Energy Efficient Routing Protocol in UWSNs using ACO Algorithm

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Abstract - *Underwater Wireless Sensor Network (UWSN) has recently become an important area due to the importance of underwater exploration. The unique characteristics of the underwater environment make designing routing protocols a difficult task. Optimal use of energy in UWSNs is very challenging and an active field of research. The replacing of the energy sources in such an environment is very costly. In this paper, we have proposed a routing protocol using the ant colony optimization algorithm which base on the swarm intelligence. Our simulation was performed using AquaSim which is an underwater simulator based on NS2 simulator. The evaluation results show that the proposed multi metric DBR protocol performs better than the original DBR protocol in terms of packet delivery ratio, saving energy and increasing network life.*

***Key Words*: Underwater Wireless Sensor Networks, Routing Protocol, Depth Based Routing Protocol, Ant Colony Optimization Algorithm, Energy Efficiency, Energy Consumption and Optimal Path.**

1. INTRODUCTION

More than 70% of the Earth's surface is covered by water, that is why a lot of research has been done on the systems used exploration of the underwater world and its secrets, and methods of monitoring this environment and collecting data on it have become a basic element of research. This made it necessary to find an effective way to do so. For this reason underwater wireless sensor networks have emerged as a suitable option. Underwater Wireless Sensor Network (UWSN) is a type of Wireless Sensor Network (WSN), Figure 1 shows the architecture of an underwater wireless sensor network. According to Figure 1, an underwater wireless sensor network consists of a large number of randomly deployed sensor nodes [1] at different depths Water, where the underwater nodes communicate with each other by means of sound signals, and with the nodes of the sink located on the surface water by means of radio signals.

Underwater wireless sensor networks have the characteristics of large propagation delay, high error rate, and bandwidth low frequency and limited power [2]. Therefore designing UWSN routing protocols is extremely difficult. UWSN applications are rapidly gaining popularity to enable advances in ocean monitoring, observing systems, and deep sea monitoring. It tracks various entities of the aquatic environment, and also applies UWSNs in areas such as oil and gas extraction, military surveillance, reconnaissance, mine detection, pollution monitoring, natural disasters such as tsunami and hurricane prediction, coral reefs and monitoring habitats for marine life and fish farming [2].

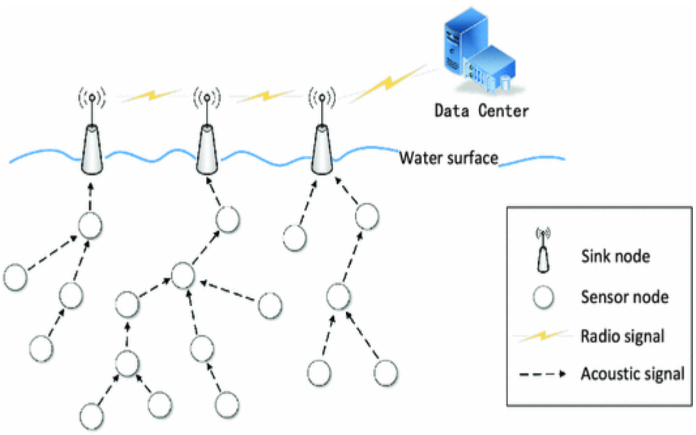

Fig -1: Underwater sensor network architecture [3]

2. CLASSIFICATIONS OF UWSNS ROUTING PROTOCOLS

Underwater routing protocols divided into two categories depending on the location information and they are [4]:

2.1 Localization-Based Routing Protocols

Localization-Based Routing Protocols use 2D or 3D position coordinates of node information to create routing tracks. This information is helpful in creating optimal routing paths from the bottom to the water surface, which may improve performance parameters such as propagation delay and other parameters. However, the calculation of the location information of the sensor nodes represents a challenge as the sensor nodes move with the ocean currents.

Energy is also consumed in calculating information of location of the sensor nodes. These protocols are used in tracking the underwater object and knowing the precise location of the target or any application that requires precision (calculating the position of the sensor nodes or tracked objects) are necessary.

