Original Research

Improving Network Energy Consumption Using Novel Proposed Geographic Routing with Mobile Sink in WSNs

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Abstract
Recent advances in energy harvesting technology cause Wireless Sensor Networks (WSNs) to be one of the most common communications in different fields. In this paper, a new and appropriate solution based on geographic routing in WSNs with mobile stations is presented to decrease the number of routings and ultimately reduce the usage of energy in the network. In the proposed method named Geographic Routing with the Mobile Sink (GRMS), in the process of selecting the Cluster Head (CH) element, each node that is selected as the CH announces its new role to the other network nodes. By announcing this information, other nodes are also connected to the cluster. In each cluster, the CH creates and broadcasts a schedule in the cluster that contains the time slots assigned to each cluster member. The proposed GRMS method is compared with GEAR, GAF, and GMR methods. The simulation results show that the GRMS has reduced energy consumption compared to GEAR, GAF, and GMR methods. Also, the end-to-end delay in packet delivery has decreased and the number of dead nodes has decreased.

Keywords- Wireless sensor network; Geographic Routing; Clustering; Mobile station

INTRODUCTION

Nowadays, life without wireless communication is unimaginable. Innovation is introduced as any change in technology [1]. So it must be said that wireless networks are an innovation. Wireless sensor networks are used in most products, and the use of this technology can be considered as one of the factors of innovation in companies [2].Recent advances in the technology of manufacturing integrated circuits in small sizes and the improvement of wireless communication knowledge have laid the foundation of Wireless Sensor Networks (WSNs). If the nodes can move in the WSN, they can be considered as a group of small robots that work together and are designed to deliver the information to the specific destination.

In recent years, advances in the electronics and communications industry have made it possible to produce multi-purpose, low-cost, and low-energy Sensor Nodes (SNs) in small dimensions and with the possibility of establishing communication in short distances [3]. The WSNs consist of many small devices called SNs. In each node, several sensors and actuators are distributed. The sensor network strongly interacts with the physical environment. It takes information from the environment through sensors and reacts through actuators. Communication between nodes is wireless and each node operates autonomously without human intervention [4].

In WSNs, each node works individualistically without human interference which is usually physically very small and has limits in processing power, memory capacity, and power supply. These limits create problems that are the basis of many research topics in this field. This network follows the protocol stack of traditional networks, but due to limits and changes depending on the application, the protocols should be revised.

These SNs, which include components for sensing the environment, data processing, and communication, have provided the necessary platform for the emergence of WSNs. A WSN deploys a large number of SNs with high density inside the desired phenomenon. It is not necessary to predetermine the SN's locations. This feature makes it possible to deploy these types of nodes completely randomly in inaccessible or dangerous places. This feature suggests the need to consider the self-reconfigurability capability in the protocols and algorithms specific to these networks.

Another feature of WSNs is the cooperation of SNs to send data to the sink. SNs are equipped with a simple processor to perform brief processing of the data instead of sending the raw data received from the environment and performing local calculations only with the help of their nearby nodes. This action means sending a small number of necessary and processed data instead of sending multiple raw data, which reduces network traffic and makes the data fusion operation better and simpler. Some effective parameters in WSNs are as below:

1. Network dynamics: Most sensors in WSNs are static. There are only some networks where some sensors are mobile. In the presence of moving sensors, the issue of path stability is very important.
2. Placement of sensors in the network: According to the variety of applications, the placement of sensors in each network differs from each other, which can directly affect the entire network's efficiency. In some applications, the locations of the sensors are predetermined, but in most WSNs, this is not the case. In networks where the location of the sensors is determined in advance, information is also sent through predetermined routes, but in networks where the location of SNs is not determined, they must perform routing automatically.
3. Energy limitation: The finding of routes in WSNs is strongly affected by the energy constraint of the SNs. Considering that the power transmission in WSN is related directly to the second (and higher) power of the distance, therefore the usage of multi-hop transmission methods causes less power to be wasted.
4. Information transmission model: According to the application of a WSN, the information transmission model can be time-driven, query-driven, event-driven, and hybrid-driven [5]. In a time-driven model, each sensor sends its information intermittently. In the query-driven model, based on the request, the node will send its information. In an event-driven model, whenever a predetermined event happens in a part of the network, this event is reported. The hybrid-driven model is created by merging event-driven and time-driven models.
5. Data aggregation: Many sensors may create duplicate data. By using the data aggregation technique, the amount of information sent can be greatly reduced.

Considering that routing is a process of choosing the best path in internal and external networks and has an effective role in sending data in a network, routing protocols can be established between different types of networks. In other words, routing protocols are used to identify networks and destinations as well as find the best path to deliver the information to the destination [6]. After a certain period, each router sends the entire contents of its routing table as routing protocol interfaces for use by other routers in the network. When such information is received, all routers place the information in their routing table and start retransmitting. This process ensures that all networks connected to each router are eventually identified to all routers [7].

In some sensor networks, the nodes change their location regularly, and in such networks, due to the dynamics of the nodes, the routing method has many limitations. Routing methods that operate based on the geographic location of the nodes have more success due to saving costs related to route discovery and maintenance of routing tables. To create location-based routing, the sending node must know the location of the destination and its neighbors in addition to its location [8].

In this paper, by presenting a new solution based on geographic routing, it has been tried to decrease the number of routings and overall consumption of energy in the WSN. In Section 2, a literature review of routing methods in WSNs will be presented. Section 3 describes the clustering algorithms in WSNs. Section 4 is dedicated to the proposed Geographic Routing with the Mobile Sink (GRMS) method. In Section 5, the simulation of the GRMS and its comparison with other methods is given. Finally, in Section 6, the conclusion of the paper is expressed.

ROUTING IN WSNS

The method that transfers data and queries between the BS and the target node is called routing. From one point of view, routing can be considered as a method of data transfer between SNs, and from another point of view, the transfer of information between SNs in the network and the final BS can be defined as routing.

Routing in WSNs has differences from conventional networks in some aspects. These networks are unstructured, wireless communication is uncertain, and SNs may fail, therefore, routing protocols should be energy efficient as much as possible.

