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Enhanced DV-Hop algorithm for energy efficiency and network quality in wireless sensor networks

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Abstract
Wireless Sensor Networks (WSN) are wireless networks with many sensor nodes covering a relatively large area. One of the weaknesses of WSN is the use of relatively high energy consumption, which affects the quality of network services. Although the WSN network routing using the DV-Hop algorithm is widely used because of its simplicity, improvements need to be made to improve energy efficiency so that the network lifetime is more optimal. This article proposes an enhanced DV-Hop algorithm compared to other algorithms to improve network energy efficiency and quality of service. There are three approaches to improving the DV-Hop algorithm. First, the selection of the CH node is based on the distance to the Base Station so that the selected CH node does not have a long distance from the base station. Second, the selection of CH nodes must have a number of neighbouring nodes above the average of other sensor nodes. Finally, each selected CH node calculates the minimum distance to the previously selected CH node to ensure that the selected CH nodes are not adjacent to each other. The proposed approach obtains better total data packets sent to the base station, energy efficiency, and network age using Matlab simulation software by comparing the enhanced DV-Hop algorithm with the original DV-Hop algorithm and three other routing algorithms.

1. Introduction

Wireless Sensor Network (WSN) is a network with a large area and consists of many sensor nodes. Each node in the WSN has specific sensing, computing, sending data packets, and storage capabilities [1] [2]. Sensor nodes are typically battery-powered and positioned in areas where monitoring is always required to maintain system continuity on the WSN [3] [4]. There are numerous applications for WSN, such as safeguarding crops in farms, conducting environmental surveillance of specific locations, monitoring submerged sites, ensuring a healthy environment, supporting military operations, and others. [5] [6]. When data or events are monitored, it is often necessary to know the geographic position of these events simultaneously. Because data is needed in the form of factors that affect WSN performance. Sensing data without location information is useless [7] [8].

Acquisition of node position in WSN is referred to as localization, an important technology of WSN [9] [10]. Based on the exact angle or distance between nodes that must be known during localization, there are two types of node localization algorithms in WSN: range-based and range-free [11] [12]. A range-based localization algorithm must know the exact distance or angle between sensor nodes. High precision is an advantage of range-based algorithms but requires additional and more expensive hardware [13] [14]. The reach-free algorithm requires only knowledge of node connectivity and no additional hardware. However, localization accuracy is also inferior to range-based algorithms [9], [15].

Distance Vector Hop (DV-Hop) is an algorithm for reach-free localization that has been widely used. Although DV-Hop is easy to implement, its precision is insufficient for some applications [16] [17] [18]. Considering this, many researchers have proposed some better DV-Hop-based algorithms. The modified algorithm based on DV-Hop can be divided into three categories based on the principle of improvement: (1) increasing the accuracy of the hop size of the sensor nodes to obtain the ideal distance between the CH node and the Base Station, thereby optimizing the network quality of service [19] [20]; (2) consider the distribution of CH nodes by calculating the distance between CH nodes [15], and (3) pay attention to the number of neighboring nodes to optimize the energy used and extend network life [21].

Although the improved algorithms improve the node localization accuracy to some extent, they ignore the following facts. The chosen CH node is too far from the Base Station, so transferring data to the Base Station requires more energy. The selected CH node has too few neighbors, which causes inefficient energy use in sending data. There is a buildup of CH nodes in several regions, which causes data flow routes not to be spread optimally and can cause overload on some nodes. This paper presents an enhanced DV-Hop algorithm based on the optimal subset of CH nodes (enhanced DV-Hop algorithm). The CH nodes self-localize to obtain the optimal data termination route with an even distribution of CH and apply it to localize the closest sensor nodes.

The main contribution we propose is the three criteria in selecting CH nodes in the WSN area. First, the location of the CH node to be selected does not exceed 80% of the distance of the farthest node in the network. Second, each CH node is to be selected at a distance that is more than the minimum distance from the previously selected CH node to prevent the positions of the CH nodes from overlapping. Third, the CH node to be selected has several neighbours above the average compared to other sensor nodes.

