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A Fuzzy Based Energy Efficient Clustering Routing Protocol in Underwater Sensor Networks

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***Abstract*- The provision of proper routing methods in wireless sensor networks is important due to the sensors' limited hardware and software resources. Some important metrics should be achieved with the use of an efficient routing algorithm, such as low packet loss, improved quality of service, and low energy consumption. Clustering-based routing algorithms have a more efficient performance in the case of link breakages, compared to the other table-based methods. Therefore, a new clustering-based routing algorithm is proposed in this paper that takes the sensors' energy limitation into consideration. The proposed method is designed based on a three-step fuzzy logic. The steps are used to determine the cluster head node and to discover and select a suitable route. In the proposed fuzzy system, the best selection is done based on the existing real-time information. Simulation results show that the proposed method results in a 7% reduction in the network energy consumption simultaneous with a higher packet delivery ratio up to 4% in comparison with IDACB, as the basic algorithm.**

***Index Terms*-** underwater wireless sensor network, clustering, fuzzy logic, energy consumption.

I.INTRODUCTION

The earth is an aquatic planet where oceans occupy around 140 million square miles. However, only 10% of the whole oceans have been discovered yet [1]. Underwater sensor networks (UWSNs) can be used to explore the oceans more. Relative changes of the environmental parameters, such as temperature, pressure and so on can be sensed and presented by sensors. Based on the received information from the sensors, it is possible to survey the environment and control its changes [1,2].

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There are various motivations for the development of underwater wireless sensor networks. Geological processes in ocean level, studying the water specifications that includes temperature, salinity, oxygen, bacteria and its pollution levels, Mines discovery, weather changes forecast, studying the humankind influence on the marine ecosystems, discovering the underwater oil fields are some examples of these motivations [1-5].

In spite of these numerous utilities, several challenges are faced by these types of networks. High and various propagation delays due to very low propagation speed of acoustic waves and limited existing bandwidth are the most important ones. It is notable that the bandwidth is also decreased, as the transmission distance increases. In addition to the above mentioned challenges, the sensors are placed underwater and there are many solutes in the environment. Thus, they are exposed to corrosion. Furthermore, faults in the nodes' communications, high bit error rates, high number of disconnections and high costs are caused by scattering, fading and multipath transmissions. Another important issue is the battery and its energy limitation. It's usually impossible to recharge the batteries. Therefore, energy efficiency should be considered in designing the network protocols. Using of power saving mode in the idle state, indirect routing and clustering are some methods for the power saving in UWSNs [6].

In this paper, a clustering based routing protocol is proposed to improve the energy efficiency while providing good quality of service. In the clustering based methods, selecting a suitable cluster head is crucial for energy conservation. In the proposed method, fuzzy logic is used for routing, cluster head selections and also the relay node assessments. Best choices are gained by fuzzy logic, based on the existing data and with suitable speed.

The rest of the paper is organized as follows: related works pertaining to routing methods based on energy efficiency, clustering, or fuzzy logic in underwater wireless sensor networks are mentioned in Section 2. In Section 3, the proposed method is studied in details, while its simulation and evaluation are explained in Section 4, and finally in the last section, the paper is concluded.

II. RELATED WORKS

An energy efficient localization-free routing protocol for UWSNs (EEDBR) is proposed to consume energy efficiently. EEDBR is a depth-based routing protocol without location consideration. Depth and remaining energy of the sensor nodes are the effective factors considered in routing to send data to the sink by a multi hop pattern. In EEDBR, closer nodes to the sink suffer more traffic load in comparison with farther nodes. Therefore, closer nodes' energy will be depleted sooner and hot spots are created [3].

An energy balanced routing algorithm for WSNs based on virtual MIMO is proposed in [7]. The proposed algorithm has some improvements in cluster selection and energy consumption. It declines the bad effects of cluster head's inconsistent distribution compared to traditional LEACH routing protocol. Remaining energy and recent energy consumption of the nodes are considered in cluster head selection by the algorithm to balance the energy consumption of different sensor nodes.

Network lifetime and energy consumption have been improved by Cooperative Energy-Efficient Protocol for Underwater WSNs (Co-UWSN). Cooperative strategy and signal to noise reduction are the main reasons of improvements. Relay nodes are selected based on link conditions and also the distance between neighbor nodes to successfully cooperate and transmit the packets to the destination [8].

