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Optimizing Mobile Sink Movement Using Bee Algorithm in Wireless Sensor Networks

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ABSTRACT

Wireless Sensor Networks (WSNs) consist of a large number of spatially distributed wireless sensor nodes that monitor and collect environmental data, subsequently transmitting it to a central base station for processing and analysis. Efficient and energy-aware data collection remains a critical challenge in WSNs due to the limited power resources of individual sensor nodes. One widely adopted strategy involves the use of a sink node to aggregate data from across the network. Recently, mobile sink approaches have gained significant attention for their potential to reduce energy consumption and improve data collection efficiency. In this thesis, a novel routing strategy is proposed that leverages the Artificial Bee Colony (ABC) algorithm for managing the trajectory and data aggregation process of a mobile sink. The ABC algorithm, inspired by the foraging behavior of honeybees, is applied to dynamically optimize the path of the mobile sink, minimizing communication overhead and balancing energy usage across the network. The proposed approach is designed to reduce the latency in data acquisition and prolong the overall lifetime of the network. Comprehensive simulation experiments were conducted to evaluate the performance of the proposed method against conventional techniques. The results demonstrate that the ABC-based routing method significantly reduces energy consumption and minimizes data reading delays. Consequently, it contributes to enhanced quality of service (QoS) and greater sustainability of the wireless sensor network infrastructure.

1. INTRODUCTION

A sensor network consists of numerous sensor nodes that interact with the physical environment. Sensors collect environmental data and send it to a base station wirelessly. Each node operates independently without human intervention and is typically very small physically, with limitations in processing power, memory capacity, and power supply. These limitations lead to challenges that are the focus of many research discussions. One significant

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issue is data collection from the network and sending it to the base station. Using a sink node is one solution, and the use of a mobile sink is a method to address this. This paper discusses how mobile sink movement within the network and data collection can be optimized [1-10].

2. LITERATURE REVIEW

Dong Han et al. [11] proposed a novel approach for studying network and information detection protocols based on energy metrics in wireless sensor networks (WSNs). Unlike previous methods that focus on overall energy efficiency statistics from a network or protocol, our approach targets network detection protocols, application workloads, and topology information through fine-grained energy metrics at nodes. We designed a set of features based on various aspects of energy data and utilized these features for classifying and detecting network activities. Experimental results across three testing phases indicate that our approach can achieve 97% accuracy in identifying routing protocols and 98% accuracy in determining network topology.

Dpa Joz et al. [12] introduced a method for optimizing energy in wireless sensor network routing algorithms using mobile sinks. The primary challenge is the limited energy resources of sensors, which affects their effectiveness. The intriguing feature of these sensors is their ease of deployment for information collection or device monitoring. However, due to their small size, storage capacity, processing, and memory are severely constrained. Applications using wireless sensor networks require continuous connectivity to the deployment area; otherwise, the effectiveness of the sensors will be compromised. To maintain network longevity, optimizing the use of available energy is crucial. Each layer of the protocol stack has its strategies for reducing energy consumption. Our focus is on the network layer, where routing plays a crucial role. We find that communication processes consume more energy compared to data sensing and processing. Hence, routing protocols are more critical in energy efficiency to extend the lifespan of wireless sensor networks. The new method involving mobile sinks is simulated extensively, demonstrating the impact of the proposed mobile sink on the suggested algorithm (MSA). The algorithm is presented in three phases:

1. Network partitioning
2. Mobile sink routing
3. Data collection

It employs one fixed sink and four mobile sinks, with the mobile sinks collecting data and transferring it to the fixed sink. The method is compared with Leach, M-Leach, SH, and ABC methods, and simulations are performed using Matlab.

Dpa Joz et al. [13] presented a new scheme for improving energy efficiency in wireless sensor networks. These networks consist of numerous small batteries and sensors that are wirelessly networked for prolonged operation without human intervention. Given the numerous sensors and environmental constraints, replacement is not feasible. Therefore, the only practical solution is to use available resources effectively. Energy efficiency remains a major concern in networks, even with energy harvesting techniques. There is growing interest in understanding and developing new strategies for wireless sensor networks, particularly routing, with a focus on optimizing the use of limited resources such as energy, memory, and processing capabilities. Routing is emphasized because a significant portion of energy is consumed compared to data reception and processing. This paper provides information on existing bio-inspired routing protocols and describes a new approach using mobile sinks to optimize routing energy consumption in wireless sensor networks.

