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An Energy Efficient Technique for Improved Network Lifetime in Wireless Sensor Network (WSN) Through Energy, Distance, and Density-Based Clustering

Asha Rawat*, Mukesh Kalla

Department of Computer Engineering, Sir Padampat Singhania University, Udaipur, Rajasthan 313601, India

Corresponding Author Email: asha.rawat@spsu.ac.in

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ABSTRACT

The intelligent networks utilize smart and AI federated technologies especially in Industrial Internet of Things (IIoT), as it is the need of the hour to gather the data from sensor devices deployed at diverse locations for the drawing inferences from the gathered data. The data transmission operation requires smart technologies to move the data between base stations and mobile devices. Usually, the sensor devices have limited resources for storage as well as for preserving energy. The design of the network should be done in such a way that it can reduce the energy consumption and the data transmission time. This can help improve the lifetime of the network. With the advent of AI based technologies, it is possible now to integrate the underlying technologies such as data-mining, IoT and AI federated technologies to create the clusters of sensing nodes to minimize energy usage. Thus, this study discusses three different cluster-based models for data collection and transmission. The first model is used to create a cluster and then select its head based on the energy parameters. The second model, on the other hand, uses a clustering method to create the cluster and then select its head. The third model in this paper presents the main contribution of the cluster creation process by considering the various parameters that affect the density and energy of the cluster. The simulation experiments are performed for all three models using JUNG simulator. The experimental results show that the third approach with considering energy, distance, and density for selecting the clustering head achieves the optimal results for enhancing the lifetime of the network.

1. INTRODUCTION

It is the fundamental goal of Artificial Intelligence to develop systems that are capable of replicating the logical and communication abilities of a human being. It implies to develop the infrastructure which is smart sense the data in real-time and capable of communicating in an effective way. The Internet of Things (IoT) is a network of interlinked equipment and entities called sensors that communicate with each other through the internet, allowing the sensor nodes to receive and transmit data. The system works in unseen yet intelligent manner that senses, regulates, and can be programmed [1], and it does so by utilising embedded technology to connect with other nodes in the network. The Internet of Things (IoT) allows for instant access to information pertaining to any device while maintaining high quality and performance [2].

Approximately 5 billion smart gadgets have already been connected as of today, with an estimated 50 billion devices will be connected by 2020 [1]. The quantity of people who are literally interacting may surpass the quantity of smart objects that are virtually communicating to them. This will lead to an accumulation of traffic, with humans becoming a minority of both the generators and recipients of traffic [3]. Because of the opportunities and challenges presented by the IIoT, several research fields are being investigated. The World Wide Web serves as a conduit for connecting the virtual modern landscape towards the reality. A network of small sensors or actuators that are connected to one another is in charge of sensing and sending information towards the Internet. From the perspective of a system composed of sensor nodes, with sensors cooperating between themselves and formulating a collective system whose component would be to collect information about the physical variables of systems. A wireless sensor network (WSN) is a type of device that is designed to monitor various environmental and physical characteristics. It can be placed in a variety of communication ranges to provide its users with the necessary information. However, it is very important that the network's routing technique is designed in a way that is both long-term and efficient.

In a typical WSN node, there are four major components: a sensor device, which is typically used for sensors to detect a physically quantifiable and measurable parameter; an Analog to Digital Converter (ADC), which is used for converting analogue signals to some different downloads; a processing unit, which provides basic data analysis and information processing capabilities; and a power unit, which is responsible for extending the sensor node's operational life span. In general, it is recognized that WSN is a resource-constrained infrastructure in which energy efficiency is always the most important consideration, due to the fact that the operation of WSN is strongly dependent on the average lifespan of the sensor nodes' batteries. Among the WSN operations, the Ethernet frame routing activity is the one that consumes the most energy. While the WSN shares some traits with conventional networks, it also has several distinct characteristics. As a result, when addressing issues and challenges such as network, runtime configurations strategic planning, node distribution and administration, node mobility power efficiency and usage, network deployment, implementation details and environments, and so on; these distinctive features are frequently taken into consideration.

