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A NOVEL APPROACH TO IMPROVE ROUTING PERFORMANCE IN UNDERWATER CHANNEL MODELLING AND CLUSTER HEAD SELECTION

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ABSTRACT

Underwater monitoring and communication are crucial for studying the environment, including seismic waves, underwater robots, and water pollution. Wireless sensor networks (WSNs) are being developed to address the challenges of energy efficiency in underwater wireless communication. Batteries are used to power underwater sensor nodes, which are limited in power resources and difficult to recharge. This requires new protocols for routing, considering the differences between terrestrial and underwater networks. However, underwater communication faces challenges such as attention, noise, and energy consumption. Despite these challenges, underwater wireless communication remains a growing field of research. To overcome these issues, we present a novel approach which considers three different aspects as sink localization, channel modelling and Cluster Head (CH) selection. The localization scheme divides the network into multiple layers and appoints a sink for each layer, channel modelling considers underwater noise, attenuation, SNR, propagation delay for channel modelling. Later, the CH selection scheme is presented which uses residual energy, and distance from sink to select the cluster head. Before finalizing the CH, it appoints a temporary CH which helps to improve the stability of Cluster Head selection mechanism. The comparative analysis shows the significant improvement in the network performance in terms of network throughput, and lifetime of the network for varied nodes and radius of network.

Keywords: *Underwater networks, Cluster head selection, Localization, Channel modelling, Network Lifetime*

1. INTRODUCTION

Water is one of the significant components of environment and it covers almost 70% of the Earth's surface. The majority of this undersea world has yet to be discovered. Exploration and monitoring of this habitat are becoming increasingly popular. AUVs (Autonomous Underwater Vehicles) have been determined by monitoring and gather data from the sea bed in recent years [1]. Tethers or cables are not required to operate AUVs. Moreover, the behaviour of these AUVs is restricted due to underwater communication issues. The underwater communication channels have a restricted bandwidth, significant path loss and multi-path fading, huge propagation delays, and a high bit error rate (BER) [2]. Large-scale wireless sensor nodes that wirelessly send monitored data from the surface to the AUVs and vice-versa, can alleviate these challenges.

Currently, wireless sensor networks are adopted in different actual-time applications for monitoring purpose such as environment monitoring. Figure 1 depicts the overall architecture of underwater wireless communication system. Generally, these types of networks consist of

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onshore sinks, surface buoys, underwater sink and sensor nodes. Satellites, ships, and remotely operated vehicles underwater can also be employed to increase the range of detection and communication. Pressure, sound, temperature, and other physical or environmental factors are monitored by underwater sensor nodes, which collaboratively transmitted to the underwater sink node. The message is sent through wired link onto a surface buoy and then received via radio transmission to the on present onshore or surface sink.

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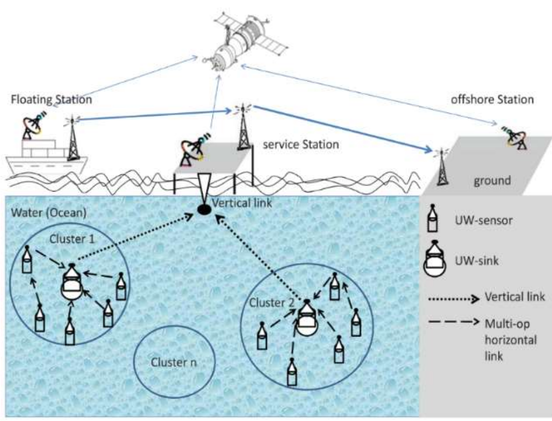

