58.050 -> CH_Prob       ==> 0.5060
16:22:58.094 -> ================================
16:23:03.426 -> CH_Prob        ==> 0.51
16:23:03.511 -> CH Node        ==> 3
```

Figure 12. Node 3 Successfully becomes CH

```
15:08:46.529 -> Calculate & Save CHProb
15:08:46.562 -> CHProb        ==> -0.1000
15:08:46.562 -> CProb         ==> 0.7333
15:08:46.596 -> CH_Prob       ==> 0.0000
15:08:46.629 -> ============================
15:08:58.835 -> CH_Prob        ==> 0.49
15:08:58.875 -> CH Node        ==> 1
```

Figure 13. Node 1 Successfully becomes CH

The results of the testing process for Cluster Head (CH) determination are illustrated in Figures 11 through 13. As shown in Figure 11, the initial phase of the CH selection procedure involves broadcasting the residual energy information of each node. The experimental results indicate that the time required for all nodes to complete the energy broadcasting process is approximately one minute, ensuring that each node has sufficient time to disseminate its current energy status to neighbouring nodes.

Once all nodes have successfully broadcast their respective energy values, the subsequent phase requires each node to independently compute the CH probability (Chprob). This calculation is performed locally by each node and serves as the basis for determining eligibility to assume the role of Cluster Head. The decision-making process is therefore distributed, allowing the network to dynamically select a CH based on the computed probability values.

The results presented in Figure 12 demonstrate that Node 3 was selected as the Cluster Head following the initial computation of Chprob. Furthermore, repeated testing reveals that the CH role is not static and can change over time in response to variations in node conditions, particularly residual energy levels. This behaviour is illustrated in Figure 13, where Node 1 successfully assumes the role of Cluster Head, replacing Node 3. These results confirm the adaptive nature of the CH selection mechanism, highlighting its ability to dynamically redistribute the CH role among nodes to support balanced energy consumption and prolonged network lifetime.

```
23:26:57.647 -> DHT: 75% | 29 C
23:26:57.681 -> Send message! ==> 200:3:0:0:000 ==> CH NODE   ==>  Success
23:27:27.702 -> CH_Prob       ==> 0.49
23:27:27.734 -> CH Node       ==> 1

23:32:22.007 -> DHT: 78% | 28 C
23:32:22.045 -> Send message! ==> 200:2:28:78:000 ==> CH NODE   ==> Success
23:32:51.921 -> CH_Prob       ==> 0.49
23:32:51.953 -> CH Node       ==> 1
```

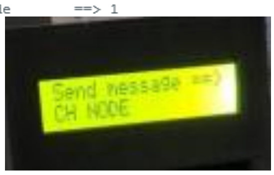

Figure 14. Nodes 2 and 3 send message to CH node

```
23:32:29.754 -> RSSI: -78
23:32:29.754 -> Incoming message:
23:32:29.754 -> 200:3:0:0:00
23:32:29.788 -> ================================================
23:32:29.819 -> Node                   ==> 112Temperature         ==> -19200 C
23:32:29.885 -> Humidity               ==> 1817 %
23:32:25.502 -> ================================================
23:32:55.423 -> RSSI: -80
23:32:55.423 -> Incoming message:
23:32:55.423 -> 200:2:28:78:00
23:32:55.455 -> ================================================
23:32:55.521 -> Node                   ==> 112Temperature         ==> -19200 C
23:32:55.553 -> Humidity               ==> 1817 %
```

Figure 15. CH node receive data