A wireless sensor network (WSN) that can be employed in different scenarios, such as reconnaissance, home monitoring, and logistics, for adding a sensing component, a calculation element, and data gathering, in addition to multiple fields such as environmental and healthcare, among others, to disaster forecasting and transport systems is useful. The network is made up of tiny sensor nodes (SN) that can track and process data from a particular geographical location before sending it to a remote location known as the sink node or base station (BS) [1].

A wireless sensor network (WSN) is a type of device that can be used in low-cost, resource-constrained devices. It can be used to distribute small packets of data over a multi-hop wireless network. Each node is a type of sensor that has its own unique set of features, such as a low-power radio and a limited memory. The location of a battery node is very important, as it can be used in large areas even if the battery is not attached. Researchers must develop a way to route and transmit the wireless sensor network (WSN) in order to extend its lifespan and improve its energy efficiency.

For meeting WSN criteria such as energy consumption, the Cluster-based algorithms perform more effectively than the other routing protocols suggested for WSNs [2-5]. By forming SNs of each cluster or grouping them into those that are given to Cluster Heads, the SNs use their information and data and pass it to those to the group's heads (CH). The CH nodes subsequently transmit the information they have gathered to the BS. Because CH nodes are critical to the effectiveness of cluster-based scheduling algorithms, the policy for selecting CH nodes has a significant effect on the system metrics such as the network lifetime and the rate at which energy is consumed.

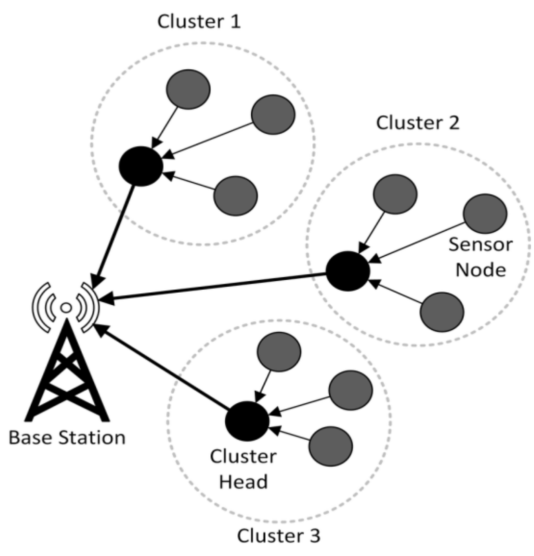

Figure 1. Schematic model of cluster based network

The typical WSN architecture as shown in Figure 1 is composed of multiple sensor nodes and devices that are distributed in a given area to provide the best possible sensing coverage. These nodes are then aggregated to form clusters. Each cluster head has its own data processor that is responsible for collecting and disseminating the data from the sensing nodes. The researchers discussed in this paper have developed various protocols that are commonly used in wireless communication [6-8]. One of these is the LEACH cluster-based network architecture. It is one of the most widely studied and utilized WSNs. The LEACH algorithm doesn't Take into account the amount of energy used by the sensor nodes as well as their locations throughout the selection process. This leads to sensor nodes failing prematurely and reducing the lifetime of WSNs.

This paper presents our proposal for a more efficient clustering of the LEACH routing system, which goes above and beyond the base mechanism that has been proposed in the standard version. We suggest two new clustering methodologies based on the LEACH routing protocol, one based on energy and the other a combination of energy and distance from base station. Two concerns are discussed in our proposed routing protocol. A candidate node's distance from the BS must be as small as possible in order for it to be considered. Second, the node considering to become a Cluster Head should have more remaining power than just the average residual energy of all living nodes in the WSN in order to be considered.

The main focus of this study is on density-based clustering algorithms, in which judgments are made based on the extent of a node. It refers to the number of nodes that surround a certain node. The proposed technique is not only dependent on the degree of the node, but also on how widely distributed the neighbours are. Dense areas have a high presence of sensing nodes in a smaller space, i.e., neighbours are in close proximity to one another. As a result, nodes positioned in the heart of a heavily populated regions are capable of achieving higher connectivity while using less power since they can identify more nearby neighbours. As a result, becoming a cluster leader is highly recommended (CH). A low density, from the other hand, indicates that a small number of nodes have been scattered over a big region of land. As a result, nodes in these places have minimal neighbours and require more potential to transmit with each other since they are located further out from the core.