Figure 1: UWSN Model

The network employs various sensor types like as optical, acoustic, image, motion, chemical, weather, temperature, and pressure sensors that are installed for sensing the data. Wireless Sensor Networks have various real time applications, like military, health-care, defence, agriculture, and day to day life. Due to their diverse applications in monitoring, these networks are attracted the research community of underwater WSN monitoring. Waterways, reservoirs, and oceans are all monitored via these networks. Data collection of oceans, monitoring of oil spill, training in military, tactical surveillance, disaster risk reduction, underwater environment monitoring, submarine detection, aquatic ecosystem monitoring, and other applications are examples of applications. Acoustic waves are commonly employed for communication in underwater. The disadvantageous of the acoustic channel, on the other hand, results in large bit error rate (BER), poor bandwidth, and propagation delays for long time, among other things. These difficulties result in excessive power usage by nodes in the network and reduced data dependability. Due to these scenarios, the energy cost in the UWSN becomes a challenging task and so minimizing the energy consumed, increasing network lifetime, and ensuring the packet delivery are the important aspects for underwater communication. Cluster-based network design is commonly employed in UWSNs to enhance the lifetime of the existing network. The cluster's sink-node, which gathers and passes on the packets intra-cluster and inter-cluster, is designated as a cluster-head (CH) node. As a result, CH consumes much energy than the member nodes. Sensor nodes are chosen as CHs for balancing energy consumed and increase the lifetime of the entire network. The election methodology might be based on residual energy, optimum energy depletion, or optimal number of CHs.

Mitigating the aforementioned challenges and improving the network performance are the important aspects of these networks which need to be discussed. In this work, we focus on these issues of UWSN and develop a new approach to prolong the network lifetime. The prime contribution of the work are as follows:

In this work, we focus on two main issues of UWSN: (a) localization and (b) CH selection. The approach is worked towards reducing the amount of energy consumed to prolong network lifetime. In first phase, we present a localization scheme to identify the coordinates of sink node. for simplicity, we deploy networks in multiple layers and sink node is placed at the centre of each layer. the sensor node in the corresponding layer communicate with the sink via cluster head [15]. In next phase, we present a channel model which considers several parameters such as underwater noise, attenuation, SNR, propagation delay [20]. finally, cluster head selection strategy is presented.

Section II gives an overview of the survey on recent methods in this field of underwater WSN, section III gives the proposed solution for the better performance related issues of the network, CH selection mechanism and channel modelling [17,18-19], section IV presents the comparative analysis where accomplishment of method employed is differentiated with the available schemes of underwater WSN and finally section V presents the concluding remarks

2. LITERATURE SURVEY

Rani et al. [3,16] reported that the underwater sensor networks are widely used for under water communication purpose. However, these sensor networks suffer from various challenging issues which lead to congestion such as conflicts, several to single communication, dynamic topology of the network and many more. These

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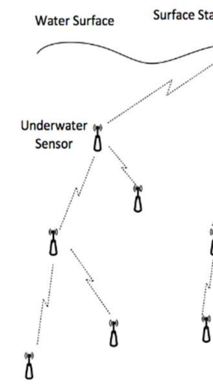

issues degrade the network performance thus to deal with these issues authors introduced a mechanism to control the congestion which used cross layer technique to mitigate and overcome the issues of MAC protocol disputes. The MAC layer updates the information about occupancy of radio buffers and congestion levels in the local node. The proposed scheme of cross layer adjusts dynamically the precedence of accessing the channels in MAC layer and regulates the rate at which data is transmitted to supervise the network traffic.

Chenthil et al. [4] presented a communication strategy for UWSN to overcome the issues of energy depletion. Moreover, the acoustic medium affects the communication due to multipath fading, high path loss, bandwidth, salinity of water, and temperature, etc. Due to these issues, maintaining an efficient network lifetime becomes a challenging issue for underwater scenarios. To deal with these issues, authors developed an algorithm-Multilayer Clustering-based Butterfly Optimization Routing (MCBOR). These schemes uses sense of butterflies and formulates the packet delivery as an optimization problem to deliver the packets successfully.

Bereketli et al. [5] discussed the energy and several other issues related to communication performance and introduced acoustic backscatter communication technique where sensor nodes exchange the data with the help of modulation and reflection of signal, therefore, it minimizes the overall energy consumption. Moreover, this backscatter network approach derived the concept of efficient communication range and energy harvesting. The improved communication coverage and energy harvesting helps to improve the system performance.

