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A Hybrid Protocol to Enhance the Lifetime and Reliability of WSN

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Abstract: - Wireless Sensor Networks (WSN) are networks composed of spatially distributed, autonomous devices called sensor nodes that monitor and collect data about environmental conditions. These sensor nodes communicate wirelessly to transmit data to a central system for analysis. WSNs use these numerous nodes distributed in a network to perform various tasks such as data collection, processing, organization, communication, management, etc., and energy is the most crucial resource for properly functioning these nodes over the network. Hence, its primary concern is optimizing energy consumption and extending the network lifespan. The sensor nodes can be clustered to increase their lifespan further. A secondary concern is a random distribution of sensor nodes within a predefined network area which presents challenges such as incomplete coverage, connectivity issues, and inefficient energy consumption. The proposed system detects coverage holes and improves node participation by placing monitor nodes strategically within the network to ensure complete coverage and combines it with an energy-efficient routing approach and optimized Shortest Path Routing through minimum spanning trees. This combination minimizes distances between nodes, reducing energy consumption and enhancing network efficiency.

Keywords: Wireless sensor networks; Routing; Batteries; Lifetime; Sensors;

I. INTRODUCTION

In the contemporary landscape of technology, Wireless Sensor Networks (WSNs) have emerged as a critical component in a multitude of applications, bridging the gap between physical environments and digital data processing. A WSN comprises a group of spatially distributed sensor nodes that communicate and collaborate to monitor specific phenomena, collect relevant environmental data, and transmit this information to a central repository or sink for analysis. The versatility of WSNs allows them to be utilized across various domains, including environmental monitoring, healthcare, industrial automation, and smart cities, underscoring their significance in modern society.

Structure and Functionality of Wireless Sensor Networks

At the core of a WSN are its sensor nodes, typically characterized by their small size, low cost, and low power consumption. Each node is equipped with capabilities to sense environmental parameters such as temperature, humidity, pressure, or motion, as well as the ability to process collected data and transmit it to neighboring nodes or directly to a central sink. This localized processing capability is vital in minimizing data transmission costs and enhancing overall energy efficiency.

The operation of a WSN can be broadly categorized into five key stages: sensing, processing, transmission, reception, and actuation.

1. *Sensing:* Sensor nodes continuously monitor environmental variables, gathering important data concerning specific phenomena.
2. *Processing:* Upon collecting data, sensor nodes may perform preliminary processing to filter out unnecessary information and retain only the most relevant data.
3. *Transmission:* This processed information is then transmitted to neighboring nodes or ultimately to a sink. Methods of transmission may include using radio frequency, infrared signals, or other wireless communication protocols.
4. *Reception:* Neighboring nodes receive the transmitted information and can further relay it toward the sink, effectively creating a multi-hop communication pathway.
5. *Actuation:* In some applications, WSNs also involve actuators that can respond to collected data, allowing for real-time adjustments and interventions based on the monitored environment.

Applications of Wireless Sensor Networks

The applicability of WSNs is vast and varied, making their potential impact significant across numerous fields:

- *Environmental Monitoring:* WSNs play a crucial role in observing environmental parameters, such as climatic changes, air and water quality, and wildlife tracking. For instance, they can facilitate early warning

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systems for natural disasters like floods and earthquakes, providing essential data to inform timely response actions.

- *Healthcare Applications*: In the realm of healthcare, WSNs enable remote patient monitoring, collecting vital signs and health metrics from patients in real-time. These networks can enhance the quality of care, particularly for elderly or chronically ill patients, by enabling continuous health tracking and timely interventions.
- *Industrial Applications:* WSNs are increasingly utilized in manufacturing and industrial automation for monitoring production processes, equipment health, and resource allocation. The integration of WSNs can lead to improved operational efficiency and reduced downtime through proactive maintenance.
- *Smart Cities:* As urban areas transform into smart cities, WSNs are instrumental in managing city infrastructure, traffic flow, and resource consumption. They enable the deployment of intelligent transportation systems that optimize traffic patterns and enhance safety.

Challenges in Wireless Sensor Networks

Despite their numerous advantages and applications, WSNs encounter a range of challenges that can impact their effectiveness and reliability.

1. *Energy Constraints*: The limited battery life of sensor nodes is a significant concern, as many nodes are deployed in locations that are challenging to access for maintenance or battery replacement. Implementing energy-efficient protocols and optimizing data transmission routes are critical for prolonging network life.
2. *Coverage Holes:* As previously mentioned, coverage holes can arise due to the random distribution of sensor nodes. These gaps in communication can lead to data loss and decreased network performance. Effective deployment strategies and the incorporation of monitor nodes can help reduce the occurrence of coverage holes.
3. *Scalability*: As the number of sensor nodes in a network increases, maintaining effective communication and data management becomes increasingly complex. Developing scalable algorithms and architectures is essential for accommodating larger networks without compromising performance.
4. *Security Concerns:* With the increasing reliance on WSNs for sensitive applications, security becomes a paramount concern. Risks such as data interception, node tampering, and denial-of-service attacks must be addressed through robust security protocols to ensure data integrity and privacy.