This article is organized as follows. The first part provides the background and problem statement. In Section 2, a review of the relevant literature is presented. In Section 3, the enhanced DV-Hop algorithm is explained in detail. In Section 4, the proposed algorithm is simulated, and the corresponding experimental results are analyzed. Finally, Section 5 concludes whether the proposed DV-Hop algorithm is worthy of further development.

2. Research Method

The enhanced DV-Hop algorithm in this study is applied to Cluster-based Wireless Sensor Networks to improve the network quality of service and energy efficiency. Each cluster has a CH node responsible for managing communication between nodes. The types of nodes on the WSN are shown in Figure 1.

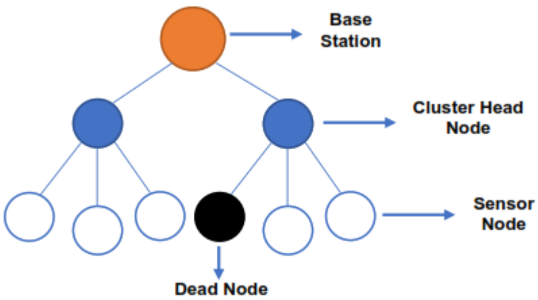

Figure 1. The types of nodes on the WSN

Figure 1 illustrates the types of nodes in a Wireless Sensor Network (WSN). There are four types of nodes in a WSN, namely sensor nodes, cluster heads (CH), base stations, and dead nodes. Sensor nodes are devices responsible for collecting environmental data such as temperature, humidity, and wind speed. Sensor nodes have the ability to process the collected data and send the data to cluster heads. Cluster heads, represented by blue circles in the figure, act as intermediaries between the sensor nodes and the base station. The base station, represented by an orange circle, is the main node in the WSN responsible for receiving data from cluster heads and sending the data to the end-user device. Black circles depicted in Figure 1 indicate nodes that are no longer functional due to depleted energy, which are commonly referred to as dead nodes.

All sensor nodes in the WSN area communicate with each other with other sensor nodes using a certain routing algorithm. In the WSN system, sensor nodes and CH nodes work together to collect data from the locations we will monitor and send data to end-user devices via the base station. Sensor nodes are represented by white circles in Figure 1 [22] [23] [24].

During cluster formation, each sensor node initially decides whether to serve as a CH node for the current loop. The system makes a decision by selecting the probability value of selecting the sensor node as a CH node randomly in the range 0 to 1 [13]. If the sum exceeds the threshold, a node will become the CH node for the current round. The threshold equation for CH node formation is as follows Equation 1.

$$T(i) = \begin{cases} \dfrac{p_{CH}}{1 - p_{CH}\left[r mod\left(\dfrac{1}{p_{CH}}\right)\right]}, & \text{if node } i \in G \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

The probability (p_{CH}) of choosing a sensor node as a CH node is included in Formula 1, and it depends on two variables: the current round (r) and the cluster of sensor nodes (G) that were not chosen as CH nodes in the current round. The equation also contains the term $(\frac{1}{p_{CH}})$. Using a predefined threshold, each sensor node will become a CH node at some point in the round. The $\left(\frac{1}{p_{CH}}\right)$ round, where each vertex becomes CH once, is called a period. Each sensor node selected as the CH node broadcasts an advertising message to all other sensor nodes. Sensor nodes continuously receive advertising messages from CH nodes. The sensor nodes decide which CH nodes to join based on the distance and signal strength received. Once sensor nodes have made their decision on which cluster to join, the CH node needs to be verified as a member of the cluster. To accomplish this, every node transmits a message to each CH node, requesting to join [25].

A comparison of node localization using original DV-Hop Algorithm routing and Enhanced DV-Hop Algorithm is shown in Figure 2.

