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OPTIMIZED ROUTING IN WIRELESS SENSOR NETWORKS THROUGH PARTICLE SWARM OPTIMIZATION AND BREADTH FIRST SEARCH TECHNIQUES

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Abstract: Wireless sensor networks (WSNs) are becoming an increasingly important and challenging research area. Advances in WSN technology enable a wide range of applications, including environmental monitoring and object tracking systems. WSNs consist of small, low-cost sensor nodes with limited transmission ranges, processing power, storage capacity, and energy resources. This study focuses on energy-constrained WSNs deployed over a specific region, where the primary task is to collect data from sensor nodes and transmit it to a base station for further processing. Each bit of data requires a fixed amount of energy to receive and an additional amount to transmit, which varies with the transmission range. If all nodes were to transmit directly to the base station, they would rapidly exhaust their energy reserves. Efficient routing in WSNs, given their constraints on power, energy, and storage, poses a significant challenge. In this work, we propose a Particle Swarm Optimization-based Routing protocol (PSOR) that prioritizes energy efficiency in routing and optimizes data forwarding paths to the base node. The PSOR algorithm generates optimized routing paths by using energy consumption as a fitness value to select the best path. Our novel strategy enhances route optimization by integrating the Breadth First Search algorithm with PSOR to achieve more energy-efficient and shorter paths. Effectiveness of the proposed method was evidenced by experimental results obtained through the NS2 (Network Simulator 2) tool.

Index Terms - Breadth First Search (BFS), NS2 (Network Simulator 2), Particle Swarm Optimization (PSO), PSOR (Particle Swarm Optimization-based Routing), Wireless Sensor Networks (WSNs)

I. INTRODUCTION

Recent advancements in Wireless Sensor Networks (WSNs) have significantly reduced costs and energy consumption while also addressing congestion issues, thus attracting considerable research interest. The broad applications of WSNs, ranging from environmental monitoring to object tracking systems, make them an active and engaging area for researchers. WSNs consist of numerous small, low-cost sensor nodes distributed to sense various environmental conditions such as sound, smoke, pressure, vibration, temperature, and pollution. These sensors gather data and transmit it to a central node, known as the sink or base station, where it is processed.

Despite their potential, WSNs face several limitations, including restricted storage space, limited communication range, and constrained energy resources. Among these, energy is the most critical factor, as in many applications, it is not rechargeable. The energy available determines the lifetime of the WSN, making it imperative to reduce energy consumption to prolong network operation. Energy in WSNs is primarily consumed through data processing and communication between nodes, with communication being the most significant energy drain. Therefore, developing efficient routing protocols that minimize energy consumption is crucial for enhancing the network's lifespan.

However, using routing protocols that only focus on energy efficiency is not sufficient. Other parameters, such as congestion control, must also be considered to create more effective routing protocols. Congestion can lead to significant packet loss within the network, necessitating retransmissions that further deplete energy reserves. One of the main causes of congestion in WSNs is storage space constraints at the node level, where insufficient buffer space leads to packet loss. Retransmitting these lost packets results in additional energy consumption.

Advances in sensing, computing, and communication technologies, along with the need for continuous monitoring of physical phenomena, have driven the development of WSNs. These networks are formed by densely deployed sensor nodes within a specific area, which typically possess self-organizing capabilities to collaboratively perform tasks. WSNs are a subset of wireless ad hoc networks where sensor nodes collect, process, and communicate data from the physical environment to a central location. Unlike traditional wireless networks, WSNs face numerous constraints related to processing power, energy resources, memory, and storage capacities.

The primary goal of WSNs is to deploy sensor nodes randomly in unattended locations and establish wireless connectivity. Traditional routing algorithms, designed to enhance performance in terms of latency and delivery ratio, are often inadequate for the complex and dynamic environments of the Internet of Things (IoT). The rapid development of IoT systems has introduced numerous network and information threats that hinder their growth. Data aggregation and forwarding schemes in WSNs can be categorized into structure-free and structure-based schemes. Structure-free schemes collect sensor information without a fixed structure and perform data aggregation based on partial information. Conversely, structure-based schemes divide the network into clusters, with each cluster having a local data-aggregator node to collect and process data from its members before transmitting aggregated information to the sink node.

Given these challenges, this study proposes a Particle Swarm Optimization-based Routing protocol (PSOR) that prioritizes energy efficiency and optimizes data forwarding paths to the base node. The PSOR algorithm generates optimized routing paths by using energy consumption as a fitness value to select the best path. Our novel strategy enhances route optimization by integrating the Breadth First Search algorithm with PSOR to achieve more energy-efficient and shorter paths. Experimental results, obtained using the NS2 (Network Simulator 2) tool, demonstrate the effectiveness of the proposed approach, highlighting its potential to extend the operational life of WSNs and improve overall network performance.

