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Enhancing Wireless Sensor Networks Features Using Software-Defined Networking Techniques and ACO Algorithms

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ABSTRACT: Wireless sensor networks (WSNs) are the most important networks for things such as monitoring natural phenomena, agriculture, health care, and so on. There are several challenges associated with using WSNs, the most important of which are energy consumption, expansion issues, or even data routing issues. There are many techniques and algorithms that can address these challenges and make it easier to use WSNs. These techniques and algorithms vary depending on the challenge to be overcome. In this study, Software Defined Network (SDN) technology was used for the purpose of improving WSNs and saving energy for nodes in those networks. The Ant Colony Optimization (ACO) algorithm, which is an algorithm that follows ants' foraging method, was also used. This algorithm was used to find the shortest data path from the starting node to the target node. The results of the proposed system was a significant improvement in the performance of WSNs. The system saved energy, removed dead nodes, and found better and shorter paths to reach the target nodes. The proposed approach was versatile and adaptable, making it suitable for various WSN applications and deployment scenarios. The results of the proposed system led to energy savings of up to 0.891 mj and only 35 nodes compared to traditional methods, which can have up to 74 dead nodes.

Keywords: Wireless Sensor Networks, WSNs, SDN, ACO, Energy

1.INTRODUCTION

A wireless sensor network (WSN) is a framework for the development of wireless networks made up of sensors, communication, and computing devices that enable network administrators to interact with, observe, and record phenomena and events in a variety of environments. A WSN can also be an ideological system or a framework for information technology. The official is frequently a file from a civil entity, such as a government agency or a commercial or industrial company. Observers predict that, in the coming years, WSNs will have a wide sensory range for many different applications, particularly regarding national security [1, 2].

When developing WSNs, special considerations are given to sensing metrics such as temperature, vibration, humidity, seismic activity, sound, and so on. Wireless communication, control, and physical factors in various locations and regions of interest are also considered when building WSNs. WSNs utilize data processing within the network and can deal with sensors in environmental phenomena [3].

The data is gathered and either given to contacts or transmitted to operators. Resultantly, wireless sensor networks may be used to monitor battlefields, human health, earthquakes, and a variety of other events. They are also useful for identifying and tracking objects [4].

SDNWSN, which is a more advanced version of software-defined networking (SDN) and wireless sensor networks (WSNs), [73] provides high flexibility for simpler network management [5].

Tasks are divided into different layers (or hierarchies) in SDN systems. These are the data layer, the control layer, and the application layer. The hardware that is responsible for transferring data to the control layer is included in the data layer [6].

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Considering the lightness of the WSN routing protocols due to the resources they provide on the network, numerous energy-saving protocols have been designed to reduce the energy used [7].

The most efficient solutions routes must be discovered. For this reason, researchers attempted to identify appropriate solutions, including Ant Colony Optimization (ACO), which is a sophisticated probabilistic computational approach for resolving issues including identifying the most effective network design strategies [8].

Using ants' behavior, this algorithm is meant to emulate how they find the best and most efficient route between their food source and their colony. This contemporary technology reduces energy consumption and removes obstacles in their way [9].

2. LITERATURE REVIEW

The authors of [12] suggested a tiny software specific measurement (TSDM). It is an SDN scaling architecture for WSNs that employs Tiny Code Language (TCL)—a language that is comparable to regular C programming. Moving the binary code makes it simple for TSDM to handle coding operations like task measurement and transfers.

One of the SDN implementations is shown in [13]. It modifies SNs in OF based on fresh data in stream tables. A WSN-based architecture that uses an OF protocol via a controller module was also given by the research in [14].

The fundamental difficulty facing WSN networks, energy efficiency, is one of the crucial questions addressed in this research. SDWSN is employed in this study to address traffic issues, such as information gathering and transmission, as well as energy usage.

Individual nodes in a classic WSN typically run the appropriate algorithm for estimating power consumption and communicate the outcome to the master node. The SDN model has made it possible to migrate processes from individual nodes to the SDN controller, which is considered a breakthrough in power optimization and other areas. We can represent this by allocating communication channels [15], performing traffic analysis [16], expressing intrusions [17], or forecasting energy consumption.

Notably, the authors [18] showed that consumption by country transitions can play a pivotal role in making the final product. This means that accurate power consumption models must account for power consumption in processing, sensing, communication and transmission work.

Kobo et al. [19] carefully reviewed the SDWSN literature, discussed the challenges of this model, and discussed the basic SDWSN design requirements in order to overcome these challenges.

Mahdi Abed Salman and Muhammed A. Mahdi's research described a multi-strategy fusion model for localization that included optimization techniques (ABO, DSA, EHO, KNN) with neural computing techniques (BP, MTLSTM, BILSTM, and Autoencoder) to improve localization accuracy in WSNs. This was done in three stages: data collection, model development, and implementation. The data collection and implementation were done in the field, whereas the model development was done in a lab. The ABO and DSA optimization approaches performed similarly, with lower mean square error (MSE) values than EHO and KNN. ABO and DSA have comparable mean absolute error (MAE) values, implying reduced mean absolute errors. BP outperformed other neural computing algorithms, achieving higher accuracy with lower MSE and MAE values than MTLSTM, BILSTM, and Autoencoder. Finally, the multi-strategy fusion model for localization proved to be an effective method for improving localization accuracy in wireless sensor networks. The article addressed the link between wireless device placements and signal strength in order to enhance the localization process. The findings proved the model's significance and relevance in the field of localization in WSNs [20].

Hemanand D et al.'s study aims to create an intelligent IDS architecture that will considerably improve WSN security by utilizing a deep learning model. The preprocessed data set was created by performing at least two normalization and data separation processes. The Intelligent Prairie Dog Optimization (IPDO) method was then utilized to minimize the feature dimensions by determining the optimal solution with the highest convergence rate. Furthermore, an autonomous deep neural network (DANN)-based classification algorithm was employed to properly forecast the data class while reducing false alarms and increasing detection rates. A complete study is done to assess the performance and detection outcomes of the proposed IPDO-DANN model [21].