Introduction to the Ant Colony Optimization and Particle Swarm Optimization Algorithms:

In the proposed method, the initial phase involves using Ant Colony Optimization (ACO) to determine cluster heads based on the remaining energy levels. Cluster heads then send messages to neighboring nodes, which assess the received messages and select the cluster head with the strongest signal.

In the subsequent phase, the movement of mobile sinks is planned. Four mobile sinks collect data from the cluster heads. When a cluster head detects that a strong signal from a nearby sink is present, it communicates with the sink and offloads its collected data.

Advantages:

1. Selecting cluster heads based on remaining energy addresses the energy challenge.

2. Not all nodes need to transmit their data; they can remain in sleep mode for most of the time.

3. Redundant data is significantly reduced.

4. The energy level of cluster heads remains stable for an extended period as long as information transmission is not required.

5. The reduction of intermediate nodes (hops) and the selection of cluster heads contribute to decreased energy consumption, thus enhancing network lifespan.

The proposed method is simulated in Matlab and compared with the Ant Colony Optimization (ACO) method in terms of average packet delay and average energy consumption.

Jasleen Kaur et al. [14] compiled recent methods for traffic control in wireless sensor networks (WSNs). WSNs represent a vast research area within network studies, with several challenges stemming from the battery-operated nature of these networks. In WSNs, sensors are small hardware devices connected to nodes, responsible for sensing specific events occurring nearby. The sensed data is transmitted wirelessly via radio/antenna connected to the sensor nodes. Essentially, WSNs involve four discussed layers: physical layer, MAC layer, network layer, and application layer.

Rouhollah Rahmati Zadeh et al. [15] proposed a mobile sink routing protocol using virtual coordinates in a wireless sensor network. Geographic routing can provide significant benefits in WSNs; however, in many sensor networks, determining the precise locations of nodes is challenging or costly. Virtual coordinate techniques allow the creation of a coordinate system without relying on geographic locations. This paper introduces MS-DVCR, an extension of the Virtual Coordinate Routing Protocol (DVCR) with mobile sink routing capabilities. We describe the design and implementation principles of the proposed protocol through an empirical study, demonstrating that its performance aligns with a simplified format of DVCR with significantly low energy consumption.

The objective of this paper is to design a routing protocol that enables efficient routing toward the sink in a virtual coordinator system. Our approach optimizes the DVCR protocol, introducing a new protocol named Mobile Sink DVCR (MS-DVCR).

Weifa Liang et al. [16] investigated extending network lifetime through controlled mobile sinks in wireless sensor networks. This paper explores the mobility of a mobile sink to prolong the lifespan of a WSN. Since the mobile sink's movement is powered by gasoline or electric flow, the total distance traveled by the sink must be limited. To minimize data loss during the transition from the current location to the next, the distance traveled should be restricted. Additionally, due to the overhead of a routing tree at each temporary residence of the mobile sink, which requires a minimum time duration at each temporary location, finding an optimal movement plan for the sink to maximize the total time of temporary residences while adhering to the above constraints is challenging. We first formulate the problem using Mixed-Integer Linear Programming (MILP). Due to its NP-hard nature, we subsequently develop a new heuristic method. Extensive simulations are conducted to evaluate the performance of the proposed algorithm in terms of network lifetime. The experimental results show that the solution provided by the proposed method is near-optimal compared to the MILP formulation but with significantly shorter execution time.

Andrew Weichman [17] presented the development of a smooth path and its optimization for multiple mobile sinks in wireless sensor networks (WSNs). Multimedia wireless sensor networks can provide a much clearer picture of the monitored area, significantly enhancing various applications. However, the increased data volume leads to energy consumption issues and reduced network lifetime when traditional data collection networks, where packets are forwarded in hops to the destination, are used. To mitigate these problems, researchers have investigated the movement of mobile sinks across the network and the collection of generated data. Although using mobile sinks results in a significant increase in delivery rates and a reduction in energy consumption, the physical speed of mobile sinks causes delays in data collection. This paper focuses on how to utilize mobile sinks more efficiently to minimize physical data collection delays while improving other performance metrics (such as delivery rate and energy consumption). Such mobile sinks often have movement constraints and require a smooth path to follow these constraints. Accordingly, we first developed a preliminary smooth path algorithm based on the Traveling Salesman Problem (TSP). We then extended it by adjusting the path according to the communication time required by each node. Finally, we allowed multiple mobile sinks, each of which provides a further reduction in delay per packet compared to the previous algorithm. Through extensive simulations, we found that our algorithm enables faster data collection than current solutions while flexibly adapting the speed of mobile sinks, maintaining increased delivery rates and reduced energy consumption.