Solutions to Address Coverage Holes

To overcome the challenge of coverage holes and enhance the reliability of WSNs, several strategies can be employed:

- *Strategic Node Placement*: Implementing advanced algorithms for node placement can help minimize gaps in coverage. By analyzing the terrain and environmental characteristics, nodes can be strategically positioned to ensure optimal coverage and communication.
- *Adaptive Clustering:* Utilizing adaptive clustering techniques allows for dynamic reconfiguration of the network, where nodes can adjust their roles based on current conditions and energy levels. This adaptability helps maintain connectivity even if some nodes fail or become inactive.
- *Deployment of Monitor Nodes:* Introducing additional monitor nodes specifically tasked with filling coverage gaps can significantly enhance network reliability

II. RELATED WORK

Recent developments in Wireless Sensor Networks (WSNs) have focused on improving energy efficiency and overall network performance, addressing challenges such as power consumption and data transmission reliability. Several innovative approaches and algorithms have been introduced to enhance these networks' operational capabilities, with a strong emphasis on clustering, energy-aware routing, and optimization techniques.

Multi-Hop Gateway and Cluster Head System

Mohammed, Kaddi, et al. [1] present a protocol enhancement involving a multi-hop gateway system that significantly contributes to efficient data transmission. This protocol architecture organizes the network into four distinct regions, each managed by a designated cluster head (CH). The innovative use of gateway nodes plays a pivotal role in reducing power consumption during data transmission. By aggregating data from various CHs before relaying it to the base station (BS), the gateways minimize the amount of redundant data sent over the network. This aggregation process not only conserves energy but also optimizes the overall data flow within the WSN, facilitating more effective communication and an extended network lifespan.

Dynamic Cluster Head Relay (DCHR) Algorithm

In a pioneering study by Abhishek, Kapoor, et al. [2], the dynamic cluster head relay (DCHR) algorithm is introduced to assess the energy levels of individual nodes. The effective formation of CHs is contingent upon the energy status of these nodes. By establishing a threshold energy level, the DCHR ensures that only those nodes with an energy capacity exceeding this threshold participate in the clustering process. This selective participation helps optimize energy consumption across the network, thereby enhancing the efficiency of the data collection and transmission processes, ultimately leading to a more resilient WSN framework.

Hybrid Routing Techniques

Ashutosh Kumar Gupta et al. [3] explore an energy-efficient routing technique that employs a hybrid approach combining multi-hop LEACH (MR-LEACH) and particle swarm optimization (PSO). This method primarily focuses on clustering techniques designed to maximize network performance while minimizing energy constraints. By optimizing the routing paths and ensuring effective load distribution among nodes, this approach results in an increased packet delivery ratio and extended network lifetime. However, the study recognizes the challenges associated with scalability and security that arise with the implementation of such hybrid models, highlighting the need for ongoing research in these areas.

Optimized PEGASIS Routing Protocol

Ni Chen et al. [4] propose an improved version of the PEGASIS (Power-Efficient Gathering in Sensor Information System) routing protocol, which integrates ant colony optimization techniques to form optimal chains within clusters. This enhancement aims to prolong the network's lifespan by achieving a balanced energy distribution among nodes and dynamically updating the roles of CHs based on real-time energy levels. While this approach offers significant benefits for energy management, it does introduce complexities related to implementation, scalability, and sensitivity to environmental variations, necessitating further investigation and refinement.

Power Consumption Optimization Strategies

C. Sivasankar et al. [5] delve into the optimization of power consumption within WSNs by proposing energy-aware routing algorithms alongside multi-hop routing strategies. Their study emphasizes reducing both energy expenditure and travel distances during data transmission, thereby enhancing data transmission efficiency. This focus on sustainable practices is crucial for extending the operational life of WSNs. Nonetheless, Sivasankar et al. caution about potential scalability issues and the impact of environmental conditions on the performance of their proposed routing solutions.

Resource Management in Wireless Body Area Networks

Farman Ullah et al. [6] focus on enhancing the energy efficiency of routing schemes specifically within Wireless Body Area Networks (WBANs). They introduce a method involving node selection and rotation techniques, which effectively addresses resource limitations inherent in these specialized networks. Their experimental results, obtained using the M.A.T.L.A.B. platform, reveal a notable improvement in energy management, achieving a 26% enhancement in performance. This innovative approach not only solidifies the importance of strategic node management in WSNs but also exemplifies the potential benefits of integrating interactive graphical environments for performance analysis.

The evolution of protocols and algorithms within Wireless Sensor Networks reflects a concerted effort to address the inherent challenges of energy consumption, data transmission efficiency, and network durability. As researchers continue to innovate, the integration of advanced techniques such as multi-hop gateways, dynamic clustering algorithms, hybrid routing methods, and optimized energy management systems will be critical in enhancing the functionality and sustainability of WSNs. These advancements not only promise improved network performance but also support the expanding applications of WSNs across diverse fields, from environmental monitoring to healthcare solutions, ultimately contributing to smarter, more efficient technological ecosystems

III. Architecture of Hybrid Protocol

The architecture of the Hybrid protocol of WSN is shown in Figure 1. Initially, all the sensor nodes are deployed in the network with sink node. Delaunay Triangulation Algorithm (DTA) checks the large edge in the network with its neighbor nodes. If a large edge is detected, a monitor node will be deployed in the middle of the large edge by DTA. Cluster head formation will start once all nodes are in the range of their neighbor nodes; CH will be formed with equal sensor nodes. Now all sensor nodes will send data to their CH node and the CH node will send it to the sink node using the Data Transmission and Routing algorithm. After every round of communication, the residual energy level of each node is determined using the energy dissipation model. If any node has less than the minimum threshold level of energy, the node will be declared a dead node, and a gap will be formed. Once a gap or coverage hole is detected, the monitor will deploy and CH formation will start. After CH formation again, continue with communication from source to sink.