3. WSN Model in SDN

In sensor networks, modeling is done by groups of various potentially heterogeneous components. In response, the array places sensor nodes in the desired area. These nodes, which have been placed in various locations in accordance with the established mechanism, function according to a set of incentives that ultimately produce a report on the information about that area and send their reports to the main station or base. Three types of sensor nodes are used in this process:

- The node from which the data is sent, known as the source node.
- The nodes sending messages, keeping an eye on events, and gathering data.
- The target, or destination, node issues the final report describing what the node was published for (the final destination of the target reports). It also specifies pathways and issues control instructions [22].

This approach creates a complete framework that can simulate and incorporate protocols as well as numerous features and security.

A. Node

The node's task is straightforward: it gathers a sample and sends information through a wireless network to other nodes or to a device or receivers. The node has three concurrent units—the transformer, the controller, and the transmitter—that perform similar tasks to those of the node's main parts.

The transmitter sends the data via the wireless network, and the microcontroller carefully regulates every step of the operation [14].

B. Sink

The basin consists of a primary control unit and receivers. Several types of data which are delivered across the nodes are gathered and processed by the receiving node. SDN instructs the nodes to choose the shortest path for the data [8].

C. Monitoring and Stimulation

The SDN keeps tune of the closest pathways and signals the supply node to transmit statistics through those pathways in order to reach the target node wherein the statistics will be acquired and examined. The information is driven through those pathways because they are short and have numerous strong nodes [23].

4. SDN Technique

The manipulate plane and facts plane of the network are separated in a network design called software-defined networking (SDN). SDN can offer a flexible and programmable structure in WSNs to control network assets and improve overall network performance [24].

The capacity to centralize network manipulation is one of the foremost blessings of SDN in WSNs. This permits more useful resource allocation and routing, which can boost network efficiency and decrease strength depletion. SDN can also allow the network's dynamic reconfiguration to guide new applications and modify occasions [25].

However, integrating SDN into WSNs comes with a host of problems. For instance, it is difficult to enforce a complete SDN controller in WSNs considering they frequently have limited resources, including processing speed and memory. Furthermore, because WSNs are built on Wi-Fi, their network topology may be quite dynamic, which makes it hard to create a strong manage aircraft [26].

SDN has the potential to noticeably improve the overall performance and flexibility of WSNs; however, it is crucial to consider each of their distinct features as well as the limitations of the hardware and software available to us [27].

5. ACO Algorithm

This algorithm emulates the behavior of ants—specifically their methods of searching for food. While studying the ant, it was discovered that they emit a certain quantity of pheromones, which can affect their behavior. Pheromones are chemicals which are secreted from an animal's body. Sometimes, while moving from their nest to their food source, an ant will actively produce pheromones [24]. Other times, the pheromones are produced when the ant returns, and the other ants go along the path that was marked by those pheromone residues, repeating the process and leaving pheromones in their wake [18].

In this procedure, it is normal for the ants who choose the shorter road to return earlier than the ants who choose the longer path. As a result, the pheromone residue rises in the shorter path more quickly than it does in the longer path. ACO's foraging serves as inspiration. In this instance, the ants use the pheromone deposition procedure to mark the path they take so that the rest of the colony may follow [19].

However, one of the most well-known optimization algorithms, the ACO, is capable of resolving extremely challenging and intricate optimization problems [15]. This algorithm looks for the best possible path by using the performance and behavior of ants looking for food as a model. Ants produce pheromones while moving around as they search for food. In other words, the pheromone distribution mechanism aids in establishing a back channel to their nest.

When the ant encounters an obstacle along its route, it can use the pheromones to choose which direction to go.
The paths, however, are connected at random and may be created on the fly when the ants are out foraging [22].

A prescriptive algorithm methodology called the ant optimization method is used to address a variety of computational problems and arrive at solutions in accordance with the algorithmic process. The initial algorithm, known as ACO, was suggested or presented to find the best route between the food supply and the colony. The concept was then expanded to encompass numerical issues [23].

6. The Proposed System

The proposed system goes through several stages in order to improve the characteristics of WSN and choose the best path for sending and receiving data:

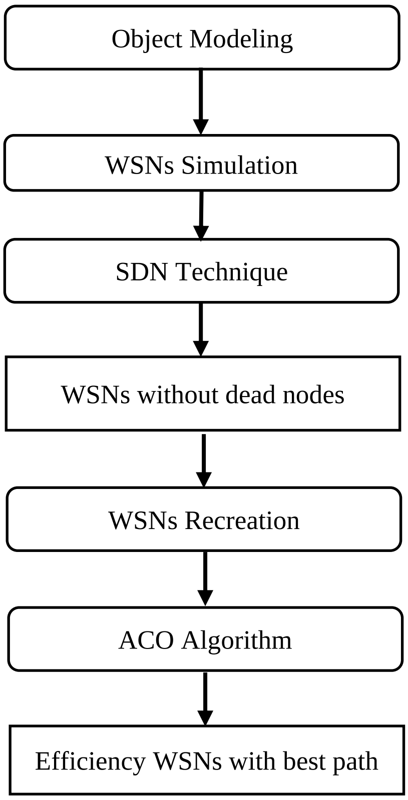

Fig 1. Flow Chart of the Proposed System

A. Object Modeling

Modeling is a technical term used in the computing industry to describe systems, knowledge, or information that can be shaped into a structure and gathered via a well-coordinated set of guidelines. To make the contents of the structure clearer, it is defined by a set of rules.

Giving full modeling requirements is the first step toward creating and refining an application that models the topics that have been covered. First, the issue will be divided into groups, linked to one another, and used in a simulation.

- In this case, we can easily distinguish three main parties:
- Without a doubt, the ant is able to detect the pheromones and navigate the pathway.
- A region inhabited by ants. Pheromones and ants are two-dimensional examples of them.

