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An Efficient and Energy Aware Routing Protocol for Underwater Wireless Sensor Network

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Abstract:

The study of oceanic atmospheres has been enhanced by the use of the Underwater Sensor Networks (UWSNs), which require acoustic channels for node-to-node communication since they are appropriate for use in underwater environments. UWSNs are distinguished by the placement of sensors at various depths in the sea and differ from the terrestrial networks. This research incorporates an EA in the UWSNs to improve the transmission efficiency in the network system. In particular, the Energy-Aware Clustering Protocol for Underwater Sensor Networks (EAC-UWSN) is improved with help of evolutionary approaches. The proposed Evolutionary Density and Grid-based Clustering Algorithm (EDA-UWSN) is a two-step process of using grid and density-based to find out the dense cells and then to clusters them optimally. The algorithm uses the probabilities of cluster generation to change transmission protocols and thereby increase efficiency. The analysis of simulation results proves that the proposed EDA-based clustering algorithm provides better performance comparing to traditional UWSN and improves the communication in the underwater networks.

Keywords: Grid based cluster, density-based cluster, sensor network, fitness function, cluster generation, population.

1. Introduction

The increasing research interest in Underwater Sensor Networks (UWSNs) is rooted in their increasing applicability in a wide range of fields, mainly military, industrial and environmental resource management [1, 2]. These networks, aside from the terrestrial ones like surveillance and navigation, are designed to address the problems of the underwater world. The increasing use of oceanographic applications has thus contributed to a need to improve the underlying protocols and the way networks are deployed to improve on performance and operation [3, 4].

UWSNs used the radio frequency for communication; however, owing to the high attenuation and poor range of the radio signal in water, acoustic signals are subsequently used [5]. However, acoustic signals are not without their drawbacks; major of which include; a low bandwidth, high signal attenuation and considerable delay in signal transmission [6]. Furthermore, UWSN nodes are battery operated and recharging them underwater is very much difficult hence the need for efficient power consumption. The mobility of nodes is another issue in the underwater environment because water flow and pressure are different underwater depending on the depth [7].

Static routing techniques fail to cope with such issues in most cases thus causing inefficiency in routing as well as high energy consumption. Multi-hop routing schemes have come up as a feasible solution to the problem since they bring advantages such as low overhead, energy and delay in transmission. Such schemes allow to better manage the network's limitations and utilise resources more effectively, whatever they may be. Besides, collision avoidance procedures contribute to reduction of retransmissions and other transmission problems, as well as boosting the availability of the network [8].

In light of these challenges, this paper proposes an evolutionary based approach that enhances the UWSN by combining the grid and density based clustering approaches [9]. One of the approaches that has been proposed is the partitioning of the transmission range into a number of grids in which the nodes are placed. Cells with no nodes are referred to as inactive and are not included in the transmission process thus freeing resources to areas with nodes [10-15]. The clustering and the data transmission is influenced by the number density of nodes in every grid cell. The density calculation derived from the number of nodes, whereas the approach improves the transmission and the clustering actions [16]. Also, probabilistic updates are applied to fine tune the transmission processes and improve the routing and decrease the latency [17-19].

While the proposed evolutionary-based clustering approach solves issues that the previous methods have, it also enhances the general performance of the network [20]. The proposed method is free from the limitations of the energy consumption, bandwidth and the dynamic nature of the underwater environment when both grid and density-based techniques are used. The results reveal the improvement in the routing efficiency, less latency, and better reliability of the communication which shows the usefulness of this approach for the efficient deploying of UWSN. Thus, further development of the clustering and routing algorithms will become a critical factor in the further development of UWSNs and related applications [21].

The rest of the paper is organized as Section 2 gives the related works of UWSN, Section 3 explains Integration of Evolutionary Algorithm and EDA cluster for UWSN, Section 4 shows the analysis of simulation, section 5 concludes the paper and references are at the reference section.