An application-specific protocol architecture (LEACH) is proposed for wireless micro-sensor networks. LEACH is the first clustering based routing protocol for WSNs. The Key idea of LEACH is the random selection of a set of sensor nodes as the potential cluster heads. Cluster head role will be alternately assigned to different nodes of the set to evenly distribute the energy consumption in the network. Cluster heads send the aggregated data to the sink by a single hop communication way. Even though multiple versions of the LEACH protocol are proposed, they are not suitable for UWSNs. LEACH based protocols assumed static sensor networks. Therefore, they cannot be adaptive to the UWSNs' congenital dynamic characteristics such as propagation delays and data rate [9].

An energy aware routing protocol for long lasting applications named Distributed Underwater Clustering Scheme (DUCS) is presented by Domingo and Prior that supports random motion of the nodes too. Although DUCS is simple and energy efficient with high delivery ratio and low network overhead, node's movement due to the water motion is not considered. Cluster's lifetime can be decreased by this movement. Furthermore, a cluster head can only send data to another cluster head in this algorithm. Two cluster heads can become far from each other by the water's movement that cause them not to be able to communicate directly [10].

Location-based Clustering Algorithm for Data Gathering (LCAD) is proposed by Anupama et al. that decreases the energy consumption of the data transmission phase. Sudden energy depletion problem of the nodes, located around the sink was solved in LCAD. However, performance of the LCAD depends on the network’s structure, especially the position of the cluster heads. Efficiency of LCAD was evaluated based on the network lifetime and without any information about the nodes' movement. LCAD is not suitable for the dynamic underwater circumstances [1].

Distributed Minimum-Cost Clustering Protocol (MCCP) is proposed by Pu et al. aimed at more energy conservation and higher network lifetime. Hot spots formation around the sink is avoided with the use of more cluster heads that helps to balance the network load. However, multipath routing is not supported and it will be dependent on routing patterns for the data transmission. Furthermore, it plans to re-cluster the network with a period of several days or several months, which has absolute effects on its efficiency [11].

To resolve sudden energy depletion of the nodes around the sink and to balance the energy consumption throughout the network, Temporary Cluster Based Routing (TCBR) algorithm is proposed by Ayaz et al. In the TCBR, multiple sinks are placed on the water's surface and two kinds of typical and relay nodes are used in the network. The relay nodes have different depth levels and stay in their location for a specific time duration. Data packets are sent to the nearest relay nodes by typical nodes at an appropriate time. TCBR is not suitable for delay sensitive applications [10].

Enhancing the Reliability of Head Nodes in Underwater Sensor Networks (ERHN) is proposed to improve the reliability of cluster heads in UWSNs. It keeps the cluster head's state variables (remaining energy and its operational capabilities) and compensates its loss rapidly. During cluster head selection phase, additional supportive nodes with the same state variables are selected. The whole gathered data that are transferred to the cluster head by the cluster members are kept in the supportive nodes. Cluster head state is controlled by the supportive nodes periodically. If the cluster head has a hardware or software problem, one of the nearest supportive nodes will be replaced. Storage overhead is the main problem of this algorithm [12].

A cluster head selection algorithm based on energy condition, distance and maximum nodes' communication level is proposed in an Improved Clustering Mechanism to Improve Network life in UWSN (ICMIN). A reserved cluster head is also selected based on minimum distance and maximum energy parameters. The replacing cluster head will be activated, only if the main cluster head is died [13].

In [14], an energy-efficient and mobility-based dynamic cluster head selection routing protocol (EE-MDCHSRP) is proposed for UWSN. Nodes' density, remaining energy, and mobility are considered to determine the cluster-head nodes. This paper aims to reduce the response time and power consumption. It also avoids overload and enhances the network lifetime and throughput.

In [15], a new routing protocol (EEARP) is proposed in UWSNs to enhance the performance of the DBR protocol. DBR is a location-free algorithm in which the sensors will send the packets only if it is received from a sensor at a lower depth. EEARP makes a directed acyclic graph with the sink as its root. Sensors gather information such as depth, energy, and the number of their parents. Then, a sensor will send the packets to one or more of its parents. In this way, EEARP improves energy consumption by limiting the number of forwarders.

Under Water Density Based Clustered Sensor Network (UWDBCSN) is also designed for a distributed environment that is based on clustering concept and considers the sensor nodes’ density to select the cluster head. Utilizing of heterogeneous sensor instruments that have different energy capacities is enabled by this algorithm. Communication cost of the cluster head selection is also decreased that leads to overall lifetime increase of the network [16].