2. RELATED WORK

In the Internet of Things, one of the most significant issues is the high cost of maintaining and maintaining the vast number of sensor nodes that will be deployed [9]. A time-consuming process [10] can be involved in changing sensor batteries that have already been installed in the network region. It is essential that the batteries of a sensing element designed for use on a certain organism or breed be able to last significantly longer than that of the organisms in order for the sensor to be feasible. This leads to another significant issue: power management. Other major issues in WSN [11] include efficient end-to-end data transmission, adequate congestion management, and a low packet loss ratio.

The authors [12] of the LEACH clustering algorithm suggest a distance-energy cluster composed of various nodes. It takes into account the different factors that affect the network's location and distance. The three authority layers of the cluster are then divided into three. These layers are designed to reduce the cluster's power consumption. In addition, they eliminate the key linkages between the nodes.

The researchers [13] provides the detailed structure of the energy-efficient cluster model called EECS. This model works for data collection in periodical manner, and works in large scale sensor network. The model designed by the researchers [13] consist of the cluster-head selection process. In this phase a cluster head is selected from the number of cluster nodes. Here, CHs are chosen via a localized competition that takes account both means of supplying and transmission radius of clustering algorithms. Once this is done, a weighted function for the plain component is introduced during the cluster creation step, which is used to determine whether proper cluster should be joined and which should not. The cost of correlation communication, as well as the value of information exchange between both the CHs and the BS, are used to calculate the value of the function.

Furthermore, the authors [14] suggest a WSN partitioning algorithm based on the k-nearest neighbour algorithm (KNN). A clustering algorithm are proposed, each of which has a BS as well as all sensor nodes directly interact with the BS included inside the cluster in which they are situated. The authors [15] present a trustworthiness derivation process for WSN-based Internet of Things connections that is both energy-efficient and reliable. Using risk strategy analysis to determine the ideal amount of recommendations, the system is able to reduce communication load while simultaneously increasing efficiency. The energy-aware method provides enough security while also reducing network latency. It is proposed by Junping et al. [16] to use a time-based CH selection method known as TB-LEACH to set well-distributed clusters and increase longevity by 20 to 30%. The spacing among nodes and the BS is taken into consideration for minimum level CH selection [13], which enhances longevity by 10% compared to the previous method.

Imperialist competitive algorithm is essentially algorithm that is inspired by social phenomena and is used to solve optimization problems. This algorithm requires the colonial system to be a step in the growth of society and politics. An imperialist competitive algorithm can help improve the performance of the LEACH. It can also determine the optimal location for the cluster's head. This method can also help improve the abnormalities that are present in the LEACH framework. One of the most important factors that this strategy can consider is the amount of energy that each node has. The authors [16] calculated an adjustment to the likelihood of selecting CH. Additionally, the optimal value of CH is taken into consideration in the article, although only for fixed values like 1 and 6. This results in a 40- to 50 percent increase in the network's lifetime.

The authors [17] presents the strategy for selection of cluster head. These cluster head work for the aggregation of data. While aggregation cluster head eliminates the redundant data. This technique improves the overall lifetime of the network with reduction in resource utilization. In the technique, the threshold value of the sensor is changed based on the external temperature of the sensor node. If the temperature of the sensor node is higher in comparison to the entire network the threshold of the node varies.

CH is chosen [18] by using particle swarm optimization to determine its location (PSO). Optimal CHs are chosen based on an objective function, which is represented by the node degree, the cross - functional and cross distance, based on residual, and the number of optimal CHs. The following is the definition of the objective function: According to a range of various network indicators, the model beats other routing algorithms when compared to the others. It is explained in the study [19] how to determine PSO-based CHs based on distances between nodes and from a base station (BS) as well as residual energy, among other considerations. The approach provided in the study [20] is advantageous if the sensor nodes are distributed unevenly over the sensing area, as this is the case in practice. Energy consumption and network lifetime are reduced and extended respectively when the chance of engaging in clustering is adjusted in real time on a network. The most significant reduction in power requirements occurs in densely inhabited locations, where the likelihood of a node bypassing a cycle of clustering is higher than in less heavily populated areas.