A very simple way for routing is that each SN tries to exchange its data with the BS directly; However, a single-hop method is very expensive because the nodes that are far from the BS may have their reserve energy discharge faster and thus severely limit the network lifetime. This issue is especially important in cases where wireless sensors are arranged to cover a large geographical area or in cases where wireless sensors are mobile and may move away from the BS.

To deal with the shortcomings caused by the single-hop method, the data exchange between the sensors and the BS is usually done by multi-hop packet transmission methods and on a small communication radius. Such a method of data transmission leads to a clear saving in energy consumption and a significant reduction in telecommunication interference between SNs competing for access to the channel. In response to queries issued by the user or when certain events occur within the controlled area, the data collected by the SNs are conducted to the BS through multi-hop routes [9].

A multi-hop routing protocol with consideration of distance and energy is suggested by Asqui et al. [10]. This protocol creates a smooth path route from nodes in the cluster, Cluster Heads (CHs), and sub-CHs to the BS. Karmakonda et al. [11] proposed a learning automata-based Particle Swarm Optimization (PSO) relay selection scheme. The random number in the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol [12] will be stabilized with the SN energy. Then with the use of the PSO algorithm, each SN estimates the best routes to the sink. If packet loss happens, instead of retransmissions, learning automata will be used for successor node selection. Finally, with the use of the learning automata, the selection probability of the next node using multi-objective parameters will be calculated. Wang et al. [13] proposed a protocol with a combination of the enhanced Snake Optimizer (SO) and Golden Jackal Optimization (GJO) which is multi-hop. First, the SO algorithm is used and integrated into the exploitation stage of the Brownian motion function. Then energy consumption of the CH, node degree of CH, and distance between the node and BS are integrated to make a fitness function. Finally, an energy-efficient multi-hop routing path between CH and BS is created using the GJO.

Chekuri and Bhandari [14] for energy consumption improvement selected the CH by LEACH protocol initially; then it was further investigated by the Simulated Annealing (SA) algorithm to get a better neighboring node compared with the selected CH. Rahman and Dewangan [15] have suggested a hybrid C-means donkey-smuggler optimizing approach to enhance the efficiency of routing in WSNs. Sadhana et al. [16] have proposed the Extended Power-Efficient Gathering in Sensor Information Systems (E-PEGASIS) protocol to enhance the energy efficiency of data transmission in WSN based on the PEGASIS protocol. They considered the average distance between the SNs for the outermost node's radio range value to the BS. Then they chained the related nodes available in the radio range. Therefore, the chained node will check its distance with the next nearest end node to go on with the chaining procedure which will enhance the performance of data transmission.

A routing scheme that minimizes energy consumption in WSN by using clustering and washbasin mobility has been explained in [17]. In the method, first, the entire network is clustered, and then investigated how many mobile sinks affect the longevity of the WSN. A centralized tree-based routing system with a mobile sink was suggested in [18]. The centralization takes advantage of the BS's limitless capacity and for the control of mobile sink and load, a tree-based technique has been employed. Their results have shown that the protocol decreases the overhead of the control packet and the average amount of energy compared to the Clustered Tree-based Routing Protocol (CTRP) [19] and Tree-based Data Dissemination (TEDD) [20] protocol.

The energy-awareness Honey Badger Optimization Algorithm (HBOA) that provides minimum end-to-end packet delay and low packet loss is proposed in [21]. This method selects paths with high throughput to transfer data packets over a WSN. To increase the reliability of the network, a void bypass is used when it reaches the gaps. To improve the lifetime of SNs, energy management is carried out by reducing the radio coverage amount to a required range.

The Energy Efficient Hybrid Routing Protocol (EEHRP) to select the best route is proposed in [22]. EEHRP uses a Pareto optimal solution to choose the best multi-objective optimization-based route from the source node to the sink node. Jabbar and Alshawi have suggested a Spider Monkey Optimization Routing Protocol (SMORP), to extend the lifetime of WSNs. The SMOP chooses a node with maximum residual energy, minimum traffic load, and distance to the sink to decrease excessive routing messages from the source node to the sink [23].

Altuwairiqi [24] suggested a model to reduce energy consumption in WSNs based on an Improved Honey Badger Algorithm (I-HBA). The I-HBA picks energy-efficient CHs and the SNs send their data through the chosen CH, which sends it to the BS using the efficient number of hops. The nature of the given scheme C-GSA by Kumar and Agrawal [25] is based on a hybrid of both the Crow Search Algorithm (CSA) [26] and the Gravitational Search Algorithm (GSA) [27]. By utilizing the concepts of CSA cluster formation, residual node formation can be controlled. After that, GSA is used for routing.

Protocols presented for routing in WSNs can be divided into four general categories, which are: Data-centric, hierarchical, location-based, and quality of service.

I. Data-centric

In various applications of WSNs, it is not possible to assign a global identifier to each node. The lack of a global address along with the random arrangement of nodes makes it hard to choose a certain number of sensors to perform the query. Therefore, data is usually sent from each node within the network area with high redundancy. In this situation, the energy consumption of the network will be inefficient.

Routing protocols can select a set of sensors and aggregate the data at transmission time. These considerations lead to data-centric routing, which is quite different from conventional address-based routing. In data-centric routing, the sink node sends a query for a specific area of the network and waits to receive data from the sensors of the selected area. Given that the data is requested through a query, attribute-based naming can be used to specify the attribute of the data.

Flooding and gossiping protocols are old mechanisms for sending data in WSNs that do not have any routing algorithm. In the flooding protocol, a node sends a copy of the desired data to each of its neighbors to send data to the destination. If an SN receives the new packet, it copies the packet and sends it to its neighbors except the node from which it received the packet. The protocol ends when the data reaches the destination or the maximum number of hops to send the data has been completed.

In the Energy-aware routing protocol, based on the remaining energy of the network nodes, the path that is optimal in terms of energy consumption is selected to increase the network lifetime. Path selection is selected by a probability function that depends on the amount of energy consumption in the path. There are three phases in this protocol as follows:

Setup phase: In this phase, the sending cost of each node is calculated and centrally placed in a table called Forwarding Table (FT). For example, the cost of sending from node N_i to node N_j is calculated according to (1).

$$C_{N_j,N_i} = \mathrm{C}(N_i) + \mathrm{M}(N_j, N_i) \tag{1}$$

where $\mathrm{C}(N_i)$ is the cost of node *j* and $\mathrm{M}(N_j, N_i)$ is metric from N_i to N_j.