Protocols that belong to this category: VBF, HH-VBF, FBR, MMBR, EEIAR, FVBF,... [4]

2.2 Localization-Free Routing Protocols

Localization-Free Routing Protocols do not require the two or three dimensional position coordinates of nodes sensor. Instead, these protocols use pressure sensors as the water pressure gauge on the sensor nodes, which in turn it measures depth of the sensor node. Then the depth sensing nodes are used to construct the routing paths. This strategy provides an amount of energy and reduces propagation delay in sensor node position calculation. These protocols are used when the scalability of the network is required. For example Military field or general surveillance.

Protocols that belong to this category: DBR, EEDBR, ODBR, QERP, OMR,… [4]

3. RELATED WORK

In this section, we present some of the relevant routing protocols available in the literature. We take into account the proposed routing protocols are well-known networks UWSN. In [5], a routing protocol called (Depth Based Routing Protocol) DBR was proposed. DBR protocol uses the depth is only for creating a routing path and does not require the full location information. In[6],a routing protocol called (Constraint Depth Based Routing Protocol) and (Constraint Energy Efficient Depth Based Routing), in CDBR and CEEDBR the authors proposed two protocols to solve the problem of power unbalance and redundant transmissions in the DBR protocol by limiting the number of data forwarding nodes, energy consumption can be reduced. In [7], a routing protocol called (Intelligence Depth Based Routing Protocol) IDBR was proposed, In IDBR protocol the authors proposed a routing protocol to solve the problem of energy holes in the EEDBR protocol through an assignment more energy for nodes near the surface of the water due to frequent use of nodes near the sink node. In [8], a routing protocol called (Depth and Noise Aware Routing Protocol) DNAR was proposed. In DNAR protocol the authors proposed a routing protocol to solve the problem of sensor node death propagated near the sink node faster, by allocating more energy to the sensor nodes that have a depth level of 150 m and selects the forwarder candidate that have lowest depth and minimum channel noise at the receiver. Previous studies in which researchers have relied on the use of AI. In [9], a routing protocol called (Fuzzy Depth Based Routing Protocol) FDBR was proposed. In FDBR protocol the authors proposed a routing protocol improvement of DBR protocol by making routing decisions depend on fuzzy cost based on the residual energy of receiver node in conjunction with the depth difference of receiver node and previous forwarder node and the number of hops traveled by the received packet. In [10], a routing protocol called (Improve Clustering Depth Based Routing Protocol) ICDBR was proposed. In ICDBR protocol the authors proposed a routing protocol to solve the problem of power consumption due to excessive transmissions through use the clustering and the cluster header as a forwarder node. In [11], a routing protocol called (Energy-Efficient Depth based Opportunistic Routing algorithm with Q-learning Depth Based Routing Protocol) EDORQ was proposed. In EDORQ the authors proposed a routing protocol to solve the power consumption problem due to power holes and excessive transmissions by combines the respective advantages of Q-learning technique and opportunistic routing (OR) algorithm.

This paper will suggest improving the DBR protocol through swarm intelligence using the Ant Algorithm for the following reasons:

1- Dynamic topology: This allows for high adaptability to the current network structure.

2- Local work: Unlike other routing methods, the improvement of ant colony depends only on Local information, that is, no routing tables or other blocks of information need to be sent to neighbors or to all nodes the network.

3- Support for multi path: Each node has a routing table with entries for all of its neighbors, which also contains pheromone. The decision rule, for determining the next node. Depends on the amount of pheromone for the current node.

4- Alternative path: Finding an optimal alternative path in the event of an obstacle and interruption on the road.

This paper will also contribute in the following:

1- Reducing energy consumption and increasing energy efficiency.

2- Finding the optimal path that reduces the total energy expended in sending a data packet from source node to the sink node.

3- If a path to the sink is cut off, there will be another path due to the dynamic nature of the Ant Algorithm.

4. SWARM INTELLIGENCE

Swarm Intelligence is a relatively new branch of artificial intelligence used to model collective behavior for social flocks in nature, such as ant colonies, honeybees and flocks of birds [12]. Although these factors (Insects or Swarms) are relatively undeveloped and have limited capabilities on their own, except that they interact with a certainly behavioral patterns to achievement the tasks needed cooperatively for their survival. Social interactions can be between individuals of the swarm is either direct or indirect.

There are two important characteristics that are necessary in the system in order to acquire the characteristic of swarm intelligence, and they are:

1- Self-organization: which represents a set of dynamic mechanisms and movements as a result the interaction

between the components of the system, which this constitutes colony structure.

