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A Novel Approach for Enhancing Routing in Wireless Sensor Networks using ACO Algorithm

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INTRODUCTION

The rapid development of miniaturization has driven the exponential growth of wireless sensor networks (WSNs). The network is formed by a large volume of sensor nodes deposited in a target field, a base station called the sink node, and the network operator. Each node is basically composed of four units: the sensing unit, the computing unit, the communication unit, and the power unit figure (1). This architecture allows the node to collect, process, and wirelessly transmit data in the area of human interest [1] [2].

Nowadays, the advancements in WSN enable a wide range of applications like military and defense sector, health care, event detection and monitoring [3] [4] [5]. Most of these applications require hundreds or thousands of tiny and low-cost sensors that collect and wirelessly transmit data to the base station. However, one major challenge that persists is the energy constraints faced by sensor nodes, impacting the overall operation time of WSNs [6] [7]. Most of the sensor nodes' energy is consumed in complex routing mechanisms. As referred to in [8] [9], more than 50% of the sensor energy is consumed during the transmission of the sensed data to the base station, and much more with the multi-path routing data. To address this issue, researchers have proposed many energy-efficient routing protocols or enhancements to existing ones.

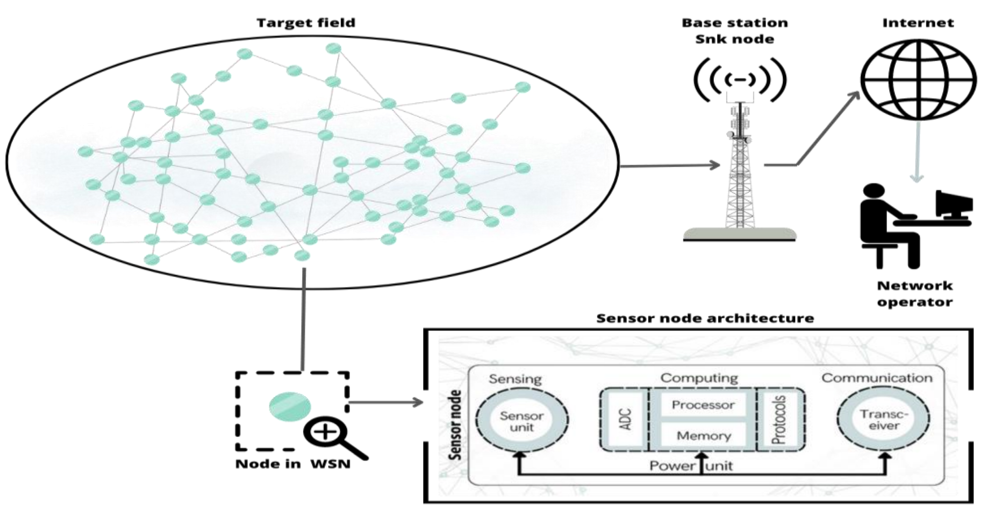

Figure 1 Wireless sensor network (WSN)

In literature, most routing protocols focus on the manner to minimize the number of communication hops and optimize paths between nodes and the base station. To achieve this, a lot of work proposed optimized-based routing protocols that provide optimal solutions and reduce the energy consumption in communication. Routing in large-scale applications of WSN is considered an NP-hard problem, it requires advanced metaheuristic methods like Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Fuzzy Logic (FL), and Ant Colony Optimization (ACO). One of the most popular adopted approaches is ant colony optimization (ACO) [10], which is the focus of our work. The main contributions of this paper are outlined as follows:

1. We conduct a comprehensive study of existing routing protocols based on the Ant Colony Optimization (ACO) algorithm and demonstrated their impact on energy consumption in wireless sensor networks;
2. We integrate an enhanced ACO algorithm into a novel routing protocol aiming to achieve better routing performances in WSNs. Our protocol could be implemented to overcome the challenges faced by traditional routing algorithms in terms of energy efficiency, network scalability, and adaptability to dynamic network conditions.

The remainder of this paper is organized as follows: Section 2 surveys different ACO-based routing protocols presented in the literature. Section 3 presents the overall operation of the proposed ACO-based routing protocol. To evaluate the performance of our approach, we have conducted in section 3 a theorical performance analysis, considering key metrics such as packet loss, communication and packet delivery times in dense WSNs, communication overhead, and energy consumption. Finally, section 4 provides future directions of search and perspectives in the field of enhancing routing in wireless sensor networks.

I. RELATED WORK

Routing in WSN is of utmost importance topics addressed by a significant number of studies. In literature, researchers have proposed different nature-inspired algorithms to solve routing problems in WSNs. A recent database gathering the leading bio-inspired algorithms for WSNs is discussed in [11] [12]. Ant Colony Optimization (ACO) is a widely used method in WSNs problem domains. M. Dorigo, V. Maniezzo, and A. Colorni have firstly proposed this approach to optimize the difficult combinatorial problems [13]. They have evaluated the potential of the ACO for traveling salesman problem (TSP) and the quadratic assignment problem (QAP). Further, they introduced the Ant-Colony-Optimization (ACO) as meta-heuristic algorithm inspired by the foraging behavior of ants in nature. While searching for food, the ant emits pheromone in the path. Then, the other ants select the optimal path with a high intensity of pheromones [14]. This process is proven as a prominent solution for routing schemes that enhance the network lifetime in WSNs [15].

The authors in [16] proposed an ant-based routing protocol for WSNs named as (EEABR). The efficiency of EEABR was validated based on minimizing the communication load and extending the network lifetime compared to both protocols BABR and IABR. In [17] the authors proposed a method to enhance routing in WSN based on ant colony optimization. Simulation results revealed that the proposed approach yields better performance in terms of decreasing the node power consumption and increasing the network lifetime compared with the two popular sensor network routing protocols SPEED and EAR. Authors in [18] proposed an improved version of the traditional ACO algorithm to reduce power consumption of the routing process. They present a comparison between their proposed approach and the both algorithms Ad-hoc On-demand Distance Vector (AODV) and Directed Diffusion (DD). The comparison tests are basis of the retransmission counts to the destination node, and the power consumption of neighbors of destination nodes. The result shown that the proposed ant colony algorithm has efficiently improved the network lifetime. The authors in [19] have proposed an efficient ACO-based routing approach for sensor deployment. They reported that the proposed algorithm outperforms and prolongs the network lifetime compared to both AODV and LEACH protocols. In [20] authors proposed the protocol LTAWSN as a lifetime-aware routing algorithm for wireless sensor networks. The effectiveness of the proposed algorithm was evaluated based on reducing the consumption of energy compared to the three routing algorithms, EAACA (energy-aware ant colony routing algorithms for the routing of wireless sensor networks), ACLR (ant colony optimization-based location-aware routing algorithm for wireless sensor networks), and ACA (traditional ant colony routing algorithm). Simulation results showed that the proposed LTAWSN achieved better performances than the three existing protocols.