Paths with a lot of energy consumption are removed. Each node assigns a probability to its neighbors in FT according to the paths. The probability of sending a data packet from node N_i to N_j (P_{N_j,N_i}) can be calculated as (2).

$$P_{N_j,N_i} = \frac{1/C_{N_j,N_i}}{\sum_{k\in FT_j} 1/C_{N_j,N_i}} \tag{2}$$

Then N_j calculates the average cost of the data packet reaching the destination with the use of the neighbors in the FT through the (3).

$$\mathrm{Cost}(N_j) = \sum_{i\in FT_j} P_{N_j,N_i} C_{N_j,N_i} \tag{3}$$

This average cost for N_j is placed in the sending cost field.

Data sending phase: Each node randomly selects a node from the FT table and sends its packet to it.

Route maintenance phase: The FT table is periodically updated.

II. Hierarchical

Scalability is a very important characteristic in the design of WSNs. A single-layer network might cause high overhead at the network connection gateways, which leads to increased communication delays. Also, a single-layer architecture is not scalable for a large network with many numbers of sensors. To scale the network without reducing the QoS, the idea of network clustering has been used in some routing protocols. The main goal of routing in hierarchical protocols is to decrease the energy consumption of nodes by sending multi-hops and also to aggregate data to reduce sending data packets to the sink.

Cluster creation is based on energy storage in SNs and its proximity to the CH. In hierarchical routing, the data moves from the lower cluster layer to the higher region, and jumping is carried out from one node to another node covering a larger distance, so the data movement towards the BS becomes faster. The cluster provides optimization capability at the CH.

The idea of LEACH is to form clusters of SNs based on the intensity of the received signal and use local CHs as routers to the sink node. The network in LEACH is considered as two layers. In this protocol, nodes are organized into clusters, and one node is considered as the cluster vertex or CH. The members of each cluster send information to the CH to send their information to the sink; For this reason, the CH node loses its energy earlier than other nodes. LEACH sends information to other network sensors in a flooding manner. Then, each SN is clustered based on the intensity of the received signal from the CHs, which somehow represents the distance from the node to the CH. After all the nodes are identified by the CHs, each CH prepares a TDMA-based schedule [28] for the nodes in its cluster. Therefore, each node knows when to send its data and keeps its radio components off except at scheduled times. In this way, the energy consumed by the sensors reaches its minimum.

When a CH receives the information about all the nodes under its coverage, it aggregates the data and then sends it to the sink. To distribute the amount of energy consumption in the network, in the LEACH, the CH is not selected in a fixed way, but randomly and based on the residual energy of the nodes. A node is selected as a CH if its value is not less than the threshold value.

The PEGASIS is an improved LEACH. In the PEGASIS, instead of forming several clusters, chains of SNs are formed in which each node sends and receives information from its neighbor node. In this chain, only one selected node from the chain can send data to the sink. The data is transmitted from one node to another node and collected at a selected node and finally sent to the sink from there. As shown in Figure 1, node C_0 sends its information to node C_1. Node C_1 sends its information together with information from node C_0 to the chain leader, namely node C_2. Node C_2 waits for the information to arrive from another neighbor, namely C_3. After receiving information from nodes C_3 and C_4, node C_2 sends the information to the BS or sink.

$$\begin{array}{c} C_0 \rightarrow C_1 \rightarrow C_2 \leftarrow C_3 \leftarrow C_4 \\ \downarrow \\ \text{BS (sink)} \end{array}$$

FIGURE 1
SENDING AND RECEIVING INFORMATION IN THE PEGASIS ALGORITHM

The difference between the PEGASIS and the LEACH is that it uses multi-hop routing by constructing a chain, and also only one node is selected to send data to the sink. The problem of the protocol appears when the length of the created chain increases with the increase of SNs, so the delay in sending data from nodes far from the chain leader increases. Also, the presence of a sender to the CH can be a bottleneck in the protocol.

The Threshold-sensitive Energy Efficient sensor Network Protocol (TEEN) is designed for time-critical applications where network response time is very important. The TEEN is a hierarchical protocol that uses a data-driven mechanism and is designed to react to sudden and drastic changes in sensed properties such as temperature. Sensors are clustered so that nodes that are close to each other form a cluster. This process continues on the second level until reaching the sink. This means that several clusters together form a larger cluster and one of the CHs is chosen as the head of all clusters. Figure 2 shows this architecture. After forming the clusters, CH sends two hard and soft thresholds for the sensed data features to the cluster members. The hard threshold is the lowest possible value of the feature that will cause the sensor to activate its transmitter and send it to the CH. Therefore, this threshold allows nodes to transmit only when the sensed features are in the range of interest. Once a node senses an attribute greater than the hard threshold, it can transmit data when its attribute value changes to or greater than the soft threshold value. It can be concluded that the soft threshold prevents sending unchanged or low-value data. Therefore, the TEEN is not suitable for applications that require periodic reporting, because the threshold limit may never be reached. The problem with this protocol is the high overhead and its complexity due to having several levels as well as the implementation of the threshold limit functions.

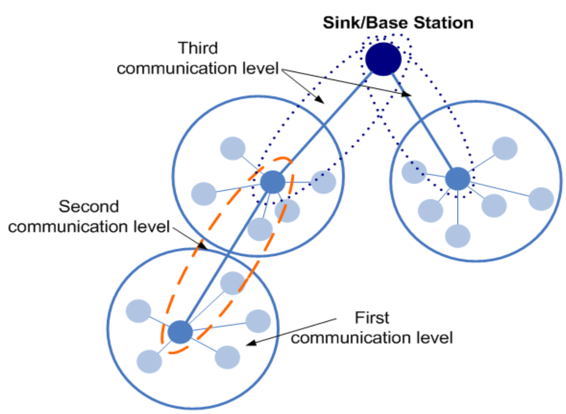

FIGURE 2
TEEN ARCHITECTURE

III. Location-based

Many routing protocols for WSNs require location information of sensors. In these protocols, this information is used to calculate the distance between two nodes. In this way, the amount of energy needed to send data between two nodes can be estimated. For example, if the area where the data should be sent is known, using the location information of the nodes, the data will be sent only to the desired location. Therefore, the amount of data transmission will be saved a lot. Most of the protocols that fall into this category are ad hoc network protocols that can be developed for WSNs.