2- Division of Labor: where there are multiple simultaneous tasks within the colony that are performed by specialized individuals, and this feature enables the swarm to respond to any changing circumstances that appear within space search.

5. MOTIVATION

DBR protocol is a simple routing protocol because it requires only depth information for sensor nodes [5]. DBR protocol uses Greedy Algorithm to route data which may fail to produce the optimal solution, and may produce unique solutions that may be the worst possible solution. Also, the DBR protocol depends on only one parameter when selecting the forwarder node, in addition to a large energy consumption due to the forwarder node forwarding the data packet to all neighboring nodes (Broadcast) and the power holes are formed due to the frequent use of the nodes close to the sink node.

Sensor nodes are devices with a very limited power capacity. This means that the quality of a particular path between the sensor node and the sink node, must be determined not only in terms of distance, but also in terms of the energy level of this path, so we propose the ACO_DBR protocol by improving the performance of data routing using the ant algorithm by adding parameters of depth, remaining energy to the node, the distance and also the number of hops.

6. PROPOSED APPROACH

Energy efficiency is one of the most important issues in UWSNs. Our paper offer an energy efficient routing protocol for UWSNs. We present functionality of our protocol in details. The proposed protocol consists of two phases:

6.1 Path Discovery and Selection Phase

The path discovery and selection phase is the phase responsible for creating the path between source node and destination node.

The proposed ACO-DBR protocol uses four criteria for path selection that is optimized in terms of the distance and energy that will be used to transmit the data packets between the source node and the sink node, the criteria are:

1- Depth.

2- Distance.

3- Residual Energy.

4- Number of Hops.

We note that our proposed protocol is based on many criteria and not the depth criterion as in the DBR protocol basic.

In this phase, all nodes within the transmission range and participations are processed in routing process of data, as you must fulfill the following two conditions:

1- The depth of the participating nodes is less than the depth of the source node:

$$d_c < d_s$$

Where d_s is the depth of the sending node and d_c is the depth of the current node.

Because routing data in the underwater wireless sensor networks is always is towards the sink node located on the surface of the water.

2- That the node is not dead (its energy is equal to zero) and also that the nodes with residual energy are limited to 25% of the total energy.

Then, all nodes that fulfill the requirement of depth and energy will participate in the path detection and selection process through the Ant Algorithm used.

6.1.1 Improved Ant Colony Routing Algorithm

The Ant Colony Optimization Algorithm was used in order to choose the appropriate path [13], we modified the algorithm of the ants to be as follows (this is shown in Figure 2, 3, 4 and 5):

1- In the network, each of the source nodes creates an ant with the task of finding a path to the destination.

2- In order to balance the energy consumption of the node, the optimized ant colony algorithm provides the energy factor based on the basic ant colony orientation algorithm to find a shorter high- energy path ,In each node i, the ant chooses the next hop node using the improvement probability from node i to the node j as follows:

$$P_k(i,j) = \begin{cases} \dfrac{[\tau(i,j)]^{\alpha}[\eta(i,j)]^{\beta}\xi[(i,j)]^{\gamma}}{\sum_{r\epsilon\Gamma}[\tau(i,j)]^{\alpha}[\eta(i,j)]^{\beta}[\xi(i,j)]^{\gamma}} & r\epsilon\Gamma \\ 0 & otherwise \end{cases}$$

Where:

- $P_k(i,j)$: The probability of the ant moving from node i to node j.
- $\tau(i,j)$: Represents the pheromone on the pathway between i and j.
- $\eta(i,j)$ Represents the inverse of the distance between the two nodes and will represent $\frac{1}{d(i,j)}$.
- $\xi(i,j)$: Represents the inverse of the residual energy to node j and will represent $\frac{1}{energy(j)}$.
- Γ: It is the list that contains all the paths that the ants have already traversed, which should not be selected again and this is a memory for the ants.

- α,γ,β: are parameters that control the relative importance of the path.

3- Update pheromone according to the following equation:

$$\tau(i,j)(t) = (1-\rho).\tau(i,j)(t-1) + \Delta\tau_k$$

Where:

- $\Delta\tau_k$: The amount of pheromone released by ant on the path from i to j.
- ρ: Evaporation coefficient.