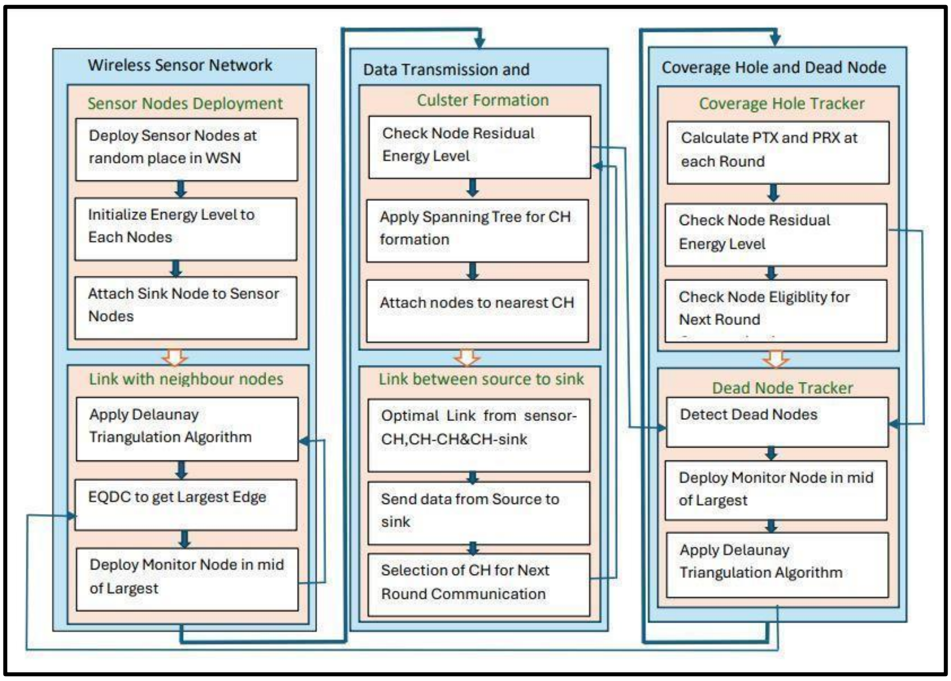

Fig 1: Architecture of Hybrid Model

IV. Proposed Methodology Used for Hybrid Protocol

The proposed Hybrid protocol for WSN enhances the lifetime and reliability of WSN with the combinations of eight algorithms in simulation environments. These algorithms are: 1. Node Deployment Algorithm, 2. Delaunay Triangulation Algorithm, 3. Enhanced Cluster Head Election Algorithm, 4. Energy Dissipation Model, 5. Data Transmission and Routing Algorithm, 6. Gap Identification and Monitor Node Placement Algorithm, 7. Dead Node Tracking Algorithm, and 8. Performance Metrics Calculation Algorithm.

A. Major Parameters Used in Algorithm of Hybrid Protocol

1. C: Cluster structure stores all CHs with IDs, coordinates, and distance to the sink.
2. DT: Delaunay Triangulation, DT Algorithm generates links with all neighbor sensor nodes and creates robust network topology by dividing the sensor field into triangular regions.
3. EDA: Energy Dissipation for Aggregation, EDA: 5.00E-09, It indicated energy consumption by the sensor node during the process of aggregation of data at CH.
4. ERX: Energy Required for Reception, ERX: 5.00E-08, It is energy calculated by the EDA model during the energy consumption of the sensor nodes (CH) while receiving the data from sensor nodes.
5. ETX: Energy required for the transmission, ETX: 5.00E-08, It is energy calculated by the EDA model during the energy consumption of the sensor nodes while sending the data to CH or sink from sensor nodes.
6. Efs: Energy consumption factor of the sensor node white transmission of the packet in the free-space model of transmission, Efs: 1.00E-11. Efs is mostly used in the short coverage area.
7. Emp: Energy consumption factor of the sensor node white transmission the packet in the multipath model of transmission, Emp: 1.30E-15. Emp is majorly used in the long coverage area.
8. En: Remaining Energy of a sensor node: after every round of communication, each sensor node's residual energy level will be calculated. En helps to keep track of live nodes and dead nodes after comparison with the minimum threshold energy required for transmission.
9. E0: The initial energy of a sensor node is set to 0.5.
10. LeaderNodeThreshold: Hybrid protocol decides the next round of CH for communication if any sensor node has LeaderNodeThreshold: 0.03.

11. MN: Monitor Nodes, these nodes placed at large distances or coverage holes or dead node's replacement
12. MNx: x-coordinate of a specific MN, MNy: y-coordinate of a specific MN.
13. PACKETS_TO_BS: Number of packets sent from source node to sink node.
14. S: Sensor Node Structure, stores required properties of each sensor node in WSN. These properties are position, energy level, type (normal or cluster head), and distance to the sink, making it central to node operations and simulations.
15. SN: Static Nodes in the Wireless Sensor Network (WSN).
16. STATISTICS: It keeps track of WSN performance metrics such as dead/live nodes, packets transmitted, and residual energy, helping analyze the network's efficiency and lifetime.
17. T: Distance between sensor nodes to sink node, distance is calculated using the formula of Euclidean. It helps with routing protocol to decide the link for the next round of communication.
18. X: X-coordinates of Cluster Heads, Y: Y-Coordinates of Cluster Heads
19. XR: X-Coordinates of Sensor Nodes, YR: Y-Coordinates of Sensor Nodes.
20. all_dead: Number of nodes, not capable of communication in WSN.
21. alive: Number of available nodes for communication in WSN.
22. 5. Proposed Hybrid Protocol