The author [21] proposed that the selection process for CH involves the residual energy. After comparing the two different methods, it was found that one of the methods, the Multi-hop approach, outperforms the other. He also proposed a non-probabilistic method, which involves clustering the networks into zones. ANP is a decision tool that can be used to analyze the various characteristics of a cluster. After generating a set of parameters, the tool chooses its head.

The authors of this study [22] propose an energy-efficient method for clustering and localization that is based on a genetic algorithm (ECGAL). In this method, the fitness function is constructed by combining residual energy, distance estimation, and coverage connection. The execution of this function takes very little time. A lower quantity of energy is used by the ECGAL that has been proposed, which in turn enhances the life of wireless networks.

This study [23] presents a novel form of the LEACH protocol known as LEACH augmented with probabilistic cluster head selection. The goal of this protocol is to extend the lifetime of sensors (LEACH-PRO). LEACH-PRO presents a number of new methods for extending the lifetime of nodes in WSNs. One of these methods is the selection of cluster head nodes through the application of a probabilistic function that is based on the highest amount of residual energy and the shortest distance to the sink.

The purpose of this study [24] is to execute communications between sensor nodes in a way that is efficient with energy and to lengthen the lifetime of the network by distributing the load across gateways that are under less energy constraint. Clustering is an efficient method for reducing the amount of energy that is lost by the sensor nodes in a wide-range wireless sensor network. This helps to extend the lifetime of the network as well as achieve scalability and robustness.

The fuzzy-GWO algorithm is used for the identification of CH in the protocol that is suggested in this work [25]. Because of its quicker rate of convergence, GWO was selected as the optimal metaheuristic method to use rather than any of the alternatives. In addition, GWO causes a constant shrinking of the search area and brings about a reduction in the number of decision variables.

The authors of the paper [26] propose a new mechanism for fully connected energy efficient clustering (FCEEC). This mechanism makes use of the electrostatic discharge algorithm in order to construct a densely integrated communications system with shortest path routing from sensor nodes (SNs) to the cluster head (CH) in an environment that involves multiple hops. The electrostatic discharge algorithm (ESDA) that was presented improves the network's life time while simultaneously achieving full connectivity between sensor nodes in an energy efficient manner. Because to ESD, the number of dead nodes in the network is greatly reduced, which results in an increase in the network's longevity.

Following a thorough examination of the literature, it was discovered that the primary advantage of the fat-based routing protocol was its simplicity in operation, as well as the fact that it would have a proper communication framework with both the base station, in which all nodes were permitted to take an active part even during routing operation. For the sake of convenience, individual nodes only require information about their directly connected neighbors and no further information. While nodes are spread out in a fast approach and all nodes are seeking to participate equally, the significant disadvantage is that the nodes nearest to the sink drain their power more quickly than those positioned farther distant from the sink. This is primarily due to the high volume of data being transmitted. This is having a negative impact on the nodes that are nearer to the sink in terms of keeping them alive for a longer period of time. As a result, the nodes located further away from the base station may be unable to interact with it over a period of time due to a network isolated segmentation fault in the WSN. A huge number of nodes are unable to engage in routing as a result of which they are never able to make full use of their available energy. More research is deemed necessary in order to address the energy efficiency of WSNs from this perspective. Furthermore, fast routing is still plagued by challenges such as data conflict overhead, links built on the fly without synchronized, energy dissipation that varies based on traffic patterns, and fairness that isn't always ensured w.r.t. standard encryption models in the next section of this text.

