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Research Paper

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Energy-Aware Routing in UWSNs Using Cuckoo Algorithms for Improving Network Lifetime

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***Abstract*—**Today, the use of Wireless Sensor Networks (WSNs) is increasingly growing. The WSN consists of a number of sensor nodes that are spread across an environment and communicate with each other to collect information about the target environment. Underwater Wireless Sensor Networks (UWSNs) are a type of sensor network that is located in the underwater environment and communicates with each other by sound waves. These networks have a big number of limited energy nodes scattered in a limited area. Due to the limited energy in this type of networks, increasing the lifetime by reducing energy consumption has always been considered. Most of the nodes' energy is used to send information to the central station. Given that our country has long water borders in the Persian Gulf region, it is worthwhile to be able to monitor this environment. The aim of this paper is to present a cuckoo routing algorithm based on fuzzy clustering in order to properly distribute energy consumption. The results of the simulations indicate the benefit of the proposed method in the number of packets sent and the network lifetime compared to other similar methods. The results show an 18.13% advantage of the proposed algorithm in sending messages and also a 10.34% increase in network lifetime over the SH-FEER protocol.

Keywords—Underwater Wireless Sensor Networks, Cuckoo Algorithm, Routing, Fuzzy Clustering.

I. INTRODUCTION

A wireless sensor network (WSN) is a special type of case network and consists of a number of small nodes capable of sensing the environment [1]. The purpose of these sensors is to process information, store, exchange information with other nodes, as well as adaptability. Usually all nodes are the same and practically work together to achieve the overall purpose of the network. The main purpose of WSNs is to control and monitor atmospheric, physical or chemical conditions and changes in an environment with a certain range [2].

In recent years, the use of underwater wireless sensor networks (UWSN) has been considered to make smart and accurate information from the seas and oceans. UWSNs have very applications, including gathering oceanographic information, pollution control, coastal research, disaster prevention, naval assistance, military applications, and exploration of underwater natural resources. UWSNs are of particular importance due to the special conditions of underwater environments. Underwater equipment equipped with sensors will be able to collect the scientific information they need from underwater. In order to achieve these goals, it is necessary to enable communication between underwater equipment [3].

In UWSN, all sensors move freely with the ocean current, leading to a dynamic network configuration. Thus UWSN is often referred to as a dynamic 3D network, but WSN is a static 2D network. network [4]. Given that most of the node energy is used to transmit information, in the present study, the presentation of a routing algorithm is also considered. Most routing algorithms in sensor networks are based on clustering. In this research, the combination of FCM clustering algorithm and cuckoo optimization is used to find the optimal and reliable path.

In the continuation of this paper, we will review some of the latest researches done in Section II. Section III presents the proposed routing approach. The results of the simulations of the proposed algorithm are given in Section IV and the conclusion is mentioned in Section V.

II. RELATED WORK

Multi-route protocols can generate more paths for routing work. These types of protocols, therefore, can prevent the repetition of a particular link that leads to increased traffic. These protocols also increase the reliability of UWSN. Very papers have suggested multi-path routing in WSNs [5], but these protocols cannot be applied directly to UWSNs. Priya and Kumari [6] developed an underwater multi-route protocol called the multi-route power control transfer protocol. This method intelligently integrates multi-route routing control and power consumption for data transmission. However, in this protocol, route request message consumes relatively much energy, which reduces the capability of this method in UWSN.

Kumar et al. [7] proposed an inevitable opportunistic routing for UWSNs. The OVAR (Opportunistic Void Avoidance Routing) is suggested for UWSN, which varies by recovery mode method based on topology control. The redirection method is performed by adjusting the depth of the empty nodes. Patil and Mishra [8] used the mobicast protocol to reduce power consumption at UWSNs. The mobicast as well as the geocast mobile network focuses on the problem of 3D UWSNs and solves the problem of holes and minimizes the energy consumption of nodes.
Gjanci et al. [9] developed finding a way to maximize the amount of information in multi-purpose UWSNs. In this scenario, the problem is to find a route to the submarine so that the information value (VoI) of the delivered data is maximized. Here is an adaptive-greedy innovative routing (GAAP) for collecting data from VoI-based nodes. Abbasi et al. [10] proposed a rectangular routing protocol for efficient energy balance in UWSNs. The suggested rectangular routing protocol using energy balance (BEER) covers network-level movements and collects data from sensor nodes using direct transmission.