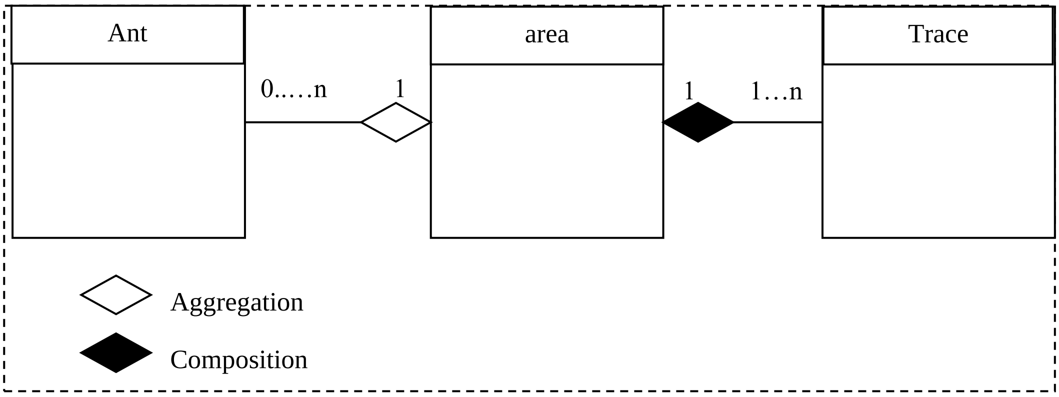

Fig 2. Basic Class Diagram [20].

B. WSN Simulation

These procedures may be used in Matlab to simulate a WSN with 100 nodes and a topology:

- Establish the topology: For the WSN, design a topology using deterministic or random methods. One of the most crucial methods to generate a random topology is to randomly arrange nodes in a two- or three-dimensional space.

• Describe node attributes: Describe the characteristics of every node, such as its battery life, communication routes, and status. You can choose values that make sense to you or that align with your own ideals.

• Decide on a community: You may select between WirelessHART, Zigbee, or Bluetooth Low Energy (BLE) depending on your needs.

• Explain the simulation scenario: Specify the environment in which the WSN will be improved. For example, by adding a WSN at a certain time, nodes can find how much strength is being used.

• Network implementation: The network is implemented using Matlab. You can make use of new features or enhance those that are already present.

• Run the simulation: Run the simulation and compile the findings. Examine the outcomes to ascertain the WSN community's effectiveness.

C. SDN Technique

To enable centralized network control and management, a communication technique known as software program-defined networking (SDN) separates the control plane from the information plane. Although SDN was first developed for strained networks, wireless sensor networks (WSNs) can benefit from using it. Below is an explanation of how SDN may be used in WSNs.

• Distinguishing between the records and control planes: The control plane of an SDN-based WSN handles network administration, whereas the data plane handles information transfer between nodes.

• Network programmability: The SDN controller may be used to apply the community by identifying the WSN nodes. For example, a controller can establish network policies, manage data flow at a certain point in the network, and appear after the routing tables of the nodes.

• Virtualization: An SDN-based WSN may use virtualization to build many logical networks within of a single physical community. In digital networks, rules and laws work.

• Security: WSNs that use SDN technology can enhance security by providing local access to nodes and managing their content since the controller in those networks can detect node defects and remove corrupted data in them.

• A specific software framework: One of the most important requirements for implementing SDN technology in WSNs is a specific software framework such as virtualization. These frameworks include SenSDN, OpenWSN-SDN, and SoftSensor-SDN.

• Dead nodes: To enable SDN technology in WSNs, the system removes dead nodes to increase availability, reliability, and rebuild the network.

• Central tracking: The central controller of the WSN that uses SDN technology stores the data. The interface allows several properties to be tracked in real time, including node connectivity and battery life.

• Dynamic network reconfiguration: The SDN controller allows WSNs to be rebuilt and reconfigured, eliminating dead nodes.

D. WSN Recreation

• Include node mobility: One of the most important functions of SDN technology and controllers is to configure nodes to move to locations with suitable connectivity or to recharge their battery, which increases node life and full area coverage.

• Avoiding problems and errors: One of the functions of the controller in WSNs that use SDN technology is to provide standards, paths, and backup nodes to avoid network downtime in the event of node failure or any other problems.

• Network testing: To ensure that the required security, stability, and performance of WSNs are met, network measurements must be analyzed, the network simulated, and potential vulnerabilities looked for.

Reconfiguring WSNs using SDN technology is very important to achieve the security, reliability, and performance of the network, through the possibility of node mobility, avoiding challenges and problems, and dynamic restructuring through central processing and the flexibility provided by SDN technology, which ensures that the network continues to operate and does not stop if it encounters problems or disturbances.

E. ACO Algorithm

Ants use pheromone paths to move from their colony to their target, which is the food sources, which is the fastest and best path. This behavior is emulated in the ACO algorithm to improve the features of WSNs and enable them to choose the best path in the community of wireless sensors.

Using ACO, a wi-fi sensor community's bottom station and sensor node may choose an appropriate path for record transmission. The objective is to provide fast, dependable statistics distribution as an effective means of reducing energy use.

These fundamental steps are followed by the ACO algorithm for path selection in WSNs:

• Connect the bees, which represent statistics packets that may be sent from the base station to the sensor node, to begin the setup procedure. Each larva has a starting gland, and there are significant amounts of the usual pheromone content substance in the mouth at first.

• Action: Using a probabilistic method that counts the number of pheromones at the edges and the distance between nodes, each bee chooses which node to visit next. In each cycle, pheromone amounts change according to how successfully the bees are able to gain access to it.

• Other nearby pheromones: Each bee deposits a pheromone in its mouth based on the kind of journey it undertook. If their strategy worked, additional bees may wish to employ a similar strategy.

• Global pheromone replication: Pheromone tiers at the rims are replicated globally as each bee acts over the whole range. The kind of route determines how many pheromones are produced.

• Termination: The algorithm comes to an end when a preventing condition, such as this kind of convergence threshold or a maximum number of iterations, is satisfied.

Following these suggestions can help the ACO approach store energy usage, choose the nice channel in WSNs effectively, and provide reliable statistics transmission.

Using ACO for route selection can improve WSNs' dependability and performance. The ACO algorithm may determine the best route by taking into account a number of variables, including node location, battery level, and signal strength. Possible results include reduced packet loss, increased energy economy, and improved network coverage.

7. RESULTS AND DISCUSSION

This paper proposed a MATLAB® R2021b simulation method for intelligent SDN control using an ACO algorithm. We randomly dispersed 100 sensors throughout the square sensing area, with a transmission distance of 25 m between each sensor. Figure 3 shows the zone's implementation process. The sensing nodes generate traffic at the start of every scheduling period. In other words, the sensors conduct low-flow to high-flow. After that, the flow will be directed toward the Forwarding Cluster Head. Congestion is lessened by the SDN controller. Congestion can be classified as Forwarding Cluster Heads.

