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# Energy Efficiency and Reliability in Underwater Wireless Sensor Networks Using Cuckoo Optimizer Algorithm

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**ABSTRACT:** Energy efficiency and reliability are widely understood to be one of the dominant considerations for Underwater Wireless Sensor Networks (UWSNs). In this paper, in order to maintain energy efficiency and reliability in a UWSN, Cuckoo Optimization Algorithm (COA) is adopted that is a combination of three techniques of geo-routing, multi-path routing, and Duty-Cycle mechanism. In the proposed algorithm, by presenting a cost function in COA algorithm, a hop-by-hop method of route selection is performed using power consumption and energy content of the current node; while in Greedy Geographic Forwarding based on Geospatial Division (GGFGD) algorithm, data transfer is based on the closest route to a destination criterion. Simulation results show that despite the increase in path lengths and the resulting increase in propagation delay, the remaining energy of the UWSN increases using the proposed technique compared to GGFGD algorithm. Besides, we will show that while improving energy consumption, the number of paths found and, therefore, reliability of the network in the proposed method that uses duty-cycle mechanism are higher than the ones in GGFGD algorithm.

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## 1- Introduction

In recent years, Underwater Wireless Sensor Networks (UWSNs) have absorbed much attention as a subset of wireless sensor networks. Ocean pollution monitoring, ocean resources management, and climate change forecasting are among the most important applications of these networks. Since routing protocols are used for the effective and safe transfer of information from source to destination, designing these protocols has been paid attention to by many researchers. On the other hand, unique features of the underwater environment, such as 3D topology, the mobility of the nodes and limited energy resources provide a great challenge for designers. Also, the most important issues affecting underwater routing are mobility of the nodes, low sound speed, limited bandwidth, multiple failures, and energy constraints. Usually, in designing routing algorithms, it is not easy to consider all these issues; therefore, there is a compromise between these constraints. In UWSNs, like other networks, setting up the path and providing a secure and efficient transmission of information is of great importance. Hence, in recent years, several routing algorithms have been proposed for these networks. It is worth mentioning that routing algorithms are based on geographical information of nodes.

In [1], two multiple-routing algorithms based on geospatial divisions, called GGFGD and GFGD[1] , have been proposed. In these algorithms, geo-routing techniques are proposed along with multi-paths and duty-cycle techniques. In this regard, with the goal of energy efficiency in the routing of UWSNs, a routing algorithm based on GGFGD algorithm functions in a way that selection of the appropriate node using hop-by-hop method is optimized has been developed. In GGFGD algorithm, parameters such as energy, distance, density, data loss, latency, and sleeping and awakening of sensor nodes are considered for an optimal routing. To reduce the path length and propagation delay in GGFGD algorithm, the main goal is sending the information to the nearest node toward the sink.

Vector-Based Forwarding (VBF) routing algorithm is proposed in [2] for Underwater Sensor Networks (USNs). In this algorithm, according to the location of the source and destination nodes, a virtual channel is chosen for data transfer. In this algorithm, only the nodes inside the channel contribute to the transmission of information; consequently, repeated use of the nodes in the channel prevents the balanced energy consumption in the network. In [3], Hop-by-Hop-VBF (HH-VBF) algorithm is introduced to solve the problem VBF algorithm in multipath construction [2,3]. In this algorithm, instead of using a routing vector from source to destination, a vector and a routing channel are created at each step.

Also, in [4], Adaptive HH-VBF (AHH-VBF) algorithm is proposed based on HH-VBF in UASNs due to the important feature of sound signals for underwater transfer. Through focusing on power levels, the distance to the destination nodes and communication range, this algorithm has a better performance than HH-VBF algorithm, especially at the delivery rate, power consumption, and end-to-end latency. An

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[1] Geographic Forwarding based on Geospatial Division

initial research on UASNs has also been investigated in [5]. Also, in [6], Information-Carrying based Routing Protocol (ICRP) algorithm has been proposed for UASNs. In this algorithm, the generated path control packet is carried by a data packet; as a result, the data transmission mechanism has a low data delivery delay in addition to energy saving.