The subsequent structure of the article unfolds as follows: Section two delves into a comprehensive literature review, Section three focuses problem statement, and Section four elaborates on proposed system. The fifth section unveils system design, while Section 6 encapsulates the implementation. The seventh section deals with results and discussion and eighth section presents concludes and future enhancement.

II. Related Works

A reliable security mechanism for data aggregation is highly sought after due to the rapid growth in wireless sensor network (WSN) applications. Numerous research efforts have been dedicated to ensuring confidentiality and integrity. Data aggregation is a challenging process, partly because security issues can arise at the aggregation node. In this paper, we propose a double secure optimal partial aggregation (DS-OPA) method, which provides secure data aggregation without compromising network performance. The proposed DS-OPA technique consists of two phases.

In the first phase, we introduce a multi-objective differential evolution-based inference (MDEI) model to identify the most trusted aggregation node among neighboring nodes. The time-varying constraints collected from the aggregation nodes are optimized using the proposed Jaya optimization algorithm. The selected aggregation node successfully receives multiple inputs and produces a single output without loss.

In the second phase, we use a hybrid encryption public key algorithm to protect data privacy and prevent data modification at the aggregation node. To demonstrate its performance, we implemented our proposed DS-OPA system in a network simulator tool with a large network size. The simulation results prove that our proposed DS-OPA system is better suited than existing systems [1].

Wireless sensor networks (WSNs) are inherently constrained by energy limitations, which pose significant challenges for clustering algorithms over extended periods. We propose a novel method for coordinator head (CNH) selection using a mixed hierarchical cluster-based algorithm. This involves selecting the CNH based on the highest value of the coordinator node (CN) and its fitness value. Our analysis introduces two algorithms: the mixed hierarchical cluster-oriented routing program and the hybrid hierarchical secure algorithm. The mixed hierarchical cluster-based algorithm is designed to generate CNH and CN, identify malicious nodes, and ensure secure packet delivery. The source node sends packet details to the CN, which then selects the shortest path based on the trust value between intermediate nodes and the sensor node. The

CNH monitors the behavior of all nodes, and if any node exhibits suspicious behavior, the CNH identifies and isolates the malicious node. The CNH then switches to an alternative pathway and securely transmits the packet to the target destination in a timely manner [2].

Modern Wireless Sensor Networks (WSNs) have unique requirements for routing protocols due to their distributed nature and dynamic topology. The primary need for WSNs is an energy-efficient routing protocol that optimally conserves energy, thereby extending the network's lifespan. Recently, various energy-efficient routing protocols have been proposed by researchers. However, both security and energy efficiency in data collection and transmission must be addressed simultaneously to meet security challenges and overcome the limitations of WSNs. In this paper, we propose a new and effective routing protocol called the "Intelligent Energy Aware Secured Algorithm for Routing (IEASAR)," which is both secure and energy-efficient, utilizing a trust-based approach. To achieve this, we introduce a new energy-efficient protocol based on Fuzzy C-means clustering. Additionally, we apply a modified minimum spanning tree approach to determine the shortest path between the sender and destination nodes, ensuring an optimal and secure routing path. Extensive simulations have been conducted to validate our claims [3].

Due to the strict energy limitations and inherent vulnerabilities of Wireless Sensor Networks (WSNs), ensuring efficient and secure data gathering in WSNs is a critical challenge. Compressive data gathering, which leverages recent advancements in compressive sensing theory, has been proposed as an effective approach for data collection in WSNs with low communication overhead. However, compressive data gathering is vulnerable to various attacks due to the open nature of the wireless medium. In this paper, we propose a novel Efficient Privacy-Preserving Compressive Data Gathering Scheme, which utilizes homomorphic encryption functions in compressive data gathering to prevent traffic analysis and flow tracing, thereby ensuring privacy preservation. This scheme offers two key privacy-preserving features: message flow untraceability and message content confidentiality. Extensive performance evaluations and security analyses confirm the validity and efficiency of the proposed scheme [4].

III. PROBLEM STATEMENT

1. Wireless Sensor Networks (WSNs) face significant challenges due to their energy-constrained nature and specific operational limitations.
2. These challenges include limited energy resources, varying energy consumption based on node location, high transmission costs, and restricted processing capabilities.
3. Traditional routing protocols often fail to address these issues effectively, resulting in inefficient data packet routing within WSNs.
4. Moreover, the uneven distribution of energy consumption across the network leads to premature node failure and reduced network lifespan.
5. Therefore, there is a critical need to develop optimized routing protocols that prioritize energy efficiency and distance considerations to extend the longevity of sensor networks while maximizing overall system performance.