Akbar et al. [11] proposed efficient information collection in 3D linear UWSNs (3D-SM) using a moving sink. In this research proposal, a Mobile Sink (MS) is used as an AUV as well as sever Courier Nodes (CN) to reduce energy consumption in sensor nodes as much as possible. Souiki et al. [12] introduced a fuzzy logic-based clustering approach as well as an energy-based routing algorithm for UWSNs. In this research, two new clustering methods based on c-means mechanisms are proposed. In the first method; the headers are selected according to their proximity to the center of the cluster, and the headers send the collected information directly to the central station. In the second method, the multi-jump mode is used to send information from the head to the underwater sink.

III. METHODOLOGY

In this paper, according to the radio range of the sensors, the sensors are initially randomly distributed with a uniform distribution in the network environment. Therefore, the location of the sensors must be managed in such a way that all sensors are able to communicate with other nodes (at least one node). The scenario of data transmission in UWSNs starts with the sense of environment by the sensors. To reduce energy consumption, sensors in an area transmit the collected information through a single node. In order to determine the regions, sensor nodes are clustered and nodes with close distances are placed in similar clusters. In this research, an improved FCM algorithm has been used to cluster the nodes. When transmitting data over a network, the energy of the nodes decreases over time and eventually runs out. In order to solve this problem, we change the headers according to the amount of energy remaining between the members of the cluster. This technique leads to increases the network lifetime and thus balanced energy consumption of all nodes. In the following data transfer scenario, the data header combines the data received from the members of the cluster and removes duplicate information. Finally, the collected data is sent in the form of a package to the central station. The policy of routing protocols at the central station is different. In this research, a custom cuckoo algorithm is proposed to find the path of packet transfer from threaded nodes to the central station. Finally, after routing and packet transfer, the energy vector is updated.

A. *FCM-based node clustering*

In the clustering of sensors, the radio range of the sensors should be considered. The headers must be on the sensing radius of all member nodes of the cluster to be capable to collect all the information of member nodes. Therefore, each cluster must have at least one threaded candidate node. In the proposed method, we have improved the FCM algorithm in order to automatically determine the number of clusters as well as to create clusters with at least one threaded node. The pseudo-code of this method is illustrate in Figure 1.

Improved FCM Clustering Algorithm
Input: number of nodes (N); Output: Optimal number of clusters (k), members of each cluster (C) and candidate nodes (CH^c)
1. Start 2. Set the number of default clusters to 1 ($\mathrm{k} = 1$). 3. Place all nodes in the radio range of the sink in cluster k ($C\{k\}$). 4. All nodes in the radio radio range belong to the candidate nodes ($CH^c = C\{k\}$). 5. Increase the number of clusters by one ($k = k + 1$). 6. Apply FCM clustering for the remaining nodes with k clusters (N^r number of nodes remaining). 7. Created for k cluster ($C\{2\ to\ k\}$): – Calculate the candidate nodes of the current cluster j (CH_j^c). – Set ω_j equal to the number of candidate sensors in cluster j. – If $\omega_j < N^r.Rate_{CH}$ then go to step 5. 8. End

Figure 1. Improved FCM clustering pseudo-code

B. *Selection cluster heads*

Generally, only nodes that are part of the candidate nodes can be selected as headers. If CH_j^c are the candidate nodes of the j-th cluster; from this, a node is selected as the header that has the least set of distances to the members of the cluster and has at least one of the following two conditions. 1) The remaining energy of that node must be bigger than the average energy of total nodes in the cluster. 2) Have at minim 25% of their initial energy. The emphasis of this method is on the two remaining energy factors and sum of distances sent. In the absence of a node with these conditions, the candidate node with most energy is selected as CH.

C. *Data routing based on cuckoo algorithm*

Depending on the selection of a node from each cluster to send information, in routing, the source nodes are always the headers and the destination nodes are synchronized. Once the origin and destination are known, other nodes in the path are searched by the proposed cuckoo algorithm.