An unbalanced clustered energy efficient algorithm, named fuzzy based clustering and aggregation technique for underwater wireless sensor networks is proposed by Goyal et al. In this method, a technique for data aggregation and fuzzy clustering is proposed. Fuzzy logic module is used to manage the uncertainty in cluster head selection and to define the cluster size. In this algorithm, residual energy, distance to the sink, node density, link quality and load amount parameters are considered as fuzzy system inputs. The selected cluster heads operate as data collector nodes. Although delay and energy consumption in the proposed method are reduced and the data delivery ratio is improved, bandwidth is not efficiently used due to the lack of data aggregation technique [17].

In the fuzzy based clustering and energy efficient routing for underwater wireless sensor networks, two new clustering algorithms based on the Fuzzy C-Means mechanism are proposed by Souiki et al. In these algorithms, cluster head role is being changed among the network nodes to avoid rapid battery depletion. Two suggested algorithms have been tested for static and dynamic arrangements. Although the network longevity is increased by the suggested algorithms, considering only the most residual energy for cluster head selection is not a proper choice [18].

In [5], an Improved Data Aggregation for Cluster-Based underwater wireless sensor networks (IDACB) is proposed. In IDACB, a suitable solution to collect and transmit data to the base station is proposed with the aid of clustering and data aggregation methods along with sleep-wake up techniques. Intra and inter cluster collisions are also avoided in aggregated data transmission through the use of Time Division Multiple Access (TDMA) based transmission schedule. IDACB is selected to be compared by the proposed algorithm due to its similarity in the usage of clustering and also the date aggregation.

III. PROPOSED METHOD

The proposed method includes three fuzzy logic systems, each of which is used to analyze a section of the method. Network sensor nodes are informed of the network initialization by receiving the massage broadcasted by the sink node. After that, sink selects several nodes as the initial cluster heads, considering the nodes’ depth and also their distance from the sink node.

It is notable that each node’s depth is available by its depth meter and nodes' direct distance from the sink can be calculated by Equation 1.

$$D_n = V.\ t \tag{1}$$

Here, D_n is the distance of node n from the sink. *V* is the acoustic wave speed and it is considered 1500 meters per second and t is the required time to send a packet and receive its response.

Finally, some initial cluster heads are selected by the sink by taking the mentioned parameters into consideration. After that cluster heads’ advertisement message are sent to the non-cluster head neighbor nodes. The ordinary nodes that received this advertisement message, select the nearest cluster heads and send a join-request message to the selected cluster heads and finally, cluster members are determined. After a while, data are collected by non-cluster head nodes and are sent to their associated cluster head. For this purpose, a TDMA-based scheduling method is used by the cluster head. Now, every cluster head should send the aggregated received data to the next appropriate hop toward the sink. Next appropriate hop selection is done by the first fuzzy system in the cluster heads. A message is sent by each cluster head to its neighbors, and their energy level and also their link quality are requested. After the reception of the requested information from the neighbors, the fuzzy system will be used to select the next suitable hop. State of the network and the nodes' energy level are being changed by the time to which the proposed method is adapted. Energy level of the cluster head and the average energy level of the cluster nodes are continuously monitored. When energy level of the cluster head becomes insufficient and average energy level of the other cluster nodes is still higher than the threshold energy level, algorithm will enter the second fuzzy system to choose another suitable cluster head from the other cluster members. Threshold energy level is considered equal to 20% of the assumed initial energy. This limit has been selected after a sequence of simulation runs with different values of threshold level. It is worth noting that if the average nodes' remaining energy is higher than the threshold value, cluster structure will be kept but the cluster head will be changed to maintain the network stability. If the cluster head remains unchangeable, its power will be depleted soon, due to the frequent transmissions of data. To select a new cluster head in the clusters, energy, depth and distance of the nodes to the sink are considered in the second step of fuzzy system and finally, the new cluster heads are selected and replaced the old ones. After making necessary changes, the nodes are informed of the changes and the same procedure will be continued for the data gathering and transmission. However, if the average energy of the cluster members is less than the threshold, the third step of fuzzy system will be started. In this step, as the cluster members have low energy levels, no one is suitable to be the cluster head. Therefore, relay node is used to send the data towards the sink. The proper relay node is selected by fuzzy logic based on the nodes' average delay (including processing, queuing, transmission and propagation delays), nodes' distance from the cluster head, node's energy level and clusters' density in the proximity of the candidate relay node. After the selection of the relay node, data packets are sent to it and the first step of fuzzy system is used to select the next transmission hop, as before. As it is obvious, the relay node is a supportive node in the data transmission which takes the cluster head's place. This cluster head has data to transmit but it's unable to send data, due to the lack of energy. The flowchart of the proposed method is shown in Fig. 1.