3. ENERGY BASED CLUSTER ROUTING

The suggested protocol is a clustering algorithm that consists of setup stage and steady-state performance. Firstly, in set-up procedure, sensor nodes are distributed all through the infrastructure and separated into clustered led by a CH who is responsible for data gathering from sensing nodes. The content is fused to decrease the quantity of data by deleting any superfluous bits. This transpires even during relatively stable stage, and it is during this period that data is actually routed to the BS by the network's CHs. After a first round of generation using the usual LEACH method, cluster and Cluster Head is selected using the following equation.

$$T(n) = \begin{cases} \frac{p}{1-p(r \bmod \frac{1}{p}}; for\ all\ \cup G \\ 0; otherwise \end{cases} \quad (1)$$

The energy expended by each node in the network following data transmission varies from node to node and is determined by the amount of data transmitted by each node. The distance between both the transmission and reception nodes, which is denoted by the letter ‘d’, determines the amount of power that is used in the transmission. Therefore, the CH is selected for the following round by means of an improved equation, which is as follows:

$$T(n) = \begin{cases} \frac{p}{1-p(r \bmod \frac{1}{p}} \times \frac{E_{residual}}{E_{initial}} k_{opt}; for\ all\ \cup G \\ 0; otherwise \end{cases} \quad (2)$$

where, $E_{residual}$ denotes the node's remaining energy level and $E_{initial}$ signifies the node's initial allocated energy level. The study [22] can be used to discover the optimum no. of cluster k_{opt}.

$$k_{opt} = \sqrt{n/2\pi} \sqrt{\frac{E_{fs}}{E_{amp} d^4 (2m-1) E_0 - m E_{DA}}}\ M \quad (3)$$

The network diameter is represented by the letters "M" and "E_0," and the value of each node's initial supply of energy deduced from the number. The CHs that are participating in the current round of the program distribute notifications to the clusters that are part of their respective clusters. The signal intensity of the request is evaluated by the sensing nodes before it is sent to the central hub. This ensures that the CHs are only sent to the appropriate areas. Data conflicts are avoided by using Time Division Multiple Access (TDMA) protocols, which allow nodes to send data at different times of the day or night. Continue repeating the process for the second and third rounds once all of the nodes within the network have exhausted their available resource allocations.

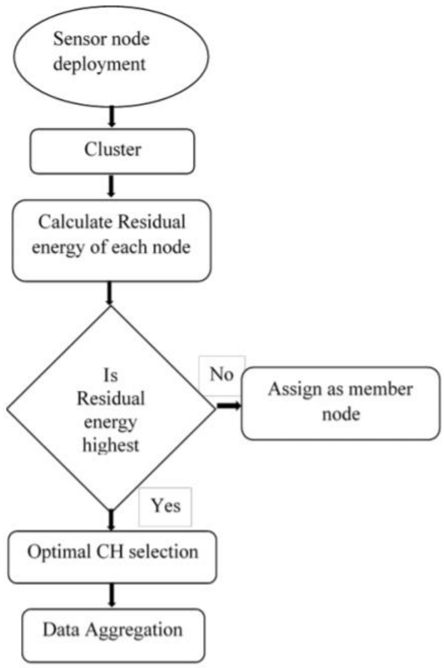

Figure 2. Flowchart of energy based cluster routing

CHs receive data within the time slot that has been allocated to every single node in the network. Because of the need to conserve energy, just the transmitting node is kept active, while the other nodes in the cluster turn down their radios. Following the completion of data transmission by all of the cluster's nodes, the CH will begin processing of the data received from them. It collects data and aggregates that to remove redundancy before compressing it to the greatest extent possible to maximise bandwidth utilization. The CHs communicate with the BS or sink using either multi-hop or single-hop communication. The entire technique is shown in Figure 2.