Kumar et al. [29] divided the location-based routing protocols into two general categories including GPS and Non-GPS, and each of these two cases is also analyzed in two categories with mobile and stationary stations. They investigated location-based routing protocols in different aspects and described the advantages and disadvantages of different methods.

The Minimum Energy Communication Network (MECN) protocol [30] is very suitable for sensors that are not mobile. The main idea of the protocol is to find a subnet that has fewer nodes and send data between any two nodes that require less energy. In this situation, the path with minimum energy is found without considering all the nodes. In this protocol, a low-energy GPS is used to create a network with minimum energy. MECN creates a relay area for each node. The relay area contains nodes through which data transmission is more efficient in energy usage than direct transmission. Enclosure of node *i* is obtained from the community of all relay areas of node *i*. Figure 3 shows the relay area for the pair of nodes *(i, r)*.

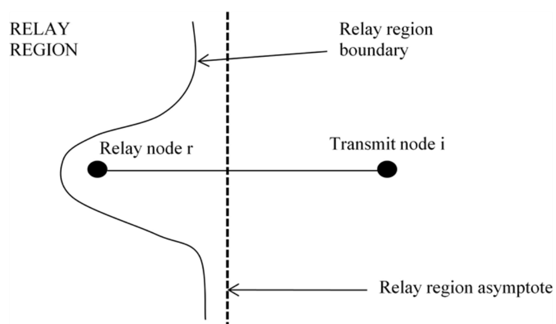

FIGURE 3
RELAY AREA FOR THE NODE PAIR (*i, r*)

This protocol consists of two phases:

1) It receives the position of the two-dimensional surface and constructs a sparse matrix (enclosures graph), which includes the enclosures of all data-sending nodes. This matrix includes optimal links based on energy consumption.

2) It finds the optimal links from the enclosures graph. For this, it uses the Belmann-Ford distributed algorithm [31], in which energy consumption is a function of cost.

The MECN protocol is self-configurable and can adapt to dynamic changes, such as the failure of nodes. The Small Minimum Energy Communication Network (SMECN) [32] is an extension of the MECN. In the MECN, it is assumed that each node can send data to another node at any time. If this is not possible due to the presence of an obstacle between two nodes, the SMECN is used, which also considers the existence of an obstacle between two nodes. In this protocol, it is still assumed that the network is fully connected. The subnet created in this protocol to transmit data with minimum energy consumption is smaller than MECN. Therefore, the number of hops to send data is reduced. The simulation results show that SMECN is more energy efficient than MECN. Also, the cost of maintaining its links is lower. On the other hand, finding a subnet with fewer nodes imposes more overhead on the protocol.

Geographic Adaptive Fidelity (GAF) [33] is an energy-aware, location-based algorithm that turns off unnecessary nodes to avoid energy consumption. This algorithm creates a virtual grid and each node has a GPS that shows the location of the node as a point in the virtual grid. The nodes that are placed in a cell of the created grid are equivalent to each other in terms of energy consumption. In GAF, the nodes that are equivalent to each other go to sleep mode to save their energy. Only one of the nodes is periodically turned on to participate in the routing operation; thus, the energy consumption between the nodes will be proportional. Figure 4 shows an example of the GAF algorithm.

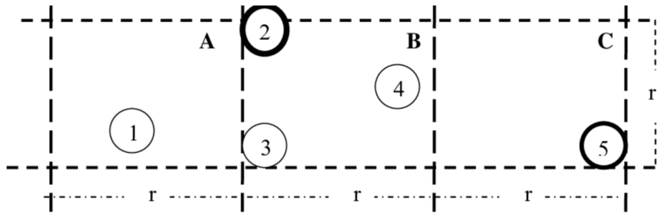

FIGURE 4
EXAMPLE OF THE GAF ALGORITHM

In Figure 4, node 1 can access to the nodes 2, 3, and 4. Also, each of nodes 2, 3, and 4 can access node 5. Therefore, nodes 2, 3, and 4 are equivalent to each other and two of them can go to sleep mode. In this algorithm, nodes are switched from sleep to active to balance the energy consumption. Three situations are defined in GAF, which are:

- Discovery, to identify neighbors in the grid;
- Active is the state in which the node participates in routing;
- Sleep, when the radio transmitter is off.

Figure 5 shows the transmission between these three states.

The duration of sleep depends on the type of application and the parameters are determined according to the routing process. To support mobility, each node estimates its time to leave the grid and informs its neighbors. Before the end of the active time of a node, one of the sleeping nodes becomes active.

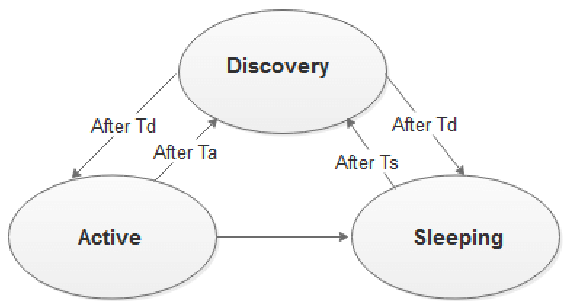

FIGURE 5
THREE DEFINED STATES IN GAF

The Location-Based Routing Protocol (LBRP) protocol uses the location information of nodes and applies a greedy forwarding and receiving approach for packet routing [34]. If the source does not receive the ACK packet within a timeout period, the LBRP resends the location-finding procedure. However, congestion may cause the ACK packet lost, and more congestion may be produced with the location discovery.

The Geographic and Energy Aware Routing (GEAR) protocol [35] replaces communication in the whole network with communication limited to a specific geographic area. This protocol uses the idea of an aware selection of neighbors based on the amount of energy and geographical area to send data to the desired area. In GEAR, each node has an estimated cost and a learning cost to reach the destination through its neighbors. The estimated cost will be calculated as a combination of the remaining energy and the distance to the destination. Learning cost is the estimated cost in which routing around a hole in the network is considered. A hole happens when a node has no neighbors that are closer to the destination area. If there is no hole, the estimated and learning costs are equal. When a packet arrives at its destination, the learning cost is one hop back, thus setting the route for the next packet. There are two phases in this algorithm.