Since the parameters' behavior related to the decision process of the fuzzy selections are based on the Mamdani method, triangular model is used in the proposed method. Each step's related parameters enter the proposed fuzzy system and after the adjustment with the fuzzy rules, fuzzy system's outputs are generated that will be considered as the node's cost ($NC_{(n)}$) that is the system's Fuzzification.

The node's cost is calculated by Equation 2 [18].

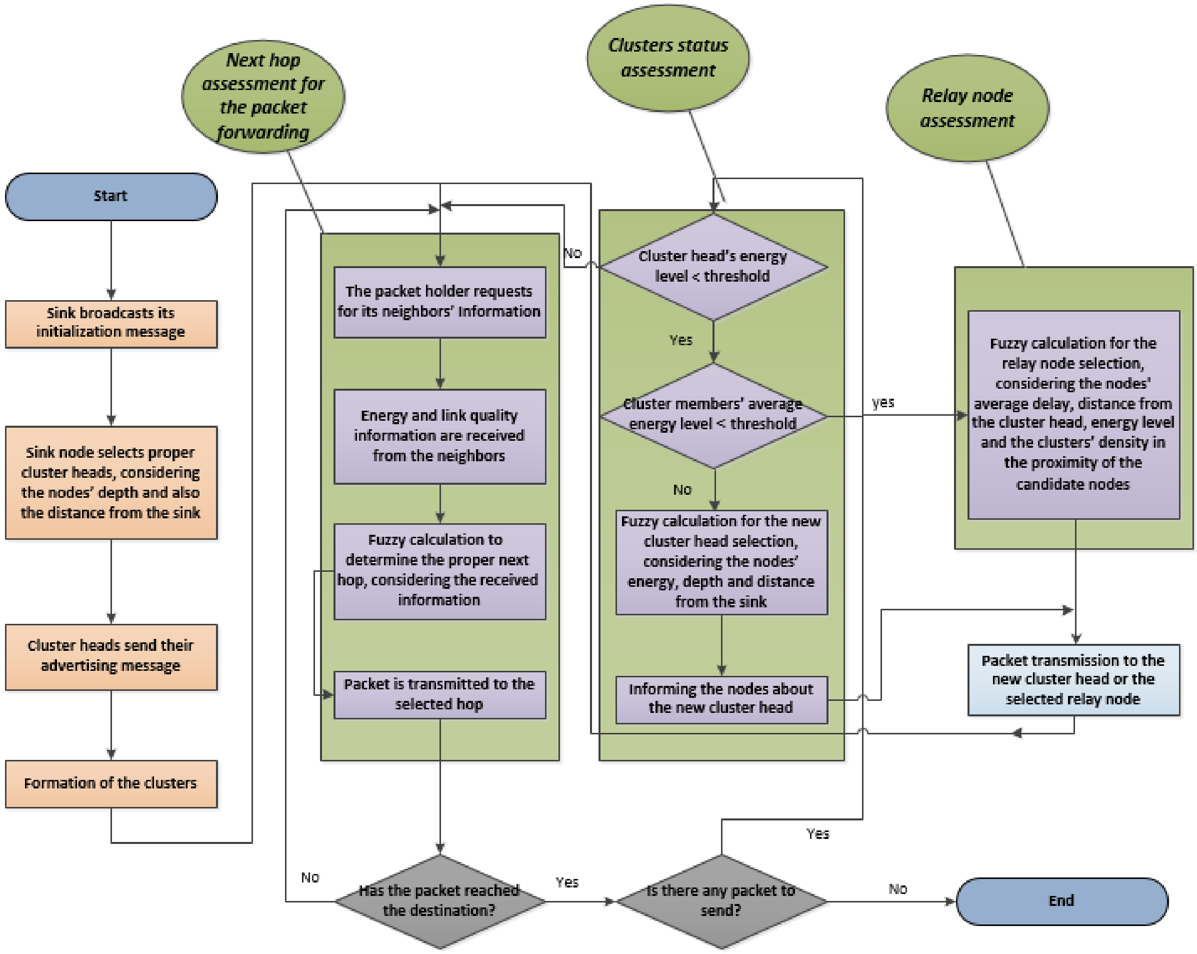

Fig. 1. Proposed method's flowchart

$$NC(n) = \frac{\sum_{i=1}^{n} U_i \times C_i}{\sum_{i=1}^{n} U_i} \tag{2}$$

In the above equation, n presents the number of rules, U is the fuzzy quantity of each rule, and C is the weight coefficient of each rule that is elicited based on fuzzy rules. In one step, for instance, the input variables are defined as the node's depth, its distance from the sink, and the node's energy. Since every input can take 3 different values, the total number of fuzzy inference rules in the system will be 3 * 3 * 3 = 27.