2. Related Works

Channel Aware Routing Protocol (CARP) for UWSN was proposed in [22], this scheme uses the cross layer routing method. CARP had improved the quality of the transmission link. Node poses successful transmission history was considered as a relay node. Transmission was accomplished around the shadow and null zone. CARP also had the capability to combine the links having high quality with the help of topology. CARP was also efficient in power control mechanism. Optimized On-Demand Multi-cast Routing Protocol (ODMRP) for UWSN was explained in [23]. In the UWSN due to the varied nature of the environmental context the network faces the latency problem and the shadow zone issue. ODMRP uses the multi-hop and route-discovery-suppression schemes for data transmission and overcome the shortcoming of the network. Delay and shadow zone problem is solved with the ODMRP scheme. Energy Optimized Path Unaware Layered Routing Protocol (E-PULRP) was proposed in [24]. It used the on the fly routing strategy to enhance the performance. The transmission was split as layering phase and transmission phase. In the initial phase, distribution of node across the network is done and the transmission is accomplished in the further phase. Throughput and the latency of the network were achieved with the E-PULRP.

Void-Aware Pressure Routing (VAPR) for UWSN is proposed in [25]. It is a location and pressure based protocol. Transmission of data was initiated with the depth information and pressure gauge. 3D voids were efficiently handled using the sparse coverage area. VAPR uses the information about the depth, hop count and the sequence number of the packet. The transmissions were established even in the regions of void. In this work robust routing strategy and loop freedom network achieve efficient rate of packet delivery. VAPR had shown best result over other UWSN protocols. A Machine-Learning-Based Adaptive Routing Protocol for Energy-Efficient and Lifetime-Extended for UWSN (QELAR) was developed by the [26]. In order to handle the characteristics of UWSN an effective protocol design is projected. An effective routing, adaptive lifetime and energy management were considered in designing the protocol. Effectual forwarders were elected using the reward function that is estimated with the help of residual energy distribution among the nodes. QELAR shows the better lifetime than the other UWSN protocol [27, 28].

3. Integration of Evolutionary Algorithm and EDA cluster for UWSN

Deployment strategy of UWSN is established by placing the nodes at several levels of the sea. Due to the vast distribution and under water nature made the transmission process complicated. UWSN is entirely diverse in nature from the terrestrial approaches. In order to attain the successful transmission Evolutionary Algorithm (EA) is embedded with the UWSN. The newly proposed EDA based UWSN uses a blend of two approaches grid and density based technique which eventually discover dense cell and relevant clusters. For the complicated problems, retrieval of the solution is executed using the optimization scheme called Evolutionary Algorithm (EAs). An EDA clustering segregates the cluster method that identifies the clusters using the deployed network. EDA clustering algorithm spots the compact areas in the network, which is definite to the adjacent portions of the cells with high density. The cluster discovery is initiated at the midpoint of cluster set.

The EDA Clustering incorporates the grid and density based approach for the generation of clusters. Definite high compact cells are spotted by the algorithm and the identification process is initiated at the small portions of cells to the midpoint of the cluster. Based on the threshold value density of the cluster is maintained and the progression of cluster development is iteratively includes the cell.

The acoustic power Aq(D) is obtained by the spectral density which is embedded with the propagated acoustic signal $ASi_l(frq)$ over the frequency with the bandwidth $BW(D)$ of

$$Aq(D) = \int_{BW(D)} ASi_l(frq)\, df \text{ --------- (1)}$$

The recipient side signal is influenced by the compactness of the noise, power spectrum, acoustic range, and attenuation. The ratio for the noise to signal is signified in equation 2,

$$SNR(D, frq) = \frac{ASi_l(frq)}{NL(frq)AL(D, frq)}$$

$$ASi_l(frq) = SNR((D, frq)\frac{NL(frq)}{AL^{-1}(D,frq)} \text{ --------- (2)}$$

where the intensity of an acoustic range is $ASi_l(frq)$, intensity of attenuation is $AL(D, frq)$, level of noise is $NL(frq)$.

