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Research Article

Energy-Efficient Markov-Based Lifetime Enhancement Approach for Underwater Acoustic Sensor Network

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The multihop underwater acoustic sensor network (M-UASN) collects oceanographic data at different depths. Due to the harsh underwater environment, the route is a major research problem. In this article, the routing path from source to sink is adapted by the vector-based forwarding (VBF) protocol. In VBF, based on the vector size, the packets are transmitted within the pipe from hop to hop. The limitation is that every node inside the pipe vector receives the same packets. That results in a waste of battery energy and, in turn, reduces the lifetime of the acoustic node. To enhance, in this article, it is divided into two parts. The first part is that the first hop nodes from the source are optimally divided into subsets such that all the second hop nodes will receive packets from each subset. This optimal route cover subset is identified with an evolutionary memetic algorithm. The election of subset is done through a voltage reference model, and the battery voltage is modeled mathematically and the role of the nodes is given based on the voltage profile and Markov probability approach. This method enhances the lifetime of the underwater acoustic network when compared with the VBF algorithm. The proposed model also provides improved throughput and equal load sharing. The results are compared with VBF, quality-of-service aware evolutionary routing protocol (QERP), and multiobjective optimized opportunistic routing (BMOOR).

1. Introduction

Around two-thirds of the earth's planet is surrounded by water. It has been discovered that only five percent of the ocean environment has been explored. In view of that, many researchers and scientists are interested in expanding research in depth. Traditionally, for monitoring the oceans, scientists deploy a manual water buoy at a certain depth to explore the particular area of interest. This leads to the missing out of real time and wide area coverage for monitors [1]. In this light, an underwater sensor network helps to give real-time and dense area data to the sink.

Due to the underwater restrictions, characteristics like different temperatures, pressure, and salinity for different depths lead to crucial communication. Initially, electromagnetic waves were tested for short-distance communication, but it required a large size of antennas to propagate low bits. It is not preferred to communicate for a long distance [2]. Then, the optical wave is used for underwater communication, which results in a lot of reflection and refraction problems. After much research has been done, it is observed that acoustic communication is the best suit for the underwater compared to radio and optical waves. But acoustic signals carry their own disadvantages, like long propagation delay, Doppler effect, multiple sources of noise, and limited bandwidth problems [3]. A lot of emerging applications are employed for commercial, scientific, and military purposes. Depending upon the application, the node sensors are attached with adapting topology like static or mobility. A lot of research is attracted towards static nodes, since the

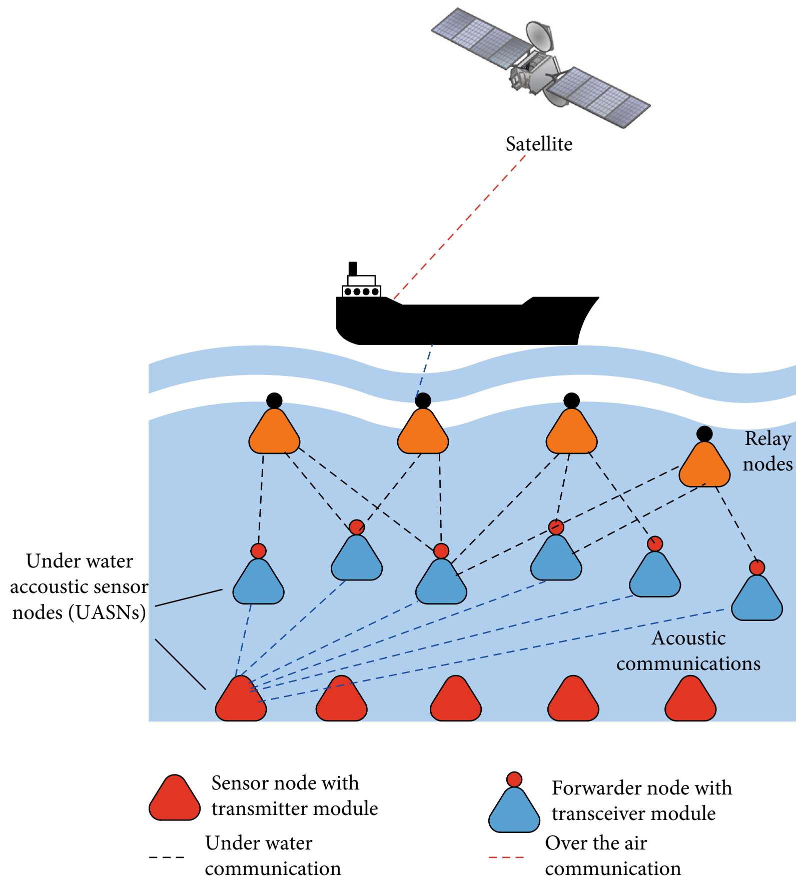

Figure 1: Underwater acoustic network architecture.

practicality of mobile nodes is still in the void zone. In this article, a routing protocol is proposed for anchored semimobility nodes.