Finally, the sensor node with maximum amount of $f(n)$ (Equation 3) will be the best candidate node to participate in the routing process. According to Equation 3, fewer hop count from the sensor to the sink can affect $f(n)$ and higher $f(n)$ indicates higher energy, lower distance to the cluster head, fewer delay and higher density. This can leads the sink to be accessible with fewer hop counts (Defuzzification).

Table I. Simulation parameters

PARAMETERS	IDACB	Proposed method
QUEUE TYPE	TAIL DROP	TAIL DROP
NETWORK DIMENSIONS	1500*1500*1500 M^3	1500*1500*1500 M^3
SIMULATION TIME	100 SEC	100 SEC
SET UP TIME	10 SEC	10 SEC
POSITION OF THE SINK	WATER SURFACE	WATER SURFACE
INITIAL ENERGY OF THE SINK	1000 J	1000 J
TRANSMISSION RANGE OF THE SINK	1000 M	1000 M
NUMBER OF NETWORK NODES	10,30,50,70,90	10,30,50,70,90
THE INITIAL ENERGY OF A TYPICAL NODE	100 J	100 J
TRANSMISSION RANGE OF A TYPICAL NODE	400 M	400 M
PACKET SIZE	128 BYTES	128 BYTES
QUEUE LENGTH	200	200
THE AMOUNT OF ENERGY REQUIRED FOR THE PACKET TRANSMISSION	0.5 J	0.5 J
THE AMOUNT OF ENERGY REQUIRED FOR THE PACKET RECEPTION	0.15 J	0.15 J
NETWORK TRAFFIC'S TYPE	CBR	CBR

$$f(n) = \frac{1}{MinHop} + NC(n) \tag{3}$$

IV. SIMULATION AND RESULTS

The efficiency of the proposed method is evaluated by the NS2 simulator. Sensor nodes are randomly deployed in the environment and inter-cluster and intra-cluster communications are considered based on TDMA and Code Division Multiple Access (CDMA) respectively. In this section, the proposed method is compared with the IDACB protocol and considering the evaluation parameters of the amount of remaining energy in the entire network, the difference between the number of the sent and received packets, the ratio of the transmitted packets, the normalized routing load, the number of lost packets of the network, and the operational power of the algorithm. Simulation runs with different seed numbers are done 10 times for each scenario, and the collected data over these runs are averaged to be shown as the simulation results. Since the protocol is designed for delay tolerant applications, delay-related parameters are not considered in the evaluation. The simulation parameters are set as shown in Table 1.

A. Average remaining energy of the network's nodes

One of the most basic and controversial parameters is how to use the energy of the network nodes in UWSNs. The average remaining energy of the nodes after 100 seconds of the protocol run is shown