Routing protocols	Authors	References	Year	Summery
ETPS-MAC: Energy Traffic Priority Scheduling-based QoS-aware MAC Protocol for Hierarchical WSNs	Kaur et al.	[21]	2019	Scheduling algorithm to prolongate the network lifetime and maintain the quality-of-service (QoS) in hierarchical WSNs
HEEMP: Hybrid energy-efficient multi-path routing for wireless sensor networks	M. Sajwan et al.	[22]	2018	Hierarchical routing for maximizing energy efficiency
FRP: A novel fast rerouting protocol with multi-link-failure recovery for mission-critical WSN	Riaz et al.	[7]	2018	Establish primary and backup routes before transmitting data for fast routing and handle failures in WSNs. It provides minimum end-to-end delay and low energy consumption.
WECRR: Weighted Energy-Efficient Clustering with Robust Routing for Wireless Sensor Networks	K. Haseeb et al.	[6]	2017	Maintaining balanced energy consumption and improving the clustering for robust routing
OQoS CMRP: An optimized QoS-based clustering with multipath routing protocol for Wireless Sensor Networks	Deepa et al.	[23]	2020	Applying the Modified Particle Swarm Optimization (PSO)-based clustering algorithm to reduce the energy consumption in the sink coverage.
CL-LEACH: An energy efficient routing protocol for correlated data using	Marappan and Rodrigues	[24]	2016	Cross Layer-Low Energy Adaptive Clustering Hierarchy model (CL-LEACH), to increase the lifetime of the battery and provide an energy efficient transmission schemes for WSN
PDORP: Energy Efficient Direction Based PDORP Routing Protocol For WSN	Brar et al.	[25]	2016	Identify energy-efficient optimal paths by applying hybridization of Genetic Algorithm (GA) and Bacterial Foraging Optimization (BFO)
(CBCCP): Chain Based Cluster Cooperative Protocol	Rani et al.	[26]	2015	An improved hierarchical clustering to reduce the transmission time and energy consumption of WSNs

Table 1 Summary of some existing routing protocols for WSN.

II. THE PROPOSED ROUTING PROTOCOL

In this study, we introduce a model that utilizes an improved ACO algorithm, complemented by multi-agent systems. The system employs both proactive and reactive approaches to create routes between nodes, ensuring multiple paths to the sink node. Its operation revolves around three key components: route discovery, data routing algorithm, and link failure management, as shown in the provided figure.

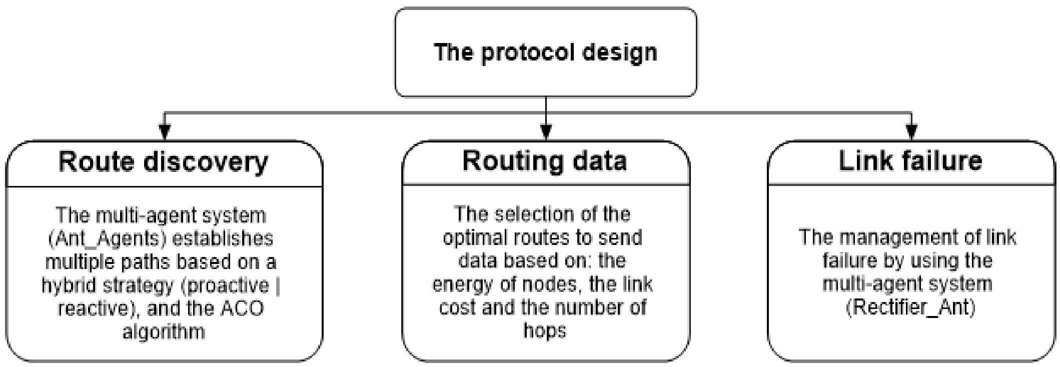

Figure 2 The components of the proposed protocol

a. The route discovery phase

In this phase, a multi-agent system is built in the network. Each sensor is called the origin node, periodically creates an ant-agent that moves between nodes. The ant-agent has a TTL value that limits its time to live in the network. This value depends on the size of the network and decreases after each hop communication between nodes. The ant-agent has also a unique identifier <node_ID, Ant_ID> where: node_ID is the identifier of the Origin-Node and Ant_ID is the agent identifier. This last is incremented at every creation of a new agent in order to avoid routing loops.

The proposed system adopts a hybrid approach to save routes in the route discovery phase. The ant agents explore the network and swishes between proactive and reactive modes to establish routes.

By default, the ant-agent adopts the proactive mode. For each hop, it creates a new path called the Go route between the current node and its Origin-Node. Before moving to the next node, the agent saves the path newly created in the current routing table. Also, it shares with that sensor information about:

- Type of information detected by the Origin-Node (temperature, humidity, etc.)
- The current value of the detected information.
- The lifetime of the current value

The ant-agent explores the network until the expiration of its TTL value. In this case, it returns to its origin node using the reverse path of the Go route previously established. At this level, the ant-agent establishes the back route between the last visited node and the current node until reaching the origin node. The back route is also saved or updated in the routing tables of the intermediate nodes. When this process ends it disappears from the network.

In the reactive mode the system has to establish new routes to the sink node which are not previously used in the network. This means that the requested route was not saved in the routing table of the demander during the proactive mode. The demander node creates a new route request and locally saved it. This request will be spread by the multi agent system unlike protocols that use the broadcast technics. When the ant-agent finds a route request during exploration, it returns to its origin node. Similar to the proactive mode, the agent establishes back routes between the last visited node which is the demander, and nodes of the reverse path. In addition, it deposits a pheromone quantity on each traversed node to attract the ant-agents to the requestor destination. The life cycle of this agent ends when it arrives to the origin-node. Different ant agents practice this routine. Consequently, many routing tables will be updated with a path leading to the demander node, and the pheromone informs the other Ant-Agents by the existence of this route request.