IV. PROPOSED SYSTEM

The proposed work focuses on enhancing the energy efficiency of routing paths in wireless sensor networks (WSNs). The goal is to develop a robust routing protocol that optimizes energy consumption while effectively delivering packets from source to destination nodes.

A Particle Swarm Optimization-based Routing protocol (PSOR) is introduced as a novel approach. PSOR utilizes two key concepts: Pbest (Particle best) and gbest (global best). Pbest represents the best node within a cluster and its neighboring nodes, selected based on local optimization criteria. On the other hand, gbest represents the best node chosen from the entire network, ensuring global optimization for routing decisions.

The novelty of this work lies in integrating the Breadth First Search (BFS) algorithm into the PSOR framework. BFS is employed to systematically explore and discover routes from the source to the destination node. By leveraging BFS within PSOR, the proposed protocol ensures that the routes selected are the shortest paths available in terms of hop count, thereby minimizing energy expenditure during packet transmission.

This combined approach of PSOR with BFS addresses the dual objectives of energy efficiency and route optimization in WSNs. By dynamically selecting optimal nodes (Pbest and gbest) and employing BFS for route discovery, the protocol not only conserves energy but also enhances the reliability and efficiency of data transmission across the network.

In summary, the proposed PSOR protocol with BFS integration represents a significant advancement in routing strategies for WSNs, offering a practical solution to the challenges of energy efficiency and effective routing path selection in dynamic wireless environments.

4.1Advantages

- **Enhanced Energy Efficiency**

PSOR optimizes energy consumption by dynamically selecting optimal nodes (Pbest and gbest) for routing decisions. This ensures that energy resources are efficiently utilized throughout the network.

- **Optimized Routing Paths**

Integration of BFS allows for the discovery of shortest paths in terms of hop count from source to destination nodes. This minimizes transmission delays and reduces energy expenditure during packet transmission.

- **Global and Local Optimization**

PSOR balances global optimization (gbest) for network-wide efficiency with local optimization (Pbest) for efficient clustering and neighbor node selection. This dual approach ensures both overall network performance and localized energy savings.

- **Reliability and Fault Tolerance**

By selecting the best nodes (Pbest and gbest), PSOR enhances the reliability of data transmission paths. It also improves fault tolerance by dynamically adapting to changes in network conditions or node failures.

- **Privacy Preservation**

Utilization of PSOR with BFS ensures secure and private data transmission. BFS helps in avoiding traffic analysis by selecting routes that minimize exposure to potential eavesdropping or interception.

- **Scalability and Adaptability**

The protocol is scalable to varying network sizes and adaptable to dynamic changes in network topology. This flexibility allows it to maintain efficient routing paths even as the network expands or nodes relocate.

- **Real-world Applicability**

PSOR with BFS integration offers a practical solution for real-world deployments of WSNs. It addresses the challenges of energy efficiency and effective routing path selection, making it suitable for diverse applications such as environmental monitoring, healthcare systems, and industrial automation.

4.2 Requirement Analysis

Requirement analysis is a crucial phase in the development or improvement of any system or technology. In the context of the proposed PSOR protocol with BFS integration for routing in wireless sensor networks (WSNs), conducting a thorough requirement analysis is essential to ensure that the protocol meets the needs and expectations of its stakeholders. Here's an elaborate explanation of requirement analysis.

4.2.1 Understanding Stakeholder Needs

Requirement analysis begins with identifying and understanding the needs of various stakeholders involved in or affected by the PSOR protocol and its implementation in WSNs. Stakeholders may include:

- **Network Operators**
  They require efficient use of energy resources, reliable data transmission, and scalability.
- **End Users**
  They seek reliable connectivity, minimal data transmission delays, and secure data privacy.
- **Researchers and Developers**
  They aim for innovative solutions that advance the field of WSNs while addressing current limitations.

4.2.2. Gathering Requirements

4.2.2.1 Functional Requirements

- **Energy Efficiency:** The protocol must optimize energy consumption to prolong the lifespan of sensor nodes.
- **Routing Efficiency:** It should discover and select optimal paths that minimize transmission delays and maximize network performance.
- **Security:** Ensure data privacy and integrity through secure routing mechanisms.
- **Scalability:** Support varying network sizes and adapt to changes in network topology.

4.2.2.2 Non - Functional Requirements

- **Performance:** Specify latency requirements, throughput expectations, and reliability metrics.
- **Usability:** Ensure ease of deployment, configuration, and maintenance of the protocol.
- **Compatibility:** Compatibility with existing WSN infrastructure and protocols.
- **Reliability:** Ensure robustness against node failures, environmental conditions, and network disruptions.