```
23:32:29.981 -> Forward message   ==> BASE NODE   ==>  Success
23:32:48.774 -> CH_Prob        ==> 0.49
23:32:48.774 -> CH Node        ==> 1
23:32:48.805 -> ================================================
23:32:48.838 -> DHT: 78% | 28 C
23:32:48.870 -> Send message! ==> 200:1:28:78:000 ==> BASE NODE   ==>
Success
```

Figure 16. Node CH forward to base

Based on the experimental results, Figure 14 illustrates that Nodes 2 and 3 successfully transmitted data messages to the Cluster Head (CH) node. This result confirms that the intra-cluster communication mechanism operates effectively, allowing member nodes to reliably deliver their data to the designated CH node. The successful transmission indicates that the network topology and communication parameters support stable data exchange between cluster members and the CH.

Furthermore, as shown in Figure 15, the CH node successfully received and processed data packets from each member node within the cluster. This outcome demonstrates the CH node's capability to function as a central aggregation point, collecting incoming data from multiple nodes without transmission errors. Subsequently, Figure 16 presents the successful forwarding of the aggregated data from the CH node to the Base Node. This result verifies that the CH node not only performs data reception and aggregation but also effectively relays the collected information to the Base Node, thereby completing the end-to-end communication process within the clustered network architecture.

c. Energy Usage Testing

This testing procedure was designed to evaluate the extent to which the Hybrid Energy-Efficient Distributed (HEED) routing protocol can optimize energy consumption in wireless sensor nodes operating within a LoRa-based network. By systematically measuring energy usage during network operation, the experiment provides a comprehensive assessment of the HEED protocol's influence on sensor battery performance. Such evaluation is essential for understanding how routing strategies contribute to prolonged sensor lifetime and improved efficiency in energy resource management within wireless sensor networks.

The energy consumption test was conducted by activating all sensor nodes simultaneously under identical initial conditions, with each node operating at a fully charged battery level of 100%. The nodes were then observed over a predefined operational period, during which energy consumption was recorded at regular time intervals. Measurements were taken every 10 minutes over a total duration of up to one hour, allowing for a detailed comparison of battery level degradation. Two operational scenarios were evaluated: one in which the network employed the HEED routing protocol and another in which data transmission was performed without any routing protocol.

This comparative approach enables a clear analysis of the energy efficiency gained through the implementation of the HEED protocol relative to direct transmission. The resulting data reveal the percentage of battery capacity reduction over time for each scenario, thereby highlighting differences in energy consumption patterns. The overall outcomes of this energy usage evaluation are summarized and illustrated in the accompanying diagram, which presents a visual comparison of energy performance under HEED-based routing and non-routing conditions.

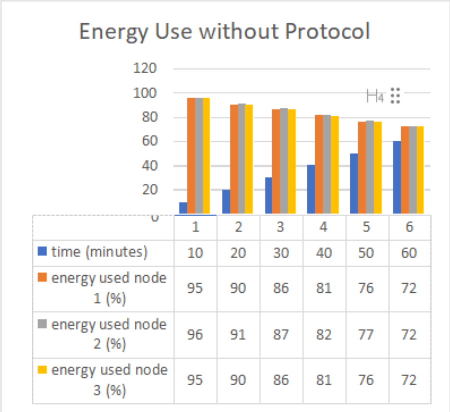

Figure 17. Energy Testing Results Diagram Without Protocol

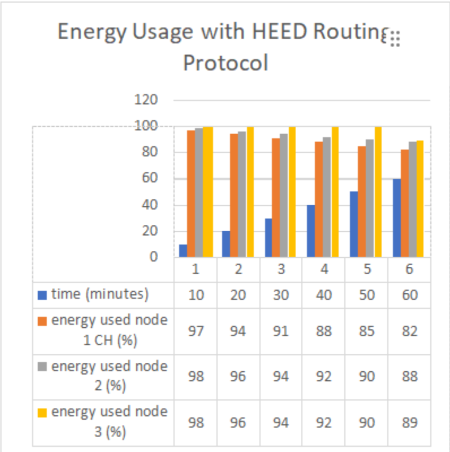

Figure 18. Diagram of Energy Testing Results with HEED Routing Protocol

Figures 17 and 18 present the comparative diagrams of energy usage test results obtained from experiments conducted without the HEED routing protocol and with the implementation of the HEED routing protocol, respectively. The diagrams illustrate the battery condition of each node over a one-hour operational period, with energy measurements recorded at 10-minute intervals and an initial battery level of 100% for all nodes. This testing framework enables a consistent and fair comparison of energy consumption behaviour under both routing and non-routing scenarios.

The experimental results demonstrate that when the HEED routing protocol is applied, ordinary sensor nodes experience an average battery reduction of approximately 2%, while Cluster Head (CH) nodes exhibit a slightly higher average reduction of around 3%. This difference is expected, as CH nodes are responsible for additional tasks such as data aggregation and forwarding, which naturally incur higher energy expenditure. Nevertheless, the overall energy consumption remains relatively low due to the HEED protocol's ability to select energy-efficient communication paths based on predefined Cluster Head selection criteria, thereby minimizing unnecessary transmission overhead.