Underwater acoustic nodes are deployed with powered batteries for their operations [4]. All those nodes are anchored at different depths where the replacement of batteries is impractical, as given in Figure 1. So it is noticed that the usage of limited energy should be kept under control to enhance the node's lifetime. In this article, the VBF model is adapted for its battery energy dissipation in order to minimize redundant packet transmission, and in-depth mathematical analysis is done in terms of node transmission and receiving the packets. The results have been compared with the VBF, DBR, and HH-VBF protocols.

The remainder of the article is organised as follows: Section 2 analyzes the VBF routing methods. The proposed memetic algorithm is discussed in Section 3. The energy analysis of the proposed method and its comparison with other ones appear in Sections 4 and 5. And, finally, Section 6 provides the results.

1.1. Related Study. To address the energy hole minimization problem, the authors in [5] suggest a three-stage routing protocol, which they describe in detail. In the first step, nodes are placed in circles around a sink node, known as the corona. The nodes in each corona are equidistant from one another, and all corona areas are equally wide. The load weights are generated for each corona in the second stage. Load on a corona influences the node range of that corona. Balanced energy dissipation is easier to achieve with this. In stage 3, real data transfer takes place depending on the established topology and transfer loads. For fixed networks with predefined topologies, this method has successfully lowered energy holes in the coronas around the sink node. It is possible; nevertheless, that performance will suffer due to this method in the event of networks where the topology is unpredictable.

The authors of [6] have developed a cluster-based routing mechanism. To ensure a symmetrical pattern, the nodes are deployed in stages, with the closest layers being narrow and the distant layers wider. The primary goal of this layered structure is to decrease the likelihood of hot spots occurring by the redistribution of node transmission power depending on the node's distance from the sink node. Each layer is made up of clusters of nodes. A cluster head is picked for each cluster by picking the one with the most neighborhood connectivity, the least residual energy, and which is the closest to the sink node. When the clusters are completed, data transmission begins. Based on remaining energy and how far the candidate relay is from the sink node, relay selection occurs. This minimizes the likelihood of nodes losing energy and dying prematurely by decreasing congestion. Contention is reduced by using cluster head parameters according to how far each cluster head is from the sink.

In [7], the authors came up with a data-gathering methodology that relies on clusters. Nodes are spread out throughout a grid and are arranged in hexagons. Residual energy levels are used to choose the cluster heads, which are then determined by their nodes' position inside the cluster. To be more specific, the nodes with the largest residual energy, which are in the heart of the cluster, should be selected as cluster chiefs. [8] has chosen to utilize an AUV, which has a programme that uses ant colony optimization to figure out the fastest paths possible to navigate the maze-like underwater routes, reducing delays and traffic jams. Through better energy management, the suggested method lowers delays and increases network longevity.

The authors' two-stage, depth-based routing method appears in [9]. In the first phase, termed the update phase, nodes update each other on remaining energy, node type, and more. This enables filling out neighborhood tables on nodes which are then utilized in routing decisions, which happens during the second step, routing. Void regions are dealt with by preemptively identifying them at the routing stage. Because the task is done locally, there is no communication overhead. Higher delivery rates are possible by optimally organising the forwarding space so that the node density ahead may be considered.

The authors describe in [10] a two-stage, multisink routing strategy. The layering step of deployment is the first stage and is in which nodes are distributed in concentric layered structures, which is what creates a grid in which a given node may be present in many grids. When the packet delivery ratio (PDR) falls below a particular value, the layers are updated. The communication stage follows the layering step, and in it, each node picks a sink node and builds a path to that sink. For better PDR and energy efficiency, route creation criteria will provide the desired results. This protocol suffers from poor connection resolution methods.

[11] examines an RMCN routing architecture which is well-suited for long-term sensing applications. One-fourth of the entire network area belongs to the sink area, while the other three-fourths belong to the node area. There are equal numbers of stationary and mobile nodes in the node area, whereas there are only sink nodes in the sink region. Candidate nodes are selected on the basis of depth, residual energy, track ID, and a cost function. By using a balance of static and mobile couriers, RMCN provides a great improvement in PDRs while minimizing energy use through a balance of redundancy and adaptation. In instances where RMCN does not work, it is because nodes may be distributed randomly, rather than according to a predetermined deployment strategy, in cases where it is crucial that the system works no matter how the nodes are put, as in cases where nodes are free to move throughout the network.