Phase one - Sending packets to the destination area: When a node receives a data packet, it checks if there is a node closer to the destination area. If there is more than one node, it chooses the one closest to the destination as the packet's next hop. If all the nodes have a greater distance from the destination area, it means that there is a hole. In this situation, one of the neighbors is selected to send the data packet to the destination based on the learning cost.

Phase two - Sending the packet to the destination area: If the packet reaches the destination area, it can be flooded in the same destination area.

Geographic Multicast Routing (GMR) [36] uses the multicast advantage of wireless communication to improve the optimality of packet propagation in previous location-based multicast protocols. Also, this routing, like the other protocols, supposes centralized membership management in the multicast root. In this protocol, each node along the multicast tree tries to send the data packet to several branches using a broadcast transmission. More precisely, each sending node that broadcasts multicast information must select a subset of its neighbors as sending nodes to the destination. In GMR, nodes make this choice using greedy discovery, which optimizes cost over progress. GMR separates the costs of the multicast tree in terms of transmission (which it tries to minimize by using broadcasting) and the progress made to the destination in terms of geographical distance.

IV. Quality of Service aware

These protocols consider the Quality of Service (QoS) in routing and consider the end-to-end delay when forming a route in the network. In general, quality of service-aware protocols perform routing based on a set parameter such as delay, reliability, packet loss, etc., such that they try to improve the set parameter.

CLUSTERING IN WSNS

Considering the limited energy of each sensor and the fact that most of the energy (about 80%) in sensors is used to establish communication with other sensors; Therefore, the most appropriate way to optimally use that energy is to cluster nodes. Node clustering is the process of grouping a set of objects into several classes that have similarities.

The purpose of using clustering methods in WSNs is to decrease the amount of data sent and received and thus reduce the power consumption for communication between nodes. Clustering divides the data into clusters to maximize the similarity between the data within each cluster and minimize the data within different clusters.

Figure 6 shows an example of applying clustering to a set of data that uses the distance measure as the dissimilarity between data. Data that are spatially close to each other are considered as a cluster. Hierarchical clustering [37] in WSNs can significantly affect the global system scalability, lifetime, and energy efficiency. The hierarchy path is an efficient method for less energy consumption within a cluster and aggregating data to reduce the number of messages sent to the BS. On the contrary, a single-level network may overload the gateways when the density of sensors increases, causing communication delays and unsuccessful tracking of events. In addition, the single-level architecture for a large set of nodes covering a vast area is not scalable because the sensors usually cannot communicate over long distances.

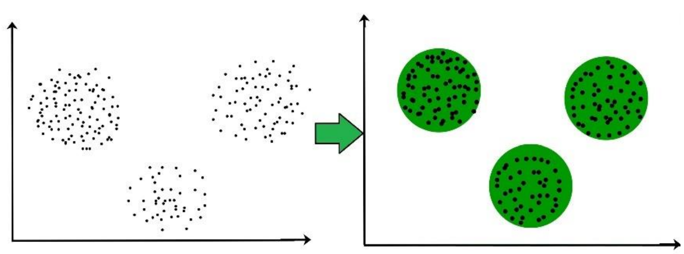

FIGURE 6
APPLYING CLUSTERING TO THE DATA

A CH can schedule intra-cluster activities so that nodes can switch to low-power or sleep mode and reduce the energy usage rate. In addition, the nodes can be used in a rotating order, and a specific time for data transferring is determined, as a result, the resending of data is banned, data redundancy in the covered area is reduced, and collisions in the access of the media are avoided.

Some important parameters that are discussed in all clustering procedures and are used as basic tools to compare and categorize clustering protocols are:
1. Number of clusters
2. Intra-cluster communication
3. Mobility of nodes and CHs
4. Types of nodes and their role
5. Cluster formation methodology
6. Selection of CHs

7. Algorithm complexity
8. Multi-layering

I. Clustering Methods

Clustering methods can be divided into several aspects:
1. Exclusive clustering and overlapping clustering: In the exclusive clustering method, after clustering, each data belongs to exactly one cluster; Like the K-Means clustering method [38]. However, in overlapping clustering, after clustering, each data is assigned a degree of belonging to each cluster. In other words, one data can belong to several clusters with different ratios, and an example of that is fuzzy clustering.
2. Hierarchical clustering and flat clustering: In the hierarchical clustering method, a hierarchical structure is attributed to the final clusters based on their degree of generality. For example, we can refer to the Single Link method [39]. However, in flat clustering, all the final clusters have the same degree of generality. The hierarchical structure resulting from hierarchical clustering methods is called a dendrogram.

Considering that hierarchical clustering methods produce more accurate information; In general, this clustering method is suggested to analyze data in more detail, but on the other hand, because it has a high computational complexity; Flat clustering methods are suggested for large data sets. In hierarchical routing protocols, higher energy efficiency can be reached when compared to the flat routing protocols.

PROPOSED METHOD

In the proposed method named GRMS, location-based routing is considered in WSN with the condition of sink mobility. In the location-based routing algorithms, SNs are addressed according to their location. Also, the distance between neighboring nodes has been estimated based on the strength of received signals. By exchanging information between neighbors, the relative coordinates of neighboring nodes can be found. Also, the location of the nodes can be obtained directly by using the Global Positioning System (GPS), if the SNs are equipped with a GPS receiver unit. The geographical and energy-aware routing method proposed in this paper is presented to improve energy consumption. The main goal of the GRMS is to reduce the energy consumption of SNs in a WSN with mobile sinks. The overall flowchart of the GRMS is shown in Figure 7.

The network considered in this paper has mobile BS. For this purpose, a mechanism should be applied to update the BS's location and nodes always obtain information about its latest status (each node must identify its neighbors in time cycles). In this paper, when the BS announces its location to the nodes and routing is carried out, the nodes start sending information packets. When the BS changes its location, it does not announce its new location to the entire network, allowing nodes to continue to operate for a specified period. A BS re-announces its position in the network when it is more than a threshold away from its set of neighbors. In this way, it is possible to avoid consecutive routings, which will reduce energy consumption in the entire network. Below are the steps of the GRMS.