In [7], considering the continuous movement of nodes, Reliable and Energy Balanced Routing (REBAR) algorithm has been proposed. In this algorithm, the nodes have different transmission ranges, depending on their distance from the sink node: the closer the node to the sink, the lower its transmission range. This algorithm reduces the excessive energy consumption of nodes near the sink, but nodes movement causes more problems and thus benefits of this algorithm are not considerable. In [8], Focused Beam Routing (FBR) algorithm is proposed for USNs. In this algorithm, to avoid excessive energy consumption, information of the location of the source and destination nodes is used to construct the route. To increase network stability, nodes dynamically change their transmission power based on network conditions. FBR algorithm is optimal in terms of energy consumption, but this algorithm is not very flexible and is not suitable for uncongested networks.

Proposed in [9], Directional Flooding-based Routing (DFR) algorithm is also another algorithm based on the geographic information of the nodes, considering the mobility of the nodes. In this algorithm, to increase the reliability of connections, their quality has been considered. In DFR algorithm, to flooding propagation of the packet a flood region has been used, thus the algorithm adjusts itself changes in network topology. Several other routing algorithms have also been proposed to energize UWSNs. For example, in [10], the non-cooperative algorithm Depth-Based Routing (DBR) algorithm has been proposed that uses nodes depth instead of their spatial information. In this algorithm, the nodes are equipped with a depth sensor, and the sending of information to the destination is based on their depth. It is worth mentioning that, data transfer model in both DBR and DFR algorithms is flooding [9, 10].

Also, in [11] various routing techniques mentioned above are categorized and reviewed thoroughly from different perspectives such as delay efficiency, energy efficiency, reliability, bandwidth efficiency, and delivery ratio in UWSNs. The article mentions that delay in HHVBF, REBAR, FBR, DFR and DBR techniques is hop-by-hop; while in VBF and ICRP techniques, the delay is end-to-end. Also, among techniques mentioned above just FBR and DBR techniques are multi-sink and the rest of them are single-sink. This paper also studies the delay productivity; FBR and DBR techniques have a high performance, and DFR and HHVBF techniques have a fairly good performance in this regard. In terms of energy efficiency, both REBAR and FBR techniques have the best performance, and VBF and ICRP techniques have a fairly good performance. It is worth mentioning that the energy efficiency of the HHVBF, DFR, and DBR techniques are very low. From the reliability point of view, HHVBF, DFR, and DBR techniques are very good, while the performance of REBAR and FBR techniques is fairly good. According to the review of the bandwidth efficiency in the article, all the mentioned techniques have a fairly good performance.

In this paper, delivery ratio of the present algorithms is also examined, and it will be shown that the DBR algorithm has the highest performance and VBF and ICRP algorithms have the lowest performance, thus, we can conclude that using the hop-by-hop method plays an important role in delivering the packet to the destination. It is worth mentioning that the performance of delivery ratio of other algorithms is also fairly good. In addition, in [11], to determine the optimal technique, overall performance of the algorithms has been evaluated from different aspects; results show that FBR and DBR algorithms have the highest performance and VBF and ICRP algorithms have the lowest performance, and the other algorithms also have a fairly good performance.

In [12], Depth-Based Multi-hop Routing (DBMR) algorithm was used to save energy and solve the problem of flooding propagation of DBR algorithm. In this protocol, the transfer of information is multi-path. In [13], MRP protocol is proposed for UWSNs. This protocol is a localization-free routing protocol that utilizes super nodes in a network to satisfy the need for localization and operates in two phases of layering and data forwarding. The algorithm is also path-based and works end-to-end and multi-sink. In the Mobicast routing protocol presented in [14], nodes near the Autonomous Underwater Vehicle (AUV) or mobile sinks form a 3D geographic area. The mobile sinks or AUVs continuously move along a predefined path and gather the nodes data in this 3D area. It should be noted that this algorithm acts single sink and end-to-end.