Shi Changhong et al. [18] introduced a virtual network-based decision-making algorithm for data collection from farm locations for mobile sinks in wireless sensor networks. WSNs used in farms aim to achieve agricultural products without human intervention and enhance seed production. The primary task involves collecting data from sensors using a mobile sink. This paper proposes a virtual network approach to determine the visit locations for mobile sinks in a farm. Virtual networks with higher scores select candidate visit locations. Additional locations are eliminated through algorithmic operations to propose a communication set that reduces visits to unnecessary locations. Simulation results show that the proposed virtual network method effectively reduces the number of visit locations by approximately 15% to 20% compared to the central clustering method, which uses the central position of a sensor group as the visit location for the mobile sink.

Bieber Nazer et al. [19] presented a mobile sink based on the Routing Protocol (MSRP) to extend network lifetime in clustering of wireless sensor networks. In WSNs, sensors near the sink rapidly deplete their energy by receiving and relaying data from nodes far from the sink, leading to significant limitations in network partitioning and lifetime. This issue is known as the hotspot problem. Recently, the formation of hotspots or energy holes near the sink has been identified as a critical issue for data collection in WSNs. In this paper, we address the hotspot problem and propose a mobile sink based on the Routing Protocol (MSRP) to extend network lifetime in WSN clustering. In MSRP, the mobile sink moves within the WSN clusters, collecting sensed data from neighboring cluster heads. During data collection, the mobile sink also retains information about the remaining energy of the cluster heads. The mobile sink moves toward cluster heads with higher remaining energy based on the energy levels of the cluster heads. Consequently, the hotspot problem is minimized by moving the sink to neighboring nodes with higher energy, resulting in a more balanced use of WSN energy and improved network lifetime. To evaluate the effectiveness of the proposed solution, extensive simulations were conducted using OMNet-4.0. The performance of the proposed solution was compared with static sinks and multi-sink solutions using metrics such as energy per packet and throughput. Simulation results demonstrate that MSRP is more effective in extending network lifetime and improving throughput compared to static sinks and multi-sink solutions.

3. PROPOSED METHOD

3.1. Introduction

The goal of our proposed method is to enhance the quality of service in wireless sensor networks (WSNs) by optimizing the data collection process through mobile sinks. Numerous studies have been published regarding mobile sinks, each evaluating and optimizing the topic from various perspectives. The trajectory of mobile sinks is one of the most critical research areas in WSNs, with optimal paths leading to increased network lifetime and, consequently, improved service quality. In our proposed method, we aim to identify and address the limitations of previous approaches and present a novel method that minimizes these issues.

Some of the previous methods include:

1. Linear Movement in the Network Environment:

    1.1 Movement in the Center of the Network Environment

    1.2 Movement Across the Entire Network Environment

2. Circular Movement

3.2. Description of the Proposed Method

In this problem, the objective is to utilize a traffic coloring concept similar to Google Maps, where the desired locations are identified based on traffic history. The mobile sink prioritizes regions with higher traffic and reads data by traversing through higher traffic nodes.

Fig. 1. Google Maps Traffic Map

In this method, the mobile sink initially scans the network to assess traffic conditions and generates a traffic map. It then prioritizes high-traffic nodes and establishes a new route to collect data. This approach aims to optimize service quality in WSNs and enhance response times. Our primary objectives are:

- Reduce Lost Data

- Increase Network Lifetime

- Decrease Data Transmission Delay

By adjusting the mobile sink's route towards higher traffic areas and managing data collection from cluster heads, the network's service quality will improve. Prioritizing high-traffic cluster heads in the mobile sink's path will significantly reduce lost data. The movement path will resemble the one shown in Figure 2.