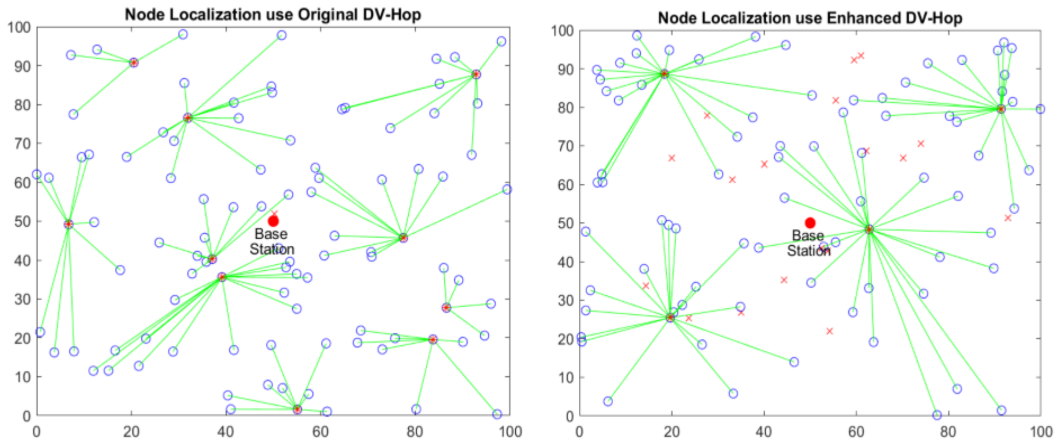

Figure 2. Comparison of selection of CH nodes in the original DV-Hop algorithm with enhanced DV-Hop algorithm

Figure 2 compares two DV-Hop algorithms, namely the original DV-Hop Algorithm and the Enhanced DV-Hop Algorithm, in performing localization on Wireless Sensor Network (WSN). The figure shows two coverage areas representing the two DV-Hop algorithms at the 100^{th} round. The coverage area of the Enhanced DV-Hop Algorithm is depicted on the right-hand side, while the coverage area of the original DV-Hop Algorithm is on the left-hand side. The figure also shows circles and crosses representing the nodes in the WSN. The circles represent nodes with remaining energy, while the crosses represent nodes that have run out of energy.

Enhanced DV-Hop algorithm to improve quality of service and energy efficiency at WSN. The DV-Hop Algorithm Scheme is also equipped with a feature to display the number of clusters and the number of nodes in each cluster, which helps optimize algorithm performance. Figure 3 presents a schematic of the DV-Hop Algorithm developed for Wireless Sensor Networks (WSN).

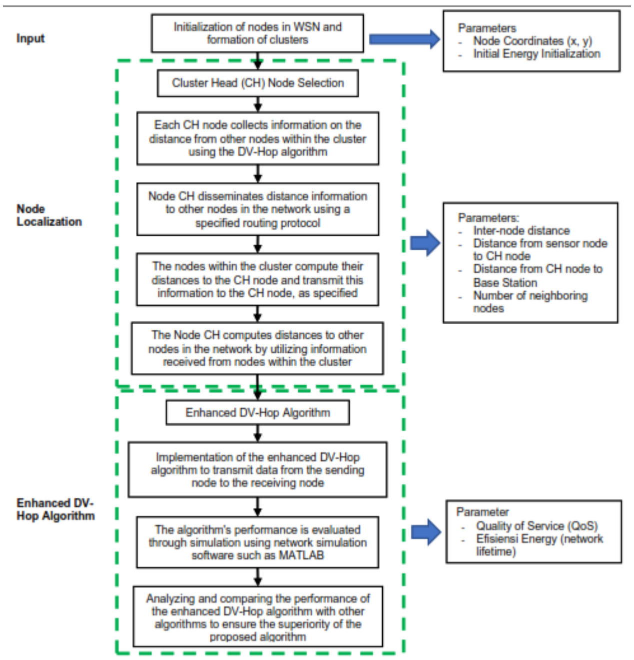

Figure 3. The Enhanced DV-Hop algorithm scheme in Wireless Sensor Networks (WSN).