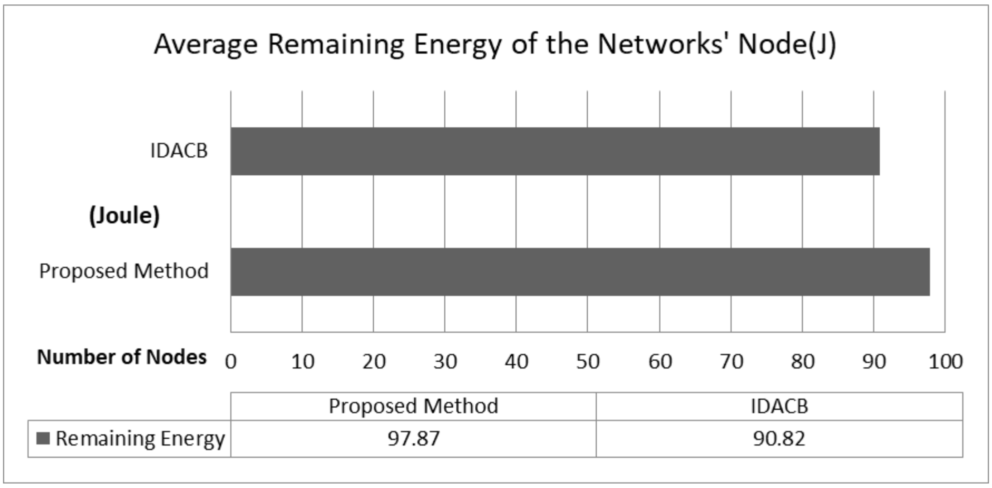

Fig. 2. Node's average remaining energy after 100 seconds of the protocol run

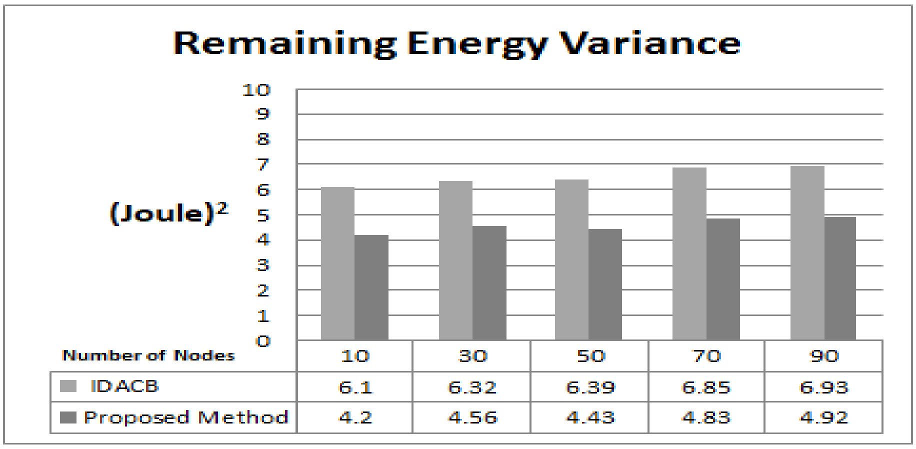

Fig. 3. The variance of the nodes' remaining energy after 100 seconds of the protocol run

in Fig. 2. For example, the energy consumption of the proposed method has improved 7% compared to the IDACB protocol, under the same conditions and with 50 nodes. Network load balancing, as well as the usage of the energy-aware routing, has led to such an improvement.

B. The variance of the remaining energy of the nodes

This parameter is used to investigate the uniformity of the nodes' remaining energy distribution after a period of 100 seconds. The less the numerical value of the nodes' remaining energy variance is, the evener the distribution of the energy consumption will be. As shown in Fig. 3, the proposed method's performance is 29% better than the IDACB protocol. The use of clustering and fuzzy logic has led to such an improvement.

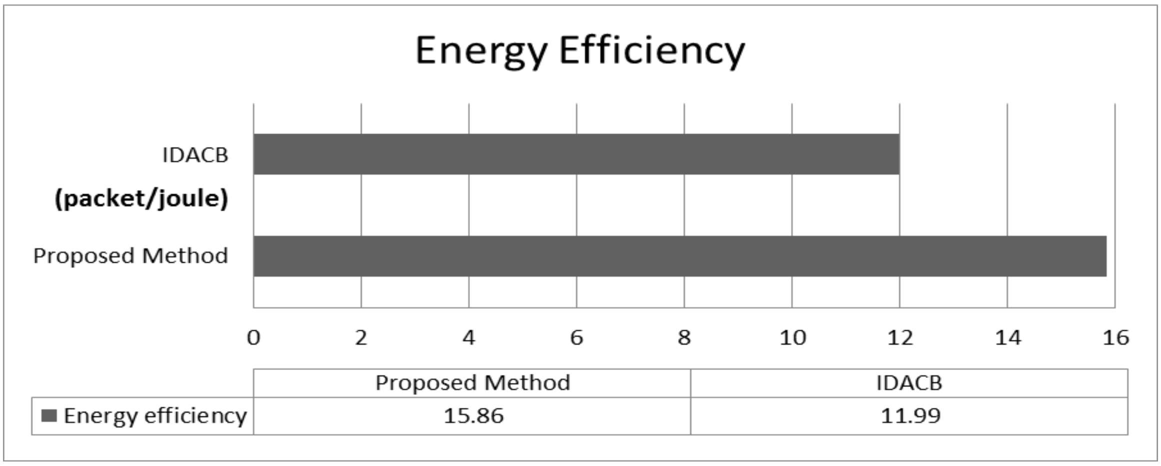

Fig. 4. Number of delivered packets per joule (energy efficiency) in the 50-node scenario

C. Energy efficiency

Energy efficiency is defined as the number of delivered packets per 1 joule of energy consumption. It can be computed as Equation 4:

$$Energy \cdot Efficiency = \frac{Number \cdot of \cdot delivered \cdot packets}{Total \cdot energy \cdot consumption} \tag{4}$$

The energy efficiency is shown in Fig. 4 in the 50-node scenario. As it is obvious, the proposed method has higher energy efficiency compared to IDACB.