I. Initial population

The WSN considered to experiment has a large range. There is no need to check the entire network to send a packet from a source to a destination. By having the geographic location of the source and the destination nodes, the desired area can be separated from the entire network and considered for routing. Therefore, in the GRMS, routing will not be performed in the entire network.

II. Sending the packet

In the GRMS, each node after receiving a packet tries to send it to a neighboring sensor that is closer to the destination than itself. In this way, instead of broadcasting the request to the entire network, it is only sent to the desired location, and as a result, more energy is saved with this method. In the GRMS, the packet transmission process to the nodes in the target area consists of two phases as below:
1. Forwarding packets to the target area: A geographic and energy-aware discovery is used to select the neighbor and send the packet to the target area, which should consider these two following items:
a) When there is a neighbor closer to the destination, the next step is selecting the nearest node to the source among the neighbors.
b) When all the neighbors are away, then there is a hole and the next node should be selected in such a way that the cost of sending the packet to the neighbor is minimized.
2. Packet distribution within the target area: In most situations, a recursive geographic forwarding algorithm is used to distribute the packet within the target area. However, in some situations where the density is low, the recursive geographic forwarding

algorithm does not terminate and moves around an empty target area until the number of packet steps exceeds the limit. In this case, using the limited flood method is suggested. It means the neighbor which is nearer to the destination among all the neighbors will select to send the packets to it.

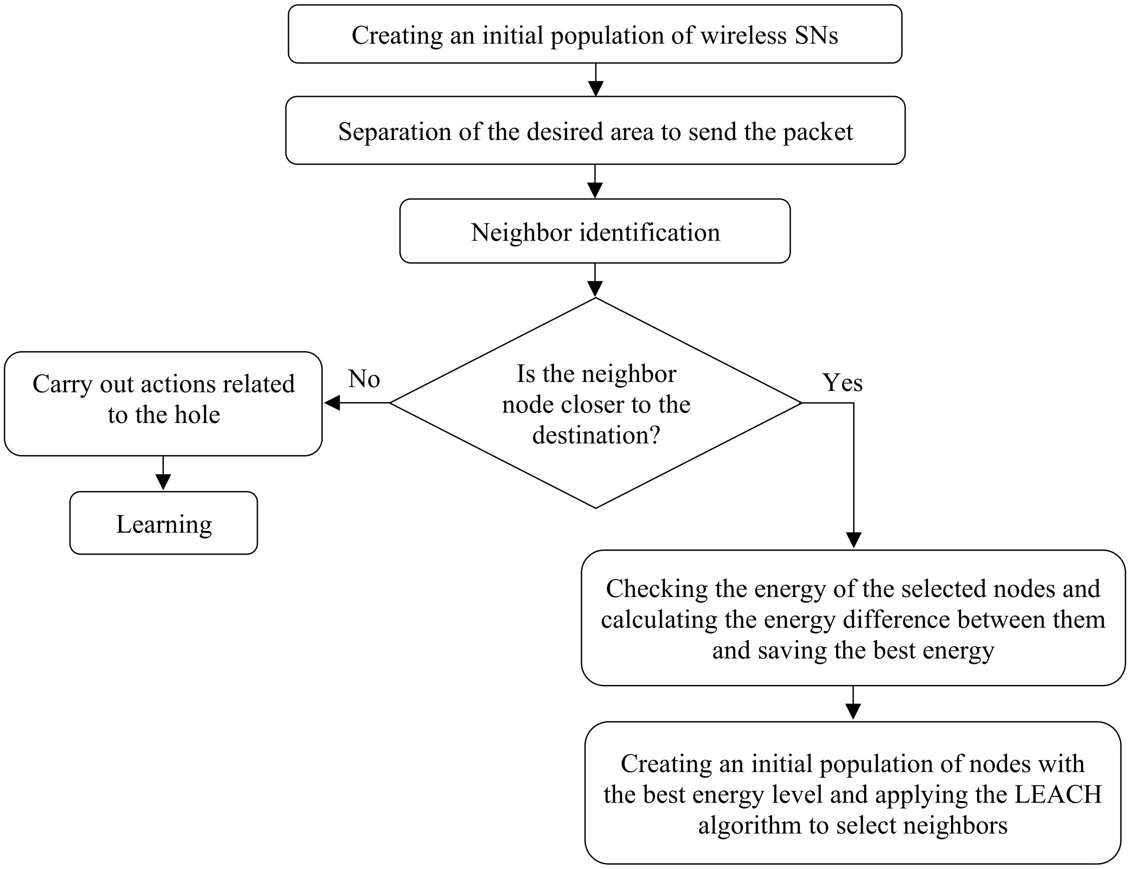

FIGURE 7
GENERAL FLOWCHART OF THE GRMS

III. Neighbor-aware energy calculation

Assume that node A sends packet P to destination area R and the center of the target area is D. After receiving the packet P, node A will forward the packet to the target area and at the same time try to balance the energy consumption among all its neighbors. Node N achieves this compromise by minimizing the learned cost $h(A, R)$ of neighbor A.

If a node does not have a cost value $h(A, R)$ for a neighbor A, it calculates an estimated cost $c(A, R)$ as the default value for $h(A, R)$. The estimated cost $c(A, R)$ is defined in (4).

$$c(A,R)=\alpha.d(A,R)=(1-\alpha).e(A) \quad (4)$$

where α is the adjustable weight, $d(A, R)$ is the distance from A to the center of D in region R that is normalized by the largest distance value among all neighbors of A, and $e(A)$ is the energy consumed at node A, which is normalized by the largest energy consumption between all A's neighbors. After each node A_{min} chooses its next step, it adjusts its $h(N, R)$ using $h(A_{min}, R)+c(A, A_{min})$. The second part of this equation is the cost of sending a packet from A to A_{min}.