Various algorithms in UWSNs have also been evaluated in [15]. It has been shown that Mobicast and MRP algorithms have a better performance regarding delay efficiency compared to VBF algorithm and like HHVBF algorithm has a relatively high performance, but lower than DBR algorithm. In terms of energy efficiency, the performance of the Mobicast algorithm, such as DBR and HHVBF algorithms, is low, while MRP algorithm has a relatively high performance like that of VBF algorithm. In terms of bandwidth efficiency, the Mobicast algorithm has a lower performance than all the algorithms tested, while MRP algorithm, like DBR, HHVBF, and VBF algorithms, has a relatively high performance. In terms of reliability, MRP algorithm, like DBR and HHVBF algorithms, has a high performance, but the Mobicast algorithm has a relatively high performance. It is also stated in the paper that the overall performance of the Mobicast algorithm is low, like VBF, while the performance of MRP protocol is high like that of DBR. In [16], energy efficiency in UWSNs using cooperative routing has been investigated. Accordingly, Cooperative Energy-Efficient routing for UWSN (Co-EEUWSN) technique has been suggested, which has been shown to be more efficient than non-cooperative protocols such as DBR algorithm.

Multi-path protocols use more than one path in the routing exploration process. In this method, repeating connections are used to increase the delivery rate and its reliability in UWSNs. Multipath Power-Control Transmission (MPT) protocol, which is one of the underwater multi-path protocols, is proposed in [17]. In this protocol, the source node begins the routing process by sending a message requesting a path to the destination. Any node that receives this request for the first time will pass it. When the destination node receives the request, it will respond to the message inversely along the route request paths. Then, in the next step, a path is selected by the destination node. Therefore, data packets are transmitted along the path selected by the destination node. It is worth noting that the limitation of this protocol is that the route request message consumes relatively large amounts of energy; therefore, MPT protocol is not so energy-efficient.

Multi-path delivery was also used in [18] to avoid competition near the sink, which is done through designing a virtual sink that includes a group of different physical sinks. Sensor nodes can send data to one or more sinks to achieve a high reliability under any network conditions. However, there is the issue of redundancy of transmission that consumes limited resources. In [19], a new routing protocol called Multi-Path Routing (MPR) protocol has been introduced. In this protocol, a multi-path technique is used to build a path between the source and destination nodes, which consists of multi-sub paths. Its innovation is in reducing the propagation delay, although its energy consumption is relatively high. The duty-cycle mechanism for the energy efficiency in wireless sensor networks based on the on and off sensor nodes has been of designers' interest in recent years [1, 20-23]. Using this mechanism causes the nodes to sleep periodically to prevent more energy consumption when no data is sent. It is worth mentioning that in this case, despite the decrease in power consumption in the network, the reliability of the network may be affected.

In this paper, COA algorithm is used for the energy efficiency in UWSNs [24]. In this paper, according to the paper [1] and using hop-by-hop method, a node-disjoint routing algorithm has been proposed to improve routing in the UWSN through combining three techniques of geo-routing, multi-path routing, and a duty-cycle mechanism, and by providing a cost function in COA algorithm for selecting the optimal route.

The rest of the paper is organized as follows. The system's model is examined in section 2. Section 3 describes the proposed technique. Also, the simulation results and comparison of the proposed algorithm with GGFGD algorithm are discussed from two aspects of UWSNs' residual energy and reliability in section 4. Finally, the conclusions are presented in section 5.

## 2- System Model

In this section, to explain the proposed method, we first describe the network model and then explain energy consumption model of the algorithm presented in [1].

### 2- 1- Network Model

In this section, we first discuss the network model used in this paper [1]. In this regard, the sensor network is considered to be a Big Cube (BC), the top surface of which is the surface of the water and the bottom surface is the sea bed. As shown in Fig. 1, this cube is subdivided into Small Cubes (SCs).

It is also assumed that a sink node is located in the upper right corner of the BC and a source node in the bottom left corner of it. Let $N_a$ sensor nodes equipped with audio modems be randomly located at different depths. All these nodes are static and do not flow with water. The network is homogeneous, i.e. all nodes have the same primary energy, transmission power, and the same range, and the connections between nodes are also symmetric. It is assumed that the sink node is equipped with an audio modem and signal modem, located at sea level, and each node knows its own location and the sink node's. Also, within an SC, there are a large number of nodes that store the SC which they belong to. It is assumed that the length of the SC is $d$ and it depends strongly on $r$, which is the transfer radius of sensor nodes. Also, duty-cycle strategy assumes that each node randomly changes its condition independently from other nodes.