D. Packet delivery ratio

Packet Delivery Ratio (PDR) is calculated by Equation 5.

$$PDR = \frac{No.of.received.packets}{No.of.sent.packets} \times 100 \tag{5}$$

In fact, it is the ratio of the packets received at the destination to the total transmitted packets in the network.

As shown in Fig. 5, the package delivery ratio for 2500 packets in the network, the proposed method is better than IDACB. The reason for this improvement can be seen in the use of proper clustering in the network.

E. Normalized routing load

Another evaluated parameter is the routing load that is calculated by Equation 6 [20]. The proposed method has operated better than IDACB as it is shown by the simulation results. In the other words, the normalized routing load is the proportion of the total number of sent and forwarded packets to the

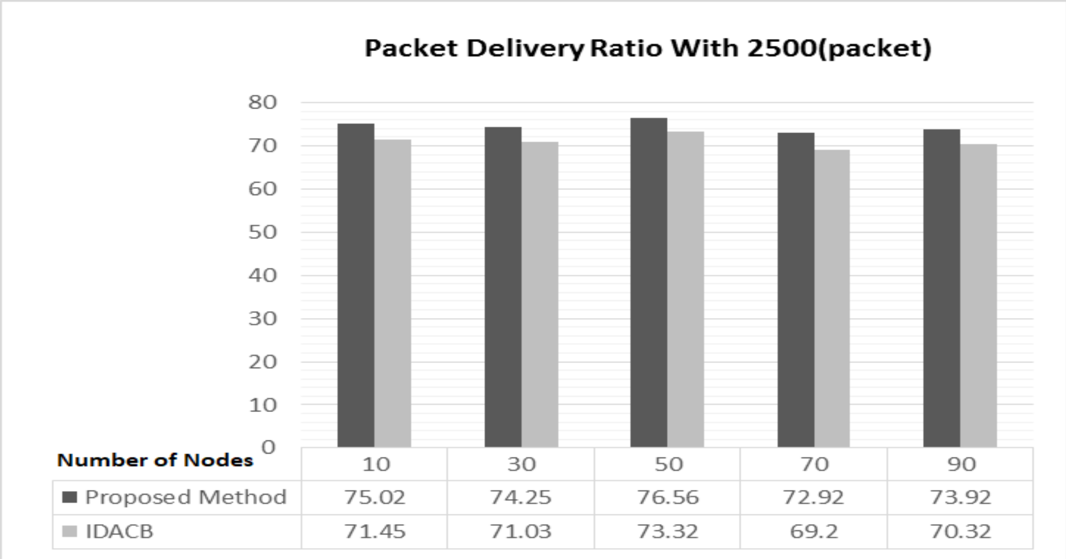

Fig. 5. Packet delivery ratio versus different numbers of network nodes

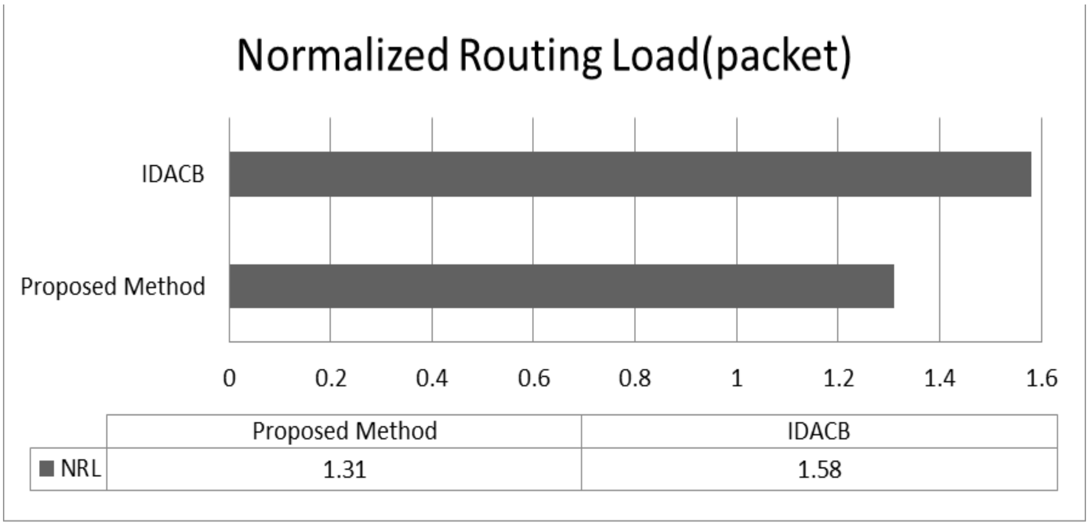

Fig 6. Network routing load in a 100 Sec of the protocol run in the 50-node scenario

number of received packets in the network. Definitely, network and also energy efficiency will be higher with less routing load in the network.