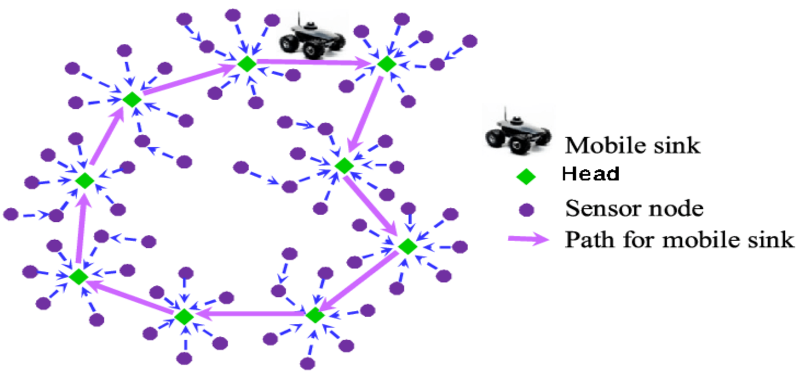

Fig. 2. Mobile Sink Path Based on Cluster Head Traffic

Generally, meeting all cluster heads with the mobile sink can be considered analogous to the Traveling Salesman Problem (TSP), where the optimal solution is achieved using optimized Ant Colony Optimization (ACO) algorithms:

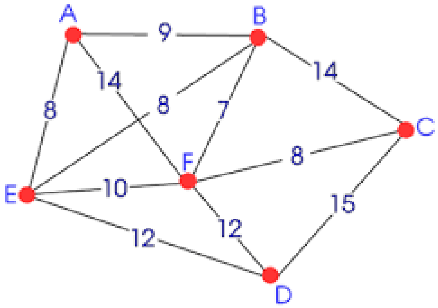

Fig. 3. Solving the Traveling Salesman Problem with ACO

3.3. Corresponding Parameters

1. Cluster Heads are the destinations that the traveling salesman needs to visit.

2. The Starting Destination is the base station.

3. Travel Cost to Each City represents the traffic load of each cluster head and its distance from the base station. Thus, a cluster head with higher traffic has a lower travel cost. This is because traveling to such a cluster head results in fewer lost data.

The problem can be addressed using various algorithms, including the optimized Artificial Bee Colony (ABC) algorithm. The ABC algorithm is one of the most effective methods for solving the Traveling Salesman Problem (TSP). The following figure, based on the study in reference [19], illustrates a novel routing approach for wireless sensor networks utilizing the Artificial Bee Colony algorithm.

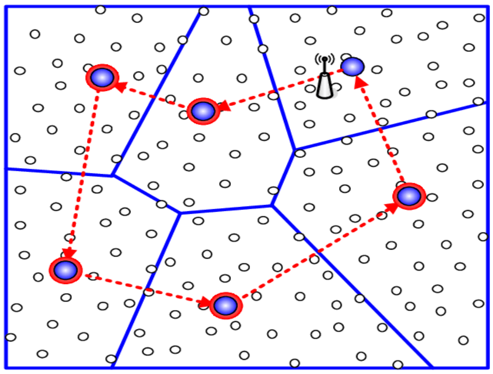

Fig.4. Bee Routing Using the Optimized Artificial Bee Colony Algorithm

3.4. Assumptions of the Proposed Method:

1. The network environment is considered two-dimensional, with sensor nodes randomly distributed within the environment in such a way that network coverage is guaranteed.

2. All nodes in the environment, except for the sink nodes, are homogeneous. Sink nodes are more energy-efficient than other nodes and operate at a height above the network layer, such that cluster heads within the sensing radius of a sink node can directly exchange information with it.

3. There is one or more backup sink nodes in the network.

4. The buffer of the sink node must be greater than or equal to the buffer of the cluster head multiplied by the number of clusters ($BS \geq BH \times NH$) to ensure that a sink node can read all data within a complete cycle.

5. The send and receive speeds between the sink nodes and the base station are much higher to ensure that all data can be offloaded efficiently.

6. It is assumed in this model that the number of sink nodes (NS) is determined based on the volume of generated data, the number of clusters (NH), the buffer capacity of the cluster head (BH), and the total distance traveled in the network environment (DN).

7. The number of sink nodes should not exceed the number of clusters.

$Max(NS) <= Max(NH)$

3.5. Data Collection Stages from the Network:

1. Determine the required number of sink nodes based on traffic history.

2. Determine the permissible distance between sink nodes.

3. Create a traffic map based on the network's historical data.

4. Obtain and illustrate the optimal mobile sink route based on the priority of high-traffic and nearby clusters using the ABC (Artificial Bee Colony) algorithm:

i. Define the maximum traffic that may occur in any cluster as a threshold, MTH.

ii. Assign a traffic number, TH, to each cluster based on its traffic. A higher value of TH indicates higher traffic and, thus, a higher priority.

iii. Calculate the cost, Cost, for each cluster using Equation (1). This cost reflects the efficiency of visiting the cluster; higher traffic in the cluster results in a lower cost, meaning fewer data are lost.

$$Cost = MTH - TH \quad (1)$$

iv. Assign a distance number, DH, to each cluster based on its distance to the base station.

v. Compute the final cost for each cluster, FH, using Equation (2):

$$FH = DH + Cost \quad (2)$$

vi. Use the optimized Artificial Bee Colony algorithm and the FH input to determine the optimal path.