This method is the simplest form of duty-cycle, and each

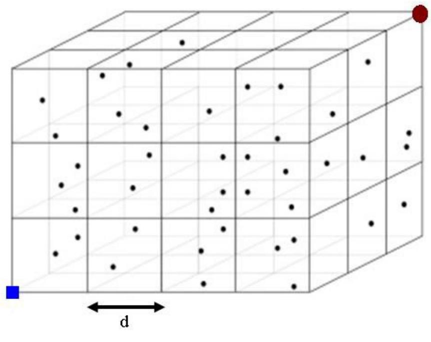


**Fig. 1. Underwater network model (the point at the upper right corner is the sink node and the point at the bottom left corner is the source node; smaller points are sensor nodes)**

node is awake for a fraction of a time period and in sleep for the rest of the period. Note that Each sensor node can record the locations of itself and the sink node, thus there is no need for global synchronization.

### 2- 2- Energy Model

In this section, energy consumption model used in this paper is discussed. It is worth mentioning that the underwater acoustic channels are affected by many factors, such as path loss, noise, multipath fading, and Doppler spread. For simplicity, we consider only path loss parameter. In this regard, if $l$ is transmission distance, $m$ is data packet length, $T_b$ is bit duration, $H$ is depth of the knot in the water, $E_{elec}$ is attenuation, and $g(f)$ is absorption coefficient, energy required to transmit $m$ bits at a distance of $l$ is calculated using the following equation [25]:

$$\mathrm{E}_{\mathrm{tx}}(m,l) = mE_{elec} + mT_b CHde^{g(f)l} \tag{1}$$

where

$$C \cong 2\pi \times 0.67 \times 10^{-9.5} \tag{2}$$

The energy required for receiving $m$ bits at a distance $l$ is calculated using the following equation,

$$\mathrm{E}_{\mathrm{rx}}(m,l) = mE_{elec} \tag{3}$$

Also, in Eq. (1), $g(f)$ is calculated as follows [27-25]:

$$g(f) = \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2} + 2.75\times10^{-4} f^2 + 0.003 \quad \frac{dB}{km} \tag{4}$$

where $f$ is the center frequency of the channel of transmission in kHz. It is worth noting that the underwater environment is corrosive due to water salinity. In this regard, if $S$ is the salinity of water ($30 \le S \le 40$) and T is the water temperature ($0 \le T \le 30$) [27], the propagation delay and path loss can be calculated using the following equations [1],

$$D = 1449.05 + 45.7T - 5.21T^2 + 0.23T^3 + \left(1.333 - 0.216T + 0.009T^2\right) \times (S - 35) + 16.3H + 0.18H^2 \tag{5}$$

$$L = l^k \exp(l \times g(f)/10) \tag{6}$$

where $k$ is the energy propagation factor, which is equal to 2 as in [1]. Remaining energy of the node is calculated using the following equation [1],

$$E_{resi} = E_{init} - \left(E_{tx} + E_{rx}\right) \tag{7}$$

where $E_{init}$ is the primary energy of each node.

It should be noted that depending on the geographical divisions, BC and SC can be vertex-adjacent, edge-adjacent or surface-adjacent; otherwise, they are completely separate. Therefore, if an SC is completely located inside the BC, it has 8 vertex-adjacent neighbors, 12 edge-adjacent neighbors and 6 surface-adjacent neighbors [1].

## 3- Proposed Algorithm

In this section, we will present the algorithm proposed in this paper based on algorithms presented in [1] and [24]. The proposed algorithm enjoys the advantages of geographic routing in which routing is based on request and routes made simultaneously. Accordingly, the routing table does not exist and thus no memory is wasted for storing the path. In addition, in order to increase the reliability of packets being received correctly, the multiple-routing technique will be used along with geo-routing and packets are sent to the destination simultaneously from multiple paths. Also, using the duty-cycle mechanism, the nodes periodically sleep to save energy when no data is sent. To implement a 3D space as in Fig. 1, the network is assumed to be a large cube subdivided into smaller cubes. To prevent the flooding propagation of packets, transmission radius is defined for the nodes, and each node can only send information within the range of this radius. Also, in the proposed algorithm, node selection is determined in the next step based on the suitability of that node.