$c(A, A_{min})$ can also be a combined function of the residual energies of nodes A and A_{min} and the distance between these two neighbors. Now that each node knows the learned cost $h(A, R)$ or the estimated cost function $c(A, R)$ of all its neighbors, the packet-sending operation is started.

IV. Neighbor selection

The sent packet contains a destination field value. Therefore, the sending node can use the LEACH algorithm to select the next step. Each time node *A* receives a packet, it will choose the next step from among the neighbors that are closer to the destination and simultaneously try to minimize the learned cost value *h(A, R)*. As it chooses the next step from the nearest neighbors to the destination, it moves progressively towards the target area until there is no hole in the network.

Without holes, the learned cost is a combination of distance and energy consumed. Minimizing the amount of learned cost is a compromise between routing to the next step closer to the destination and balancing energy consumption.

In the case that all the farthest neighbors are, node *A* knows that it is in a hole (Figure 8). When there are no holes in the path to *R*, the learned cost *h(A, R)* will be equal to the estimated cost *c(A, R)*. However, when there is a hole in the path *R*, the learned cost of the node represents the resistance to take the path to the hole. The resistance that estimated cost cannot provide.

In the GRMS for the condition that the hole is in the routing path, the neighbor that is closer to the destination among all the neighbors will select to send packets to the destination. This prevents sending a flood of packets, which reduces energy consumption. The GRMS works so that the amount of energy consumption is lower than the GEAR algorithm.

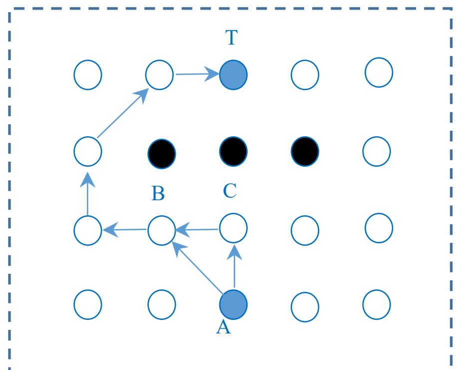

FIGURE 8
PLACEMENT OF NODE *C* IN THE HOLE

In other words, the energy of each node is calculated among the selected neighbors (neighbors that are closer to the destination node than the source node), and the energy difference between the nodes is obtained. Then, an initial population is created among the nodes with the highest energy, and using the LEACH algorithm, the neighbor that consumes less energy than the other neighboring nodes and is closer to the destination is selected to receive the packet.

It is important to note that because the sensor nodes are mobile, the latest geographical location of the nodes is always considered. Also, in each step to select the best neighbor until the termination condition is reached, the algorithm is repeated to select the best neighbor of that node.

SIMULATION

The GRMS is simulated in MATLAB 2024b software with an Intel Core i9 processor and 32 GB memory.

In the simulation of the GRMS, first, each node will have initial energy, and after each round that collects, processes, or transmits data packets, some of this energy (the energy of each node) is used. After some time when the network continues to work, the energy of the nodes gradually decreases and finally, they turn off; Therefore, by using the GRMS, this process of energy reduction will be managed in such a way that the network continues to work for a longer period.

In the meantime, the end-to-end delay parameter is also checked, which will measure and check the time that data packets are transferred from the source node to the destination node in the network. Table I shows the initial values of the parameters used in the simulation.

In this paper, the distribution of nodes is random in a two-dimensional area. Also, the initial energy of the nodes will be equal and under similar conditions. The number of nodes is considered to be 200, which is included in the network range. Also, the size of the network is considered as a square in a 100m × 100m environment.

TABLE I
INITIAL VALUES OF PARAMETERS

Parameter	Value
Number of sensors	200
Sensor range (m)	17.675
Packet length (bit)	2000 ~~bit~~
Population size	50
Network size (m^2)	100×100
Sink location	$(x, y) = (50,50)$
Initial energy (Jule)	400
Generation size	20

RESULTS AND DISCUSSION

As explained in the Proposed Method Section, the termination condition of the algorithm is to reduce the energy of the nodes below the threshold; so that there is no energy needed to send data to the sink. Figure 9 shows the network after applying the LEACH clustering algorithm. As shown in Figure 9 (left side), the number of clusters after applying the LEACH algorithm is 12. Some nodes are located at the border between the clusters, which are used to transmit data packets between the two clusters.

One of the most important factors that should be taken into consideration in the GRMS is how the amount of energy of the SNs will change. Figure 10 shows the amount of residual energy of the sensors in different iterations.

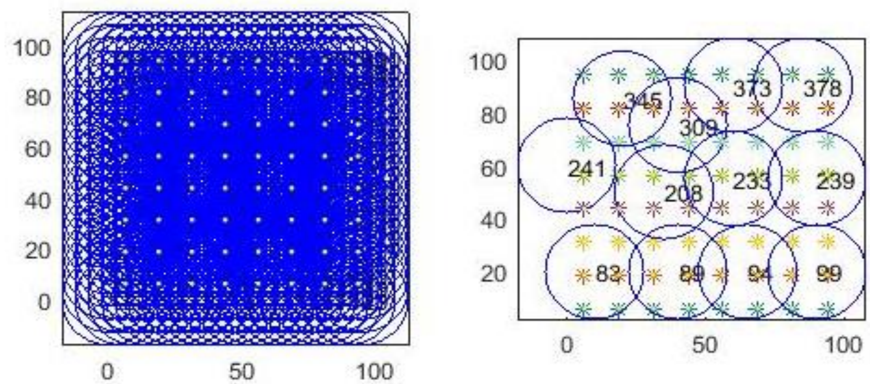

FIGURE 9
CLUSTERING WITH LEACH ALGORITHM

As shown in Figure 10, in the round zero, the residual energy is 400 Jule, then with the increase in the number of iterations and the progress of the program, the amount of energy of the nodes gradually decreases until they lose all their energy. It is possible to consider the energy consumption of all network nodes and check how much energy has been consumed in different iterations of the program, which is shown in Figure 11.

To measure the efficiency of a network, the lifetime parameter is one of the most important factors that will be used. The lifetime of the WSN means how long it takes from the time the first node is dead until the network can have operation and the information from the SNs reaches the CH and the CH sends it to the sink.