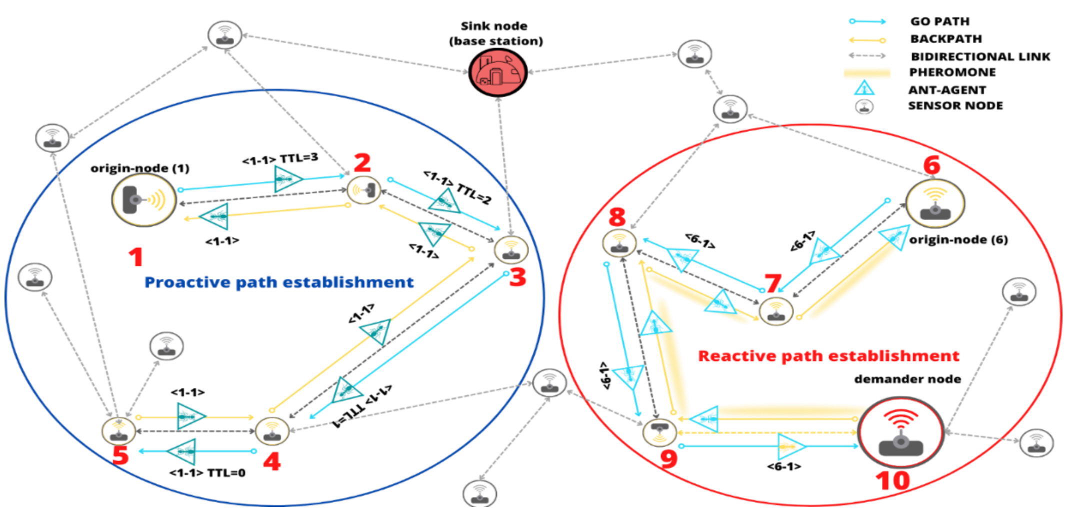

Figure 3 The hybrid mechanism to discover routes in the network

Figure 3 illustrates the hybrid approach described above for establishing routes in the network. Based on the shown scenario, tables 2 and 3 summarize the proactive and reactive modes used by ant agents to establish different routes

Node n° 1| Origin-node (1) | Ant-Agent id=<1-1>				
TTL value	current node	next node	established route	Mode
4	1	2	--	proactive
3	2	3	(2-1)	proactive
2	3	4	(3-2-1)	proactive
1	4	5	(4-3-2-1)	proactive
0	5	4	(5-4-3-2-1)	proactive
0	4	3	(4-5)	proactive
0	3	2	(3-4-5)	proactive
0	2	1	(2-3-4-5)	proactive
0	1	auto-destruction	(1-2-3-4-5)	--

Table 2 The proactive mode used by the multiagent system to discover routes in the network

Node n° 6| Origin-node (6) | Ant-Agent id=<6-1>				
current node	next node	established route	Mode	pheromone
6	7	--	proactive	no
7	8	(7-6)	proactive	no
8	9	(8-7-6)	proactive	no
9	10	(9-8-7-6)	proactive	no
10	9	(10-9-8-7-6)	proactive	no
9	8	(9-10)	reactive	yes
8	7	(8-9-10)	reactive	yes
7	6	(7-8-9-10)	reactive	yes
6		(6-7-8-9-10)	reactive	yes

Table 3 The reactive mode used by the multiagent system to discover routes in the network

The proposed system enhances the ACO algorithm to handle the energy constraint problem in WSN. In the reactive mode, the ant-agents update pheromone based on two parameters: the energy of nodes and the cost link between two nodes. The pheromone level at each node is calculated using the following Equation:

$$\Omega_{it}=\Omega_{i(t-1)}+\Delta Ph \qquad (1)$$

Where Ω_{it} is the pheromone quantity in node i at time t, ΔPh is the pheromone value added by the Ant-agent in the current node. we consider that nodes exchange hello messages to update their neighborhood list. By mean of these exchanges, nodes frequently obtain information about the neighborhood such as nodes IDs and their energy level. This last is used to calculate the pheromone value ***ΔPh*** as shown in the following equation.

$$\begin{cases} \boldsymbol{\Delta Ph = LC(i, j, d) * Ej + c,} \\ \boldsymbol{L\,C(i, j\,, d) = 1/(1 + u)} \end{cases} \quad \textbf{(2)}$$

Where *LC*(*i*, *j*, *d*) denotes the link cost between node *i* and the neighbor node *j* to reach the demander destination *d*. It is inversely proportional to the number of times (*u*) the link was used; (u) is incremented at every use of this path for routing packets. Using a link consumes the node's energy, therefore; this formula favors the exploitation of less-used routes that possess nodes with higher energy. *Ej* is the energy of node *j*. *c* is a floating parameter in the range [0; 1] which is used to control the importance of metrics.

Different agents update multiple paths to the demander destination using a pheromone, which attracts explorer agents to this same destination. The attracted agents select the next hop to reach the demander using the probability function (P). The concept is based on a stochastic manner and proportional to the pheromone values, as shown in the following equation.

$$\boldsymbol{P(k, i, d) = \frac{\Omega_{it}}{\sum_{x \in N(k)} \Omega_{xt}}} \qquad \textbf{(3)}$$

Where $P(k, i, d)$ is the probability to move from node k to node i towards the destination d. Ω_{it} is the pheromone value saved in node i at the time t. N(k) is the neighbor list of node k and, Ω_{xt} is the pheromone value in the neighbor x at time t. figure (3) illustrates the process of selecting the next node toward the destination.