In the proposed algorithm, each sensor node can communicate directly with all its vertex-adjacent, edge-adjacent, and surface-adjacent nodes. It should be noted that an SC inside the BC, has 8 vertex-adjacent neighbors, 12 edge-adjacent neighbors, and 6 surface-adjacent neighbors. As shown in Fig. 2, node $u$ is a perfect example of such SC. In this figure, node $u$ is exactly at the intersection of eight SCs, as shown in Fig. 2, the situation in one of the eight octants is depicted. Also, node $m$ is the farthest node that u can communicate directly with. Therefore, Euclidean distance between $u$ and $m$ determines the minimum transfer radius of node $u$. Accordingly, the relationship between the length of the SC edge ($d$) and transfer radius of the sensor nodes ($r$) is determined by the following equation [1],

$$(2d)^2 + (2d)^2 + (2d)^2 = r^2 \qquad d = \frac{r}{\sqrt{12}} \tag{8}$$

To describe the proposed method, as can be seen in Fig. 1, first, Na nodes are randomly distributed at different depths of H in BC space. Then, the BC is divided into a number of SCs based on the amount of d. Each node must also know its location and the sink node's location using range-based or range-free localization algorithms. In addition, each node must know which SC it belongs to. It is worth noting that the primary energy of all these nodes is equal. After the initial configuration of the nodes, the routing process begins in two stages:

- **Stage 1:** If you call the source node u, the first phase of the routing is finding all the neighboring SC subunits for the node. As stated above, an SC can have vertex-adjacent, edge-adjacent and surface-adjacent neighbors. From all neighboring SCs, we choose those that are closer to the sink than the present SC and have at least one awake node. This is to prevent the futile bypassing of the route and the getting out of the sink path. Then, the nodes in these SCs are listed and considered as candidates for the next step. After forming a set of candidate nodes, the second routing stage begins with COA algorithm as follows.

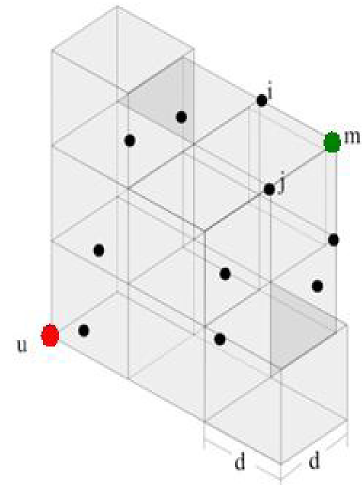


**Fig. 2. The relation between $r$ and $d$ in the network**

- **Stage 2:** At this stage, using COA algorithm, first, mother cuckoos are randomly distributed in the search field determined by a varhi and a varlow [24]. Then, in order to achieve the desired accuracy in optimization, the following steps are implemented.

**A)** Each mother cuckoo is assigned a random number of eggs. Then, with respect to this number, Egg Laying Radius (ELR) of each bird is determined by the equation [24]

$$\text{ELR} = \beta \times \frac{\text{Number of current cuckoo's eggs}}{\text{Total number of eggs}} \times \left(var_{hi} - var_{low}\right) \tag{9}$$

where $\beta$ is an integer that specifies the maximum ELR value. It should be noted that each bird can only lay eggs at its specified radius.

**B)** Mother cuckoos do their laying in this radius. After the laying process, using the cost function, which is referred to below, the profit value of all mother cuckoos and eggs is obtained. Then, to control the maximum population of cuckoos, we eliminate eggs that have a lower yield. At the end of this stage, the laying process is complete and the eggs are grown and matured over time.

**C)** A new population of cuckoos is made with the presence of young cuckoos. Young cuckoos are the current mothers of the algorithm. Then, living places of the cuckoos are clustered through K-mean clustering method. In this paper, since the search field and number of optimization variables are not high, *K* is assumed to be *1*.

**D)** After clustering, the profit of each cluster is calculated and the cluster with the highest profit will be introduced as the optimal point for the migration of other cuckoos. Also, the cuckoo that has the highest earnings in this cluster is selected as a global optimum.

**E)** If the algorithm reaches the desired convergence, it stops; otherwise, these steps are repeated. The issue in the COA algorithm is the closeness of the cuckoo's population to each other. If the cuckoo population is close to the magnitude of the convergence coefficient specified in the algorithm, the algorithm has reached its convergence.