4- The amount of pheromone released by the ant k from i to j according to the following equation:

$$\Delta\tau_k = \begin{cases} \frac{Q}{L^+} & \text{if ant select trail } i \neq j \\ 0 & \text{otherwise} \end{cases}$$

Where:

- Q: is a positive constant.
- L^+: is the maximum length of one of the ants' best paths.

Figure (5) shows the flow chart for the improved ant Colony routing algorithm.

-If we have two paths with the same energy and distance (a case of little occurrence but must be taken into consideration), we will use the criterion of number of hops and choose the path with the fewest hops.

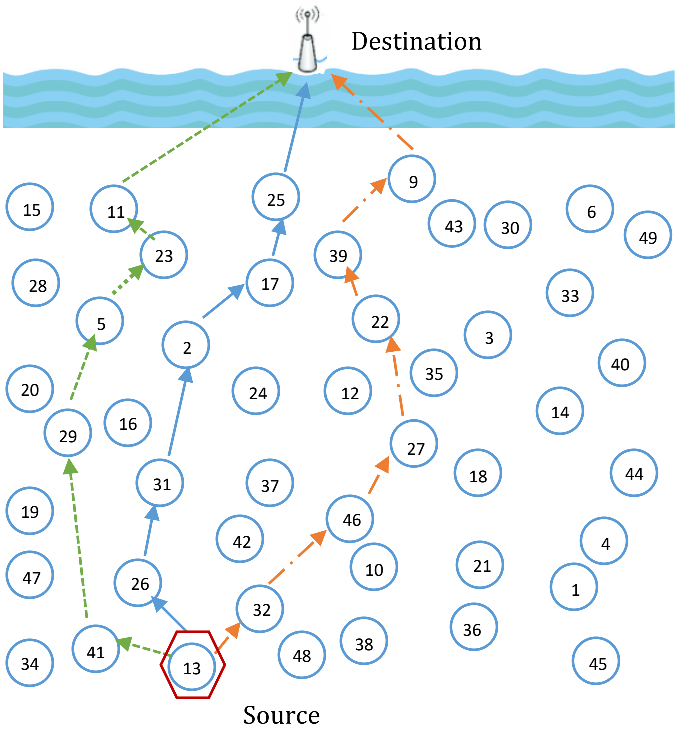