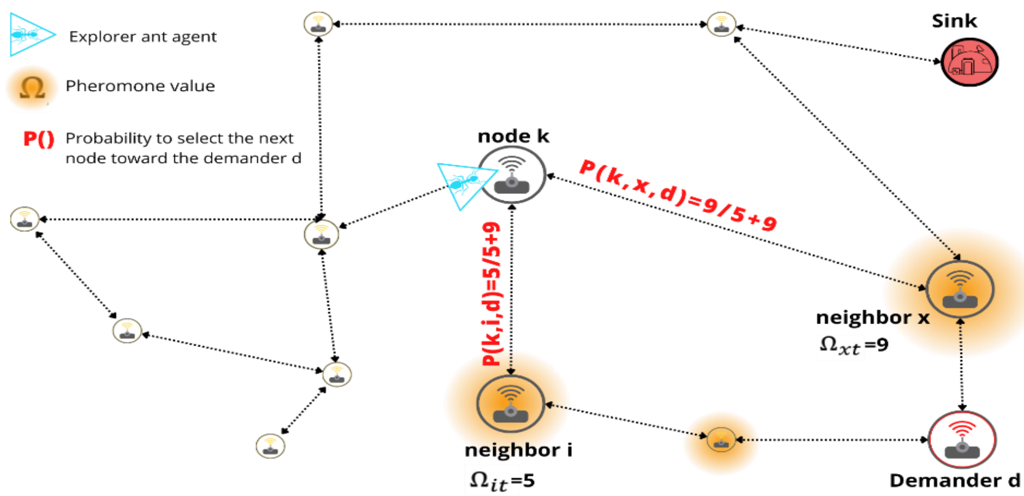

Figure 4 The process of selecting the next hope to the demander node

When an explorer Ant-Agents finds the requested path at the routing table of node k, it becomes reactive to transport the route to the demander (d) before returning to its Origin-Node. The movement of this agent depends on the higher probability value previously calculated in eq. (3). As demonstrated above in Eq. (1) and Eq. (2), the probability value is always higher with neighbors, which have a high energy level, and low link cost toward the destination. As a result, the proposed algorithm extends the network lifetime because ant agents are forwarded depending on the energy of nodes. In addition, it controls the network congestion through load balancing because link cost value guides the Ant-Agents to choose new paths to follow to reach the demander node.

The proposed system mimics the natural pheromone evaporation process. It helps to erase the satisfied route requests from routing tables. After a predefined time, the pheromone quantity of each route request stored in the pheromone table is reduced as shown in the following equation:

$$\boldsymbol{\Omega_{it} = (1-\beta) * \Omega_{i(t-1)}} \qquad \textbf{(4)}$$

β is a floating parameter in the range [0; 1].

For more clarity and evidence of the route discovery phase adopted by the multi-agent system, the flowing flowchart in figure 4 describes the different steps proposed in this work.

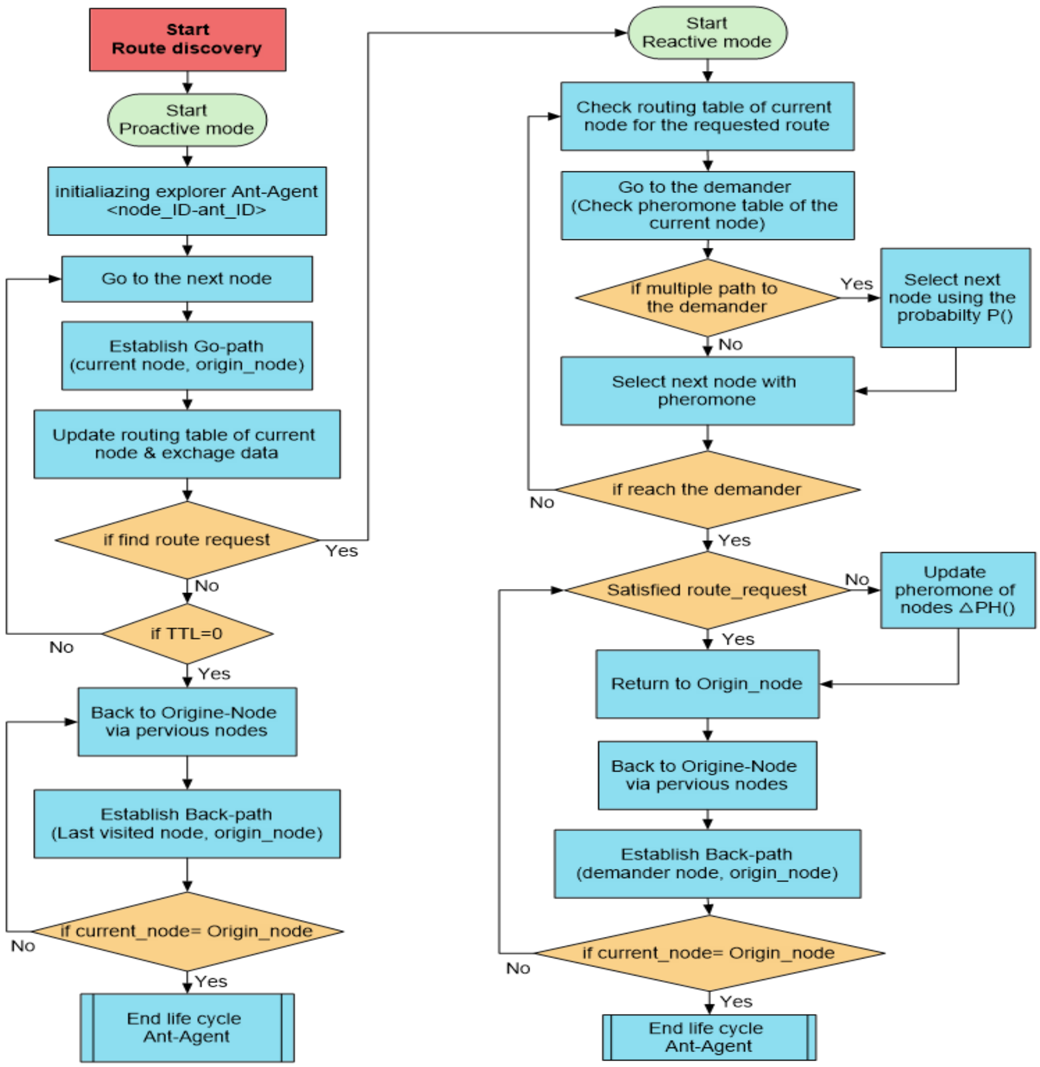

Figure 5 Flow chart of the route discovery with hybrid strategy

As detailed above, different scenarios are possible to discover routes in the network. Consequently, our system provides multi-paths to send information from sensor nodes to the sink node. To cover all desired communication cases in Wireless Sensor Networks, we integrate the situation when the Sink node tries to retrieve any information $\boldsymbol{INFi}$ from the network. The proposed model includes two methods to satisfy this request:

- $\boldsymbol{INFi}$ is updated by the explorer ant agents that share information sensed by their origin node.
- $\boldsymbol{INFi}$ is obtained by a local route request

In the first case, when an explorer ant agent arrives to the sink node, it updates the information table of this node by the recent value of $\boldsymbol{INFi}$ (see proactive mode). The second case is used when $\boldsymbol{INFi}$ is expired or does not exist in the information table of the sink node. Here, the procedure is appropriate to the reactive mode previously detailed to discover routes. The sink node initiates a local request called "information request" which will be satisfied by the multi agent system. Similar to the reactive mode, the ant agents spread this request using pheromone and probabilities in equation (2 and 3). The following figure illustrates two scenarios to satisfy the information request of the sink node.