B. *Node Deployment Algorithm*

The Node Deployment Algorithm is a systematic approach for establishing a Wireless Sensor Network (WSN) designed to optimize the placement and functionality of sensor and monitor nodes across a specified area. In this algorithm, a target network area of 100 x 100 meters is defined, within which 100 static sensor nodes and 10 dynamic monitor nodes are randomly deployed. Each node is initialized with an energy level of 0.5 joules to support its operational tasks, and a sink node is designated for central data collection. The algorithm includes steps for visualizing the network layout, distinguishing between different node types, and storing critical information such as node coordinates, energy levels, and status, enabling effective energy management and communication throughout the network. This structured deployment ensures efficient data gathering and enhances the overall performance of the WSN.

```
Input: Sensor nodes: 100, Monitor nodes: 10 and sink
Output: Wireless Sensor Network Formation
        BEGIN
        1. Set Target Network Area: 100 X  100 units(m).
        2. Deploy Normal Sensor Node: 100 and Monitor nodes: mn = 10
                set static node: 100, dynamic node: 10
                Generate random node position:
                pts = [rand(n, 1) * xm, rand(n, 1) * ym];
                mnpts = [rand(mn, 1) * xm, rand(mn, 1) * ym];
        3. Energy Initialization: E0= 0.5 Joule
        4. Deploy Sink Node:
                sinkNode= [sinkNodex, sinkNodey];
                pts = [sinkNode; pts];
        5. Set nodeVisualization:
                Static nodes plot: plot(static_nodes(:, 1), static_nodes(:, 2), 'ob');
                Monitor nodes plot: plot(monitor_nodes(:, 1), monitor_nodes(:, 2), '+r');
                Base station: plot(sinkx, sinky, '*r', 'MarkerSize', 10);
        6. Store nodeInformation: Data Structure
                nodeID, nodeCoordinates, nodeRadius, and selectionStatus
        END
```

This algorithm provides a step-by-step process for efficiently deploying a Wireless sensor network by randomly positioning nodes within a designated area, assigning energy levels, and establishing monitoring infrastructure. The data visualizations and structured data storage facilitate the management and analysis of the deployed network, ultimately contributing to its operational effectiveness

C. Delaunay Triangulation Algorithm

Once sensor nodes are deployed in the WSN by the sensor nodes deployment technique, Delaunay triangulation uses the EQDC technique to find out the coverage hole and analyze the longest distance between neighbor nodes. The Delaunay triangulation algorithm also helps to enhance the cluster formation with equal target area and number of nodes.

Input: All Node's X and Y coordinator

Output: Find the long edge/distance from sensor to its neighbor nodes and place monitor node in mid to prevent from coverage hole

BEGIN

```
1. getNodeCoordinator: All Nodes
        pts = [x_coordinates, y_coordinates];
2. Apply Delaunay Triangulation: generate all triangular mesh
        DT = delaunayTriangulation(pts);
3. Retrieve all edges:     edges = DT.edges;
4. Calculate Edge Lengths: Apply Euclidean distance
edge_lengths = sqrt(sum((DT.Points(edges(:, 1), :) - DT.Points(edges(:, 2), :)).^2, 2));
5. Find Largest length edge: Coverage hole detection
        long_edges = edges(edge_lengths > 2 * radius);
6. Deploy Monitor Node: if coverage hole: TRUE
        for i = 1:size(long_edges, 1)
        midpoint = (DT.Points(long_edges(i, 1), :) + DT.Points(long_edges(i, 2), :)) / 2;
                monitor_nodes(end + 1, :) = midpoint;
        end
7. Restart the Delaunay Triangulation Algorithm: Goto step 2
        updated_pts = [static_nodes; monitor_nodes];
        newDT = delaunayTriangulation(updated_pts);
8. Visualize Triangulation: plotTriangle
        Original triangulation: triplot(DT, 'ob');
        Updated triangulation with monitor nodes: triplot(newDT, '-or');
END
```

C. Enhanced Cluster Head Election Algorithm

If all the nodes are properly deployed in the WSN and no coverage hole is found, in this proposed work, the Enhanced LEACH algorithm is used for the Cluster Head Election Algorithm. It is a mechanism used to probabilistically select cluster heads (CHs) in a wireless sensor network (WSN). These cluster heads act as intermediaries that aggregate data from normal sensor nodes and transmit it to the base station (sink). This hierarchical approach significantly reduces energy consumption by minimizing direct communication between nodes and the sink. In this, CH selection is not static; it's dynamic and selects the next CH for communication according to the ode's residual energy level. The result of this algorithm makes WSN stable and prolongs its lifetime.

Input: Node's energy level at each round

Output: Cluster and Cluster Head Formation at each round

```
BEGIN
1. Formation of Cluster Head:
        if(node[i].ResidualEnergy> node[i+1].ResidualEnergy)
                set node[i]: CH
        number_of_nodes_CH=(totalNumber_Nodes/number_CH);
2. CH selection at nextRoundTransmission
        if(node[i].ResidualEnergy> node[i+1].ResidualEnergy)&&(CH!= recentCH)
                set node[i]: CH
        number_of_nodes_CH=(totalNumber_Nodes/number_CH);
```

```
3. Calculate Threshold for Selection:
        Eligible Threshold: G : set of nodes
                T(n): T(n) = { p / 1-p*(mod(r,1/p)
4. Random CH selection:
        if(randomNode<T(n))             set CH: randomNode;
5. Broadcast CH info to WSN.
6. nonCH node near to Sink: nodes□ Sink;
7. Each Round:
        for i=1: n
                getNodesResidualEnergy.broadcast( );
                S(i).E = S(i).E - E_loss;
END
```

D. Data Transmission and Routing Algorithm

After the formation of the cluster and selection of CH, a communication link will be generated with sensor nodes to CH and CH to a base station. In this Hybrid protocol, the routing algorithm has the major role in the effective utilization of all the sensor nodes and data transmission from the source node to the sink node. If a coverage hole occurs in the system or any nodes become dead or not able to communicate with its CH, the routing mechanism has to find an alternate communication link for data transmission. It selects the most energy-efficient path, either directly to the sink or via intermediate nodes (e.g., cluster heads). It provides reliable and stable communication from source to sink.