The authors offer a routing method that collects information from several layers of the system (physical, medium access, and network) to determine how to best route data in [12]. The forwarding decision is determined based on the state of nodes that are two hops away from the sender. Senders choose between three types of nodes: a one-hop forwarder, a relay node, and a two-hop forwarder. Reliability is obtained by using a relay node. The procedure is broken down into three parts. In the first step, community information is sent throughout the network. Stage two involves deciding which routes to take, while stage three is concerned with transmitting the data. This method increases overall dependability, which leads to better PD performance by utilizing redundant relay nodes to improve the reliability of a network, together with a primary forwarder. But it makes things more difficult for others by having to wait for this redundant message every two hops. The extra effort and waiting increase both energy use and difficulty.

The paper [13] describes a single unified protocol to do power control and opportunistic routing (PCR). This method tries to improve PDR. It has three stages of operation: stage one consists of nodes broadcasting information to each other in the form of beacons, using all of their available power levels. During stage two, information collected during phase one is used to choose the prospective forwarders. The next stage considers every potential forwarder and their associated available power levels. It picks a forwarder based on that information. To increase energy efficiency, consumption has to be considered. Stage three takes into account the data and coordination flow to get everything working together. In this way, it balances energy dissipation. Because all transmission power levels are used for beacons, several transmissions of the same information results in a big communication overhead and therefore more contention and increased energy usage. Connectivity gaps and partitions will be created, which will lead to a poor packet delivery ratio. Stage one needs to be completed occasionally, increasing the amount of energy needed dramatically.

Additionally, several additional routing algorithms have been suggested. [14] is a quality-of-service (QoS) protocol that uses a hierarchical organisation to put nodes where they may have the greatest impact on the distribution of traffic and energy dissipation. Cluster heads choose which routes to use and how to use them. These decisions are made on an ad hoc basis and are only influenced by the quality of the connections to other cluster heads. To help when there are nodes that have failed and places where connections have broken, a further transmission range variation is implemented. To increase energy efficiency and load distribution fairness, the authors of [15] provide three routing methods that operate together. Different levels of power, according to many factors including distance, traffic load, and the degree of power generated by the forwarder, are used in forwarding. Residual energy is considered while selecting a forwarder, helping the network get balanced load distribution. In [16], a proposal is made for a reactive source routing method. The ability to trace the journey from start to finish allows the source node to identify its path to the destination. The system uses a stop-and-wait automatic repeat request (ARQ) that finds overcrowded links and unexpected paths, giving it a cross-layer approach.

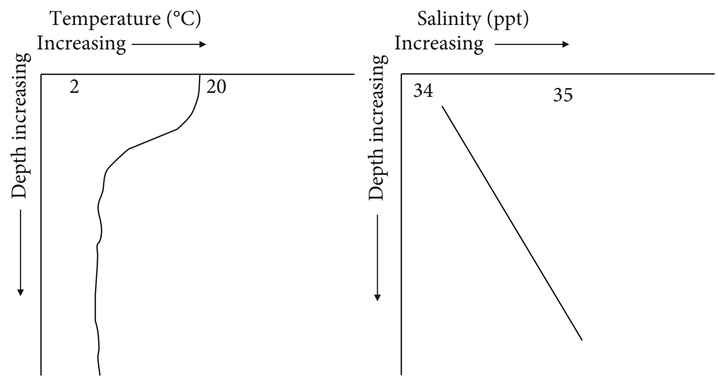

Figure 2: Temperature and salinity variation for different depth.

2. VBF Analysis

Routing underwater is classified into three main categories, namely, proactive, reactive, and location-based protocols. In reactive-based routing, the control packets are broadcast based on the table for transmission. Since the characteristics of the underwater are crucial in nature, such types of protocols are not encouraged for UWASN. In turn, proactive forwards the packet only when the source node is handling the data packets. This protocol also broadcasts control packets for establishment of a path that is not suitable for the underwater environment. The location-based routing is one where each transmits packets based on the next node's location. This minimizes the cost of energy compared to proactive and reactive. Underwater, the location of the node is shared with neighbors with positioning service.

Initially, routing for underwater was experimented with using vector-based forwarding. VBF is a purely location-based routing protocol where each node position is calculated by signal strength or angle of arrival. In the data packet, each node has a sender, receiver, and forwarder identity. Based on the vector size, transmission occurs inside the routing pipe from source to sink node. Each node inside the vector pipe is eligible to forward the packets in a multihop fashion. If the packets are received by nodes not inside the pipe, they will drop the packets. The figure shows that sea bed sensor nodes act as source nodes and that they have a communication range to communicate with first hop nodes. The second hop nodes are relay nodes through which data packets are forwarded to the sink. The relay node concept deals with nodes near the sink draining soon to reduce all relay nodes sharing their energy level with the neighboring nodes.