When this ratio is higher than the threshold, the buffer size of each node is equal to 50 packets, whereas the buffer size of CH is 250 packets. E has 0.5 J of initial energy. As demonstrated, they can be randomly distributed by making 100-point graphs (100, 100) and distributing them over BSs at (50,50).

When nodes are dispersed, the ACO method is employed. Figure 3 illustrates how the node and CH are selected before the CH is connected to the node. The four HCs may be found at locations (67,19), (20,19), (15,68), and (72,75) in the figure that shows how the k-mean is affected in order to locate HC. When the WSN model is prepared, the Intelligent ACO algorithm and the SDN controller will be applied to WSN. Utilizing the Intelligent SDN, simulations were run with parameters that produced a 100-by-100 area. There are 100 sensors with 4 HCs, each node has a 50-packet buffer, and the CH has a 250-packet buffer. E has a beginning energy of 0.5 J.

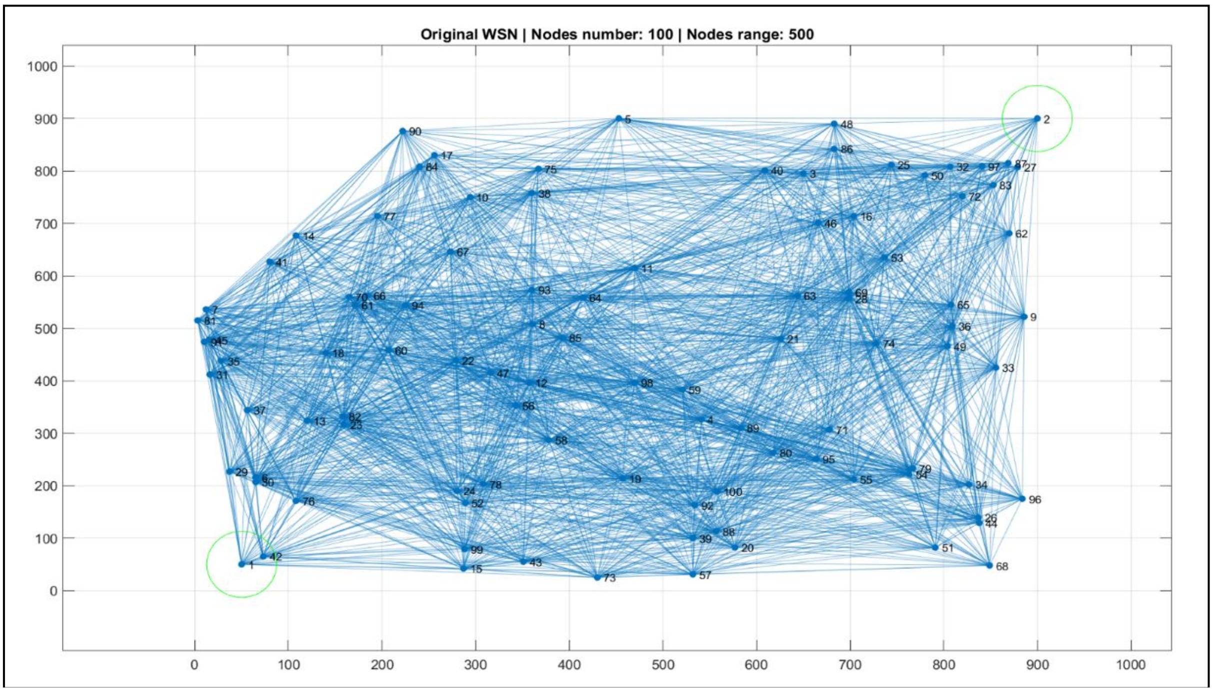

Fig 3. Topology of Original WSN With 100 Nodes

Here are five common assumptions that are frequently taken into consideration when enhancing energy consumption for Wireless Sensor Networks (WSNs) using the Ant Colony Optimization (ACO) algorithm and

Software-Defined Networking (SDN) technique. The exact assumptions used can vary depending on the implementation and research study.

A. Nodes of homogeneous sensors: A widely held belief is that all sensor nodes within a wireless sensor network (WSN) have identical capabilities and energy characteristics. The ability to allocate resources throughout the network and make routing decisions always simplifies the energy management process. In practice, however, WSNs may have nodes with different power and energy states, and it may be difficult to overcome this heterogeneity.

B. B. Static network topology: Another common reason is that the network topology does not change during WSN operation. Pre-computed routes and resource allocations based on initial network positions are made possible by this concept. However, dynamic optimization methods are needed to change resource allocation and routing options in dynamic settings where nodes may join or leave the network or where environmental influences may cause changes in the network architecture.

C. C. Idealized communication model: This model assumes that all communication channels between sensor nodes are fault-free and have infinite bandwidth. It improves energy efficiency by ignoring the effects from bandwidth constraints or connectivity problems and focusing only on energy consumption under practical circumstances so inside the communication link may deteriorate and bandwidth limitation may affect the energy consumption.

D. Centralized control and information exchange: The ACO-SDN approach broadly assumes the existence of a centralized control plane, where a central SDN controller communicates with sensor nodes and has a global view of the network. It is important to take into account the cost of the information shared between the controller and sensor nodes, as scalability constraints may arise when setting up a centralized control plane.

E. Default Energy Consumption Measures: Another assumption involves using default energy consumption measures to evaluate the success of the ACO SDN approach. These metrics can be the total energy consumption in the network, the distribution of energy among nodes, or the age of the network. While these measures statistically predict energy efficiency, they fail to account for all aspects of energy use, such as local differences in energy use or variability in energy use. It is crucial to remember that not all WSN scenarios will follow these presumptions, and researchers should carefully analyze the unique needs and features of their intended application. Realistic and efficient energy consumption optimization in wireless sensor networks (WSNs) may be achieved by modifying the ACO-SDN methodology to account for departures from these presumptions and tackle practical obstacles.