4. ENERGY AND DISTANCE BASED CLUSTER ROUTING

Energy and Distance-dependent Cluster Routing is the name given to a second routing proposal that takes into account both the energy and the distance of a cluster head. It takes into account the many different aspects that contribute to the decision that a cluster head makes. For instance, the distance between a base station and the nodes is taken into account. A second threshold is also set depending on the cluster head's distance. The aggregation delay is calculated by taking into account the current and energy consumption of the nodes when it comes to choosing CH elections. It ensures that the ones with the most transmission power will have a higher chance of being CHs. In addition to this, the selection of CH components also affects the overall performance of the WSN.

$$T(n) = \begin{cases} c \times \frac{|d_{toBSavg} - d(i,BS)|}{d_{toBSavg}} \times \frac{E_i}{E_{initial}}, if\ n \in G \\ 0; otherwise \end{cases} \quad (4)$$

The energy of a candidate node in a given round is referred to as E_i. This term indicates the initial energy that a node has before it is transferred. The region's boundary value is determined by the proximity of its sensor network and the BS to its prospective node:

$$P_{ch}(n) = \frac{P(n_{resi})\ P(n_{dist})\ P(n_{dcn})}{1\text{-}P\ (r\ mod1/P)} \quad (5)$$

$$P(n) < P_{dc}(n) < P_{ch}(n) \quad (6)$$

ch(n) – cluster head
n_{resi} – node with highest residual energy
n_{dcn} - distributed cluster node
c – number of cluster (variable)
r – number of rounds

5. ENERGY, DISTANCE AND DENSITY BASED CLUSTER ROUTING

The third technique is a density-based clustering algorithm, which means that rather than grouping data, it generates an arranged list of data, with data that are more closely related to one another appearing in the denser sections. To put it another way, the nodes having high density and those that are close together are ranked in succession in the previously described list of nodes. In this structure, it is simple to retrieve information about cluster centroids and their locations. The proposed method is based upon that Distance function between both the nodes, as well as the number of sensor nodes that come together to create a new cluster must be more than a particular threshold in order to be considered successful. Actually, the points are subjected to a DBSCAN-based preprocessing step, during which the points are sorted relying on its accessibility by that of the core points, after which the Density - based algorithm is performed to the ordered points, and lastly the points are clustered. Figure 3 depicts the flowchart for the suggested method.

According to this strategy, the CH selection criteria requires the integration of three criteria: the calculation of the aggregation delay involves taking into account the energy that the node has left in its current round. In addition to this, it takes into account the length of the path that extends from the node to the base station. The presented approaches are based on the presumption that the network does have a high node density, which is often not true. However, only a few attempts were made to develop a density measurement system. The equation that is used to determine the network density is shown below. Here the density is measured as the no. of nodes per m.

$$d(r) = lim_{|A| \longrightarrow 0} \frac{N(A)}{|A|} \quad (7)$$

where, *N* symbolizes the no. of live nodes in the particular area A, and R represents the range of data transmission in the area A.

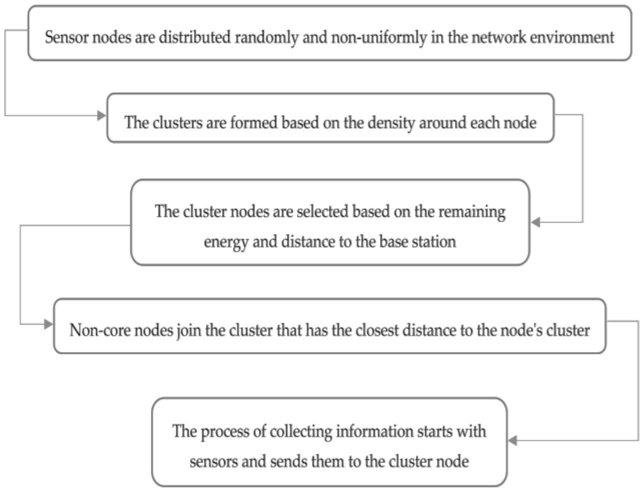

Figure 3. Flow of energy, distance and density based model

6. RESULT ANALYSIS

We implemented the system on standard machine i7 9th Gen Processor and 8 GB of RAM. The simulator used for analysis of the system is JUNG, which gives us the number of functionalities for generating and managing the network. The results obtained from the simulation are presented below:

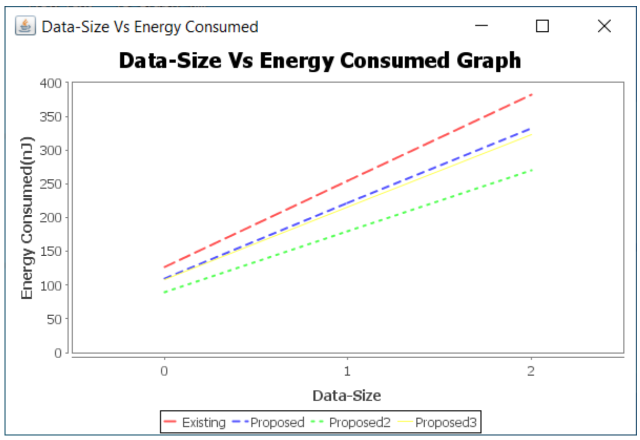

Figure 4. Energy consumption for sending the data with variable data size

Figure 4 depicts the outcomes, and Figure 5 depicts the amount of energy and time expended during the transmission of the information. We illustrated the outcomes of all five approaches in addition to allowing for a more in-depth study of the results. At the moment, the number of resources consumed during transmission contain the properties that are utilised to delay the transmission. Handling delay can be defined as the length of time it takes for component nodes to generate their encrypted messages and compare marks, among other things. The calculation of the aggregation delay involves tracking down the time it takes to test the marks that have been received from various components. It also involves collecting ciphertexts and marks. The average time spent at the end of the process on obtaining the first knowledge for the BS by checking accumulated markings and decoding collected ciphertexts is referred to as the unscrambling delay.

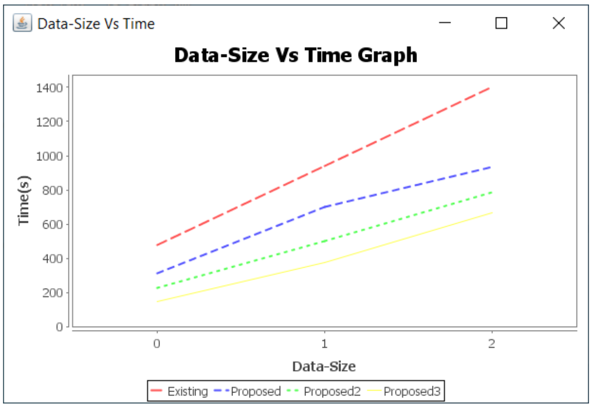

Figure 5. Time consumption for sending the data with variable data size

All the three modules have been tested with variable number of nodes. The count of nodes has been increased gradually and the performance of the system has been noted. The number of nodes used for testing the system are 20, 40, 60, 80, 100 and 120. Table 1 gives use the summary of the evaluation based on the energy consumption during the data transmission.

Table 1. Energy consumption for all the three methods

Initial energy	Number of nodes	ES	PS1	PS2	PS3
1825	**20**	717	590	504	548
3616	**40**	763	553	598	636
5457	**60**	871	873	680	748
7223	**80**	921	1133	921	820
8944	**100**	971	1157	924	822
10847	**120**	1403	1304	1192	1026

The remaining energy after the same experiment is presented in Table 2.

Table 2. Remaining energy after the data transmission for all the three models

Initial energy	Number of nodes	ES	PS1	PS2	PS3
1825	**20**	1108	1235	1321	1277
3616	**40**	2853	3063	3018	2980
5457	**60**	4586	4584	4777	4709
7223	**80**	6302	6090	6302	6403
8944	**100**	7973	7787	8020	8122
10847	**120**	9444	9543	9655	9821

The graphical comparison of the above experiment is presented in Figures 6 and 7 respectively.

We also calculated the packet delivery ration in the above experiment. Packet delivery ratio is computed by taking into account how many packets were successfully received by the network. The throughput rate refers to the amount of data that is transferred across a network. If a network is overburdened, packets may get stuck at the source and never reach the other parts of the network. The result is tabulated in Table 3 and graphically presented in Figure 8.