2.1 Original DV-Hop Algorithm

During the clustering process, the DV-Hop Algorithm is employed as a routing optimization technique in the LEACH (Low Energy Adaptive Clustering Hierarchy) protocol for WSNs. The sensor nodes in this system are organized into clusters, each of which is overseen by a CH (cluster head) node. This method is useful for promoting effective communication between the sensor nodes. [24] [26] [27]. The Cluster Head node collects data from sensor nodes in the cluster and sends it to the Base Station. The DV-Hop Algorithm is used to assist the Cluster Head node in determining the best route to send data to the Base Station [25].

The computation of estimated distances among the sensor nodes and every CH node. Each node calculates the size of its jump using Equation 2 as follows [25].

$$HS_j = \frac{\sum_{m \neq j}^{j} \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}}{\sum_{i \neq j}^{j} h_{mj}} \tag{2}$$

The CH nodes m and n have coordinates (x_i, y_i) and (x_j, y_j), respectively, while h mn denotes the count of jumps between them. After calculating its hop size, the CH node broadcasts its ID and hop size to the network. Other sensor nodes take the first hop size received as the hop size. After getting the size of the hops, the Equation 3 applied to calculate the approximate distance to all CH nodes [25] [28].

$$d_{ij} = HS_n * h_{ij} \tag{3}$$

The distance estimation between a sensor node and a CH node is denoted as d_{ij}, while HS_n represents the magnitude of the jumps made by sensor nodes. Additionally, h_{ij} refers to the count of jumps from a sensor node to a CH node.

Determining the sensor nodes coordinates involves trilateration if the node estimates a minimum of three non-collinear CH nodes' approximate distances. Assuming that the sensor node you and CH node i have coordinates (x, y) and (x_i, y_i) respectively, and the estimated distance from u to i is di, Equation 4 can be derived as follows,

$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 = d_1^2 \\ (x - x_2)^2 + (y - y_2)^2 = d_2^2 \\ \vdots \\ (x - x_n)^2 + (y - y_n)^2 = d_n^2 \end{cases} \tag{4}$$

by subtracting the n^th formula from the previous n-1 formula, Equation 5 can be obtained as follows.

$$\begin{cases} (x_1^2 - x_n^2) + (y_1^2 - y_n^2) - 2(x_1 - x_n)x - 2(y_1 - y_n)y = d_1^2 - d_n^2 \\ (x_2^2 - x_n^2) + (y_2^2 - y_n^2) - 2(x_2 - x_n)x - 2(y_2 - y_n)y = d_2^2 - d_n^2 \\ \vdots \\ (x_{n-1}^2 - x_n^2) + (y_{n-1}^2 - y_n^2) - 2(x_{n-1} - x_n)x - 2(y_{n-1} - y_n)y = d_{n-1}^2 - d_n^2 \end{cases} \tag{5}$$

Rewrite Equation 5 as AX = B in matrix form, where A, B, X are expressed in Equation 6, Equation 7, and Equation 8, respectively.

$$A = 2 \times \begin{bmatrix} x_1 - x_n & y_1 - y_n \\ x_2 - x_n & y_2 - y_n \\ \vdots & \vdots \\ x_{n-1} - x_n & y_{y-1} - y_n \end{bmatrix} \tag{6}$$

$$B = \begin{bmatrix} x_1^2 + y_1^2 - x_n^2 - y_n^2 + d_n^2 - d_1^2 \\ x_2^2 + y_2^2 - x_n^2 - y_n^2 + d_n^2 - d_2^2 \\ \vdots \\ x_{n-1}^2 + y_{n-1}^2 - x_n^2 - y_n^2 + d_n^2 - d_{n-1}^2 \end{bmatrix} \tag{7}$$

$$X = \begin{bmatrix} x \\ y \end{bmatrix} \tag{8}$$

Ultimately, the Least Square Method (LSM) is utilized to solve the AX=B matrix Equation 9, leading to the expression of the X node's unidentified position in the subsequent manner.

$$X_w = (A^T A)^{-1} A^T B \tag{9}$$

A^T and A^{-1} represent the transpose and inverse of matrix A, correspondingly.