This work proposes ACO algorithms with SDN consisting of nodes and CH to reduce redundancy and memory consumption and prolong the lifetime of sensors in the network by saving energy and increasing WSN performance. The system consists of a series of iterations in which dead nodes are removed and the network is rebuilt.

After removing the third dead node, the original iteration of the system was depicted in the accompanying figure and path 1 3 10 2 was identified as the best path for the data.

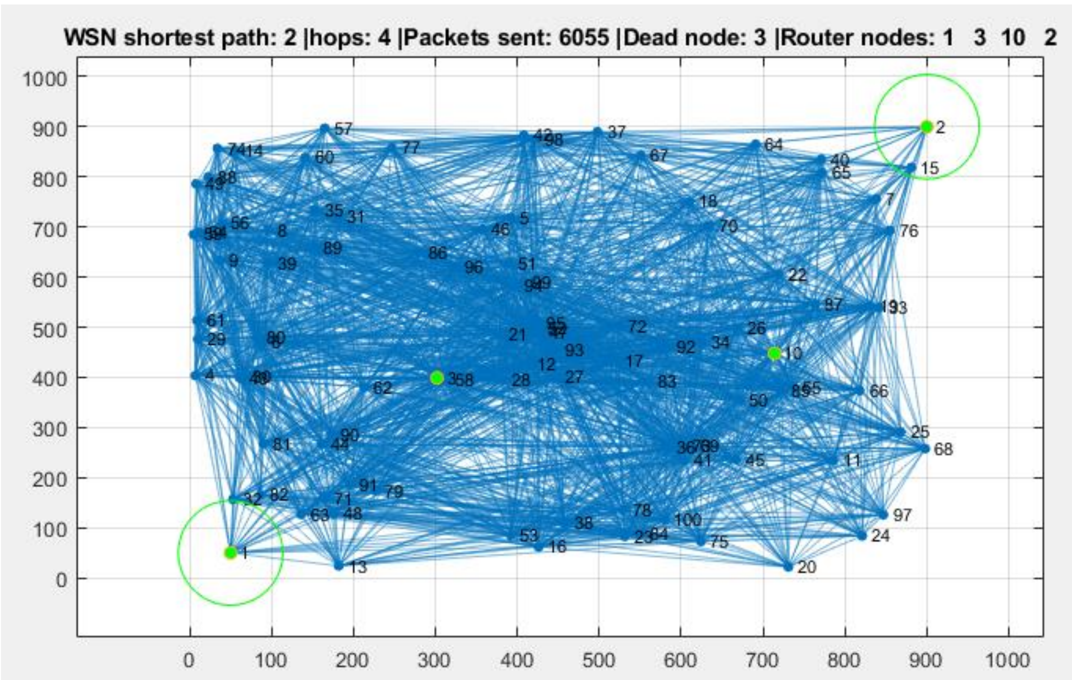

Fig 4. Topology of WSN After First Iteration

As seen in the accompanying figure, the system reconstructs the network, revisits it to eliminate dead nodes, and decides on the best route for the data in the second iteration.

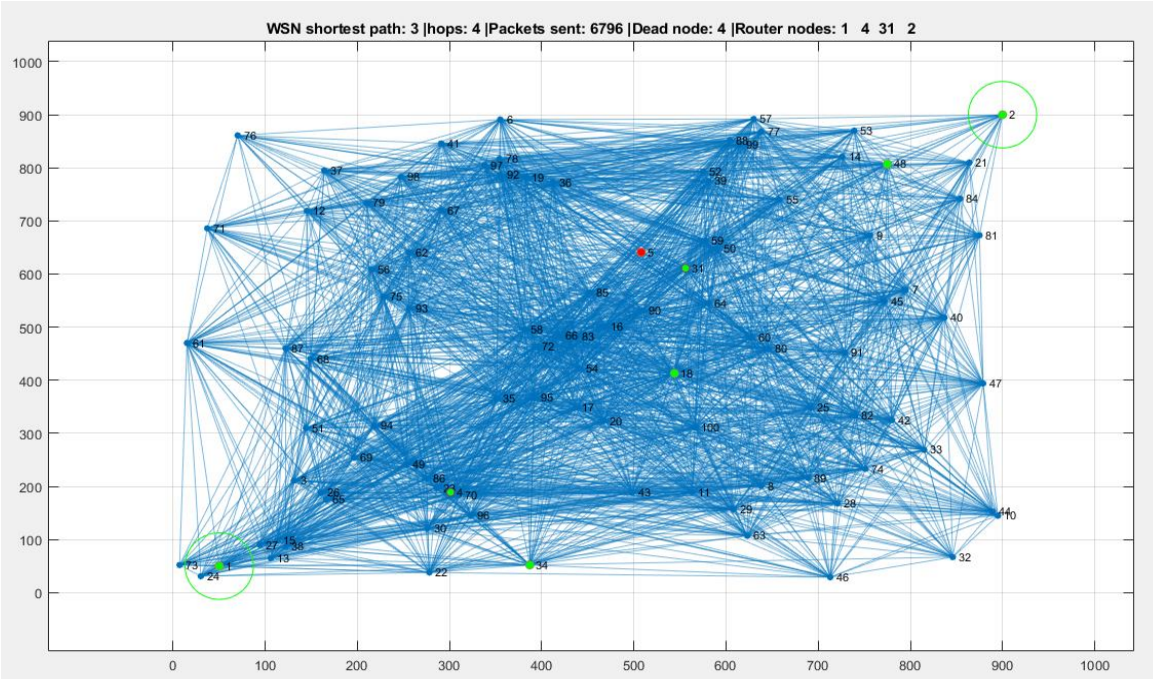

Fig 5. Topology of WSN After Second Iteration

In order to eliminate dead nodes, create a WSN while preserving power, and select the optimal network path, the system goes through a series of iterations.