With the log scale sum of the attenuation acquired is characterized in equation 3

$$10\log\frac{AL(D,frq)}{A_o} = k \times 10logD + D \times 10\log a(frq) \text{ --------- (3)}$$

where the unit for the factor of normalization is A_o, the spreading factor is k which is expressed as 2 for spherical, 1.5 for practical and 1 for cylindrical.

The absorption coefficient is characterized with the Thorps formula $a(fr)$ in dB/Km and for frq in kHz as

$$10loga(frq) = \frac{0.11frq^2}{1+frq^2} + \frac{44frq^2}{4100+frq^2} + \frac{2.75frq^2}{1000+ frq^2} + 0.003 \text{ -------- (4)}$$

Fluctuation in transmission is raised due to the fact like noise due to thermal effect, wind, turbulence and shipping. The approximation is established in equation 5;

$$10logNL(frq) = 50 - 18\log frq \text{ -------- (5)}$$

The range of power and signal that occupied the certain distance over the cases of the level of an acoustic signal, attenuation and noise for certain bandwidth for equation 1 and it is reduced as,

$$E(D) = B_3(D)AS_l(fr) \text{ --------- (6)}$$

Acoustic signal range from equation (2) is substituted to (6) which eventually presented the acoustic power in (7). Detection of the signal at the recipient side must be greater than the threshold stated by the ratio of signal to noise which is travelled a certain distance in the network area.

$$E(D) \approx SNR_o B_3(D)\ \frac{NL(fr)}{AL^{-1}(D,fr)} \text{--------- (7)}$$

Construction of Cluster

In the initial all the nodes are arranged in the multidimensional grid. Every cell in the grid posses the equal portion of size and intervals. Based on the point of the grid volume and density measure of the cluster is assigned.

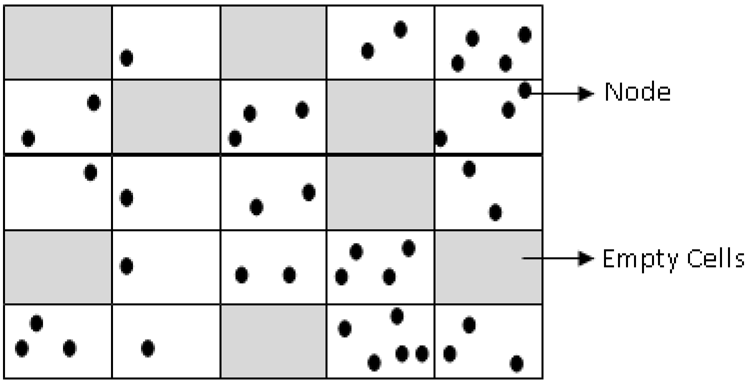

Figure 1. Representation of node in the Grid

The above Figure depicts the construction of data grid with five intervals and the nodes are positioned using the intervals.

Representation of Nodes in the Grid and Fitness function

An individual node in the grid is signified based on the cluster center which is accomplished using the EDA algorithm. Every individual node N placed in the matrix X (n*g), where Number of nodes in the grid is n. the cluster group is g and the interval of the grid is f. The fitness function of node N is correlated with the cluster's density. Average and correlated density of the fitness function is represented in the equation (8) and (9).

$$Density\ of\ the\ cluster = \frac{Number\ of\ nodes}{Number\ of\ cells} \text{-------- (8)}$$

$$Fitness = \frac{\sum_{N=1}^{g} Density(N)}{g} \text{-------- (9)}$$

Population Generation

New population is generated in accordance with the prior models and at every generation of the algorithm. Consistent distribution is pertained for variable. Probability of node updation is initiated by,

$$p_N(Y) = (1-\alpha)p_N(Y)' + \alpha \times p_N(Y)'' \text{-------- (10)}$$

where $p_N(Y)'$ is the probability value for prior iteration, $p_N(Y)''$ is the probability value for current iteration and for the α is ranges from 0 to 1.