2.2 Proposed Enhanced DV-Hop Algorithm

This section begins by explaining the principle of node routing using the Enhanced DV-Hop Algorithm proposed in this research.

2.2.1 The principle of Enhanced DV-Hop Algorithm

The DV-Hop optimization algorithm is a routing algorithm on WSN which has been improved from its previous version. The initial parameters are used in the MATLAB code to perform simulations for calculating the network quality of service value and energy consumption in WSN. The selection of cluster heads involves the utilization of probability p alongside the specification of a distance threshold that sets the maximum distance permitted between sensor nodes and cluster heads. Following this, sensor nodes select the nearest cluster heads for data transmission, with the collected data then relayed by the cluster heads to the base station [29] [30]. Additionally, in each round, statistical information, such as the number of dead and alive sensor nodes and the total network energy, is calculated and stored for further analysis.

2.2.2 The procedure of Enhanced DV-Hop Algorithm

The proposed algorithm in this proposal focuses on the selection of CH nodes. This is aimed at distributing CH nodes evenly across the WSN area and avoiding the accumulation of CH nodes in specific positions in any WSN area. Sensor nodes selected as CH nodes must meet Equation 10.

if

$$\left(S_{(i)}.E > 0\right) \,\&\&\, \left(d_{BS(i)} \leq 0.8 \times \max\left(d_{BS(:)}\right)\right) \&\& \left(n_{(i)} > r\left(\frac{1}{p}\right)\right) \&\& \left(\min\left(d_{CH(:)}\right) > \mathrm{mean}\left(d_{C(:)}\right)\right) \tag{10}$$

then

$$S_{(i)}.(x,y)\ i = \ Cluster\ Head\ Node$$

Notation:

$S_{(i)}.(x,y)$	: sensor node i which will be selected to be the CH node
$S_{(i)}.E$	: remaining energy at node i
$d_{BS(i)}$	: distance from node i to Base Station
$0.8 \times \max\left(d_{BS(:)}\right)$	: 80% distance of the farthest node to the Base Station
$n_{(i)}$	: the number of neighboring nodes of node i
$r\left(\frac{1}{p}\right)$	: value 1/p to the nearest integer. p is the probability of selecting a CH node
$\min\left(d_{CH(:)}\right)$	: the distance from node i to the nearest CH
$\mathrm{mean}\left(d_{C(:)}\right)$	: the average distance from node i to all other nodes

2.2.3 Performance Metrics

The simulation will be conducted using Matlab software with the initial parameters shown in Table 1.

Table 1. Simulation parameters.

Parameters	Value Initialization
Dimension (x*y)	100*100 m^2
Base Station	0.5x*0.5y m^2
Total sensor nodes	100
Max. Rounds	1000
p (Probability)	0.1
Eo (Initial Energy)	0.2 Joule

Data packet sent	4000 bit
Efs (Energy for Sensing)	10e-12 Joule/bit
Emp (Energy per bit to Power Amplifier)	0.0013e-12 Joule/bit
EDA (Data Aggregation Energy)	5*0.000000001 Joule (J)
$E_{elec\ Transmit}$	3,3 μJ/bit
$E_{elec\ Receive}$	0,7 μJ/bit

This sensor network simulation employs homogeneous sensor nodes that are stationary or static. Each node possesses the same initial energy level. All nodes are randomly distributed within a rectangular area measuring 100x100 m^2. The values of E_{Tx}, E_{Rx}, and *EDA* (Data Aggregation Energy) obtained from the parameters in Table 1 are then applied.