The above steps may resemble the illustration in Figure 5:

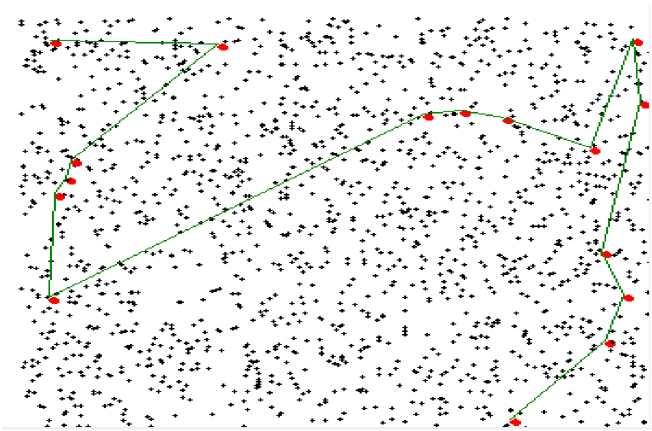

Fig. 5. Path of the Mobile Sink Node Considering High-Traffic Clusters

5. Calculation of Mobile Sink Node Speed

- Calculate Ts, which is the duration required for a sink node to traverse the entire network at a specified speed.
- Compute the number of data items generated during the time Ts.

3.6. Clustering

In this section, a clustering method will be proposed based on the new routing approach and existing traffic conditions.

3.6.1. Clustering Stages

i. Identify high-traffic nodes based on historical load data and the current network status.

ii. Determine the priority of high-traffic nodes in terms of their distance from one another and the number of nodes they can cover.

iii. Select nodes with the highest priority that can form paths with the chosen nodes.

iv. Cluster head assignment:

I. In this method, clustering is performed such that within the sensing radius of a sink node, only one node is chosen as a cluster head. The maximum number of cluster heads (Max Number Head) is calculated using Equation (3):

$$Max\ Number\ Head = 2 \times RS/DN \tag{3}$$

II. The distance between two cluster heads is calculated using Equation (4):

$$Distance\ Head = N/DN \tag{4}$$

III. Movement along the specified path across the entire network environment is measured in meters.

3.7. Communication Mechanism Between Sink Nodes and Cluster Heads

When a sink node enters the sensing area of a cluster head, it sends a signal containing the sink node's identification number (ID) and the number of data items that the sink node can read from the cluster based on its speed. If the cluster head has collected data within acceptable limits (i.e., sufficient energy to transfer the data), it sends a message containing 'S' to indicate the start of data transfer, the cluster head's ID, the data packets including the sender node's ID and data, and finally 'E' to signify the end of data transfer, along with the number of remaining data items in the cluster head’s buffer.

3.8. Use of Multiple Mobile Sink Nodes

In scenarios where the network is extensive or the existing sink nodes cannot efficiently collect network traffic, multiple mobile sink nodes can be utilized. In such cases, the network environment is divided into several regions as needed, and each region is addressed as a Traveling Salesman Problem. The ABC algorithm is then used to determine the path, and sink nodes move according to the obtained routes within their respective regions to transfer information to the base station.