Input: Sensor nodes, Cluster Heads and Sink

Output: Communication link selection for data transmission

```
BEGIN
1. Cluster Head Selection: CHs
2. nodes attach to nearest CH.
        distance = sqrt((S(i).xd - C(cluster).xd)^2 + (S(i).yd - C(cluster).yd)^2);
        if(distance<= radious)      nodes: communicate to CH
        else        deployMontiorNode: midDistance;
3. CH: aggregate sensors data and send to sink
4. if((nodesRange<=distance)&& (nodesRange>=sinkRadious)
        directCommunicate□ sink;
5. CH Data Aggregation: after firstRound
        E_aggregation = EDA * data_size;
                filterData;
                send□sink;
6. Each Round:
        for i=1: n
                getNodesResidualEnergy.broadcast( );
                S(i).E = S(i).E - E_loss;
END
```

E. Energy Dissipation Algorithm

After every round of transmission from one node to another node, CH, or sink, the energy dissipation technique ensures the residual energy updating for the next communication from that node. The Energy Dissipation Model simulates how energy is consumed by sensor nodes during communication and processing in a Wireless Sensor Network (WSN). It calculates the energy loss for tasks like data transmission, reception, and data aggregation. This model is essential for estimating the lifetime of the network and ensuring energy-efficient communication. It performs the following tasks: realistic energy simulation, network lifetime analysis, and optimization opportunities.

Input: Residual energy, PTX, PRX and Propagation model

Output: Cluster and Cluster Head Formation at each round

```
BEGIN
1. Energy Parameters: set initial_energy_node: Eo = 0.5; Joules
2. Energy dissipation constants:
        Transmission Energy: ETX=5x10^-10; Reception Energy: ERX=5x10^-10;
3. Propagation Model:
        Free Space: Efs=10^-12; Multipath Model: Emp=13^-16;
3. Maximum Threshold Distance for Communication:
        do = sqrt(Efs / Emp);
4. Energy Dissipation Model: Transmission
        if (d<do)     ETX = k.ETX − electronics + k.Efs · d^2
        else   ETX = k · ETX − electronics + k · Emp · d^4
5. Energy Dissipation Model: Reception
        ERX = k · ERX − electronics
6. Energy Dissipation Model: Data Aggregation:
        EDA = k · EDA
7. Each Round:
        for i=1: n
                getNodesResidualEnergy.broadcast( );
                S(i).E = S(i).E - E_loss;
8. Detect the Dead Nodes:
        for i=1: n
                if S(i).E <= 0       node: deadNode;
        End:
                S(i).status = 'dead';
END
```

F. Gap Identification and Monitor Node Placement Algorithm

Each node's residual energy will be tracked and updated by the energy dissipation model. If any nodes are not able to connect with their neighbor nodes or CH or sink node, a gap or coverage hole will be identified. Once a coverage gap is identified between any sensor node, monitor nodes will be deployed in between to make reliable communication and prevent unnecessary energy loss. Delaunay triangulation has a major role in the detection of coverage gaps.

Input: Coordinators of Sensor nodes, Cluster Heads and Sink

Output: Prevention and Detection of Coverage hole

```
BEGIN
1. getNodeCoordinator: All Nodes
        pts = [x_coordinates, y_coordinates];
2. Apply Delaunay Triangulation: generate all triangular mesh
        DT = delaunayTriangulation(static_nodes);
3. Retrieve all edges:
        edges = DT.edges;
4. Calculate Edge Lengths: Apply Euclidean distance
edge_lengths = sqrt(sum((DT.Points(edges(:, 1), :) - DT.Points(edges(:, 2), :)).^2, 2));
5. Find Largest length edge: Coverage hole detection
        long_edges = edges(edge_lengths > 2 * radius, :);
6. Deploy Monitor Node: if coverage hole: TRUE
        for i = 1:size(long_edges, 1)
        midpoint = (DT.Points(long_edges(i, 1), :) + DT.Points(long_edges(i, 2), :)) / 2;
7. Recomputed Delaunay Triangulation: generate all triangular mesh with updated node
        DT = delaunayTriangulation(static_nodes);
```

```
8. Visualize Updated Network:
        triplot(newDT, '-or');
END
```

G. Dead Node Tracking Algorithm

Once communication rounds cross 500 rounds, coverage holes will start because nodes energy will go below the threshold energy level. If any node goes below the threshold energy level, that component will become a dead node and unable to communicate with its neighbor node or CH or sink node. The Gap Identification and Monitor Node Placement Algorithm will check nodes at every round and declare the nodes as dead nodes. The Dead Node Tracking Algorithm monitors and identifies sensor nodes in a Wireless Sensor Network (WSN) that have exhausted their energy. Once a node's energy reaches zero or becomes negative, it is considered "dead." This algorithm records such events and updates the network's state to reflect the reduced functionality. Once a dead node is detected in the network, that node will be replaced by the monitor node. It performs the following tasks: performance metrics, dynamic adaptation, energy efficiency analysis, and network lifetime analysis.