4.2.2.3 Analyzing Requirements

- **Feasibility Analysis:** Evaluate the technical feasibility of implementing the PSOR protocol with BFS integration in WSNs. Consider factors such as computational complexity, memory requirements, and communication overhead.
- **Priority Setting:** Prioritize requirements based on their criticality to the success of the protocol. Identify must-have versus nice-to-have features to focus development efforts effectively.
- **Trade-off Analysis:** Analyze trade-offs between conflicting requirements, such as energy efficiency versus routing latency or security versus computational overhead. Find optimal solutions that balance this trade-offs.

V. System Design

System design is a critical phase in the development of any technology or system, including the proposed PSOR protocol with BFS integration for routing in wireless sensor networks (WSNs). It involves translating the requirements gathered during requirement analysis into a detailed blueprint or plan for the system's architecture, components, and interactions. Here’s an elaborate explanation of system design in the context of the PSOR protocol with BFS integration. The system architecture is shown in **Fig. 1.**

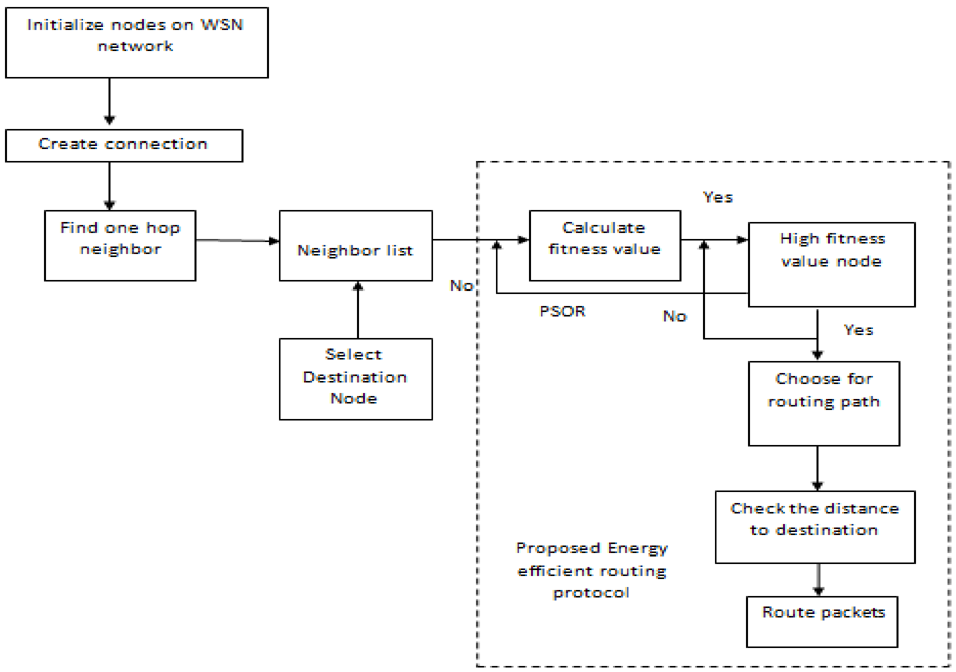

Figure 1 System Architecture

5.1 UML Diagram

In this paper, a UML diagram (shown in **Fig. 2.**) is utilized to depict the system architecture of the proposed PSOR protocol with BFS integration in wireless sensor networks (WSNs). The diagram illustrates the relationships between various components such as nodes, base stations, and communication protocols, providing a clear visualization of how data flows through the network and how routing decisions are optimized using Particle Swarm Optimization and Breadth First Search algorithms.