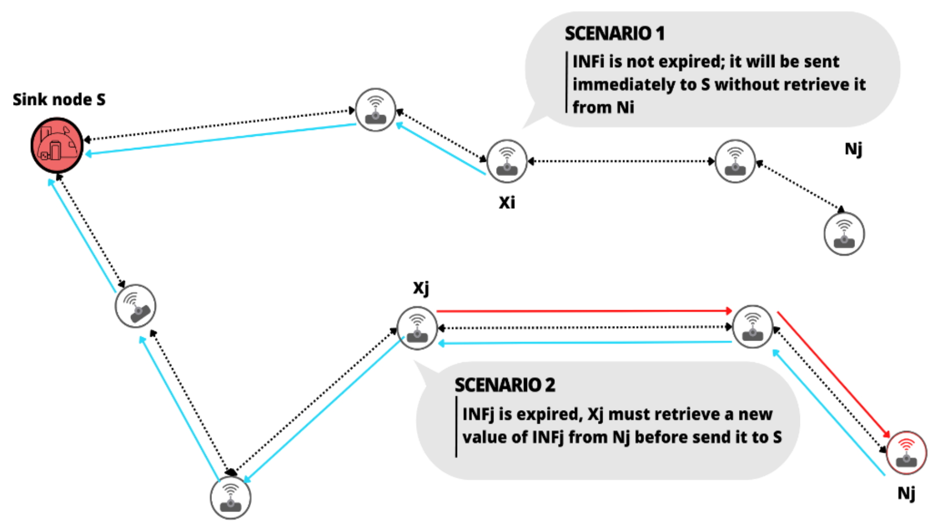

Figure 6 The sink node attempts to retrieve information from the network

b. The data routing algorithm

The route discovery phase proposes multiple paths to send packets between two nodes. Therefore, we integrate the data routing algorithm to select from the discovered routes the optimal ones. This phase optimizes the routing process based on three criteria: minimum distance between the source and the destination, the maximum energy of the intermediate nodes, and low link cost. To select optimal routes, we introduce a new metric called « Importance of route » (Imp (n, n_j, dst) which is validated using the following equation:

$$\mathbf{Imp}\ (\boldsymbol{n}, \boldsymbol{n_j}, \boldsymbol{dst}) = (\mathbf{1} - \boldsymbol{\alpha}) * \frac{\mathbf{1}}{\mathbf{1} + \boldsymbol{HP}} + \boldsymbol{\alpha} * \boldsymbol{Cost}\ (\boldsymbol{n}, \boldsymbol{n_j}, \mathbf{dst})$$

Where *HP* denotes the number of nodes between the source node *n* and the destination node *dst*. n_j denotes the adjacent node of n. α is a floating parameter that controls the importance of metrics "HP" or "Cost" depending on the routing policy of the wireless network.
The parameter "Cost" depends on the link cost LC (n, nj, dst) (previously calculated) and the energy E_j of n_j. It is calculated as follows:

$$\mathbf{Cost}(\boldsymbol{n}, \boldsymbol{n_j}, \boldsymbol{dst}) = \frac{\mathbf{LC}\left(\boldsymbol{n}, \boldsymbol{n_j}, \boldsymbol{dst}\right) * \boldsymbol{E_j}}{\sum_{k=0}^{k=x} \mathbf{LC}\left(\boldsymbol{n}, \boldsymbol{n_k}, \boldsymbol{dst}\right) * \boldsymbol{E_k}}$$

To build a route between a source and the destination, a node chooses the next node n_j among the adjacent nodes based on the probability P (n, n_j, dst). The value of P depends only on the metric importance of route previously calculated; it is determined mathematically by the following equation:

$$\boldsymbol{P}\left(\boldsymbol{n}, \boldsymbol{n_j}, \boldsymbol{dst}\right) = \frac{\mathbf{Imp}\left(\boldsymbol{n}, \boldsymbol{n_j}, \boldsymbol{dst}\right)}{\sum_{k=0}^{k=x} \mathbf{Imp}\left(\boldsymbol{n}, \boldsymbol{n_j}, \boldsymbol{dst}\right)}$$

c. Link failures

The WSN networks encounter the link failure problem due to frequent changes in the network topology. The proposed model provides a solution to this problem that maintain the robustness of the routing under any circumstances.

A link failure is announced when a node has not received hello messages in time or when the issued data requests or Ant agents have not reached their destination. These situations take place when some adjacent nodes leave the network due to energy constraints. Our system maintains good performance of the routing process in such an unstable environment. It uses a new kind of agent called Rectifier-Ant to update routing tables with information about the topology modifications. To ensure a fast response to the link failure problem, the number of Rectifier-Ants corresponds to the number of unreachable nodes in the network. For example, when a node n detects that the nodes d and f are unreachable destinations, it generates two Rectifier-Ant agents one to update the routing information corresponding to the node d and the other one for updating the routing information corresponding to the node$f$. If the node n has k neighbor nodes concerned by the unreachable destination d and f (ie. k neighbor nodes that have these two paths in their routing tables). The node n must create ($k*$ 2) Rectifier-Ant agents and then forwards them to the k neighbors to update their routing tables according to the new network topology.

III. PERFORMANCE ANALYSIS

Through performance analysis, key aspects of the proposed protocol's functionality and efficiency are illuminated, shedding light on its expected performance in various scenarios.

a. The effect of ACO on multi-path routing protocols in WSNs

In literature, the metaheuristic ACO is one of the most effective techniques to optimize routing in WSNs, leading to a reduction in energy consumption and longer network lifetime as shown in the following table.