$$NRL = \frac{No.of.sent.packets + No.of.forwarded.packets}{No.of.received.packets} \times 100 \tag{6}$$

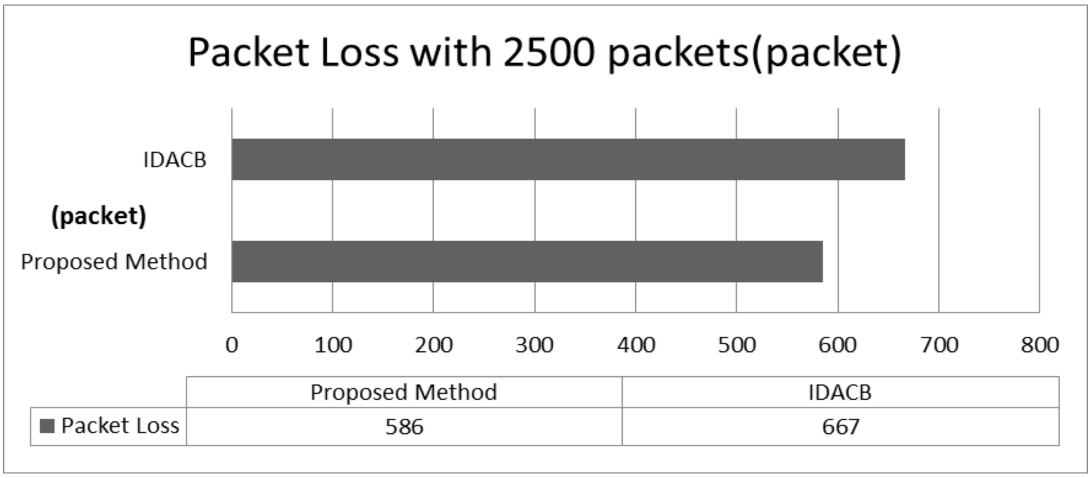

Fig 7. The number of packets lost in the network after 100 seconds of the protocol run in the 50-node scenario

As shown in Fig. 6, the proposed method has a better performance than the IDACB protocol up to 17%.in terms of the amount of routing load in the network.

F. Number of lost packets

When the routing algorithm operates well in transfering the data packets, the number of lost packets will be decreased. There are different reasons of data loss in UWSNs. Some of the important ones are link breaks, end of intermediate nodes' energy, congestion, and long delays.

Based on Fig. 7, the proposed method outperforms DABC up to 12% in terms of data packet loss too.

V. CONCLUSION

In this paper, a cluster based routing algorithm was proposed in under water sensor networks. It was designed to be efficient in energy consumption along with high packet delivery ratio. Proper cluster head selection has great impact on the energy consumption of the network nodes. In the proposed method, fuzzy logic systems are used for routing and also the clusters and relay nodes' status assessment. In the proposed method, some initial cluster heads are selected by the sink node. Data are collected by non-cluster head nodes and are sent to their relative cluster head. The received data are aggregated by the cluster head and are sent to the proper next hop. The next hop is selected through a fuzzy logic system by considering the energy and link quality status information of the neighbors. The network will continue till the cluster head's energy level becomes low and if the average of other members’ energy level is still higher than the threshold energy level, the algorithm enters its second step fuzzy to select another cluster head. The new cluster head is selected among the other cluster members, considering as the nodes' energy, depth and also the distance between each node and the sink. Afterwards, similar procedures will be continued for the data transfers. But if the average energy level of the cluster nodes becomes less than the threshold level of energy, the algorithm enters its third step fuzzy system. Proper relay node is selected by this fuzzy logic step to take the data forwarding responsibility in the network. Nodes' average delay, their distance from the cluster head, their energy level and the clusters' density in the proximity of the candidate nodes are the parameters that are considered to select the suitable relay node. As it is shown by the simulation results, the proposed method operates better than IDACB in terms of nodes' remaining energy, load balancing in the network, energy efficiency, normalized routing load, and packet delivery ratio.

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