Fig -2: Initializing the numbers of solutions in improved ACO algorithm

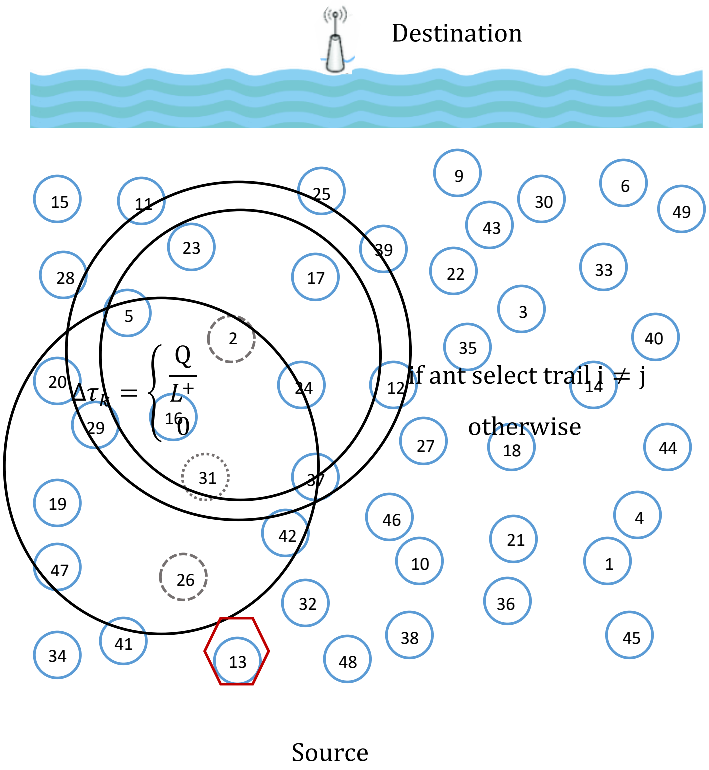

Fig -3: Search for the best path in improved ACO algorithm

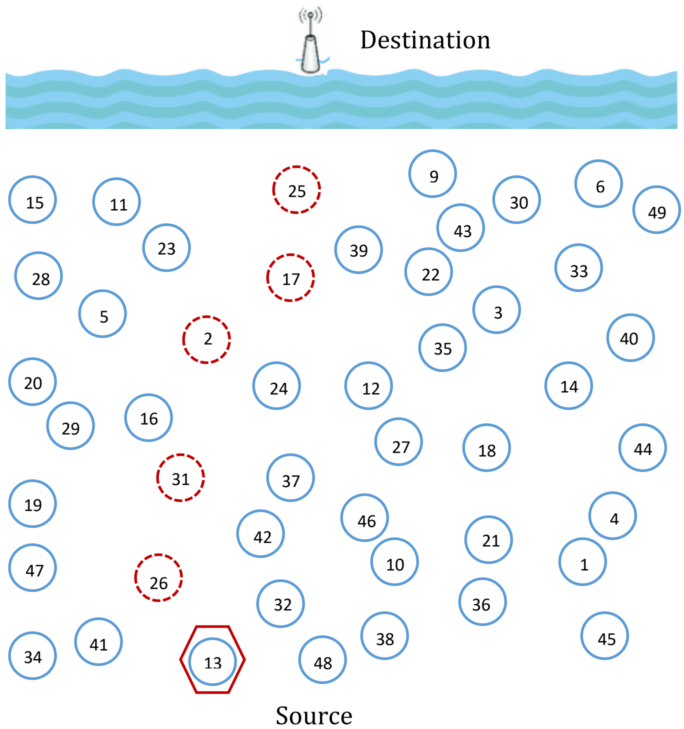

Fig -4: Path selection among the source to the destination in improved ACO algorithm

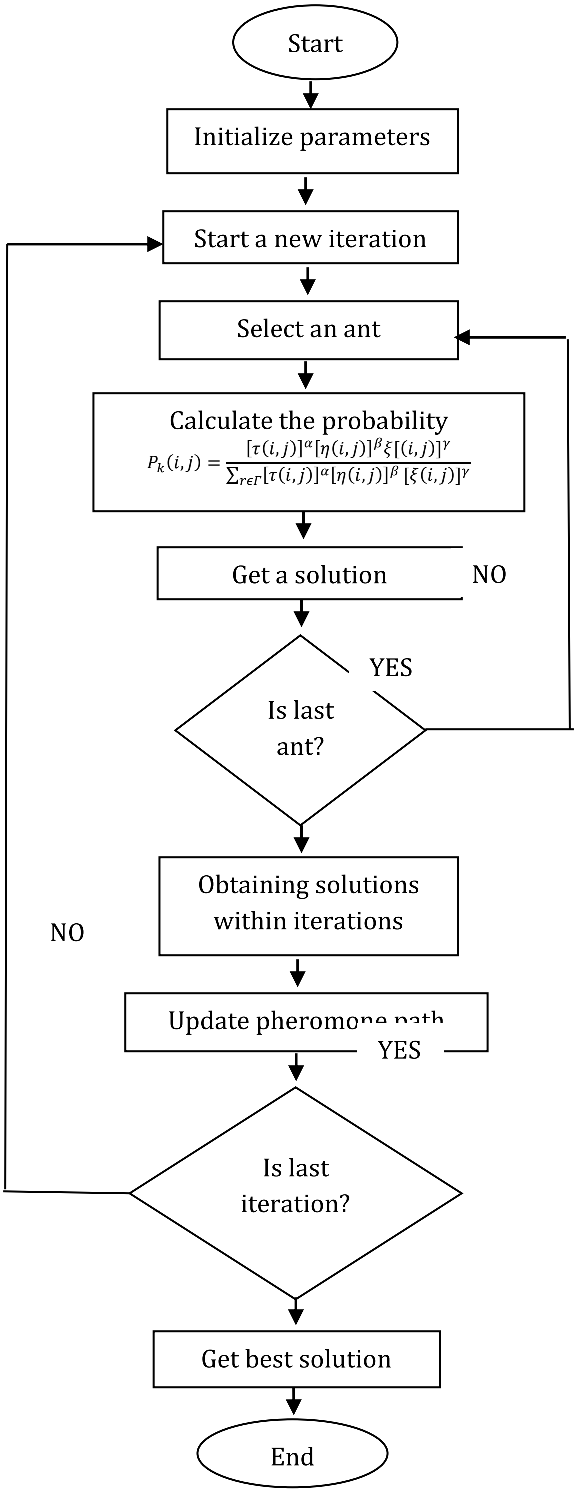

Fig -5: Flowchart of the improved ant colony routing algorithm

6.2 Data Forwarding Phase

In DBR protocol, when a node receives a packet, it first retrieves the packet's previous hop's depth d_p, which is embedded in the packet. After that, the receiving node compares its own depth dc with d_p.