Routing Protocols	**Energy Consumption without ACO (E)**	**Energy Consumption with ACO (EACO)**	**Energy Consumption Reduction (ER)%**
LEACH	566.81	433.94	23.44%
PEGASIS	2255.88	1914.04	15.13%
TEEN	1833.84	1523.94	16.91%

Table 4 The impact of the ACO algorithm on energy consumption in WSNs

where all energy consumption values are calculated in Joules with and without the use of the ACO algorithm. The reduction in energy consumption is calculated by using the following formula:

$$(\boldsymbol{E_R}) = \frac{\boldsymbol{E - E_{ACO}}}{\boldsymbol{E}} \times \boldsymbol{100}$$

The energy consumption of each protocol varies depending on the network configuration. The results presented in Table 1 were obtained for a low network density (100 nodes) with a deployment area of 200m x 200m. the network topology is cluster-based for both protocols LEACH and PEGASIS, and Flat-based for the protocol TEEN.

Based on the outcomes from Table (2) and a comprehensive review of related literature, the Ant Colony Optimization (ACO) metaheuristic has emerged as the most suitable choice. The ACO approach demonstrates promising potential in enhancing multipath routing protocols for Wireless Sensor Networks (WSNs). Integrating intelligent communication management, our proposed protocol overcomes the limitations of existing solutions, presenting an innovative and efficient approach for wireless sensor networks.

a. The communication overhead

Packets that consume significant bandwidth are those transmitted during the path discovery and maintenance phases. In protocols that use the broadcast technique, the number of control packets depends on various factors, particularly the number of route requests that consume substantial bandwidth due to multiple broadcasts. Additionally, a high number of collisions can be expected in broadcast-based protocols due to network density, resulting in increased retransmissions and a higher total packet count in the network.

The impact of broadcast-based protocols in wireless sensor networks is exemplified using a mathematical scenario as follows:

Suppose we have a wireless sensor network with N nodes, and we are using a broadcast-based protocol for route discovery. During the path discovery phase, each node initiates a route request and broadcasts it to all other nodes in the network. The number of route requests transmitted during the path discovery phase:

$$\boldsymbol{Num_{RReq}} = \mathbf{N} * (\mathbf{N} - \mathbf{1})$$

Where Num_{RReq} is the number of transmitted route request, N is the number of nodes that initiate route requests and (N-1) is the number of nodes that receive each request. Now, during the path maintenance phase, additional control messages are exchanged between nodes to update routing information and keep paths active. We assume that on average, each node sends M control messages during the path maintenance phase. The number of control messages exchanged during the path maintenance phase is:

$$\boldsymbol{Num_{CM}} = \mathbf{N} * \mathbf{M}$$

Where $Num_{CM}$is the number of control messages exchanged during the path maintenance phase, N is the number of nodes in the network and M is the control messages per node. Combining the path discovery and path maintenance phases, the total number of control messages in the network is:

$$\boldsymbol{Tot_{CM}} = \mathbf{N} * (\mathbf{N} - \mathbf{1}) + \mathbf{N} * \mathbf{M}$$

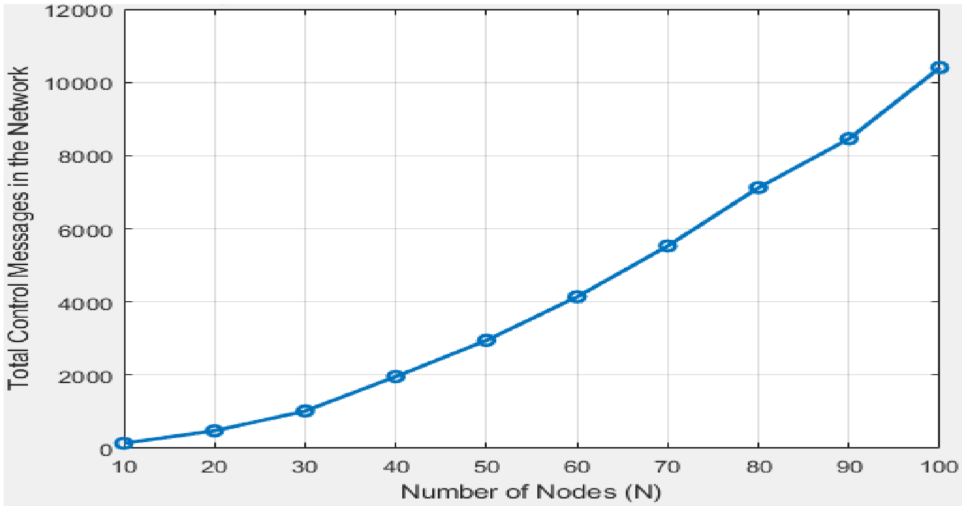

Figure 7 the variation of control messages for an increasing number of nodes using broadcast mechanism

This mathematical illustration shows how broadcast-based protocols can lead to a considerable number of control messages in the network, especially during route discovery. The high number of control messages can consume significant bandwidth and increase the overall packet count in the network, affecting its efficiency and performance.

In the design of our protocol, we aimed to gradually and linearly increase the number of control packets, whether by increasing the number of nodes or by raising network traffic. To achieve this, each node manages and controls the number of agents used for route discovery, and this number remains proportional to the total number of nodes in the network and the transmission frequency of agents. Moreover, we avoid the broadcast technique to mitigate excessive overhead. Instead, we employ a more accurate and intelligent approach inspired by ant behavior and tailored to the constraints and limitations of WSNs. This technique utilizes only the available agents in the network.

b. Energy consumption and network lifetime

The total energy consumption increases with the number of nodes in the wireless sensor network when using broadcast-based protocols. As the network size grows, the energy required for broadcasting to all nodes also increases, leading to higher energy consumption. It emphasizes the importance of energy-efficient strategies and optimizations in broadcast-based protocols for wireless sensor networks.

In the following, an illustration of energy consumption in wireless sensor networks for protocols that utilize broadcast-based techniques. The variables used in this illustration are:

- E: Total energy consumption for a broadcast-based protocol.
- E_{send}: Energy consumed when a node sends a broadcast message.
- E_{receive}: Energy consumed when a node receives a broadcast message.
- E_{amp}: Energy consumed for amplification in broadcast.