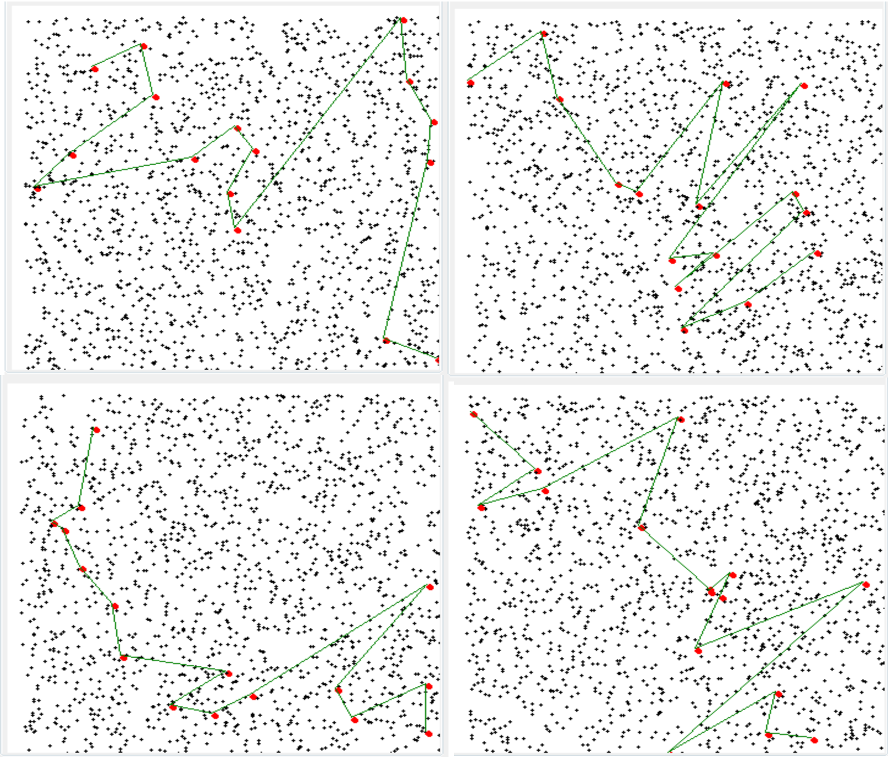

Fig. 6. Use of Multiple Mobile Sink Nodes for Data Collection from the Network

3.9. Advantages of Using Multiple Mobile Sink Nodes

1. Improved energy efficiency
2. Cost-effective deployment
3. High reliability

4. ANALYSIS AND SIMULATION

We designed a simulator using C# and compared our proposed method, which utilizes the ABC algorithm, with two other methods named GA (Genetic Algorithm) and PSO (Particle Swarm Optimization). The network parameters in our simulator include:

1. Network area
2. Number of sensor nodes
3. Number of sink nodes
4. Number of clusters

Evaluation parameters for the simulation include:

1. Amount of data read
2. Amount of data lost
3. Delay in data reading from the network

4. Network lifetime

5. Network energy consumption

The speed of sink nodes is constant, and sensor nodes send their data to the cluster heads, which then forward the collected data to the sink nodes. In our simulation, the network area is set to 2312 m², with 100 sensor nodes defined, 20 clusters assumed, and the number of mobile sink nodes varied from 1 to 20.

4.1. Simulation Results

4.1.1. Network Data Received

As shown in Figure 7, the amount of data received using the ABC algorithm is more optimal compared to other methods, and performance improves with an increasing number of sink nodes.

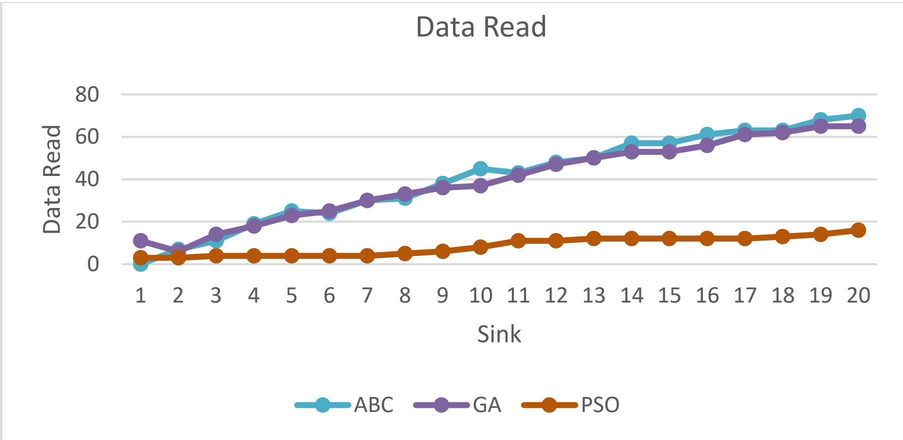

Fig. 7. Amount of Data Received by the Network Using Three Methods

4.1.2. Lost Data

As illustrated in Figure 8, the amount of lost data using the ABC algorithm is lower than other methods, with PSO exhibiting higher data loss compared to the others.