Input: Residual energy of Sensor nodes, Cluster Heads and Sink

Output: Check node eligibility for communication if it has more energy than the required minimum energy for transmission.

```
BEGIN
1. Energy Level Initialization:
        set initial_energy_node: S(i).E = Eo;
2. Monitor energy consumption:
        Each Round:
                getNodesResidualEnergy.broadcast( );
                for i=1: n
                        S(i).E = S(i).E - E_loss;
3. Check Node Energy Levels: deadNode=0;
        for i=1: n
                if S(i).E <= 0.00025        deadNode=deadNode+1;
`       End:
                S(i).status = 'dead';
4. Number of Dead Nodes:.
        dead_nodes = sum([S(:).status] == 'dead');
5. Maintain Log: First_Dead_Node, Half_Dead_Nodes, and All_Nodes_Dead.
        if dead_nodes == 1 && ~first_dead_logged first_dead_round = current_round;
                first_dead_logged = true;   end;
        if dead_nodes >= n/2 && ~half_dead_logged half_dead_round = current_round;
                half_dead_logged = true;   end
        if dead_nodes == n && ~all_dead_logged all_dead_round = current_round;
                all_dead_logged = true;     end
6. Network_status:
        active_nodes = find([S(:).status] ~= 'dead');
7. goto step 3;
END
```

H. Performance Metrics Calculation Algorithm

Performance Metrics Calculation has a major role in the WSN environment to check the lifetime, packet delivery, and throughput of the network during simulation or real-time. It computes the number of dead nodes, alive nodes, packet delivery, and residual energy of nodes in each round of communication. It helps to make early decisions about nodes or networks.

Input: Energy of the nodes, packets, and other routing details of communication.

Output: Displays throughput, packet delivery, no. of dead nodes, no. of alive nodes, and residual energy of the nodes.

```
BEGIN
1. Initialize performance metrics:
        Number of dead nodes: dead_nodes);
        Total remaining energy: total_energy;
        Packets sent to the base station: packets_to_bs;
        Packets sent to cluster heads: packets_to_ch;
                dead_nodes = 0;
                 total_energy = n * Eo;
                packets_to_bs = 0; packets_to_ch = 0;
2. Track all the Dead Nodes:
        dead_nodes = sum([S(:).E] <= 0);
3. Calculate Total Remaining Energy:
        total_energy = sum([S(:).E]);
4. Track Packets Transmitted:
        packets_to_bs = packets_to_bs + num_packets_from_ch;
        packets_to_ch=packets_to_ch + num_packets_from_nodes;
5. Calculate Throughput:
        throughput = packets_to_bs + packets_to_ch;
6. Log Metrics for Each Round:
        metrics.rounds(r).dead_nodes = dead_nodes;
        metrics.rounds(r).total_energy = total_energy;
        metrics.rounds(r).packets_to_bs = packets_to_bs;
        metrics.rounds(r).packets_to_ch = packets_to_ch;
        metrics.rounds(r).throughput = throughput;
7. Visualize Metrics:
        Plot_graphs
END
```

6. Results Discussion

Figure 2 shows that 100 sensor nodes are randomly deployed in WSN using the Node Deployment Algorithm ; these nodes are responsible for sensing environmental data and communicating it to the sink. Delaunay triangulation creates a mesh of non-overlapping triangles connecting sensor nodes and the sink. It ensures that no points (nodes) are inside the circumcircle of any triangle. The triangulation optimizes network connectivity and minimizes the length of edges, balancing energy consumption for communication. Figure 3 shows the energy level of sensor nodes using the Energy Dissipation Algorithm.