2.2.4 Power model

This paper adopts the energy consumption calculation model as follows Equation 11 [19] [25] [31],

$$E_{sd} = E_{elec} + E_{tran} = \begin{cases} E_{elec} + \varepsilon_{fs} d^2, d < d_0 \\ E_{elec} + \varepsilon_{fs} d^4, d \geq d_0 \end{cases} \quad (11)$$

The total E_{sd} energy consumed by each transmitted data bit consists mainly of the E_{elec} transmission power and the E_{tran} loss power of the power amplifier circuit. The transmission line model coefficients E_{fs} and E_{amp} establish the threshold d_o, where E_{tran} depends on the transmission distance d. [19] [25],

$$d_0 = \sqrt{\frac{E_{fs}}{E_{amp}}} \quad (12)$$

In Equation 12, if **d** is performed, the power amplifier circuit's power consumption is proportional to **d_2**. If **d** ≥ **d_o**, the power amplifier circuit's power consumption is proportional to d_1. Additionally, the energy consumption for combining data per bit is Edata, and the energy consumption for receiving data per bit is **E_{accept}**. Both are equal to **E_{elect}**.

3. Results and Discussion

Figure 4 is a line graph showing the number of data packets sent to the sink node/base station. The figure compares the quality of service on the WSN network by showing the accumulated number of data packets sent each round. Each node is initialized by sending data packets of 4000 bits. The enhanced DV-Hop algorithm has a quality of service rating of 2nd with a maximum initialization of 1000 rounds. Furthermore, a comparison of the energy efficiency of the five algorithms is shown in Figure 5.

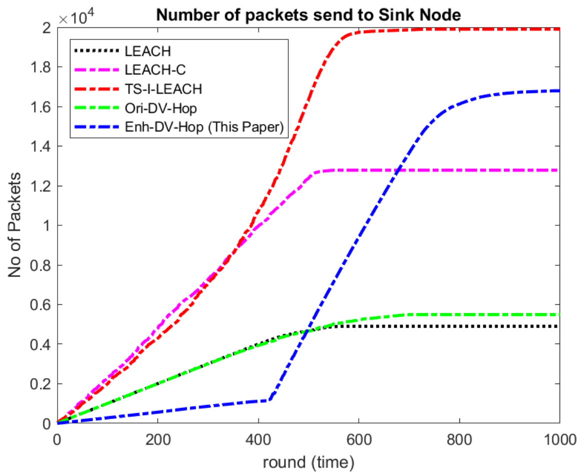

Figure 4. Number of packets sent to sink node/base station

Figure 5 is a line graph explaining the number of dead sensor nodes (sensor nodes that run out of energy) in each rotation. Each sensor node is initialized with an Initial Energy (E0) of 0.2 Joules. The figure shows a comparison of the age of the network with the output in the form of the maximum number of rounds that can be achieved from the five algorithms. The simulation results show that the enhanced DV-Hop Algorithm has a longer lifespan than the other four algorithms.