In VBF, the anchored nodes work under the concept of identifying the vector size for routing. The sea bed source nodes form a line to the sink node, and based on the density, the vector size is decided. Whenever packets are delivered to intermediate nodes, they identify whether the node is eligible to forward the data to a higher layer. Only nodes inside the forwarder vector pipe are considered to coordinate the source node packets. In this, the source node broadcasts the packets to intermediate nodes where those first hop nodes transmit the same packets to the second hop nodes. It is found that VBF has a drawback in sending repeated data via multiple intermediate nodes where energy is wasted for transmitting and receiving from those nodes. Our proposed work concentrates on energy-efficient VBF where at the first level, all the intermediate nodes are divided into subsets such that to maintain reliability, the second hop nodes will be covered by the subsets. Under each subset, the node energy level is monitored, and based on the threshold level, the packets are forwarded in multihop fashion.

3. Propagation Delay Model for Underwater Acoustic Sensor Network

UASN routes the packets both upstream and downstream with the help of a vertical acoustic transceiver. At first, the underwater nodes are deployed at different depths with initial energy of the same power and it is maintained as a power matrix. The speed of packet transmission in underwater acoustics is determined by oceanographic variables such as temperature, salinity, and depth. This has been adopted by Coppen's model [8] that shows the variations of velocity underwater at different depths.

It is given by

$$\begin{aligned} v(D, S, t) = {} & v(0, S, t) + (16.23 + 0.253t)D + (0.213 - 0.1\mathrm{t})D \\ & + [0.016 + 0.0002(S - 35)](S - 35)t, \end{aligned} \tag{1}$$

where

v: Velocity (speed of sound in underwater),
D: Depth (0-4000 m),
S: Salinity (0-45 parts per thousand),
t: Temperature (0 to 35°C).

$$\begin{aligned} v(0, S, t) = {} & 1449.05 + 45.7t - 5.21t^2 + 0.23t \\ & + \left(1.333 - 0.126t + 0.009t^2\right)(S - 35). \end{aligned} \tag{2}$$

By varying the depth in equation (1), the salinity and temperature in the underwater channel change and are stored in the propagation delay matrix. The variation in temperature and salinity for different depths are shown in Figure 2 [8]. From equation (1), the propagation delay of the acoustic signal in an underwater channel is expressed based on the temperature, salinity, and depth variability.

$$P_{\text{delay}}[S] = 1412 + 3.2t + 1.19s + 0.0167d. \quad (3)$$

All the deployed sensors maintain two matrices, namely, the power and delay matrix. It has been noted that the energy in each sensor gets depleted after transmitting and receiving the packets. The power matrix is varied after some interval of time. It is identified by the sink node. The sink node broadcasts the updated power matrix to all other nodes. The objective of this work is to transmit packets with a minimum delay and maximum residual energy path that helps to ensure a reliable path of packet delivery. This optimization problem is solved using an evolutionary memetic algorithm.

4. Energy Model for Underwater Acoustic Sensor Network

The classical acoustic modem characteristic for energy consumption underwater is discussed as follows. The passive sonar equation to calculate signal-to-noise ratio (SNR) for an acoustic link is given by

$$\text{SNR} = \text{SL} - \text{TL} - \text{NL} + \text{DI} \geq \text{DT}, \quad (4)$$

where

SL: Source level,
TL: Transmission loss,
NL: Noise loss,
DI: Directive index,
DT: Detection threshold.

All the above given SNR quantities are in dB and μPa, where the reference value of 1 μPa equals to $0.67 \times 10 - 18$ Watts/m^2 [17]. The underwater transmission loss is calculated by using the Thorp model [15] as follows:

$$\text{TL} = 20 \log \left(d_p\right) + \alpha d_p \times 10^{-3}, \quad (5)$$

$$\text{TL} = 10 \log \left(d_p\right) + \alpha d_p \times 10^{-3}. \quad (6)$$

Equations (5) and (6) specify the transmission loss for deep sea and shallow water, respectively. It is mainly caused due to depth-dependent attenuation and frequency-dependent attenuation. It is to be noted that d_p is the depth distance between the sender and receiver node and is expressed in meters. α gives the absorption coefficient for spherical loss in the deep sea and cylindrical spreading loss in shallow water that is expressed in terms of units of dB/km, and TL is in dB. The absorption coefficient for the frequency f is given as $\alpha(f)$ in dB/km [18].

$$10 \log \alpha(f) = \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2} + \frac{2.75f^2}{10^4} + 0.003. \quad (7)$$

Attenuation for the given frequency over the distance d_i in underwater acoustic link is given by

$$A(d_i, f) = {d_i}^k \alpha(f)^{d_i}. \quad (8)$$

In deep water, the noise loss is very low since there is low disturbance compared to shallow water, and in this paper, the NL for deep water is considered as 50 dB [18]. Whereas NL for shallow water arises due to wind blow, movement of ships, turbulence, and some biological noise, the value taken for shallow water NL is 70 dB [18]. The SNR and DL directly depend on hydrophones and modems attached to the sensor node. Their value is taken as SNR = 20 dB and DI = 3 dB, respectively.