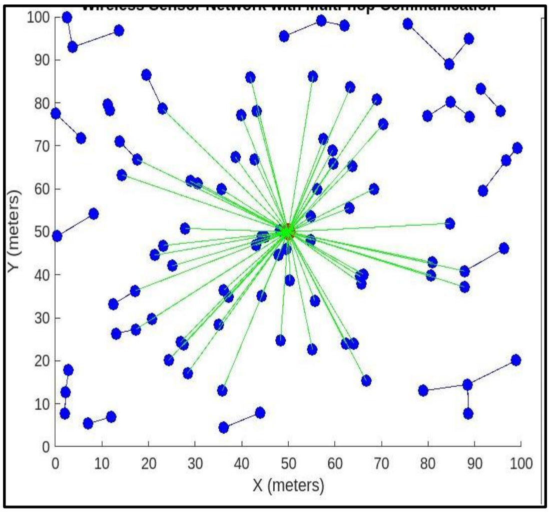

Fig 2: Randomly Placed Static Nodes

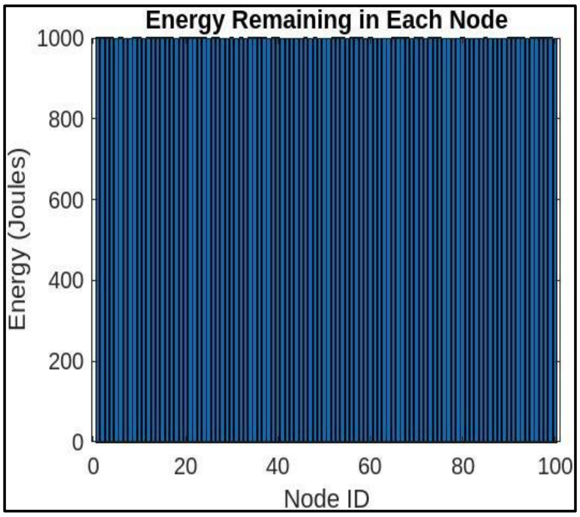

Fig 3: Initial Level of Residual Energy of Nodes

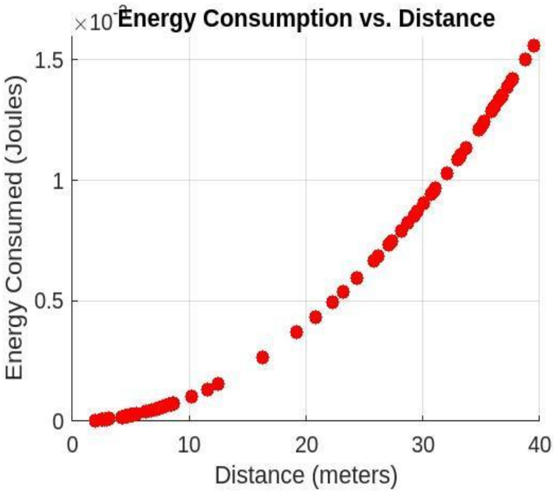

Fig 4. PTx Energy consumption with distance d

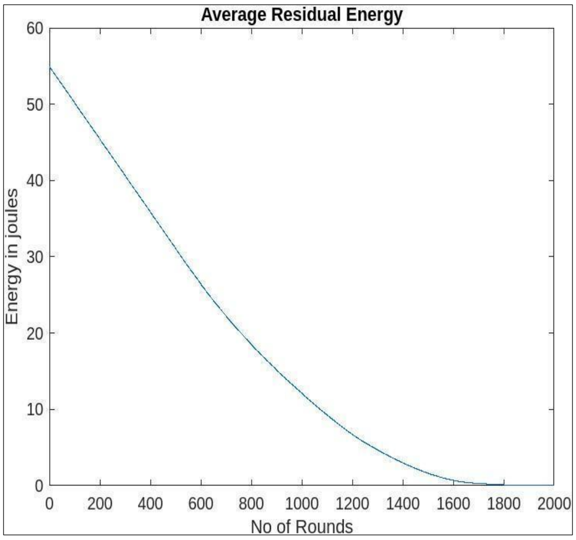

Fig 5: Average Residual Energy of WSN

Energy is a major concern in any WSN that is deployed at the critical mission. Because replacement of nodes and charging of batteries are not possible. The proposed Hybrid protocols show that nodes in the network can communicate till 2000 rounds. If distance increases between source to destination or neighbour nodes, energy consumption by PTx will be high, which is shown in Figure 4. The graph in Figure 5 illustrates the relationship between the number of rounds and the average residual energy in a wireless sensor network (WSN). It shows a declining trend, representing how energy in sensor nodes depletes over time as rounds of data transmission progress. The graph evaluates the energy efficiency of the WSN model implemented in this proposed work.

6. Conclusion

A Hybrid protocol to enhance the lifetime and reliability of WSN is the combination of eight algorithms. The result of this protocol shows that the node can participate in communication for 2000 rounds, and WSN has a better lifetime. In this coverage hole can be detected, and a monitor node will be deployed to overcome the link loss and save from the wastage of other sensor node's energy. Similarly, it can track dead nodes and replace them with monitor nodes. Formation of CH in this protocol uses a Minimum Spanning Tree, so all CH will have the same number of nodes and target areas. The CH can be changed after each round of communication based on the available residual energy level of the nodes. This protocol's result shows a long network lifetime because all nodes are effectively used in communication, better packet delivery from source to sink, more alive nodes, and high residual energy.

7. Applications and Future Work of Proposed Hybrid Protocol

Applications:

In recent years, the Micro-Electro-Mechanical System (MEMS) technology has made tremendous strides in wireless communications and WSNs. Military applications, primarily battlefield surveillance, have been the drivers of WSNs development. Currently, WSNs are widely applied in industrial process monitoring and control, machine health assessment, environmental and habitat observation, healthcare solutions, home automation, and traffic management.

Future Work:

When WSN is used for monitoring critical areas such as underwater acoustic sensor systems, sensing-based cyber-physical systems, time-critical applications, cognitive sensing, spectrum management, security, and privacy management. The cost of hardware is becoming more challenging, so work can be done on the production of less-cost devices with small sizes.

REFERENCES

Conference reference

[1]. M. Kaddi, B. Dihaj, M. Omari, M. A. A. Alnatoor, and H. Zaanane, "Energy Optimization Protocol in Wireless Sensor Networks Based on LEACH and Gateway Deployment," 2022 International Conference on Electrical and Computing Technologies and Applications (ICECTA), Ras Al Khaimah, United Arab Emirates, 2022, pp. 230-234, doi: 10.1109/ICECTA57148.2022.9990464.

[2]. A. Kapoor, Priyanka, and R. S. Bhadoria, "DCHR: Dynamic Cluster Head Replacement Algorithm for Energy Optimization in Wireless Sensor Network," 2024 IEEE 13th International Conference on Communication Systems and Network Technologies (CSNT), Jabalpur, India, 2024, pp. 54-58, doi: 10.1109/CSNT60213.2024.10545870.

[3]. A. K. Gupta and N. Anand, "Energy Efficient Routing Technique in Wireless Sensor Network using Hybrid Approach," 2024 IEEE 3rd International Conference on Electrical Power and Energy Systems (ICEPES), Bhopal, India, 2024, pp. 1-6, doi: 10.1109/ICEPES60647.2024.10653459.