The node would consider itself a qualified candidate to forward the packet if it is closest to the water surface, i.e., $d_c < d_p$, otherwise it will be ignored. As shown in Figure 6. In the ACO-DBR protocol, we proposed routing data packets from the source node to the sink node through the path that was chosen by the used ant algorithm and which contains all of nodes of less depth than the transmitter node. In addition to having the best path in terms of energy and distance.

7. PERFORMANCE EVALUATION

In this section, we compare the performance of the proposed routing protocol ACO-DBR, with that of the DBR routing protocol.

7.1 Simulation Settings

The simulation was performed using the AquaSim network simulator. This simulator an underwater supportive package attached in NS-2 simulator [14] which is dedicated to simulate wireless sensor networks and support their protocols. A 3*D* network of size 500m×500m×500m is considered with 500 nodes were randomly deployed and at different depths of the water surface. We evaluated the performance of on different number of nodes (50, 100, 200, 300, 400 and 500), within the transmission range 100 meters and the speed of sound 1500 m/ s. The acoustic modem, LinkQuest UWM1000 is used with a bit rate of 10 kbps [15], initially, the energy of every sensor node is 100 J. The size of each data packet is 50bytes. The default values of improved ant colony algorithm parameters are set to α = 1, β = 2, γ = 3, ρ = 0.7and Q = 100.

The main simulation parameters are listed in Table 1.

Table -1: Simulation Parameter

Simulation parameter	Value
Simulator	AquaSim (NS-2 version 2.30)
Deployment topology	500 m x 500 m x 500 m
Number of nodes	50-500 nodes
Transmission range	100 m
Initial energy	100 J
Communication medium	Acoustic waves
Bit rate	10kbps
Signal velocity	1500 m/s
Data packet size	50 byte