The source level is calculated using the existing passive sonar equation and is given by

$$\text{SL} = \text{SNR} + \text{TL} + \text{NL} - \text{DI}. \quad (9)$$

Equation (9) is utilized to calculate transmitted signal intensity (I_{Tr}) and it is expressed as

$$I_{Tr} = 10^{\text{SL}/10} \times 0.67 \times 10^{-18}. \quad (10)$$

Hence, the transmitted power of the source P_T (d_i) for the distance of a 1 meter with transmitted signal intensity (I_{Tr}) for shallow water is given by [8]

$$P_{T\,\text{Shallow}}(d_i) = 2\pi \times 10^{\text{SL}/10} \times 0.67 \times 10^{-18}. \quad (11)$$

For deep water,

$$P_{T\,\text{deep}}(d_i) = 4\pi \times 10^{\text{SL}/10} 0.67 \times 10^{-18}. \quad (12)$$

Equations (9) and (10) are measured in Watts/m^2, where d_i is the distance between source and receiver node.

The energy consumption model is derived based on the signal frequency (f), propagation distance (d), and other factors like transmitted signal intensity and depth of the network.

$$E(f, d) = P_T(d) \times T_{TX}. \quad (13)$$

5. Proposed System

In the proposed energy-efficient VBF, the sensor nodes are anchored at different depths to monitor the underwater environment. Depending upon the application, the sensor may adjust its communication range relatively to cover the 3D zone. The deployed UASNs are initialized with the same energy where the sample deployment is shown in Figure 3.

The bottom sea bed fixed sensor nodes are considered as source node $\alpha = \{\alpha 1, \alpha 2, .., \alpha n\}$, and their data is required to be transmitted to the sink in a multihop way through the routing pipe. Let $\beta = \{\beta 1, \beta 2, ..\beta n\}$ be the first hop connectivity to the source nodes where they may also collect data and forward it to the sink via relay nodes $R = \{r1, r2, \cdots rn\}$. These relay nodes are one hop away from β nodes and two hops away from the nodes. If $\alpha 1$ has a data packet to

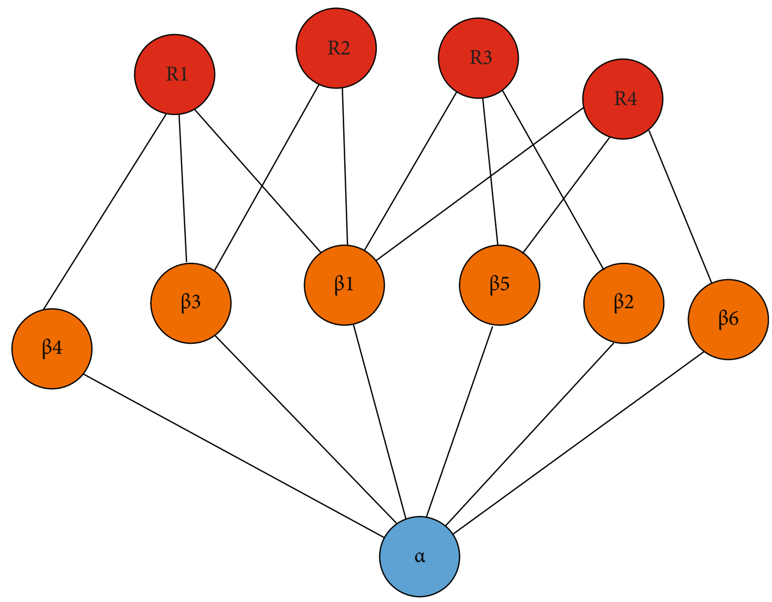

FIGURE 3: VBF connectivity model for single source node.

forward, first it creates a vector pipe towards the sink node and the nodes involved in the routing radius pipe are eligible to forward. The nodes inside the pipe will repeatedly forward the packets that lead to congestion and waste of energy dissipation among nodes, which in turn reduces the lifetime of the underwater network.

In order to optimize the energy usage in the proposed work, it is considered to divide the intermediate UASNs in the vector pipe into sub nodes. These subnodes form a set such that an individual set may have a collection of nodes to communicate with its neighbors and vertical relay nodes. This subset is identified using an evolutionary memetic algorithm to minimize redundant packet transfers. To maximize the energy, the source identifies the highest energy level in the subset and forwards the data packet to the particular. This node receives the packets and shares them with its neighbors.