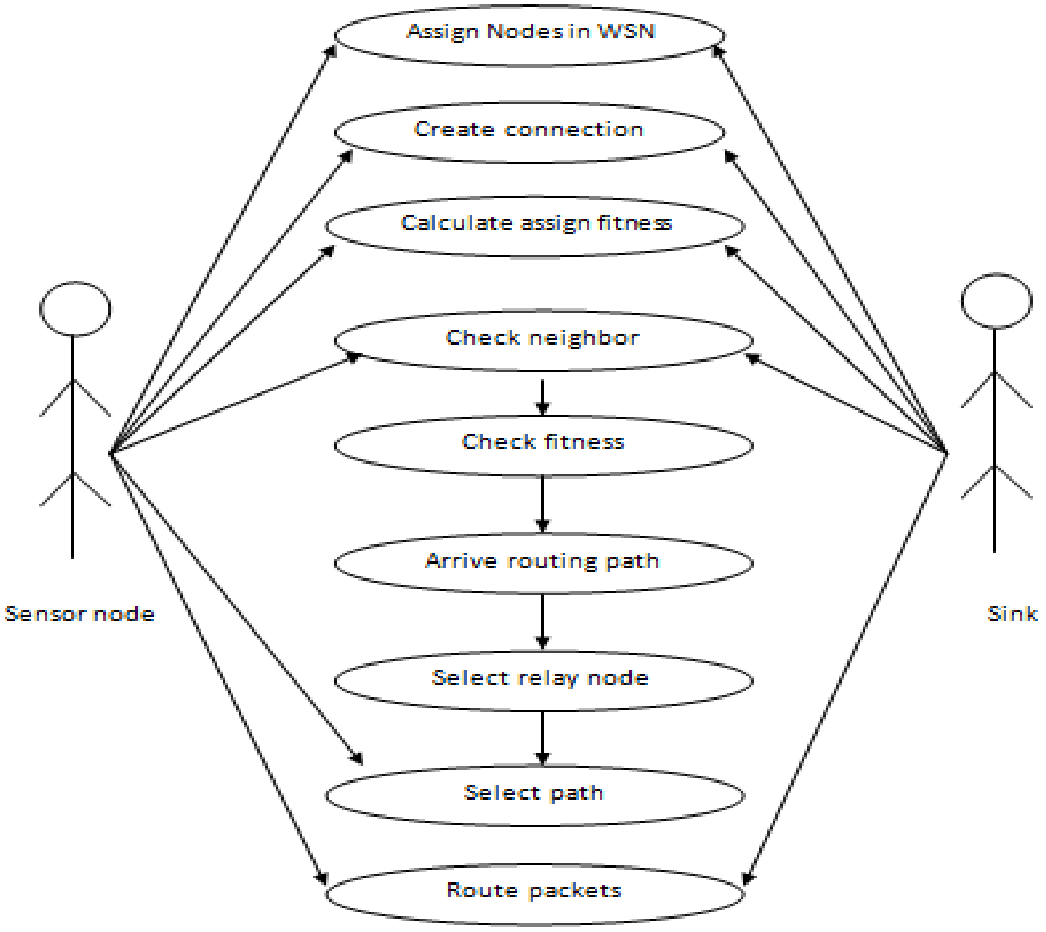

Figure 2 UML Diagram

5.2 Sequence Diagram

In this paper, a sequence diagram (shown in **Fig. 3.**) is employed to delineate the step-by-step interaction between nodes and base stations within the proposed PSOR protocol with BFS integration for routing in wireless sensor networks.

It visually represents how nodes initiate data transmission, how routing decisions are made based on Particle Swarm Optimization and Breadth First Search algorithms, and how data packets are securely and efficiently delivered from source to destination nodes.

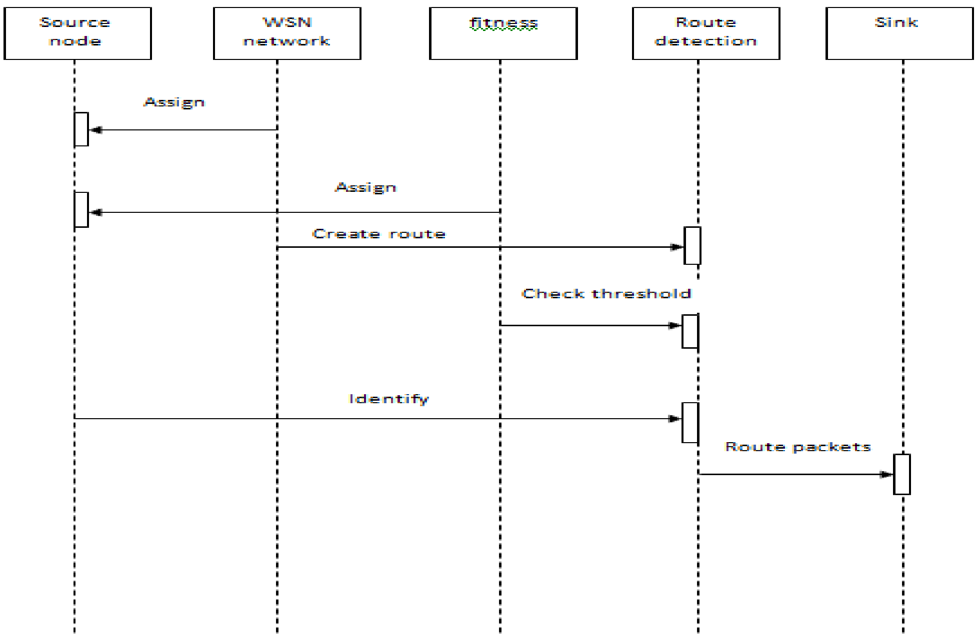

Figure 3 Sequence Diagram

5.3 Collaboration Diagram

In this paper, a collaboration diagram (show in **Fig. 4.**) is utilized to illustrate the dynamic interaction and collaboration between nodes, base stations, and network components within the proposed PSOR protocol with BFS integration for routing in wireless sensor networks. It visually portrays how these entities cooperate to optimize energy-efficient routing paths and ensure reliable data transmission across the network, highlighting the synergy and communication flow essential for system operation and performance.