Cuckoo Optimization Algorithm is one of the algorithms developed to solve non-linear optimization problems and continuous optimization problems. The algorithm is inspired by the life of a family of birds called "Cuckoo". According to other population-based optimization algorithms, cuckoo search also begins by creating an initial population. A population consisting of cuckoos. Each cuckoo in the population actually represents a habitat.

The problem coding for each habitat is a one-dimensional array, each element of which represents a node in the path. In this study, the initial quantification of the population is done randomly and with a limited radio range. In creating the initial population for each cuckoo, a path starts from the origin node. In each iteration, one node is added to the last node of the path. The added node is selected from a set of nodes on the radio with random probability (the last path node). If a sink is available in each iteration, the path is completed by adding a sink. If there is a dead end and there are no nodes available to continue the path, the path is removed by the algorithm and created from the beginning.

In the next step of the cuckoo algorithm, the suitability of each nest is calculated. Considering that the purpose of optimizing paths (cuckoos) is to increase the network lifetime. To achieve this goal, two criteria must be considered to reduce the distance to the destination and also the use of high energy nodes in the route. The suitability value of k-th cuckoo is defined as $fp(nest, k)$ in the following Eq. (1).

$$fp(nest, k) = \frac{\sum_{(i,j)\in nest} D_{node}(i,j)}{\sum_{i\in nest} E_{node}(i)} \quad (1)$$

Here, $i \in nest$ is i-th node of the path and $(i,j) \in nest$ is a hop from the $nest$ path. E_{node} and D_{node} are the energy and the distance matrix, respectively.

In the next step of the routing algorithm, the best location for each cuckoo is searched to build the nest. For this purpose, each cuckoo examines the places around it and chooses the best place. The proposed algorithm identifies the optimal local route by examining all the neighbours of each cuckoo. The local search provided is based on two operators. In the first operator, reducing the path length by searching for sub-paths with fewer nodes is considered. An example of this operator is shown in Figure 2.

A hypothetical path	$\boldsymbol{A \rightarrow B \rightarrow C \rightarrow D \rightarrow E \rightarrow sink}$			
Investigate the sub-paths of node A	$A \rightarrow sink$	$A \rightarrow E$	$A \rightarrow D$	$A \rightarrow C$
Investigate the sub-paths of node B	$B \rightarrow sink$	$B \rightarrow E$	$B \rightarrow D$	
Investigate the sub-paths of node C	$C \rightarrow sink$	$C \rightarrow E$		
Investigate the sub-paths of node D	$D \rightarrow sink$			

Figure 2. An example of a path reduction operator by searching for sub-paths with fewer nodes

In the second operator, reducing the path length by looking for alternative nodes in the path is considered. The path length refers to total distances between nodes participating in path. In this operator, for all nodes of the path (except the source and destination nodes, which are fixed), its replacement with all available nodes is checked. Figure 3 shows an example of this operator.

A hypothetical path	$\boldsymbol{A \rightarrow B \rightarrow C \rightarrow D \rightarrow E \rightarrow sink}$
Investigation of node replacement nodes B	$A \rightarrow B \rightarrow C$ $\downarrow$ X
Investigation of node replacement nodes C	$B \rightarrow C \rightarrow D$ $\downarrow$ X
Investigation of node replacement nodes D	$C \rightarrow D \rightarrow E$ $\downarrow$ X
Investigation of node replacement nodes E	$D \rightarrow E \rightarrow sink$ $\downarrow$ X

Figure 3. An example of a path reduction operator by searching for alternative nodes in the path

In the wild, some of these eggs, which bear less resemblance to the eggs of host birds, are identified and destroyed. Therefore, in the proposed algorithm, after creating solutions, pa percent of all eggs are removed with the least amount of suitability. Finally, the total number of cuckoos in relation to the maximum number of population is examined and if there are more of them, cuckoos are removed in inappropriate areas.