Algorithm 1. Data Transmission based on threshold
Procedure build cluster (centerXk)
Initialize the maximum distance value
R ←1 (distance in number of cells between a data item and the cluster center)
Create a cluster Cxk containing all data items within a maximum distance R from the centerXk
Calculate the density (Cxk) for cluster Cxk
Current Density = density (Cxk)
Repeat until the density decrease is above a threshold
R ←R + 1
find a node to node distance value

```
        If (distance value > = maximum distance value)
                Store the distance value and check minimum energy value
        Else
                Increase the distance value to maximum value node elects the cluster process
        For each data item I
                Dxki← distance to the centerXk
                If Dxki<= R
                        Add I to Cxk
        Calculate a new density (Cxk) for the cluster Cxk
        If (1 – (density (Cxk) / current density)) >= threshold then
                Remove all recently added items for Cxk
        Else
                        Current density = density (Cxk)
End
```

4. Analysis of the Simulation

To evaluate the proposed evolutionary-based grid and density-based clustering approach for Underwater Sensor Networks (UWSNs), a simulation using NS-2 is set up with the following parameters: 100 nodes distributed in 3D grid, each grid cell containing a part of the transmission range. Acoustic channels imitate the environment of the water, including signal loss and delay. Multi hop routing protocols take care of data transfer with grid based and density-based clustering algorithms being fine-tuned with the help of evolutionary algorithms. The simulation lasts for 1000 seconds and nodes are assumed to move according to some pre-defined mobility models. Some of the measures of performance are the number of packets that passes through the system per time, the amount of time that the packets take to traverse through the system, the energy used during the system, the ratio of packets that reach their intended destination, and the number of collisions that occurred. TCL scripts are used to set up the network and results are compared with the existing UWSN algorithms for the proposed approach. MATLAB or python tools are applied for data visualization of the simulation results and for the comparison of the enhancements in the network performance and communication reliability [29, 30].

Among the assessment criteria of Underwater Sensor Networks (UWSNs), energy consumption is a parameter that quantifies the total amount of energy consumed by nodes of the network during their work. It includes energy consumed in transmitting, receiving and when in the dormant state. Challenges such as efficient energy consumption are important in the enhancement of the longevity of the battery-operated underwater nodes. Latency is the time taken by a packet of data to travel from the source to the destination in the network. It represents the time that a particular packet spends in the network and is used to determine the level of response of the communication system. Throughput quantifies the amount of data that gets successfully transmitted in a network in each time interval. It shows the capability of the network to manage as well as transmit data within the required time. All these metrics give a holistic view of any given UWSN and show how effectively energy is harnessed and data is delivered at timely and efficient rates.

Table 1. Comparison of Energy Consumption

No of Nodes	VAPR	QELAR	EAC-UWSN
100	11.98	10.78	5.9
200	12.08	10.90	6.123
300	12.24	11.59	6.33
400	12.34	11.98	7.23
500	12.87	12.65	7.5

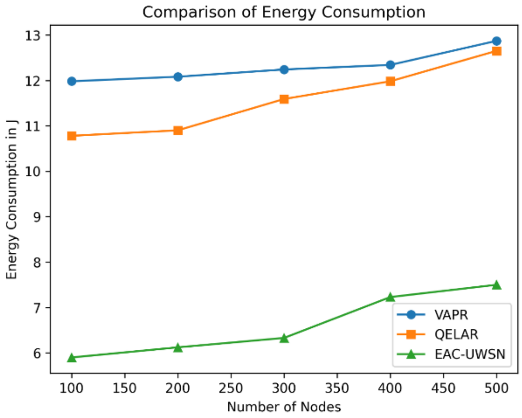

Figure 2. Comparison of Energy Consumption

Table 2. Comparison of Throughput

No of Nodes	VAPR	QELAR	EAC-UWSN
100	0.987	1.334	1.983
200	0.99	1.553	1.94
300	0.102	1.66	1.913
400	0.125	1.745	2.011
500	0.133	1.875	2.1021