For the broadcast-based protocol, the total energy consumption is represented as:

$$\boldsymbol{E} = \mathbf{E}_{\boldsymbol{send}} + \mathbf{E}_{\mathbf{receive}} + \mathbf{E}_{\mathbf{amp}} * \mathbf{N} * (\mathbf{N} - \mathbf{1})$$

Where N represents the total number of nodes in the wireless sensor network. (N-1): Since a node broadcasting a message doesn't need to broadcast it back to itself, we subtract 1 from the total number of nodes (N) to avoid double-counting the energy consumption for broadcasting. Assuming the following values for energy consumption parameters:

- E_{send}= 1 Joule - E_{receive} = 0.5 Joules - E_{amp} = 0.2 Joules.

Using these values in the formula for E, we obtain the graph of the total energy consumption depending to the number of nodes in the wireless sensor network when using broadcast-based protocols.

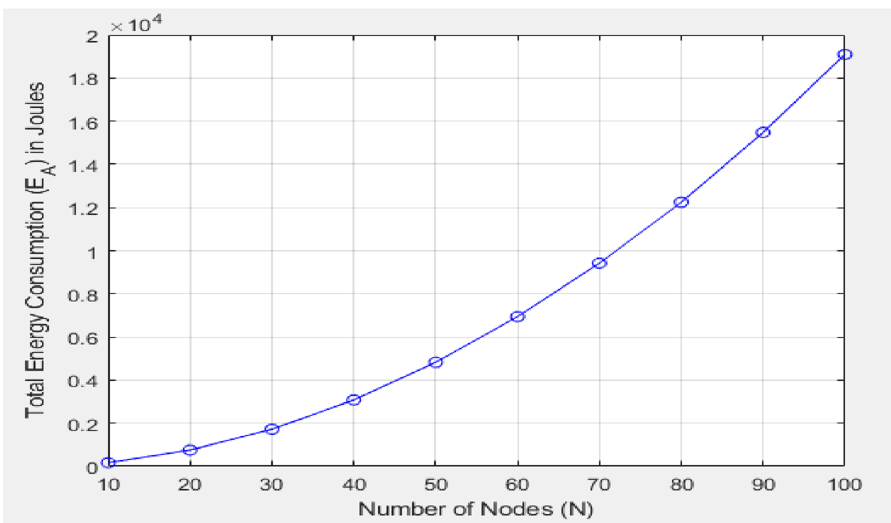

Figure 8 Variation of Energy Consumption with Number of Nodes using broadcast-based protocols

The proposed protocol stands out for its ability to preserve node energy and prolong the lifetime of the wireless sensor network (WSN). By avoiding energy-intensive broadcast mechanisms, our reactive route discovery approach significantly reduces the number of control packets and associated overhead. This enables nodes to consume less energy during routing operations, leading to a more efficient utilization of their limited energy resources.

Our protocol utilizes an Ant Colony Optimization (ACO) inspired approach for route discovery. Nodes evaluate potential paths based on criteria such as distance, link quality, and most importantly, the remaining energy of nodes along the path. Using probability formulas for optimal route selection based on node energy, our protocol favors paths that facilitate better energy management. It avoids heavily burdened nodes and prioritizes those with ample energy reserves. This intelligent approach promotes a more balanced energy utilization in the network, thereby extending the overall lifetime of the wireless sensor network.

By minimizing node energy consumption and optimizing network usage through the energy-based ACO approach, our protocol can significantly prolong the overall lifetime of the network, ensuring reliable and sustainable communication in various WSN deployment scenarios.

c. The packet loss

The packet loss metric serves as a valuable tool for evaluating and comparing the robustness and efficiency of routing protocols. Existing research has demonstrated that in networks with a large number of nodes and high traffic, the number of lost packets increases rapidly. This issue is particularly exacerbated in conventional WSN protocols that rely on broadcast mechanisms, leading to significant overhead and collisions, ultimately overloading the system and resulting in a substantial number of failed transmissions. However, our protocol takes a different approach by employing an efficient reactive route discovery procedure, which aims to mitigate the packet loss rate by avoiding the use of broadcast mechanisms. Through this proactive strategy, we seek to enhance the overall reliability and performance of data transmission in wireless sensor networks.

By efficiently handling link failures, our protocol ensures a more reliable and robust data transmission, which in turn reduces the overall packet loss in the network.

Our protocol optimizes data transmission by giving preference to nodes with higher energy levels during route construction. This selective approach minimizes connection issues and reduces data losses significantly. Moreover, our protocol empowers each node to dynamically redirect data via multiple paths, making use of criteria such as node power, and link cost. This dynamic path redirection enhances network resilience, delivering data efficiently and reliably while conserving energy.

d. Communication and packet delivery times in dense WSN

In a dense WSN characterized by a large number of nodes and data packets, broadcasting techniques exponentially increase the routing overhead and overload the network, consequently delaying the establishment of paths and the process of packet delivery. In the case of our protocol, each node actively manages and controls the number of Ant-Agents, maintaining a proportional relationship with the network size.

Also, the hybrid nature of route discovery significantly reduces transmission times. Thanks to the proactive phase, it will no longer be necessary to send a route request each time; the route may already exist in the routing table. Additionally, our protocol is multipath, enabling each node to have multiple paths towards the same destination whenever it wants to send a data packet.

Furthermore, our protocol, considers all desired communication scenarios which offers the advantage of enabling faster and more efficient communication. By integrating the capability for the Sink node to retrieve specific information from the network, the protocol optimizes data transmissions, avoiding potential delays associated with inefficient communication mechanisms.

By employing the link cost metric, our protocol achieves load balancing within the network, leading to fewer intermediate nodes with congested queues and improved end-to-end delays.

IV. FUTURE WORKS

In the future, our focus will be on several directions of search in the field of enhancing routing in wireless sensor networks. The main direction is to provide extensive simulations to demonstrate the effectiveness of the proposed approach and compare its performance against existing routing protocols. Another avenue of research concerns optimizing the proposed approach. First, we will attempt to enhance the performance of the modified version of ACO algorithm presented in this work. Then, we will expand our vision in this field by hybridizing the ACO algorithm with other optimization techniques like genetic algorithms or reinforcement learning. The main objectives here, is to provide efficient routing strategies, improved energy management, and better adaptability to wireless network conditions. Future studies can also explore security considerations. A robust security mechanisms ca be integrated into the proposed approach to ensure secure and reliable communications in WSNs.