In the cuckoo algorithm, the maximum spawning range is determined by the ELR variable. In an optimization problem, the ELR parameter for each cuckoo is calculated in proportion to the total number of eggs, the lower limit (Var_{High}) and the upper limit (Var_{Low}) of the values of the variables. In this research to improve convergence only paths with one change ($ELR = 1$) are created.

In this paper, grouping of cuckoos is done by clustering the suitability of cuckoos using k-means algorithm. By forming groups, the average suitability of each group is computed to obtain the mean fitness of the habitat of that group. Then, from the created groups, only one group that has the highest average value of the objective function is considered as the target group and then other cuckoos migrate to this group. Figure 4 shows the stages of migration of cuckoo i to cuckoo j.

Hypothetical path of the cuckoo i	$A \rightarrow M \rightarrow C \rightarrow H \rightarrow F \rightarrow K \rightarrow sink$		
Hypothetical path of the cuckoo j	$A \rightarrow B \rightarrow D \rightarrow F \rightarrow M \rightarrow C \rightarrow N \rightarrow sink$		
Common nodes of the path in order of position	F	C	M
Apply the ϕ parameter to select a common node	C		
Move cuckoo i to cuckoo j based on common node	$A \rightarrow M \rightarrow \boldsymbol{C} \rightarrow N \rightarrow sink$	$A \rightarrow M \rightarrow \boldsymbol{C}$ $\boldsymbol{C} \rightarrow N \rightarrow sink$	

Figure 4. Stages of migration of cuckoo i to cuckoo j

The ϕ parameter is used to deflect the path and selects a common node as Eq. (2).

$$\Gamma = \lceil (1 - \phi) \times L \rceil \tag{2}$$

Here, L refers to the number of common nodes and $\lceil . \rceil$ is the function of rounding the number upwards. Γ is the index of selected nodes from the list of common nodes.

IV. RESULTS AND DISCUSSION

Our goal in this part is to analyse proposed method and evaluate its performance in increasing network lifetime. In order to simulation the efficiency of proposed algorithm, a comparison with respect to several different criteria has been performed with the model presented in the study of Souiki et al. [12]. This study has developed Single-Hop, Multi-Hop and Direct Transmission models based on fuzzy clustering in UWSNs. In all experiments, the results are an average of 10 repetitions of the algorithm to ensure. The implementation was done by MATLAB and a 7-core Intel CPU with a frequency of 2.4 GHz, 8 GB of memory and Windows 10 Enterprise version. In addition, to calculate energy consumption of each node, energy consumption pattern in UWSNs has been used according to [11, 12].

The same values of energy parameters were used in all experiments and in all methods compared. Table 1 shows the specifications of the energy model parameters used in the experiments.

Table 1. Energy model parameters

Parameter	Value
E_{elec}	$50 \times 10^{-9}\ (Joule/bit)$
ε_{mp}	$100 \times 10^{-12}\ (Joule/bit)$
ε_{fs}	$1000 \times 10^{-12}\ (Joule/bit)$
E_{DA}	$2000 \times 10^{-9}\ (Joule/bit)$
d_0	$\sqrt{\varepsilon_{fs}/\varepsilon_{mp}}\ \ (meter)$
P_0	$0.1 \times 10^{-7}\ \ (Joule)$
f	$25\ \ (KHZ)$

The network topology tested in the simulation is assumed to be an underwater three-dimensional area measuring $100 \times 100 \times 100$ m. 100 nodes are randomly distributed in this area with non-uniform distribution. The sink is the destination of all packages sent in the center of the area and in the coordinates (50-50-50). The Euclidean relation is used to determine the distance between nodes. The amount of energy allocated to all nodes (as initial energy) is assumed to be 0.5 J. This energy is updated for each node after each routing round. The radio range for the sensor nodes in the proposed algorithm is assumed to be 25 meters and 4096 bits of information are sent in each routing.

A comparison of the criteria of the number of packets sent and the network lifetime is given in Figure 5. This comparison is made between the proposed method and other methods. The number of packets sent indicates number of routing cycles that have reached the sink without running out of energy for the participating nodes in the data packet path.