Simulation time	1000 s

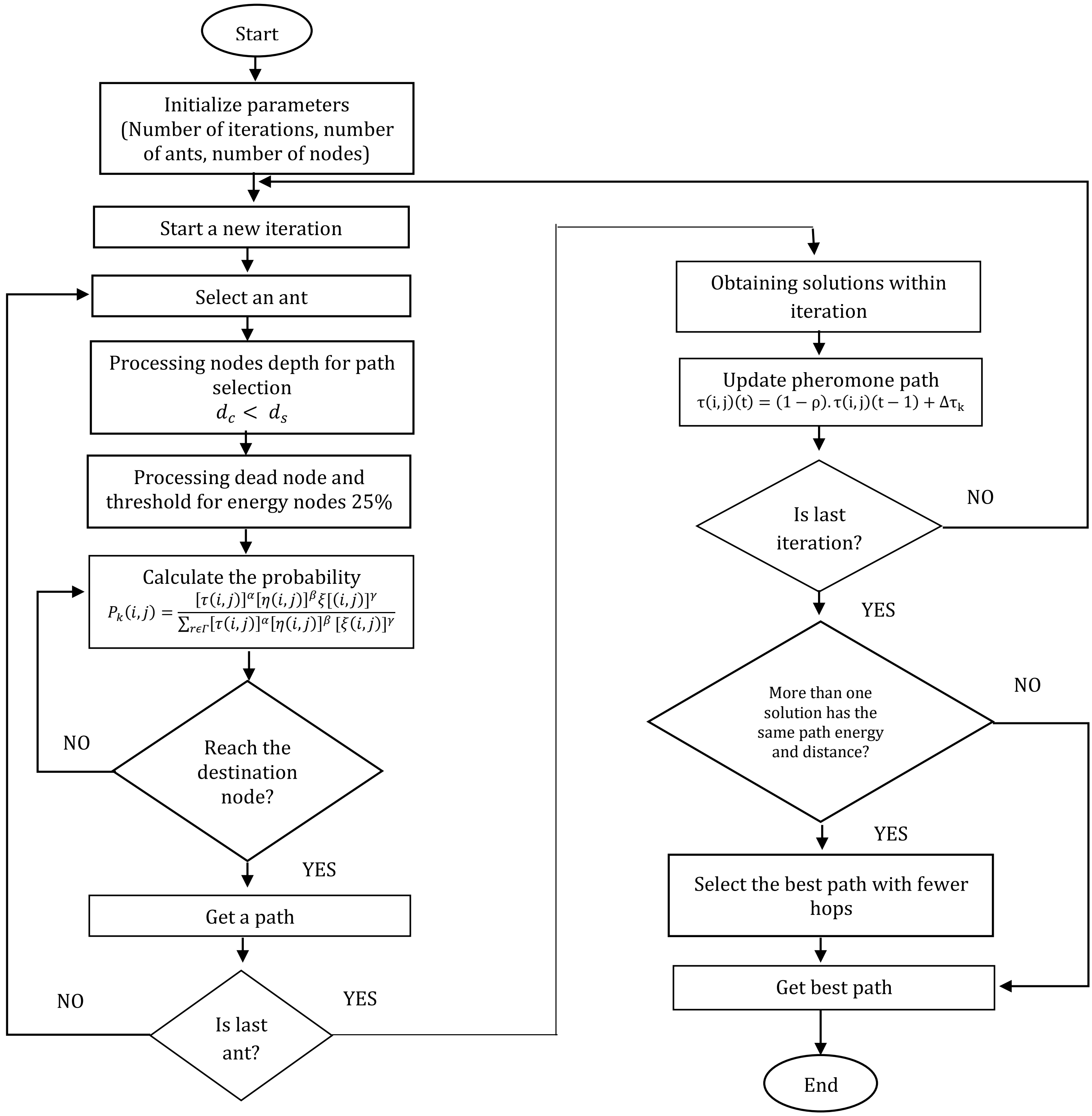

Fig -6: The flow chart for phase discovery and selection path

7.2 Performance Metric

There are several performance evaluation criteria used to evaluate the performance of the proposed protocol and compare it with the DBR protocol. Each of these criteria are described as follows:

- Total Energy Consumption: Energy consumption is evaluated by the total amount of energy the sensor nodes consume while forwarding the data packets from the source to the sink node. This parameter indicates the energy efficiency of the routing protocol.

- Packet Delivery Ratio: The ratio of the number of different packets received at the sink node to the total number of packets sent by the source node. This parameter indicates the reliability of the routing protocol.

- End-to-End Delay: End-to-end delay is the time taken for the packet to arrive from the source node to the destination node (sink node). This parameter indicates the time efficiency of the routing protocol.

7.3 Simulation Results and Analysis

7.3.1 Total Energy Consumption:

Energy consumption is very important in underwater wireless sensor networks due to the limited energy of the sensor nodes. Chart (1) shows the effect of node density on the total power consumption of the network, where we note that the energy consumption of DBR is higher than the proposed ACO-DBR protocol due to the excessive number of nodes participating in data packet forwarding and redundant packet transmissions in the DBR protocol, where we notice an increase in energy consumption with increasing network density because more nodes become eligible to forward data packets with increasing network density. However, DBR only restricts the number of nodes based on the depth of the sensor nodes while in the ACO-DBR protocol it restricts the number of nodes involved based on 4 metrics depth, residual energy of the node, distance and number of hops.

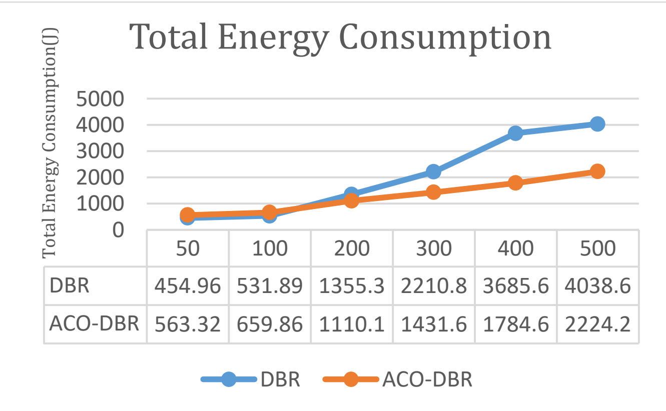

Chart -1: Total Energy Consumption vs. Number of Nodes.