[4]. Y. Yao, D. Xie, Y. Li, C. Wang, and Y. Li, "Routing Protocol for Wireless Sensor Networks Based on Archimedes Optimization Algorithm," in IEEE Sensors Journal, vol. 22, no. 15, pp. 15561-15573, 1 Aug. 1, 2022, doi: 10.1109/JSEN.2022.3186063.

[5]. C. Sivasankar, E. K. Subramanian, V. Sarala, A. Moorthy, and N. Purushothaman, "Optimizing Power Consumption in Wireless Sensor Networks for Prolonged Sustainability," 2024 Second International Conference on Advances in Information Technology (ICAIT), Chikkamagaluru, Karnataka, India, 2024, pp. 1-4, doi: 10.1109/ICAIT61638.2024.10690388.

Journal reference

[6] Farman Ullah, M. Zahid Khan, Mohammad Faisal, Haseeb Ur Rehman, Sohail Abbas, and Foad S. Mubarak, “An Energy Efficient and Reliable Routing Scheme to Enhance the Stability Period in Wireless Body Area Networks," Computer Communications, Volume 165, 2021, Pages 20-32, ISSN 0140-3664, https://doi.org/10.1016/j.comcom.2020.10.017.

[7] A. Esse, K. Abdullah, M. H. Habaebi, and H. A. M. Ramli, "Dynamic Power Splitting Simultaneous Wireless Information and Power Transfer Split Receiver for Wireless Sensor Networks," in IEEE Access, vol. 9, pp. 129407-129416, 2021, doi: https://doi.org/10.1109/ACCESS.2021.3113330.

[8] Ren, Xiaojun, Li, Jiaqing, Wu, Yongtang, Chen, Yuanfang, Sun, Hongwei, Shi, Zhichen, 2021, "An enhanced energy optimization routing protocol for W.S.N.s." Annals of Telecommunications, 343, 354, 76, 5, doi: https://doi.org/10.1007/s12243-021-00838-y.

[9] Alabady, Salah Abdulghani, Alhajji, Sukaina Shukur, 2021, "Enhance Energy Conservation Based on Residual Energy and Distance for W.S.N.s," Wireless Personal Communications, 3343, 3364, 121, 4, doi: https://doi.org/10.1007/s11277-021-08880-8.

[10] Kalpna Guleria, Anil Kumar Verma, Nitin Goyal, Ajay Kumar Sharma, Abderrahim Benslimane, and Aman Singh, "An enhanced energy proficient clustering (E.E.P.C.) algorithm for relay selection in heterogeneous W.S.N.s," Ad Hoc Networks, Volume 116, 2021, 102473, ISSN 1570-8705, doi: https://doi.org/10.1016/j.adhoc.2021.102473.

[11] Battina Srinuvasu Kumar, S.G. Santhi, S. Narayana, “An Enhanced Genetic Algorithm (EGA)-based MultiHop Path for Energy Efficient in Wireless Sensor Network (W.S.N.)", (I.J.A.C.S.A.) International Journal of Advanced Computer Science and Applications, Vol. 13, No. 4, 2022, doi: https://thesai.org/Downloads/Volume13No4/Paper_114-An_Enhanced_Genetic_Algorithm_EGA_based_Multi_Hop_Path.pdf

[12] Baniata, Mohammad and Reda, Haftu Tasew and Chilamkurti, Naveen and Abuadbba, Alsharif, “Energy-Efficient Hybrid Routing Protocol for IoT Communication Systems in 5G and Beyond”, JOURNAL Sensors, VOLUME 21, YEAR 2021, NUMBER 2, ARTICLE-NUMBER 537, URL https://www.mdpi.com/1424-8220/21/2/537, PubMedID 33451047, ISSN 1424-8220, DOI 10.3390/s21020537

[13] Srinivas Rao, Dr. K.V.S.N. Rama Rao, “Wireless Sensor Network Routing for Life Time Maximization Using A.N.F.I.S. Based Decision with Low Power Consumption," Turkish Journal of Computer and Mathematics Education Vol.12 No.2 (2021), 2893-2900 Research Article 2893.

[14] T. M. Megha and P. Mohan, "Performance Analysis using Time Splitter Method for Power Management in Wireless Sensor Network," 2021 2nd International Conference for Emerging Technology (I.N.C.E.T.), 2021, pp. 1-4, doi: http://dx.doi.org/10.1109/INCET51464.2021.9

[15] K. M. Akhil and S. Sinha, "Self-Localization in Large Scale Wireless Sensor Network Using Machine Learning," 2020 International Conference on Emerging Trends in Information Technology and Engineering (ic-ETITE), 2020, pp. 1-5, doi: https://doi.org/10.1109/ic-ETITE47903.2020.339.

[16] S. Anand and S. G., "Role of Radio Control to Enhance the Lifetime of Wireless Sensor Network," 2021 3rd International Conference on Signal Processing and Communication (I.C.P.S.C.), 2021, pp. 573-577, doi: 10.1109/ICSPC51351.2021.9451806.

[17] Jia, Y. LoRa-Based W.S.N.s Construction and Low-Power Data Collection Strategy for Wetland Environmental Monitoring. Wireless Pers Commun 114, 1533–1555 (2020). https://doi.org/10.1007/s11277-020-07437-5.

[18] S. Sinha and S. Ashwini, "RSSI-based Improved Weighted Centroid Localization Algorithm in W.S.N.," 2021 2nd International Conference for Emerging Technology (I.N.C.E.T.), 2021, pp. 1-4, doi: 10.1109/INCET51464.2021.9456134.