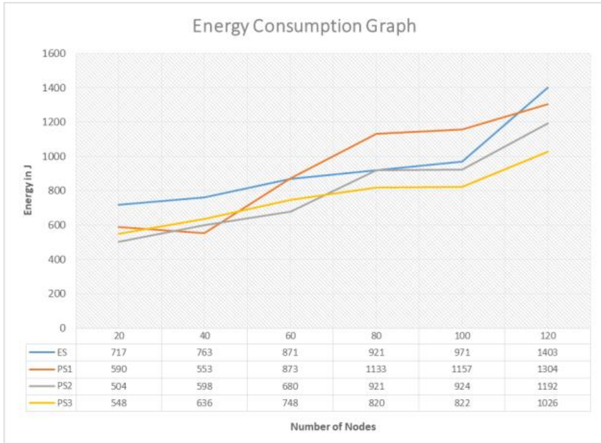

Figure 6. Energy utilization for energy, distance based cluster routing and energy, distance and density based routing

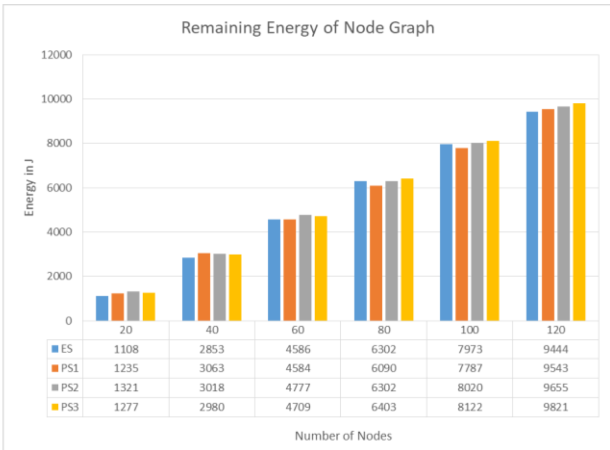

Figure 7. Remaining energy after data transmission for energy, distance based cluster routing and energy, distance and density based routing

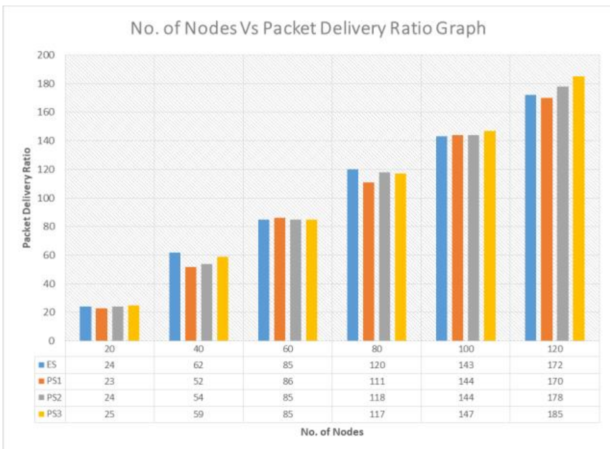

Figure 8. Packet delivery ratio for energy, distance based cluster routing and energy, distance and density based routing

Table 3. Packet delivery ratio for all the three models

Number of nodes	ES	PS1	PS2	PS3
20	24	23	24	25
40	62	52	54	59
60	85	86	85	85
80	120	111	118	117
100	143	144	144	147
120	172	170	178	185

7. CONCLUSION

To make wireless sensor networks (WSNs) more sustainable and to improve their operation, a unique energy-efficient routing protocol that is based on energy, distance, and density has been suggested in this study. This protocol was developed to address the shortcomings of LEACH by introducing a cluster head selection that takes into account the remaining energy, the distance to the base station, and the density of the nodes in the network. According to the findings of the performance evaluation, the suggested method outperforms both the LEACH protocol and the transmitter and receiver protocol in terms of the obtained network lifetime, the speed at which residual energy is depleted, in addition to the amount of traffic load that is generated on the network. The findings also indicate that the effectiveness of the proposed algorithms improves along with the size of the network. This is because the increasing density of the network's nodes is responsible for this phenomenon. The performance of the proposed mechanism will be tested in a real-time environment as part of future study, which will include implementing it on a hardware platform. The technology that is provided in this work has demonstrated some promising performance, and it has the potential to efficiently handle numerous possible applications in intelligent transportation systems.

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