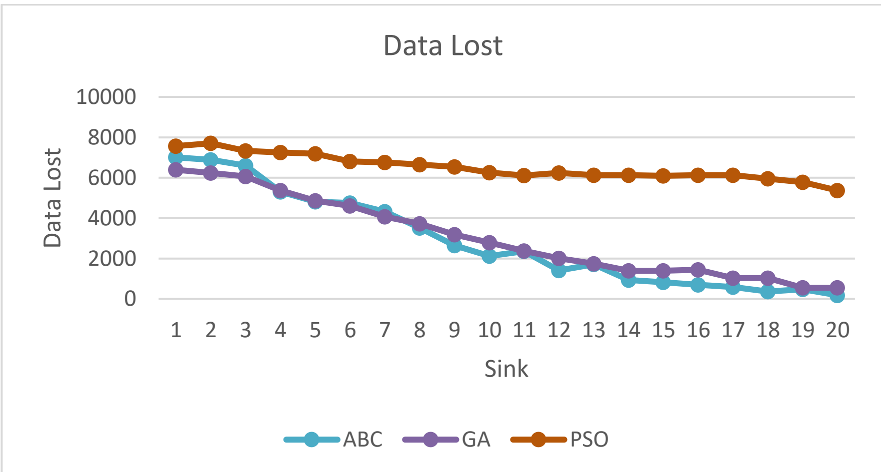

Fig. 8. Amount of Lost Data in the Network Using Three Methods

4.1.3. Delay in Data Reception

Figure 9 shows that the delay in data reception using the ABC algorithm is less compared to other methods. The GA algorithm also shows minimal delay compared to our proposed method, whereas the PSO method exhibits higher delay, even with an increasing number of sink nodes.

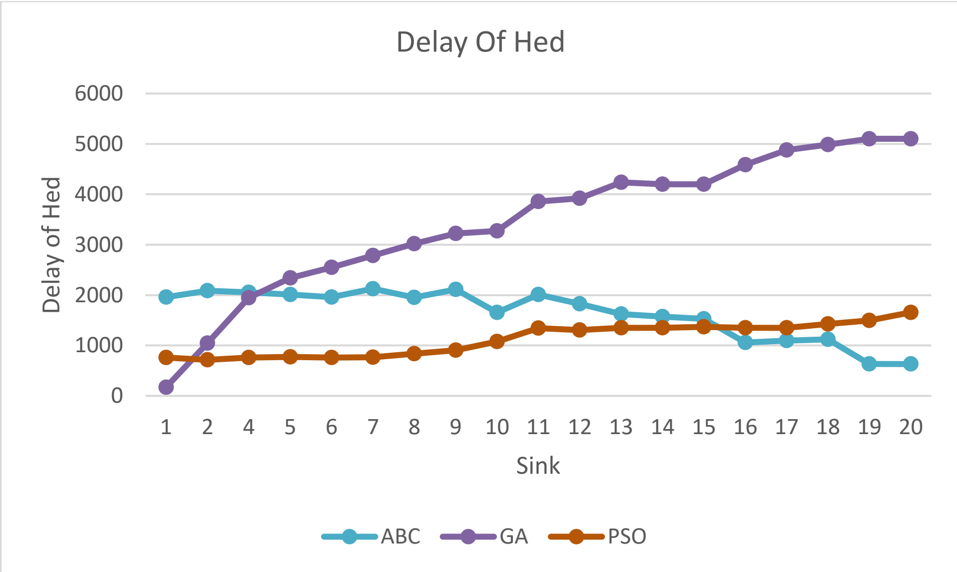

Fig. 9. Evaluation of Data Transmission Delay in the Network Using Three Methods

4.1.4. Network Lifetim e

As depicted in Figure 10, the network lifetime using the ABC algorithm is greater than with other methods. The network lifetime increases with the number of sink nodes, indicating that an increase in sink nodes enhances network efficiency.