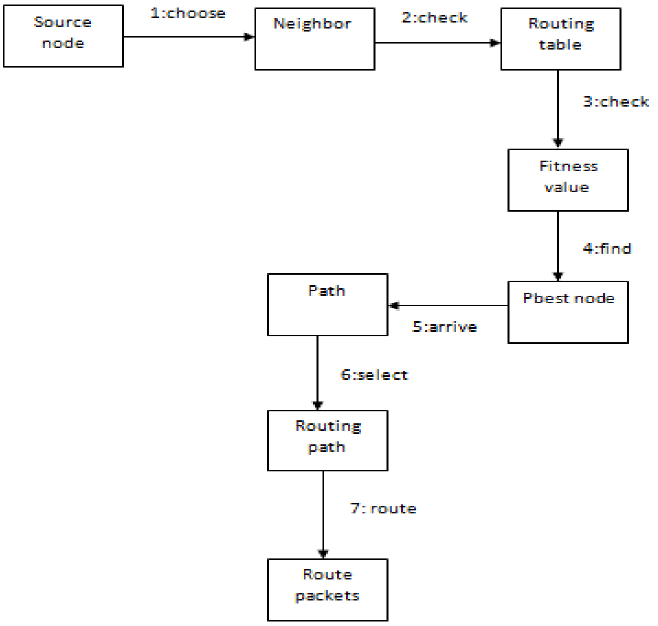

Figure 4 Collaboration Diagram

5.4 Activity Diagram

In this paper, an activity diagram (shown in **Fig. 5.**) is employed to outline the sequential steps and decision points involved in the execution of the proposed PSOR protocol with BFS integration for routing in wireless sensor networks. It provides a structured visualization of how the protocol manages energy-efficient routing decisions using Particle Swarm Optimization and Breadth First Search algorithms, depicting the flow of activities from initial node clustering to the selection of optimal paths, thereby ensuring efficient data transmission and network longevity.

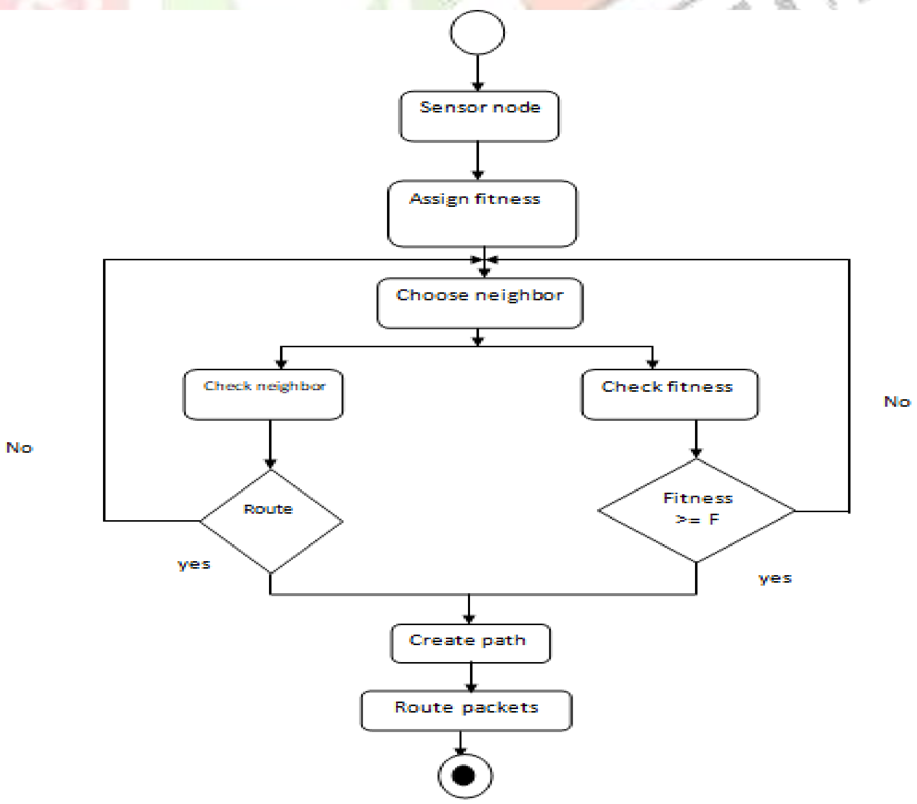

Figure 5 Activity Diagram

VI. IMPLEMENTATION

6.1 Proposed Routing Algorithm using Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is fundamentally a computational technique aimed at iteratively improving a candidate solution based on a specified quality metric. Formulating the optimization problem is the initial step in applying this method. Within this proposed algorithm, the selection of the optimal path relies on fitness values derived from minimizing the distance data travels to reach the base node. Given the emphasis on energy-efficient routing, minimizing distance is crucial to reducing energy consumption during data transmission. Thus, the PSO method is utilized to compute fitness values and determine an optimal path that encompasses all sensor nodes.