Figure 6 shows the results of comparing the proposed algorithm with other algorithms for measuring the number of living nodes. In general, energy consumption in the form of optimal distribution in proposed algorithm reduces premature energy depletion of nodes. This is due to the priority given to the use of high energy nodes in routing. The rapid decrease of the graph line indicates a large number of nodes with energy close to zero. This is less common in the multi-jump method than in other methods. As mentioned before, the reason for this is that in the multi-jump method, only clustered nodes are used in routing, and on the other hand, not all nodes can be clogged.

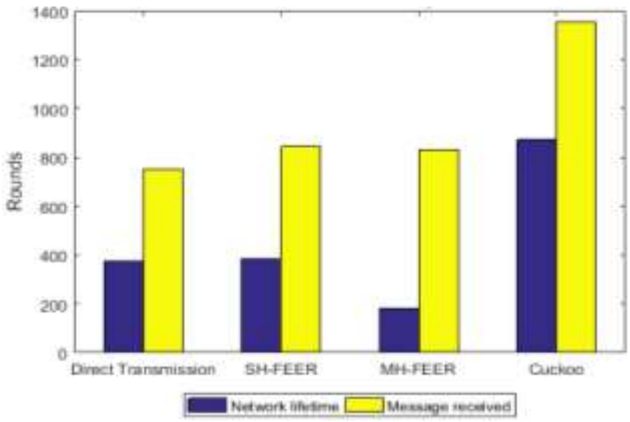

Figure 5. Total number of packets sent and network lifetime

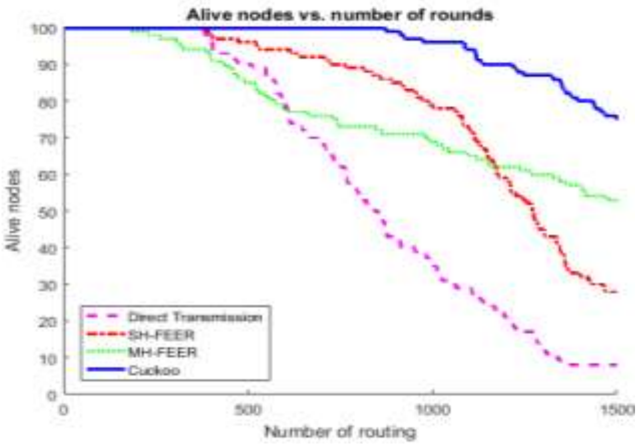

Figure 6. Number of live sensor relative to routing

The simulation results show the superiority of the proposed algorithm in many criteria over most of the compared algorithms. In other cases, the proposed algorithm reports promising results. The reason for this superiority is the optimal distribution of energy consumption by cuckoo search. The proposed algorithm tries to distribute energy properly in some transfers by consuming more energy, which ultimately leads to an increase in network lifetime. Although the proposed routing algorithm tries to improve the network lifetime as well as delay the energy completion of the first node by sacrificing more energy, but this makes the death process by continuing the network lifetime and assuming no replacement of dead nodes other nodes should be done more quickly.

V. CONCLUSION AND FUTURE SCOPE

Using underwater wireless sensor networks (UWSNs) with an optimal routing protocol to transmit information is a challenging issue. The most important goal of these networks is the wise and rational management of energy resources. Controlling the energy consumption of sensors is an active research field. In this paper, a fuzzy algorithm based method for clustering and a custom cuckoo search for routing data in UWSNs were introduced. The proposed method is based on the correct distribution of energy consumption between nodes and ultimately increase the life of the network. The introduction of two path improvement operators in the cuckoo algorithm to search for suitable habitats has increased the efficiency of the final path in transmitting information. In this regard, the proposed algorithm has better results and performance compared to many of the methods studied. In general, our proposed method has reported more promising results than other methods. The reason for the superiority of the proposed method is the proper distribution of energy consumption by the cuckoo optimization algorithm for the routing process.

In this study, the size of the clusters is constant and when setting up the network topology, clustering is done and does not change until the end of routing cycles. Nodes in one cluster may consume more energy than other clusters during data transmissions in the network. This can be considered as one of the weaknesses of the current research and it is suggested for future work that the clusters of each node are not fixed and the clustering be updated in different periods.

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