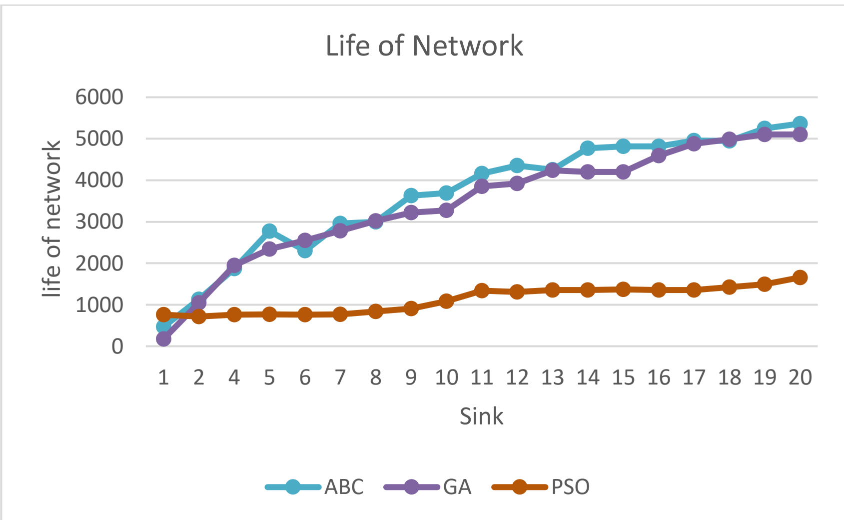

Fig. 10. Evaluation of Network Lifetime Using Three Methods

4.1.5. Network Energy Consumption

Figure 11 shows that energy consumption using the ABC algorithm is lower compared to other methods. The GA method also has lower energy consumption than PSO, which shows the highest energy consumption.

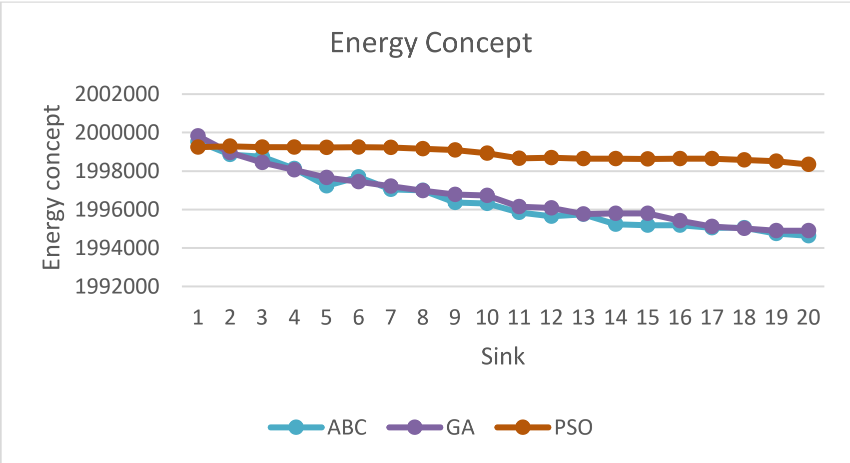

Fig. 11. Evaluation of Network Energy Consumption with Increasing Number of Sink Nodes

5. CONCLUSION

As proposed, utilizing historical load and active network traffic significantly aids in managing traffic and the movement of mobile sinks. This transforms the problem of mobile sink routing into an NP-Complete issue, which can be solved using various algorithms, including the optimized Artificial Bee Colony (ABC) algorithm. Simulation results indicate that the ABC algorithm outperforms genetic and particle swarm optimization methods. Increasing the number of mobile sinks can significantly impact network efficiency. Quality of service in wireless sensor networks is notably different from traditional networks and depends on multiple parameters for evaluating service quality. One of the major issues for extending the lifetime of wireless sensor networks is balancing the load and energy consumption among the nodes. Using a fixed sink node in such networks quickly depletes the energy of surrounding nodes. Nodes along high-traffic paths will also deplete their energy rapidly, leading to network fragmentation. Therefore, employing multiple sink nodes is highly effective. A new data collection method for wireless sensor networks has been proposed that uses multiple mobile sink nodes. This method eliminates the need for ground routing, and all information is collected from cluster nodes without overhead. With a mobile sink node present in almost every section of the network environment, cluster nodes can transfer their information to the corresponding mobile sink with reduced delay. Thus, energy is conserved, and network lifetime is increased. Simulation results demonstrate the key features of this method, including extended network lifetime, reduced energy consumption, increased data collection, and decreased data transmission delay from clusters.

6. FUTURE WORK

To further develop this method, it is recommended to use additional parameters such as the remaining energy of cluster heads and the amount of lost data for prioritizing routing. Additionally, other heuristic and metaheuristic algorithms can be explored in place of ABC to identify better routing methods, enhance network lifetime, and ultimately improve quality of service in such networks. Finding a suitable algorithm for determining the number of required sink nodes in various network scenarios should also be considered in future research.

Declaration

We acknowledge that we used ChatGPT to enhance the academic writing of our manuscript while ensuring the originality and integrity of our work.

Transparency Statement

The data supporting this study are available upon reasonable request to the corresponding author, subject to ethical and confidentiality considerations.

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Declaration of Interest

The authors declare that they have no competing interests.

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