It should be noted that COA output is the global optimal solution which is achieved by rounding it to the neighboring node with the highest profit margin. The above steps continue until there are no other nodes or SCs that provide routing conditions. In Fig. 3, a flowchart of the proposed method is shown. Note that that in this paper the next hop node is optimally selected by COA algorithm based on the node that has the most energy ($\omega$) in the target SC. What influences this selection is the distance between the current node and the selected node, the path loss based on this distance, propagation delay, and the amount of current node's remaining energy. In addition to the criteria, the energy required to send, the remaining energy of the node when information is sent to this node and the initial energy of the node are also considered in this cost function. Accordingly, since the exponential-sine functions are those functions in which small change in parameters can lead to the great changes in the results of the function [27], the cost function for choosing the next hop node based on the energy based on [1] and [28] is suggested as follows:

$$\grave{u}_{ij} = \frac{\mu}{D} + \frac{\kappa}{L} + \tau C_{ij} + \zeta E_{resi} \tag{10}$$

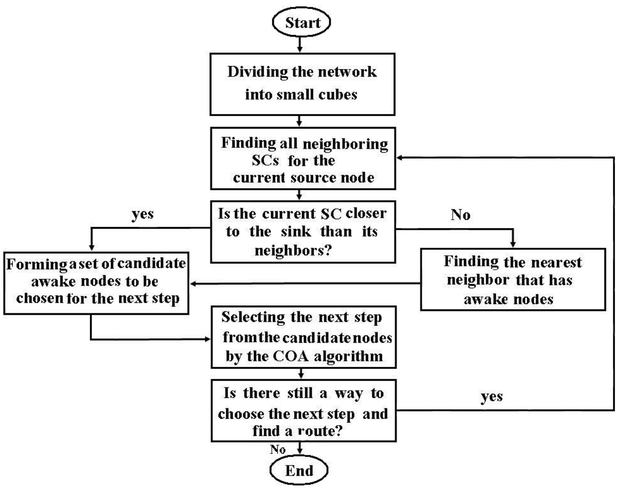


**Fig. 3. Flowchart of the proposed algorithm**

In Eq. (10), μ, κ, τ, ζ are constant coefficients and their sum is equal to 1 and they are used to control weight in the cost function. Also, Cij is defined by

$$C_{ij} = E_{ij}^{rem} exp\left[1/sin\left(\pi - \frac{\pi}{2} E_i^{rem} / E_0\right)\right] \tag{11}$$

In the above relation, $E_{ij}^{rem}$ is the remaining energy of node *i* if sent to node *j*, $E_i^{rem}$ is the current remaining energy of node i and E0 is the initial energy of node *i*. Accordingly, based on the relation (10), the optimal selection of the next step for node *i* through COA algorithm based on the node with the highest energy in the SC is made by

$$J = Arg \max_{j \in \{SC,\, N_d\}} \left(\omega_{ij}\right) \tag{12}$$

Here, $N_d = \alpha N_a$ is a set of all awake nodes in the network according to the duty-cycle mechanism, where $N_a$ is total network nodes and $0 < \alpha \leq 1$ is the duty-cycle parameter. It is worth noting that the larger $\alpha$ becomes, the more paths there are for the next selection, and so the network can route information from the source to the sink through different paths, and this will increase the reliability of the network. However, as $\alpha$ becomes smaller, due to the reduction in the number of candidate routes, an inappropriate path may be chosen for the next step that will use up energy in the candidate nodes, and in this case, the transfer of information from the source to the sink may not happen successfully. This will reduce the reliability of the network.

## 4- Simulation Results

In this section, we will examine the performance of the proposed algorithm and compare it with GGFGD algorithm in two sections of UWSNs' energy consumption and reliability. In this regard, as shown in Fig. 1, a pair of source and sink nodes are assumed for the UWSN. In Table 1, the initial values used in the simulation are listed. It is also assumed that the sensor nodes are randomly distributed and located at different depths (*H*). It should be noted that simulations are performed on average and repeated several times to achieve consistent results.