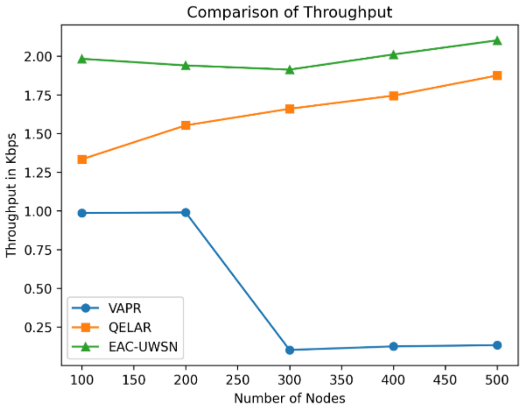

Figure 3. Comparison of Throughput

Table 3. Comparison of Latency in Seconds

No of Nodes	VAPR	QELAR	EAC-UWSN
100	4.324	3.685	1.98073
200	4.465	3.471	1.97991
300	4.567	3.461	1.99975
400	4.982	3.208	1.6898
500	5.029	3.229	1.68971

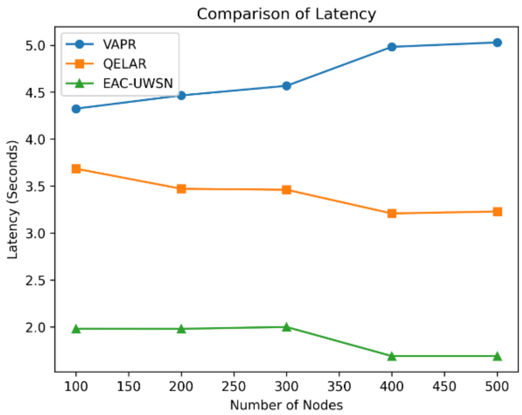

Figure 4. Comparison of Latency

The comparative analysis of energy consumption, throughput, and latency across different algorithms reveals notable differences in performance. Energy consumption, as shown in Table 1, is significantly lower for the EAC-UWSN algorithm compared to VAPR and QELAR across various node densities. For instance, with 100 nodes, EAC-UWSN consumes 5.9 units of energy, much lower than VAPR's 11.98 and QELAR's 10.78. This trend continues as node numbers increase, demonstrating EAC-UWSN's superior energy efficiency. Throughput, as illustrated in Table 2, is higher for EAC-UWSN in most cases, reflecting its better capability to handle data transmission. For example, with 100 nodes, EAC-UWSN achieves a throughput of 1.983, surpassing VAPR's 0.987 and QELAR's 1.334. This trend is consistent across different node counts, indicating EAC-UWSN's effective data handling. Latency, as depicted in Table 3, is considerably lower with EAC-UWSN compared to the other algorithms. At 100 nodes, EAC-UWSN has a latency of 1.98073 seconds, which is substantially less than VAPR's 4.324 seconds and QELAR's 3.685 seconds. EAC-UWSN maintains this advantage across other node densities, highlighting its efficiency in minimizing delay. Overall, the EAC-UWSN algorithm consistently outperforms VAPR and QELAR in terms of energy consumption, throughput, and latency, demonstrating its superior performance in managing underwater sensor network operations.

5. Conclusion

The context of oceanic atmosphere needs the efficient and robust topology as well as the protocol to handle the deployed UWSN. The salinity, water nature and the mobility of the nodes causes several issues. In this research work, Energy-Aware Clustering Protocol for Under Water Sensor Network (EAC-UWSN) protocol is proposed by considering the shortcomings of the previously developed protocols. The Energy-Aware Clustering Protocol for Under Water Sensor Network (EAC-UWSN) is designed using the evolutionary technique called EDA which is a combination of density and grid based clustering. The transmission range is partitioned into equal portions of grids and the nodes are deployed over the grid. Based on the density of the grid data transmission and clustering process is initiated. Density of the cell is estimated with the amount of the node distribution. In addition to this scheme transmission is optimized using probabilistic updation. The routing process is enriched in this scheme and the latency is reduced. In future the protocol is designed the traffic which is caused by the density of the network.

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