V. CONCLUSION

In this work, we have proposed a routing protocol based on ACO and multi-agent systems to address various issues that impact routing in WSNs. The protocol uses a hybrid approach in the route discovery phase and avoids traditional broadcast techniques, which can significantly reduce network congestion and latency. Various scenarios of route discovery are proposed including when the sink node requests information from the network. By doing so, the proposed approach improves the QoS and reduces the packet loss rate. Including a route maintenance module based on rectifier agents further enhances the reliability of the proposed protocol. These features make our proposition a strong candidate for deployment in WSNs, particularly in applications where latency and reliability are critical factors. Future work can focus on further improving the protocol's performance and testing it in real-world scenarios.

REFERENCES

[1] Singh, A., Sharma, S., & Singh, J. "Nature-inspired algorithms for wireless sensor networks: A comprehensive survey," *Computer Science Review,* 2021, pp. 39-100342.

[2] Sohrabi K., Gao J., Ailawadhi V., Pottie G.J., "Protocols for self-organization of a wireless sensor network," *IEEE Pers Commun,* pp. 16-27, 2000.

[3] Sajwan, M., Gosain, D., & Sharma, A. K, "Hybrid energy-efficient multi-path routing for wireless sensor networks," *Computers & Electrical Engineering,* 2018, pp. 96-113,.

[4] Akyildiz I.F., Su W., Sankarasubramaniam Y., Cayirci E., "Wireless sensor networks: A survey, 2002 *Communications MagazinE,* pp. 393-422.

[5] Singh A., Kotiyal V., Sharma S., Nagar J., Lee C.C.A., "machine learning approach to predict the average localisation error with applications to wireless sensor networks", 2020 *EEE Access,* vol. 8 , pp. 208253-208263.

[6] Haseeb, K., Bakar, K. A., Ahmed, A., Darwish, T., & Ahmed, I "WECRR: Weighted energy-efficient clustering with robust routing for wireless sensor networks," 2017, *Wireless Personal Communications,* pp. 695-721.

[7] Riaz, S., Rehan, M., Umer, T., Afzal, M. K., Rehan, W., Munir, E. U., & Iqbal, T. "FRP: A novel fast rerouting protocol with multi-link-failure recovery for mission-critical WSN," , 2018, *Future Generation Computer Systems,* pp. 148-165.

[8] Maratha, P., & Gupta, K. "A comprehensive and systematized review of energy-efficient routing protocols in wireless sensor networks" , 2019? *International Journal of Computers and Applications,* pp. 83-100.

[9] Mohamed RE, Saleh AI, Abdelrazzak M, et al."Survey on wireless sensor network applications and energy efficient routing protocols," , 2018, *Wireless Personal Commun,* p. 1019–1055.

[10] Mohamed RE, Saleh AI, Abdelrazzak M, et al."Survey on wireless sensor network applications and energy efficient routing protocols," 2018, *Wireless Personal Commun,* p. 1019–1055,.

[11] Meraihi, Y., Gabis, A. B., Ramdane-Cherif, A., & Acheli, D, "A comprehensive survey of crow search algorithm and its applications," , 2020, *Artificial Intelligence Review,* pp. 1-48.

[12] A. Tzanetos, I. Fister Jr, G. Dounias, s, "A comprehensive database of nature-inspired algorithm," , 2020, *Data in Brief Elsevier,* vol. 31, p. 105792.

[13] Dorigo, M., & Blum, C. "Ant colony optimization theory: A survey," ,2005 ,*Theoretical computer science,* Vols. 344(2-3), pp. 243-278.

[14] Singh, A., Sharma, S., et S. Jitendra "Nature-inspired algorithms for wireless sensor networks: A comprehensive surve," , 2021, *Computer Science Review,* vol. 39.

[15] ESLAMINEJAD, M., et RAZAK, S A., "Fundamental lifetime mechanisms in routing protocols for wireless sensor networks: A survey and open issues," , 2012, *sensors,* vol. 12, pp. 13508-13544.

[16] CAMILO, T., CARRETO, C, SILVA, JS, et al. "An energy-efficient ant-based routing algorithm for wireless sensor networks," in *Ant Colony Optimization and Swarm Intelligence:* , 2006, *5th International Workshop*, Brussels, Belgium.

[17] Hui, X., Zhigang, Z., & Xueguang, Z, "A novel routing protocol in wireless sensor networks based on ant colony optimization," , 2009, in *international conference on environmental science and information application technology*.

[18] SHIH, HC., CHU, SC, RODDICK, JF., et al " Power reduction of wireless sensor networks using ant colony optimization," , 2010, in *international conference on computational aspects of social networks*, IEEE .

[19] AHMED, M, BOUDHIR, A. A., et BOUHORMA, M, "New routing algorithm based on ACO approach for lifetime optimization in wireless sensor networks, 2012" *International Journal,* vol. 1, pp. 64-67.

[20] MEHTA, D, et SAXENA, S, "Hierarchical WSN protocol with fuzzy multi-criteria clustering and bio-inspired energy-efficient routing (FMCB-ER)," , 2022, *Multimedia Tools and Applications,* vol. 81, pp. 35083-35116.

[21] KAUR, T et KUMAR, D, "ETPS-MAC: energy traffic priority scheduling-based QoS-aware MAC protocol for hierarchical WSNs,", 2019, *International Journal of Electronics,* vol. 106, pp. 1344-1359.

[22] SAJWAN, M, GOSAIN, D, et SHARMA, AK., "Hybrid energy-efficient multi-path routing for wireless sensor networks," , 2018, *Computers & Electrical Engineering,* vol. 67, pp. 96-113.

[23] DEEPA, O. et SUGUNA, J., "An optimized QoS-based clustering with multipath routing protocol for wireless sensor networks," , 2020, *Journal of King Saud University-Computer and Information Sciences,* vol. 32, pp. 763-774.

[24] MARAPPAN, P et RODRIGUES, P. "An energy efficient routing protocol for correlated data using CL-LEACH in WSN," , 2016, *Wireless Networks,* vol. 22, pp. 1415-1423

[25] BRAR, GS, RANI, S, CHOPRA, V, et al., "Energy efficient direction-based PDORP routing protocol for WSN," , 2016, *IEEE access,* vol. 4, pp. 3182-3194.

[26] Mohamed RE, Saleh AI, Abdelrazzak M, et al. "Survey on wireless sensor network applications and energy efficient routing protocols." 2018, *Wireless Personal Communications* 101: 1019-1055.