In this, the intermediate nodes are segregated into sets where each set is capable of transmitting the source node data to all the relay nodes near the sink. The optimizer will identify the maximum connectivity and take the first row position in the routing matrix. The second row occupied an intermediate node with partial relay cover. Now, the improver will match the remaining columns with the optimal intermediate node to form a route set.

The next hop selection in the UWSN is mainly based on the current energy level and other parameters like distance and signal reliability. The status of selection does not depend on the past state, and hence, the Markov model suits the approach of selecting the next hop in the UWSN environment. These modules offer easy interaction and computation and also reasoning; hence, they can easily suit thin client hardware. Here, the state of the particular node changes with a random variable over time. The model is described as a finite channel with a set of states; the sum of state variables is always unity. In a homogenous Markov approach, the positions in the channel sequence are mentioned with the same conditional probability. Markov in a finite state space omega contains several influencing parameters. These depend on the priori assumptions on state transition probabilities.

Figure 4 shows the elucidation of the typical battery characteristic curve. The battery voltage exponentially decreases with increased loading. The battery provides low current to satisfy the load power during high voltage situations. Due to the reduced charge level on continuous loading, this results in decreased terminal voltage. The decreased terminal voltage results in an exponential increase in current level and results in further fast decay of the battery charge level. The role of the node is scheduled as per the battery characteristic curve. The node is given a high load like routing and processing more information during the high voltage phase, and its role is reduced during decreased voltage values.

The role of each node is categorized into a finite state machine with an FFD (i.e., full function device) or router shown in Figure 5, an RFD (i.e., reduced function device) or subset member, and an idle or sleep state. The node probability of being a FFD is high when the voltage and distance are within the threshold limit, i.e., as per the voltage curve and acoustic model. The probability of the node being in the subset member is also high when it is greater than the minimal threshold limit. The node less than the curve voltage value is made to sleep so as to avoid intermediate wake up disturbances.

The probability of moving to a n state from a m state is given by a conditional probability equation as given below. The probability is mainly explained by the initial state probability P_0.

$$P_{mn} = P_r(P_n = n \mid P_0 = m). \tag{14}$$

The single-step transition to move to the desired

```
Memetic algorithm
Initial Population Pop;
Analysis Pop;
While (terminal condition)
Ms=select(pop)
M1 = Ms[1,2,..q]
M2 = Ms[q+1,q+2,..n]
~untilempty(M2)
{
Optimizer()
Improver()
}
Evaluate M1
Pop=survival (M1,Pop)
```

Algorithm 1:

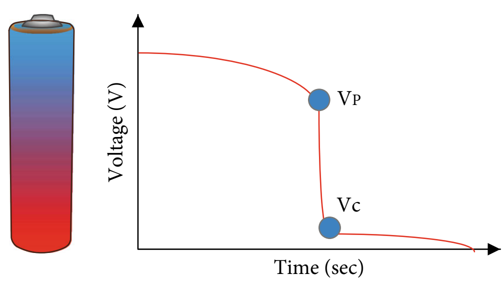

Figure 4: Battery voltage model.

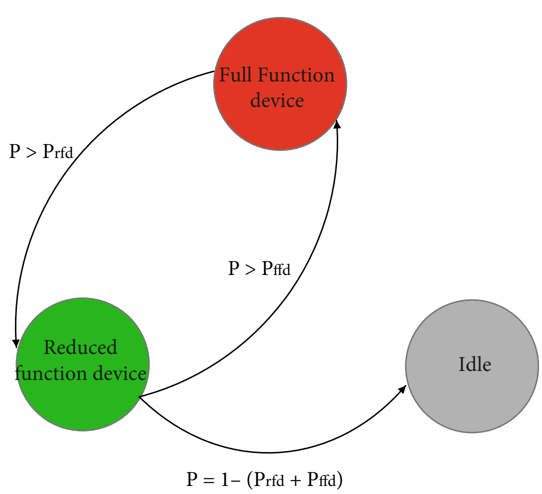

Figure 5: Markov states for the election of subset.

probability is given in the following equation.

$$P_{mk} = P_r(P_1 = k \mid P_0 = m). \quad (15)$$

In a time homogenous Markov chain, the transition probability between the r steps to reach n state is given as

$$P_r(P_n = n) = \sum_{r\in s} P_{rn} P_r(P_{n-1} = r). \quad (16)$$

Generalized probability of choosing r steps is

$$P_r(P_n = n) = \sum_{r\in s} P_{rn}\, P_r\,(P_0 = r). \quad (17)$$

Equations (2), (3), and (4) represent the probability of choosing the next state by the node in the system model.

$$P = \begin{array}{c c} & \begin{array}{ccc} S1 & S2 & S3 \end{array} \\ \begin{array}{c} S1 \\ S2 \\ S3 \end{array} & \begin{bmatrix} P_{r11} & P_{r12} & P_{r13} \\ P_{r21} & P_{r22} & P_{r23} \\ P_{r31} & P_{r32} & P_{r33} \end{bmatrix} \end{array} \quad (18)$$

Here, the probability of reaching a state in a single step and k steps and the overall probability of being in a state are clearly mentioned. The probability values are based on the present conditions and mainly predict the future generation. Nodes in the subset are chosen based on the state of the communication which is passed to other nodes inside the subset. The packets are transferred based on the energy in the battery. The results are discussed in the below section.