**Table1. Simulation parameters according to GGFGD algorithm [1]**

| parameters | amount |
|---|---|
| $T$ | 15° C |
| $S$ | 34 ppt |
| $r$ | 50 m |
| $f$ | 10 kHz |
| $d$ | 100 m |
| $T_b$ | 103 bit |
| $E_{elec}$ | 50-9 J/bit |
| $E_{init}$ | 2 J |

In the first part of the simulation, the performance of the proposed algorithm is investigated on energy consumption and the network reliability in a state where all nodes are awake (α=1). In this case, the number of nodes ($N_a$) will vary from 100 to 1000 (100 nodes are added each time). In Fig. 4, the effect of increasing the number of sensor nodes in the network on the number of paths found in the proposed algorithm and GGFGD algorithm is shown. As you can see, in the both algorithms, when the number of nodes distributed in the network is small, fewer paths are found.

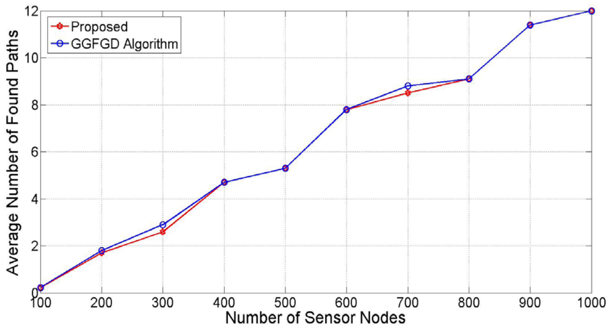


**Fig. 4. The effect of number of sensor nodes on average number of paths found**

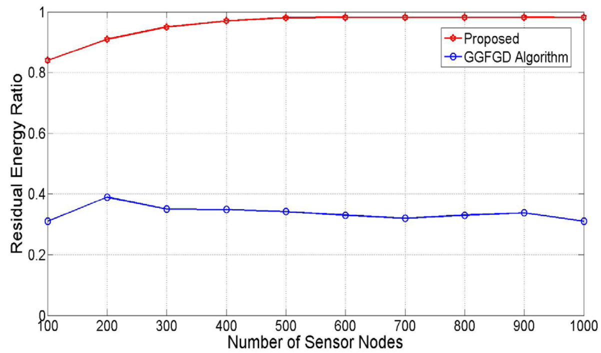


**Fig. 5.The effect of number of sensor nodes on energy consumption**

You can also see that by increasing the number of nodes, the number of paths found is also increased, which leads to increased network reliability and increased speed in finding the path inside the network. It is also noted that the number of paths found and therefore the reliability of the network in both algorithms is almost the same. In Fig. 5, the ratio of remaining energy in the network for the proposed algorithm to GGFGD algorithm is shown. As you can see, the difference between the remaining energy of the proposed algorithm and GGFGD algorithm is significant. The reason is that in GGFGD algorithm, information is sent to the nearest node to the sink located in the radius of the current sensor node which means that the distance from the sensor node to this node is more than that to other neighbors. Therefore, more energy is deducted from the node for data transmission while in the proposed algorithm the remaining energy of the entire network is more since the criterion for choosing the next step is not closeness of the node to the sink but the energy consumption,. Of course, in both algorithms, if the number of sensor nodes is low, more energy is consumed. Because when the number of nodes is low, the distance between the nodes is smaller and therefore the nodes consume more energy to ensure that the packets reach the next steps. Also, when the number of nodes increases, the energy consumption is balanced and shows a gentle gradient behavior. It is worth noting that in GGFGD algorithm when the number of nodes reaches Na=1000, the remaining energy of the network decreases since more energy is used for sending and receiving packets; however, in the proposed algorithm, reduction of remaining energy of the network is not considerable. In spite of improving energy consumption in the proposed algorithm, the length of the paths and, consequently, the propagation delay from the source towards the sink will be longer than that in GGFGD algorithm.