In contrast, experiments conducted without the use of a routing protocol such as HEED show a significantly higher average battery reduction of approximately 5% across all nodes. In this non-routing scenario, the absence of coordinated Cluster Head selection and optimized communication paths results in less efficient data transmission. Node selection decisions tend to rely solely on individual energy levels without considering network-wide optimization, which can lead to suboptimal communication patterns and increased energy consumption. These findings highlight the effectiveness of the HEED routing protocol in reducing overall energy usage and improving energy efficiency in LoRa-based wireless sensor networks.

IV. CONCLUSION

The results of the research "Implementation of the HEED Routing Protocol on LoRa-Based Wireless Sensor Network" concluded that the HEED Routing Protocol shows success in selecting Cluster Heads on LoRa-based WSN. The implementation of the HEED protocol on LoRa can also help optimize energy usage. The results of energy usage experiments with the HEED routing protocol obtained an average value reduced by 3% more efficient than without using the HEED protocol which results in an average value reduced by 5% more wasteful. Therefore, choosing the right Cluster Head can help reduce energy consumption and improve communication efficiency in the network. In addition, the increased range and overhead reduction in LoRa has the characteristics of a wider range, and the HEED protocol can be optimized to take advantage of this feature to reduce protocol overhead, message delivery can be more efficient, even at longer distances.

REFERENCES

[1] A. R. Susanto, A. Bhawiyuga and K. Amron, "Implementasi Sistem Gateway Discovery pada Wireless Sensor Network (WSN) Berbasis Modul Komunikasi LoRa," Jurnal Pengembangan Teknologi Informasi Dan Ilmu Komputer, 2019.

[2] M. Eshaftri, a. Y. Al-Dubai, I. Romdhani and M. B. Yassien, "A New Energy Efficient Cluster based Protocol for Wireless Sensor Networks," Proceedings of the Federated Conference on Computer Science and Information Systems, 2015.

[3] M. Lutfi, P. H. Trisnawan and R. Primananda, "Implementasi Routing Statismenggunakan Media Komunikasi LoRa dan Websocket untuk Pengiriman Data dari Sensor ke Cloudpada IoT," Jurnal Pengembangan Teknologi Informasi dan Ilmu Komputer, 2021.

[4] A. R. Batong, P. Murdiyat and A. H. Kurniawan, "Analisis Kelayakan LoRa Untuk Jaringan Komunikasi Sistem Monitoring Listrik Di Politeknik Negeri Samarinda," PoliGrid, 2020.

[5] A. Augustin, J. Yi, T. Clausen and w. M. Townsley, "A Study of LoRa: Long Range & Low Power Networks for the Internet of Things," Sensors, 2016.

[6] W. Berlianto, A. S. Budi and M. H. H. Ichsan, "Implementasi Protokol LEACH pada Wireless Sensor Network dengan Perangkat berbasis nRF24L01," Jurnal Pengembangan Teknologi Informasi Dan Ilmu Komputer, 2021.

[7] M. Labrador and P. M. Wightman, Topology Control in Wireless Sensor Networks: with a companion simulation tool for teaching and research, 2009.

[8] F. F. Kusumastuti, I. Wahidah and R. Mayasari, "Analisis Perbandingan Konsumsi Daya dan Masa Hidup Jaringan pada Protokol Routing LEACH dan HEED di Wireless Sensor Network," Conference on Information Technology, Information System and Electrical Engineering.

[9] R. Priyadarshi, R. L. Singh and A. Singh, "A Novel HEED Protocol for Wireless Sensor Networks," International Conference on Signal Processing and Integrated Networks (SPIN), 2018.

[10] N. Aierken, R. Gagliardi and Z. Ullah, "RUHEED-Rotated Unequal Clustering Algorithm for Wireless Sensor Networks," International Conference on Advanced Information Networking and Applications Workshops, 2015.

[11] Z. Ullah, "A Survey on Hybrid, Energy Efcient and Distributed (HEED) Based Energy Efcient Clustering Protocols for Wireless Sensor Networks," Wireless Personal Communications, 2020.

[12] S. Chand, S. Singh and B. Kumar, "Heterogeneous HEED Protocol for Wireless Sensor Networks," Wireless Pers Commun, 2014.

[13] A. R. Batong, P. Murdiyat and A. H. Kurniawan, "Analisis Kelayakan LoRa Untuk Jaringan Komunikasi Sistem Monitoring Listrik Di Politeknik Negeri Samarinda," PoliGrid, vol. 1, no. 2, 2020.

[14] O. Younis and S. Fahmy, "A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks," IEEE TRANSACTIONS ON MOBILE COMPUTING.

[15] F. Zulianti, R. Munadi and I. H. Santoso, "SMART TRAFFIC LIGHT BERBASIS INTERNET OF THINGS PADA KESELAMATAN AMBULANS," e-Proceeding of Engineering, p. 5546, 2021.