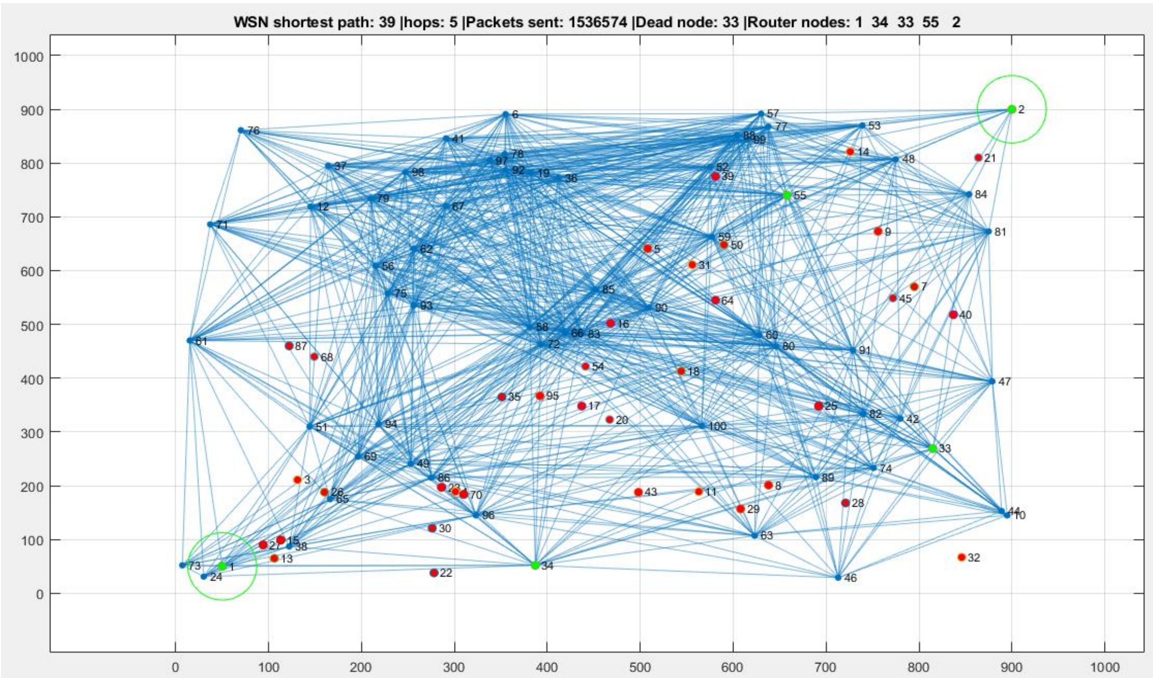

Fig 6. Topology of WSN After 39 Iterations

To create an ideal network free of dead nodes, the system has eliminated about thirty dead nodes, as shown in Figure 6.

Two approaches were used in this system to form the network and save energy: the first involved using SDN techniques without the ACO algorithm, and the second involved integrating SDN technologies with the ACO algorithm. The outcomes of both approaches are compared in the following figure:

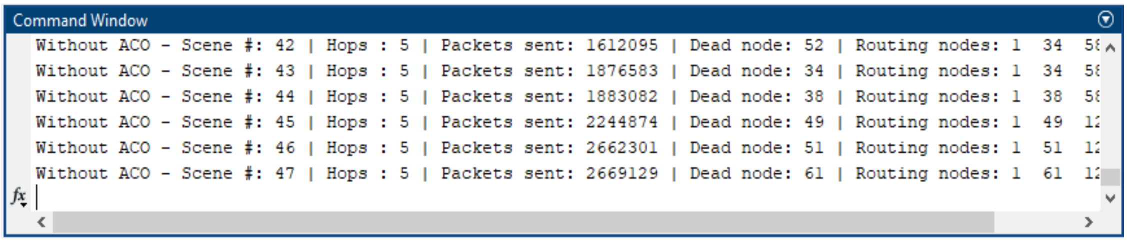

Fig 7. **The SDN System Without ACO Algorithm**

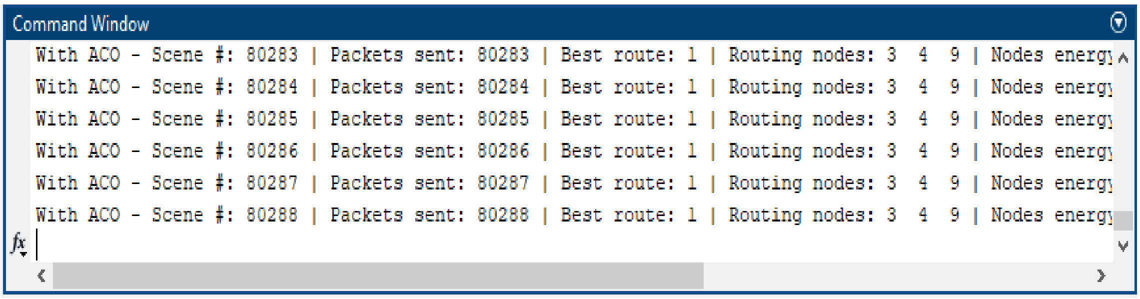

Fig 8. The SDN System With ACO Algorithm

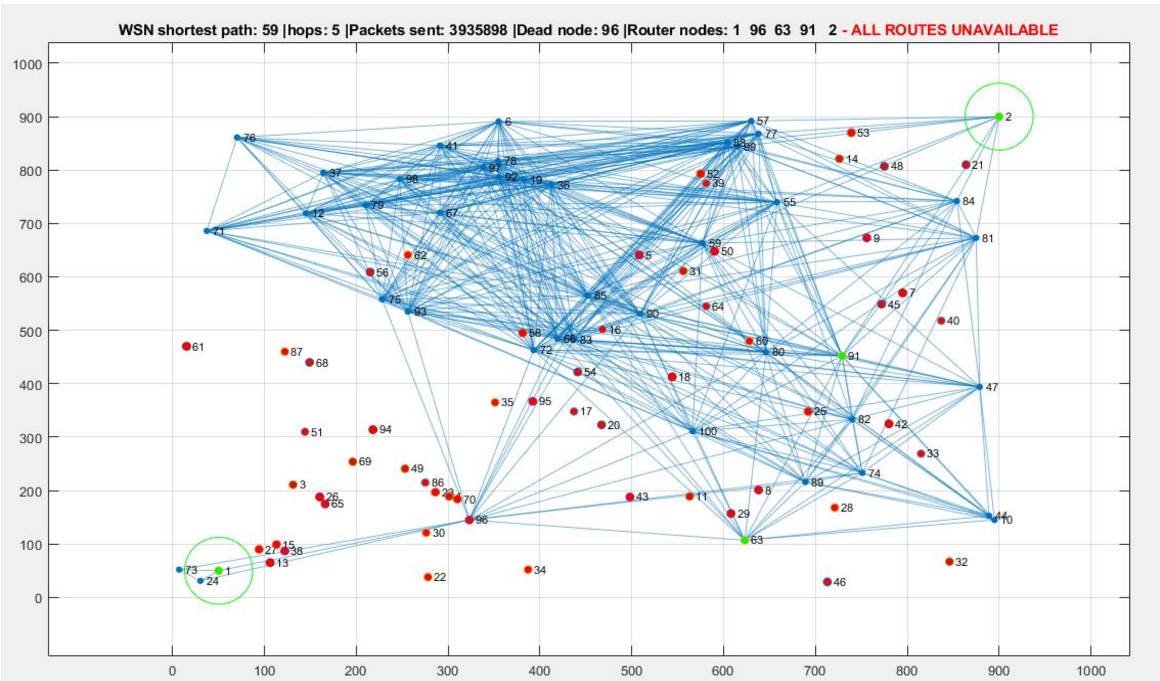

Fig 9. **Topology of WSN After Last Iteration**

As evidenced by the above figure, the system selected the optimal path in the WSN and eliminated every dead node during the previous iteration.

Let us investigate how the proposed approach for combining ACO and SDN approaches compares to the traditional approach in terms of energy consumption, dead nodes, and hub count.

Table 1. Comparison Between the Traditional Method and The Proposed Method

Metrics / Method	Number of nodes	Consumption Energy	Dead nodes	Number of hubs
Traditional Method	100	1.639 mJ	74	15
Proposed Method	100	0.891 mJ	35	23

In the table above, we can see the benefits of wireless sensor networks by comparing them to networks that use traditional methods. In our proposed system, energy consumption was 0.891 mJ. Whereas with traditional methods, energy consumption reached 1.639 mJ. In our proposed system the number of dead nodes was only 35, however, in with traditional methods, the dead number of dead nodes reached 74.

8. Conclusion

This study presents a feasible approach to improve energy consumption in wireless sensor networks (WSNs) by combining ant colony optimization (ACO) algorithm and software-defined networking (SDN) technology. The study also investigated the limitations of energy efficiency in WSNs by effectively integrating ACO and SDN, and discussed how these obstacles can be overcome.

Since sensor nodes have limited energy consumption, energy consumption is an important feature of wireless sensor networks. Traditional energy management is often not energy-efficient. Resource efficiency and routing can be achieved by incorporating the ACO algorithm into the SDN system, thus improving the energy consumption.

Ants use a pheromone pathway to detect shortcuts to food sources, a behavior that served as a model for the ACO algorithm. An ACO algorithm can be applied in a WSN to identify low-cost data transmission paths. Sensor nodes can communicate and share data on energy levels, connection characteristics and network status through the concept of pheromone channels. The ACO algorithm using this data then finds the best paths with the least energy consumption.

When combined with SDN, the ACO algorithm becomes more robust. SDN provides a global view of the network and a centralized control plane, enabling intelligent decision-making and scalable capacity. SDN makes it possible to efficiently integrate ACO algorithms into network architectures, allowing real-time control and management of energy-related resources.

Since they are static, traditional routing methods in WSNs, including LEACH (Low Energy Adaptive Clustering Hierarchy), tend to have energy-inefficient ACO algorithms in their SDN frameworks for routing stability energy levels on individual nodes. For this reason, network performance increases, energy consumption decreases, and routing is optimized.

Resource allocation and load balancing in WSNs is also possible by integrating ACO and SDN. Depending on the amount of energy and the number of operations in each sensor node, SDN controllers can allocate dynamic resources using the data collected by the ACO algorithm. Evenly distributing energy-intensive tasks throughout the network helps avoid rapid energy exhaustion in some neurons. The ACO-SDN approach reduces overall energy consumption and increases network lifetime through resource efficiency.

In addition, the ACO-SDN architecture makes it easier to manage the network, improving energy consumption. Network administrators can access real-time statistics on energy consumption, network traffic, and node health through SDN's centralized control and global perspective. Using this data, energy inefficiencies can be obtained, node failures can be predicted, and proactive steps can be taken to improve energy consumption Furthermore, energy-related products such as routing metrics and transmission power, ACOs will have large capacities. The SDN framework facilitates the creation of an efficient network environment.

Using SDN's centralized control and global perspective, coupled with ACO's dynamic routing capabilities, the ACO-SDN architecture provides efficient network management, resource allocation, and routing optimization, thus allowing for more energy efficiency, a longer network lifetime, better network performance, and higher levels of security. Subsequent research will focus on extending and refining the ACO-SDN approach in practical WSN applications, considering variables such as network configuration, traffic, and processing power requirements to maximize the benefits of WSN ACO-SDN infrastructure. This will allow advancements in ACO and SDN technology to continue.

It is possible that the proposed system can be used in the future and developed by integrating more than one artificial intelligence technique and predicting safer paths and shorter distances, which saves node energy.

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CONFLICTS OF INTEREST

None

REFERENCES

[1] D. Pal and S. K. Bhagat, "Design of an Efficient Fuzzy based Cluster Routing Protocol in Wireless Sensor Networks," 2019 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT), Coimbatore, India, 2019, pp. 1-4, doi: 10.1109/ICECCT.2019.8869199.

[2] A. Yaqoob, M. A. Ashraf, F. Ferooz, A. H. Butt, and Y. D. Khan, "WSN Operating Systems for Internet of Things (IoT): A Survey," 2019 International Conference on Innovative Computing (ICIC), 2019: IEEE, pp. 1-7, 2019.