In what follows, we will examine the performance of the proposed algorithm based on the on and off nodes, or the duty-cycle. In this simulation, the value of duty-cycle parameter varies from α=0.1 to α=0.9 and its effect on the number of paths found or the reliability of the network as well as the remaining energy ratio of the network are investigated. In Fig. 6, the effect of duty-cycle on the number of selected paths per sensor node number $N_a$=500 for the proposed method and GGFGD algorithm is investigated. Simulation results show that in both algorithms, increasing the number of nodes in the network will increase the number of paths found, and as a result reliability of the network. Also, simulation results show that when duty-cycle parameter is for example α=0.1, e.g $N_a$=50 nodes are awake in the network, probability of finding a path leading to the sink is very low and, thus, reliability of the network is very low; thus as shown in Fig. 6, the increase of the duty-cycle parameter will grow the number of awake nodes in the network, and consequently, the network reliability increases. It is also noticeable that the proposed algorithm, especially when duty-cycle is between α=0.2 and α=0.6, has a better performance compared to GGFGD algorithm. Fig. 7 shows the variation trend of residual energy ration under different duty-cycle value for the proposed and GGFGD algorithms for $N_a$=100. As you can see, when most nodes are in sleep mode, remaining energy in GGFGD algorithm is higher than that in the proposed algorithm. Meanwhile, by waking about more than half of the nodes, the remaining energy for sending and receiving information in the proposed algorithm is considerably higher than those in GGFGD algorithm. This simulation also confirms that in both algorithms, if the majority of nodes are awake, number of paths found will also be considerable, and consequently energy consumption will increase. It is worth noting that in this case, changes in energy consumption in GGFGD algorithm will be higher than that for the proposed method. As a result, the proposed method, using COA algorithm, has been able to maintain the remaining energy of the whole network at a stable level while increasing network reliability.

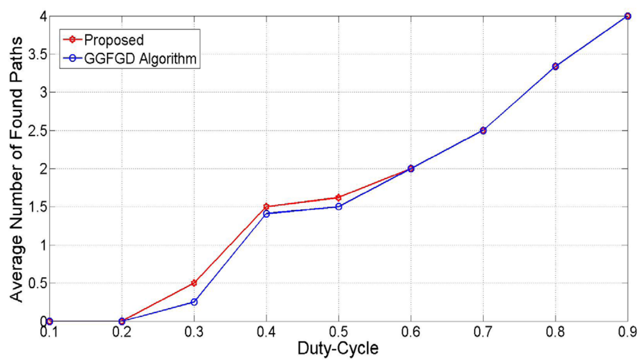


**Fig. 6. The effect of duty-cycle on the average number of paths found.**

## 5- Conclusions

In this study, using COA algorithm, a routing algorithm based on GGFGD algorithm was proposed. In this algorithm, in addition to the benefits of geo-routing, multiple routing techniques were also used to increase the confidence of packages being delivered correctly. Also, using the duty-cycle mechanism, and to save energy, nodes are periodically put at sleep to decrease energy consumption when no data is sent. In GGFGD algorithm, the criterion for transmitting data is based on the nearest path to the destination, which results in a loss of more energy than the proposed algorithm. In the proposed algorithm, by presenting a cost function in COA algorithm, the path selection was done based on energy consumption and the remaining energy of the current node. Simulation results showed that with all nodes being awake, the remaining energy of the network in the proposed algorithm is higher than GGFGD algorithm. Besides, while improving the remaining energy of the network in the proposed algorithm, length of the paths and, consequently, propagation delay is higher than GGFGD algorithm since in GGFGD algorithm nearest node to the sink is chosen, so the length of the paths found is less, and as a result, the propagation delay is reduced. It was also shown that in the proposed algorithm the number of paths found and network reliability, especially in the duty-cycle range from 0.2 to 0.6, is higher compared to GGFGD algorithm. It was also shown that remaining energy in the proposed algorithm is more than GGFGD algorithm, especially when the number of asleep nodes in the network is low.

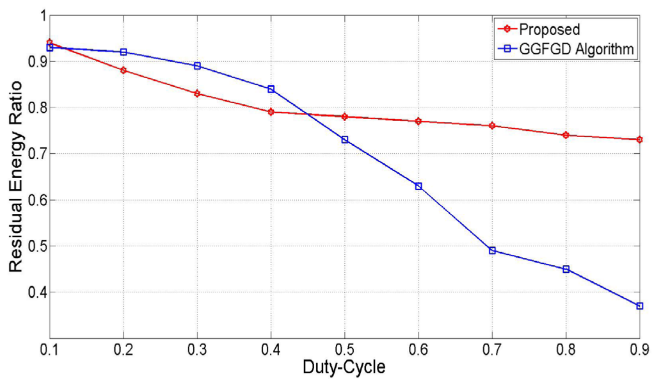


**Fig. 7. The effect of duty-cycle on energy consumption.**

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