Fitness function is calculated by using formula

Fitness function = (a/cost)*delay

(1)

Where,

a=Path cost + Energy + bandwidth, assume a=5.0 cost is assigned, cost =7.0

Choosing Pbest node:

We are calculating the fitness function for every node and assigning values to a file called “fitness”. We are checking the nodes fitness value should be above threshold value.

For example, if the fitness value in the range between 0 to 10, we are assuming threshold to be 5.

Nodes >=5 is taken as pbest, Pbest nodes are used to arrive path

Choosing Gbest node

The paths lie P1, P2, P3, P4 are arrived using above formulae. We are finding the sum of fitness value of each single path. The path with high fitness value is taken as final path to route the packets.

For example,

Fitness functions of node

Node 1 = (5.0/7.0)*(random number)

If source node is 5 and destination 14.Then we have arrive path

Condition: trust =1, fitness function greater than 1 First find neighbor source node 5. Neighbor nodes are – 6, 8, 10, and then we have to choose one node with above condition and which is near to destination. For example, we choose 8 next,

Node 8 neighbor are – 10, 12, 13, then we have to choose one node with above condition and which is near to destination. For example, we choose 13 Next nodes 13, neighbors are node 14, 16, 17, then destination available here, we stop searching process.

6.2 Algorithm

Phase 1 :[Initialization of Nodes]

for (s = 0 to number of solutions or populations).

for (d = 0 to number of sensor nodes).

Randomly solutions are selected.

Compute new route using solution.

End for.

Compute fitness value of initialized solution.

Compute global best and local best.

End for.

Phase 2 :[Update Routing Nodes] while criteria does not match

for (s = 1 to number of solutions)

for (d = 1 to number of sensor nodes).

Update solution using PSO update equation.
Generate new path based on update solution.
End for.
Compute fitness value for updated route.
Compute global best and local best.
End for.
Note the global best
End while.

VII. RESULTS AND DISCUSSION

The simulation is carried out in ns-2.34 with 35 nodes initialized in a wireless network, and routing is performed using the AODV protocol. The NAM animator size is set to 2500x2500, and neighbor nodes are detected within a distance of less than 250 units. Sensor nodes generate random values for sending data packets

The Table 1 below shows the simulation setup used for the experimental analysis.

Table 1 Simulation setup

Parameters	Values
Number sensor nodes	35
MAC protocol	MAC 802.15.4
propagation model	two ray channel
Network area	2500*2500
Routing protocol	AODV
Simulation Time	2000 s

The network throughput, packet loss, and end-to-end delay are registered and plotted below. The graph below depicts the delay during the simulation phase. The experiment ran for 5 seconds. End-to-End Delay refers to the time taken for a packet to be transmitted across a network from source to destination during the simulation. The analysis of end to end delay is shown in **Fig. 6**.

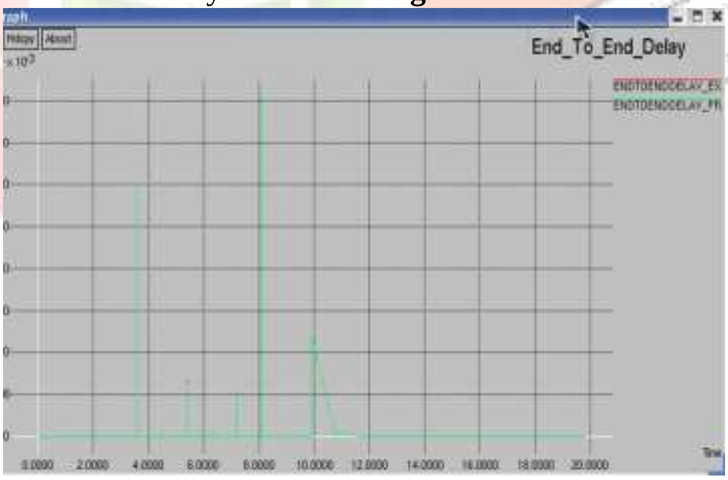

Figure 6 End to End delay

The graph below illustrates the throughput achieved by the proposed protocol over a 5-second experiment. Throughput represents the data transfer rate of a network, indicating its capacity to send and receive data, typically measured in bits per second (bit/s). The analysis of end to end delay is shown in **Fig.7**.