[3] S. S. Anjum et al., "Energy Management in RFID-Sensor Networks: Taxonomy and Challenges," in IEEE Internet of Things Journal, vol. 6, no. 1, pp. 250-266, Feb. 2019, doi: 10.1109/JIOT.2017.2728000

[4] L. Chan, K. G. Chavez, H. Rudolph, and A. Hourani, "Hierarchical routing protocols for wireless sensor network: A compressive survey," Wireless Networks, vol. 26, no. 5, pp. 3291-3314, Jul 2020, doi:10.1007/s11276-020-02260-z

[5] Al-Rubaye , R. H. K., & TÜRKBEN , A. K. (2024). Using Artificial Intelligence to Evaluating Detection of Cybersecurity Threats in Ad Hoc Networks. Babylonian Journal of Networking, 2024, 45–56. https://doi.org/10.58496/BJN/2024/006

[6] Khan, F. Belqasmi, R. Glitho, N. Crespi, M. Morrow, and P. Polakos, "Wireless sensor network virtualization: A survey," IEEE Communications Surveys & Tutorials, vol. 18, no. 1, pp. 553-576, 2015.

[7] A. Strumberger, M. Minovic, M. Tuba, and N. Bacanin, "Performance of elephant herding optimization and tree growth algorithm adapted for node localization in wireless sensor networks," Sensors, vol. 19, no. 11, p. 2515, 2019.

[8] R. V. Kulkarni, A. Förster, and G. K. Venayagamoorthy, "Computational intelligence in wireless sensor networks: A survey," IEEE Communications Surveys & Tutorials, vol. 13, no. 1, pp. 68-96, 2010.

[9] I. F. Akyildiz, et al., "Wireless sensor networks: A survey," Computer Networks 38, pp. 393-422, 2002.

[10] Kazem Sohraby, Daniel Minoli and Taieb Znati, Wireless Sensor Networks, ELSEVIER Inc., 2007.

[11] N. A. Pantazis, S. A. Nikolidakis, and D. D. Vergados, "Energy-efficient routing protocols in wireless sensor networks: A survey," IEEE Communications Surveys & Tutorials, vol. 15, no. 2, pp. 551-591, 2013.

[12] A. Z. Bholebawa and U. D. Dalal, "Performance analysis of sdn/openflow controllers: Pox versus floodlight," Wireless Personal Communications, vol. 98, no. 2, pp. 1679–1699, 2018.

[13] D. Zeng, T. Miyazaki, S. Guo, T. Tsukahara, J. Kitamichi, and T. Hayashi, "Evolution of Software-Defined Sensor Networks," 2013 IEEE 9th International Conference on Mobile Ad-hoc and Sensor Networks, pp. 410–413, 2013.

[14] N. Foster, A. Guha, M. Reitblatt, A. Story, M. J. Freedman, N. P. Katta, C. Monsanto, J. Reich, J. Rexford, C. Schlesinger, D. Walker, and R. Harrison, "Languages for software-defined networks," IEEE Communications Magazine, vol. 51, no. 2, pp. 128–134, 2013.

[15] C. Cao, L. Luo, Y. Gao, W. Dong, and C. Chen, "TinySDM: Software Defined Measurement in Wireless Sensor Networks," 2016 15th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN), pp. 1–12, 2016.

[16] Tang, F.; Fadlullah, Z.M.; Mao, B.; Kato, N. An Intelligent Traffic Load Prediction-Based Adaptive Channel Assignment Algorithm in SDN-IoT: A Deep Learning Approach. IEEE Internet Things Journal., pp. 5141–5154, 2018.

[17] Thupae, R.; Isong, B.; Gasela, N.; Abu-Mahfouz, A.M. Machine Learning Techniques for Traffic Identification and Classifiacation in SDWSN: A Survey. Proceedings of the IECON 2018—44th Annual Conference of the IEEE Industrial Electronics Society, Washington, DC, USA, 21–23, pp. 4645–4650, 2018.

[18] Segura, G.A.N.; Chorti, A.; Margi, C.B. Multimetric Online Intrusion Detection in Software-Defined Wireless Sensor Networks. Proceedings of the 2020 IEEE Latin-American Conference on Communications (LATINCOM), Santo Domingo, Dominican Republic, pp. 1–6, 2020.

[19] Gustavo, N.S.; Skaperas, S.; Chorti, A.; Mamatas, L.; Cintia, B.M. Denial of Service Attacks Detection in Software-Defined Wireless Sensor Networks. Proceedings of the IEEE International Conference on Communications Workshops (ICC Workshops), Dublin, Ireland, pp. 1–7, 2020.

[20] M. Abed Salman and M. A. Mahdi, "Multi-Strategy Fusion for Enhancing Localization in Wireless Sensor Networks (WSNs)", Iraqi Journal for Computer Science and Mathematics, vol. 5, no. 1, pp. 299–326, Feb. 2024.

[21] H. D, M. P, M. K. N, V. S, and S. P, "An Intelligent Prairie Dog Optimization (IPDO) and Deep Auto-Neural Network (DANN) based IDS for WSN Security", Iraqi Journal for Computer Science and Mathematics, vol. 4, no. 4, pp. 30–42, Oct. 2023.

[22] H. I. Kobo, A. M. Mahfouz, and G. P. Hancke, "A survey on software-defined wireless sensor networks: Challenges and design requirements," IEEE Access, vol 99, pp. 1–1, 2017.

[23] J. Aponte-Luis, J. A. Gómez-Galán, F. Gómez-Bravo, M. Sánchez-Raya, J. AlcinaEspigado, and P. M. Teixido-Rovira, "An efficient wireless sensor network for industrial monitoring and control," Sensors, vol. 18, no. 1, p. 182, 2018.

[24] 1.G Yin, G Yang, W Yang, B Zhang, W Jin. An energy-efficient routing algorithm for wireless. International Conference on Internet Computing in Science and Engineering (ICICSE'08), IEEE, China; 2008.

[25] Orey, N.S., Mehere, P.N. and Hedaoo, K., Agriculture Drone for Fertilizers and Pesticides Spraying. International Journal for Engineering Applications and Technology, Vol. 9, Issue 5, 2017.

[26] Yonglong Tian, Chen Sun, Ben Poole, Dilip Krishnan, Cordelia Schmid, and Phillip Isola. What makes for good views for contrastive learning? In Proc. Adv. in Neural Information Processing Systems (NeurIPS), 2020.

[27] Fan-Yun Sun, Jordan Hoffmann, Vikas Verma, and Jian Tang. Infograph: Unsupervised and semi-supervised graph-level representation learning via mutual information maximization. In Proc. Int. Conf. on Learning Representations (ICLR), 2020.