We also note that the ACO-DBR protocol was able to significantly reduce the total energy consumption compared to the DBR protocol.

7.3.2 Packet Delivery Ratio:

Chart (2) shows the effect of node density on the percentage of data delivery, where we note that the data delivery rate is high in the DBR protocol in the network with a number of nodes from 50 to 200 as a result of sending packets repeatedly to all neighboring nodes within the transmission range where multiple paths are followed to reach a sink node, but the higher data delivery rate in DBR protocol is at the expense of excessive energy consumption. We also note that the data delivery rate improved with the increase in density of the number of nodes in networks with the number of nodes 300 to 500 as a result of the increase in the number of collisions with the increase in the number of nodes in the DBR protocol.

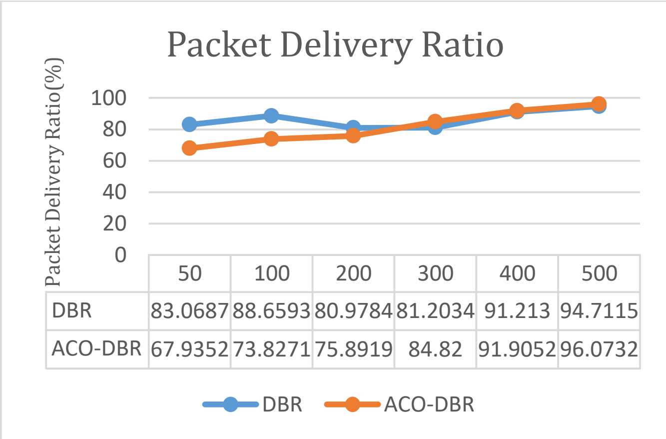

Chart -2: Packet Delivery Ratio vs. Number of Nodes.

7.3.3 End-to-End Delay:

Chart (3) shows the effect of node density on delay, we notice the decrease in delay in both protocols with increasing number of nodes because the forwarder node can find more nodes to forward packets within the transmission range.

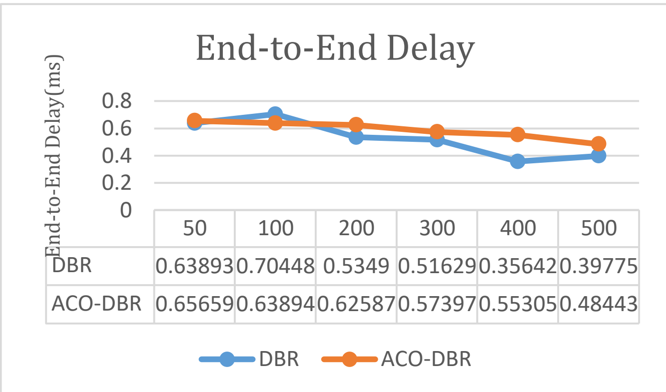

Chart -3: End-to- End Delay vs. Number of Nodes.

The delay in the ACO-DBR protocol is slightly more compared to the DBR protocol as a result of implementing the algorithm and determining the optimal path, then the data packets are forwarded to the sink node.

8. CONCLUSIONS

Energy efficiency improvement in Underwater Wireless Sensor Networks (UWSNs) is an important issue because replacing Underwater Sensor Node batteries is very costly due to the hard underwater environment. In this paper we proposed a routing protocol in order to improve energy efficiency and reduce consumption in the DBR protocol. ACO-DBR protocol uses depth, distance, residual energy of nodes and number of hops, ACO-DBR consists of two phases, namely, path discovery and selection phase and data forwarding phase. In the phase of discovering and selecting the path, the ant colony optimization algorithm was used and improved upon by entering the energy factor as describe in the data forwarding phase, in order the choose the next hop based on distance and energy. The data is forwarded through the chosen path. All nodes within this path have a depth less than the depth of the sending node.

Through simulation using the AquaSim simulator, the ACO-DBR protocol was compared to the DBR protocol based on the overall simulation, we observed that ACO-DBR protocol significantly improves energy efficiency while the packet delivery ratio roughly similar to the comparative routing protocol with little delay in the ACO-DBR protocol.

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