Due to the presence of batteries in the SNs and the lack of a permanent power source, as much as the lifetime of an SN increases, a sensor network will have a longer lifetime. Therefore, the proposed routing algorithm is such that it increases the lifetime parameter (Figure 11).

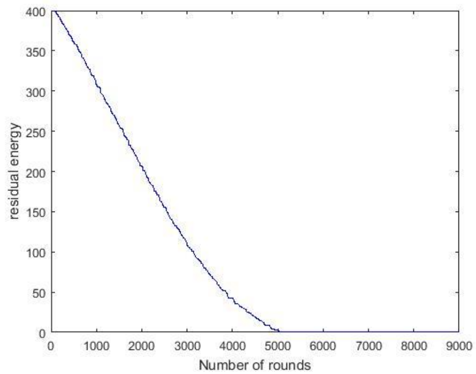

FIGURE 10
THE RESIDUAL ENERGY OF THE GRMS AT DIFFERENT NUMBERS OF ITERATIONS

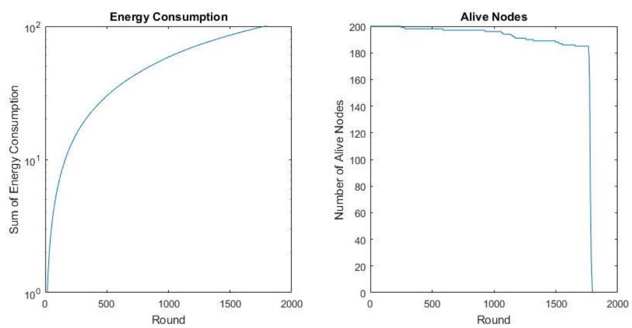

FIGURE 11
ENERGY CONSUMPTION AND NUMBER OF LIVE NODES IN DIFFERENT ITERATIONS OF THE GRMS

According to Figure 11, at zero time when the nodes have not yet started to exchange information, the amount of energy consumption is zero. In the 500th iteration, the total energy consumption of the network is about 30 joules. As much time passes since the initial establishment of the network, the energy consumption graph goes upward until the remaining 183 nodes consume about 100 joules of energy in the 1800th iteration.

In the following, the GRMS with GAF and GMR algorithms as well as the GEAR algorithm is compared. In Table II, the number of dead nodes for the four different methods is compared. As shown in Table II, the first GAF node is dead in round 428, in GMR in round 490, in GEAR in round 640, and in the GRMS in round 656. These results show that the GRMS has been able to maintain more live nodes in more rounds than the GAF, GMR, and GEAR methods.

Figure 12 shows the effectiveness of the GRMS in comparison to other methods for dead nodes in different rounds. It means that the GRMS has been kept alive network for a longer period, which means that the energy of these nodes has been discharged later and a reduction in energy consumption has occurred.

Table III shows the percentage improvement of the GRMS for the total number of network dead nodes in comparison to other methods. As shown in Table III, the GRMS method has an improvement of 27.25%, 17.15%, and 9.66%, respectively, compared to the GAF, GMR, and GEAR methods for the total number of network dead nodes.

TABLE II
NUMBER OF ROUNDS OF GAF, GMR, GEAR, AND GRMS FOR DEAD NODES

Method	1st node	50% of nodes	70% of nodes	100% of nodes
GAF	428	1143	1509	2088
GMR	490	1220	1650	2268
GEAR	640	2170	2310	2423
GRMS	656	2371	2412	2657

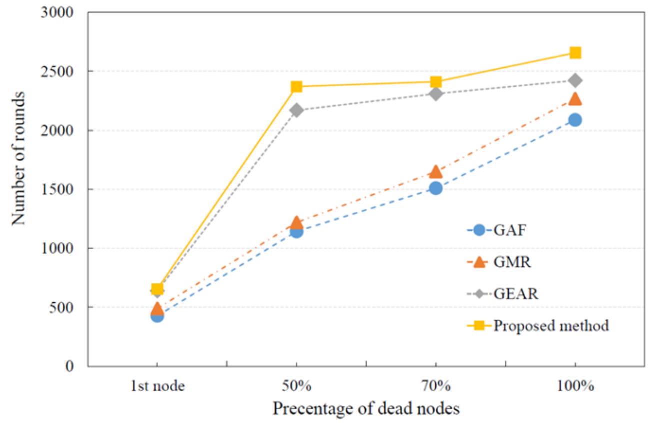

FIGURE 12
NUMBER OF ROUNDS FOR GAF, GMR, GEAR, AND GRMS VERSUS PERCENTAGE OF DEAD NODES

TABLE III
PERCENTAGE IMPROVEMENT OF THE GRMS METHOD COMPARED TO GAF, GMR, AND GEAR METHODS FOR THE TOTAL NUMBER OF NETWORK DEAD NODES

Method	Percentage improvement
GAF	27.25
GMR	17.15
GEAR	9.66
GRMS	---

CONCLUSION

One of the topics of interest in WSNs is increasing the lifetime of its nodes. Considering that the batteries used in the nodes have limited energy, it is important to use the energy in them optimally. Also, it is important for data transmission that tries to increase the lifetime of the network and to prevent the connections from being damaged through power management methods. In protocols based on geographic routing with a mobile station, when the BS changes its location, it must inform the other nodes of its new location by broadcasting its location. Each time the BS moves and informs the other nodes of its location, routing must be carried out once again. This issue causes the number of times of routing to increase, which causes an increase in energy consumption in the network. In this paper, a method for geographical routing of the WSN with a mobile sink is presented. The remaining energy and the number of dead nodes are considered as the two important factors for the subject of this paper. The results of the GRMS in comparison with GAF, GMR, and GEAR algorithms have shown the effectiveness of GRMS over other algorithms. The first GAF node is dead in round 428, in GMR in round 490, in GEAR in round 640, and the GRMS in round 656. The GRMS method has an improvement of 27.25%, 17.15%, and 9.66%, respectively, compared to the GAF, GMR, and GEAR methods for the total number of network dead nodes. These results show that the GRMS has been able to maintain more live nodes in more rounds than the GAF, GMR, and GEAR methods.

In future research, multi-hop routing algorithms based on the geographical information of nodes can be investigated to reduce energy consumption in WSNs that have mobile sink nodes.

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