6. Result and Discussion

Figure 6 shows the end-to-end delay of EEMM [19], QERP [20], and VBF [16] with varying numbers of nodes. In all the varying node densities, we see that the VBF has the highest delay and the EEMM has the lowest delay. The reason for the reduced delay in the proposed approach is due to the stable cluster head selection. Since the CH does not change frequently, the approach avoids the delays caused during the CH hand over process.

Figure 7 shows the network lifetime against the node density in a stacked graph. Due to the improved voltage profile, using the Markov probability causes an increase in the lifetime of EEMM over QERP and VBF significantly. The second reason for the increased network lifetime is due to the optimum cluster size obtained using the proposed clustering mechanism, which causes a balanced load and an increased network lifetime.

In Figure 8, we see that PDR and residual energy are plotted against the number of iterations. The residual energy of sensor nodes decreases with an increase in the number of iterations from 1 to 5000. (Please justify the reason for better residual energy using results.)

It is shown in Figure 9 that PDR increases linearly in all three approaches as the number of iterations increases. Initially, from 1 to 1000 iterations, it is seen that QERP performs better and has higher PDR than EEMM and VBF. However, with the increase in the number of iterations, it is clearly evident that from 2000 to 3500 iterations, EEMM has a huge lead in the PDR, while QERP performs second

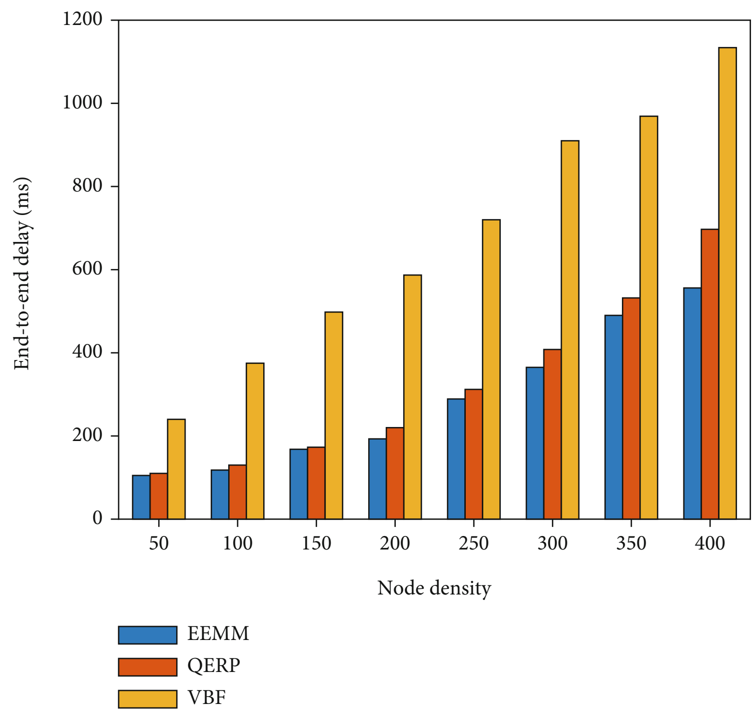

Figure 6: Node end-to-end delay for various node density.