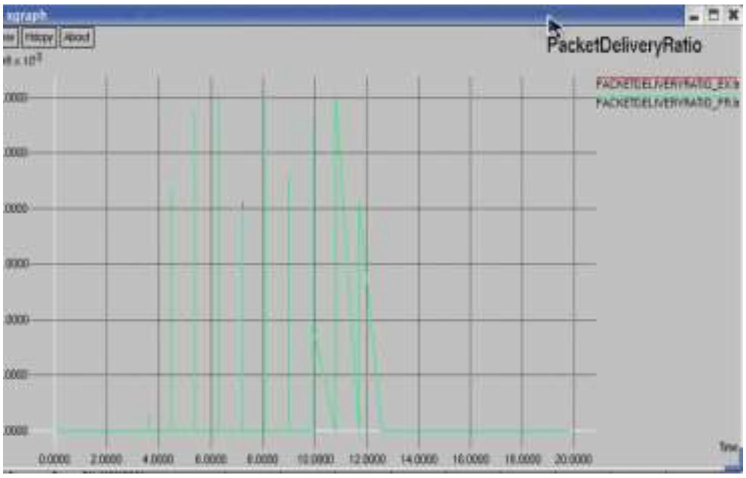

Figure 7 Throughput

The graph below shows the packet loss experienced by the proposed protocol during a 5-second experiment. Packet loss refers to the number of packets that fail to reach their destinations in a network's data transmission. The analysis of packet loss is shown in **Fig. 8**.

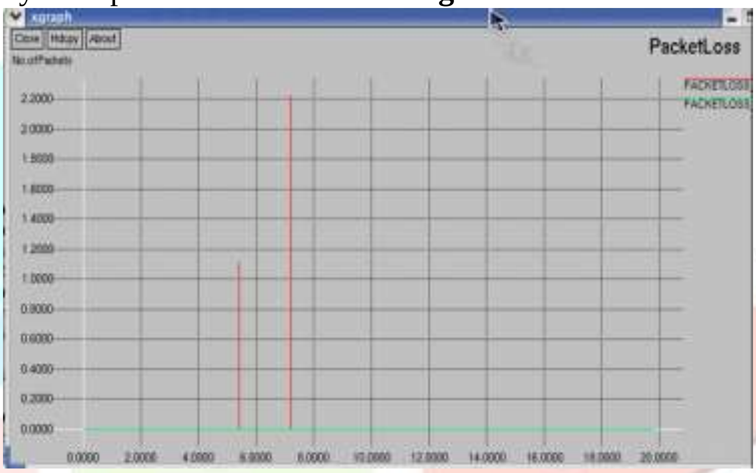

Figure 8 Packet loss

VIII. Conclusion

In this paper, we have introduced a novel scheme designed for sensor networks aimed at achieving energy-efficient routing throughout the network. The underlying concept of our model revolves around the fundamental principle that greater distances traveled to transmit data result in higher consumption of sensor energy.

The algorithm we employed leverages the concept of Particle Swarm Optimization (PSO). PSO is used to dynamically optimize the routing paths in the network. Our experimental results substantiate that our approach effectively identifies an optimal path after thorough optimization using PSO. This optimized path not only demonstrates improved efficiency but also minimizes the overall distance traveled, thereby enhancing the energy efficiency of the sensor network.

In summary, our research underscores the efficacy of employing PSO-based algorithms in sensor networks to achieve significant improvements in routing efficiency and energy conservation, thereby contributing to the advancement of energy-efficient communication protocols in wireless sensor networks.

As future enhancements, our project can be extended in two promising directions. Firstly, integrating Breadth First Search (BFS) and Depth First Search (DFS) algorithms presents an opportunity to determine optimal paths between source and destination nodes within the sensor network. BFS and DFS are renowned for their efficiency in graph traversal, offering potential improvements in routing efficiency and latency reduction. Secondly, we envision hybridizing the Particle Swarm Optimization (PSO) algorithm with existing routing algorithms. This hybrid approach aims to capitalize on the strengths of each algorithm, potentially yielding superior performance compared to standalone methods. By combining PSO with heuristic algorithms or machine learning techniques, we aim to develop adaptive routing strategies capable of dynamically responding to network changes and optimizing energy consumption. These future directions seek to further enhance our project's contribution to energy-efficient communication protocols in wireless sensor networks, advancing both theoretical understanding and practical application of network optimization.

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