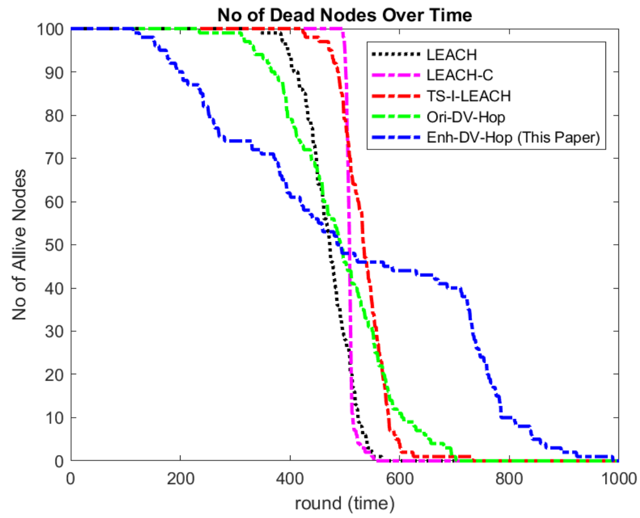

Figure 5. Number of dead nodes with increasing rounds

Figure 6 shows a curve showing the implementation of the DV-Hop Algorithm, which has been enhanced by having a longer network life than the other algorithms in this study. The lifespan of a wireless sensor network (WSN) depends on the number of surviving sensor nodes. On the x-axis is the time in units of r (cycles), and on the y-axis is the number of sensor nodes still alive in percentage. This graph displays three data series, namely "First Sensor Node Dead", "Half of Total Sensor Node Dead", and "All Sensor Node Dead". "First Sensor Node Dead" shows the amount of time or loop until the first node in the network goes dead. "Half of Total Sensor Node Dead" shows the amount of time or loop until half of all nodes in the network are dead. "All Sensor Node Dead" shows the amount of time or loop until all nodes in the network are dead.

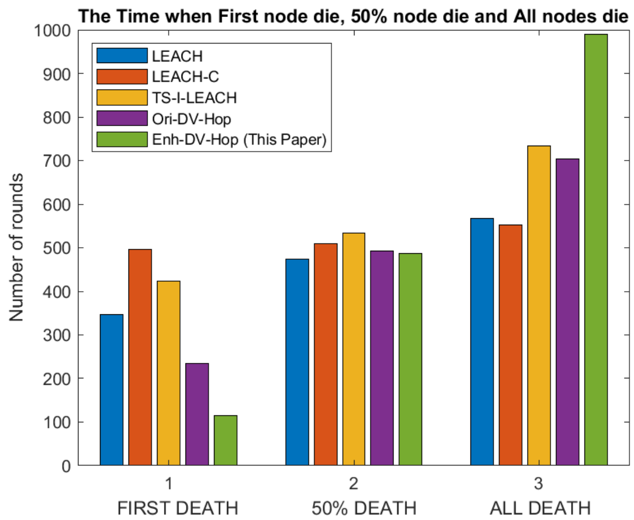

Figure 6. First Sensor Node Dead, Half of Total Sensor Node Dead and All Sensor Node Dead

On the x-axis, the unit r refers to the cycle or time it takes before a node in the network shuts down. In this graph, the greater the value of r, the longer the nodes in the network are dead. This graph is useful for evaluating the performance of a wireless sensor network (WSN) in terms of endurance or battery life. The longer the nodes in a wireless sensor network can survive, the better the network performance will be. By paying attention to this graph, researchers or wireless sensor network designers can evaluate it to determine the optimal configuration to increase network resilience.

4. Conclusion

The main problem in WSN is energy efficiency and network service quality. This study simulates the WSN with the DV-Hop Algorithm routing algorithm, which is enhanced by optimizing the position in selecting CH nodes. CH node selection is based on three conditions. That is, the CH node to be selected is not adjacent, has several neighbours above the average and has a position that is not too far from the Base Station. Based on the simulation data analyzed in this article, it can be concluded that the enhanced DV-Hop algorithm has succeeded in improving the quality of service and energy efficiency in wireless sensor networks. Improve service quality and energy efficiency occurs by optimizing the position of the CH nodes, which are spread evenly throughout the WSN area and considering the number of neighbouring nodes around the CH nodes. So that sending data packets and energy used is more optimal. This affects the age of the tissue, which can last longer.

To develop this research further, it is necessary to consider several factors, such as node movement, node density, and signal variability, which vary in each location. Further testing on more complex and realistic scenarios should also be carried out to validate the research results. In addition, it may be possible to develop more sophisticated DV-Hop algorithms to improve energy efficiency in larger and more complex wireless sensor networks. With this development, it is hoped that wireless sensor networks can be implemented more efficiently and effectively in various applications, such as environmental monitoring and security in large areas such as agriculture.

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