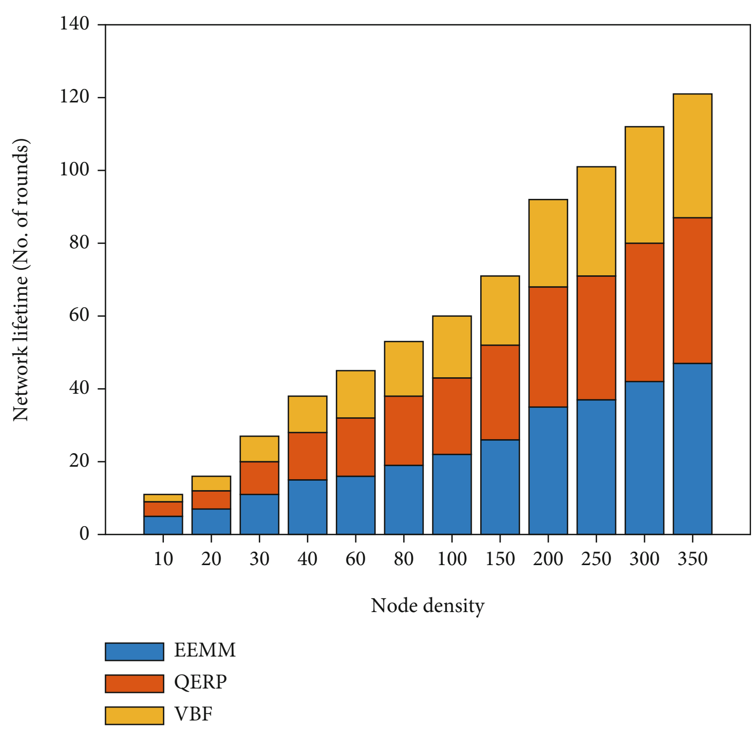

Figure 7: UASN lifetime for various node density.

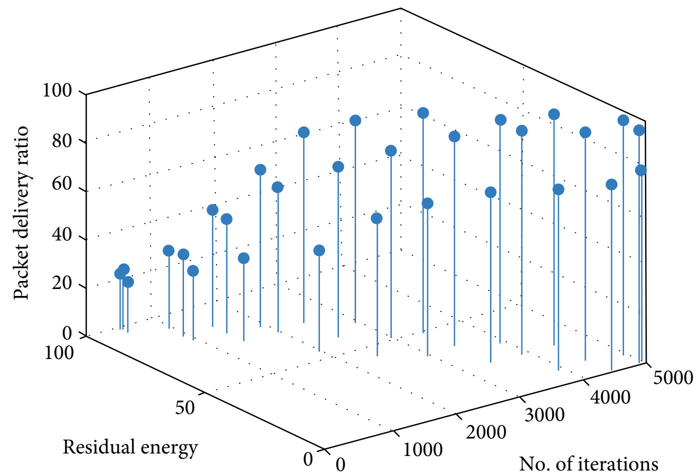

Figure 8: Packet delivery ratio vs. residual energy vs. no. of iterations.

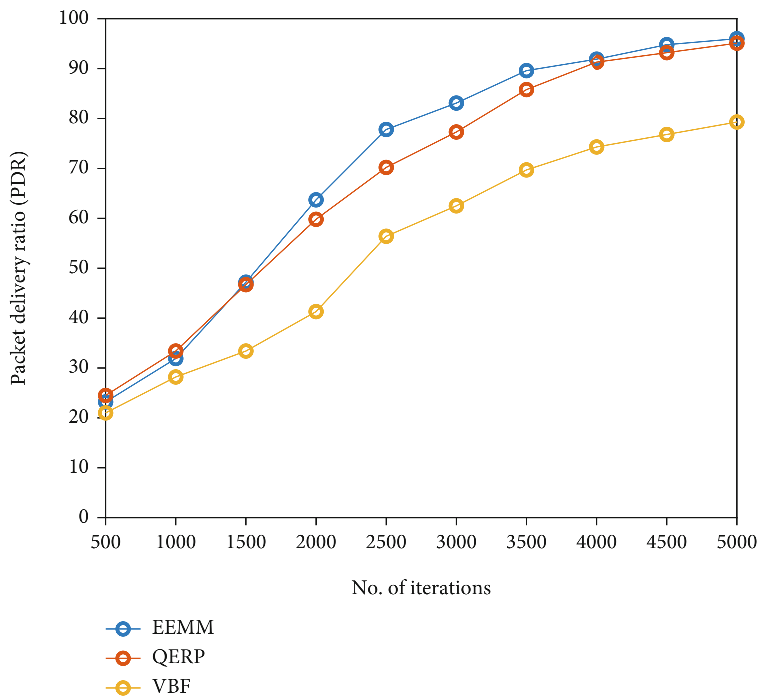

Figure 9: Packet delivery ratio vs. no. of iterations.

best and VBF has the least PDR. When the number of iterations reaches 5000, it is seen that EEMM outperforms QERP and VBF because of the effective CH selection methodology.

7. Conclusion

In this paper, the proposed energy-efficient Markov-based lifetime enhancement optimally transmits the packets from source node to relay or sink nodes. The limitation of pipe vector packets and battery energy is optimized by evolutionary memetic technique. The voltage reference model is used to select the subset, and the battery voltage is mathematically described. The role of the nodes is determined using the voltage profile and the Markov probability approach. It is observed that compared to the VBF algorithm, this strategy extends the lifetime of the underwater acoustic network. The proposed methodology also improves throughput and distributes load evenly. VBF, QERP, balanced, and multiobjective optimized opportunistic routing are all used to compare the outcomes. With enhanced packet delivery ratio and reduced end-to-end delay, this energy-aware method optimally delivers packets with reduced end-to-end delay.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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