Chaaf et al. [6] reported that the WSNs are widely adopted for oceanic applications but these networks suffer from various challenging issues such as node distribution, unequal energy consumption rate among sensor nodes, variation in network topology, inappropriate relay node for communication leads to energy consumption. Therefore, authors presented ReVOHPR a Relay based Void Hole Prevention and Repair scheme for UWSN. This scheme identifies these holes and tries to rectify them. In first phase, energy efficient cluster formation is performed by using entropy-based eligibility ranking. In second stage, dynamic sleep scheduling is performed with the help of dynamic kernel Kalman filter. This dynamic Kalman filtering algorithm is implemented to perform simultaneous sleep and awake mechanism. Final stage consists of a bicriteria mayfly optimization (BiCMO) algorithm. This approach uses optimized multihop routing to minimize the packet drop and improve the QoS.

Ismail et al. [7] identified the routing challenges in WSN and introduced a new routing technique called as reliable path selection and opportunistic routing (RPSOR). This routing scheme includes several parameters such as advancement factor which is formed on the current depth and following hop, shortest path between nodes, and packet delivery ratio. Based on these parameters multihop routing is performed.

Latif et al. [8] reported the issue caused due to retransmission of packets in underwater communication such as amount of energy consumed and loss of packets. To overcome the problems, a joint optimization strategy is developed to handle the sink mobility issue, packet hold and forwarding scheme, aggregation of data along with analysis of patterns. This scheme favours in improving the communication recital with respect to the network throughput, network lifetime, and the amount of used energy etc.

Xiao et al. [9] also reported the energy consumption issues of UWSN and introduced Genetic algorithm drew on energy-saving protocol clustering for UWSN. The member of the cluster and Cluster Head node collects the information and performs the data aggregation which is carried out with the help of back propagation neural network. Further, the data aggregated is passed onto the sink via communication using multi-hop. Moreover, the multihop energy scheme and BPNN minimizes the energy consumption.

Karim et al. [10] focused on reliable data transmission scheme for underwater WSN scenario. To improve the reliability, authors developed two scheme which are based on the multiple sink based network architecture, the first approach is based on the anchor node to establish the routing, similarly, the second stage follows a technique handling void with proposed ANCRP that handles local maximum node problem. In order to achieve this, the sensor network is split up into multiple cuboids forming clusters. An anchor node is assigned this cube which is also become the cluster head. The cluster members communicate with the corresponding cluster head. urther, a multi-hop routing process in presented to ensure the successful packet delivery.

Karimi et al. [11] identified several challenges in underwater sensor networks such as packet drop due to node shutdown, similarly, energy consumption is also a challenging task. Thus, authors adopted Depth Based Routing Protocol which also utilizes fuzzy logic and bloom filter

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based approach. The fuzzy logic helps to improve the cluster head selection process.

Ali et al. [12] developed multilayer sink (MuLSi) technique along with cooperative mechanism. In the first phase, a multi-layered network architecture is used where sinks are placed at the optimal position. This optimal placement strategy helps to minimize the extra energy consumption during multi-hop communication. Moreover, forwarding node selection strategy is also presented which uses closeness to the sink as an important criterion for sensor nodes to become as cluster head. Moreover, a collaboration behaviour is also adopted to ensure the reliability of information exchange.

In this section, we have studied several existing techniques to facilitate energy efficient data transmission for underwater sensor networks. The existing schemes have faced and reported several challenges such as routing, node placement, network connectivity, packet drop and many more.

3. PROPOSED MODEL

The underwater sensor networks have various advantages but at the same time, these networks suffer from various challenging issues. The traditional methods also face numerous challenges in this context. We focus on challenges faced in underwater WSN and develop a novel approach for underwater channel modelling and CH selection to improve the routing performance.

NETWORK DEPLOYMENT AND SINK LOCALIZATION

The underwater sensor networks are deployed for specific applications in underwater scenarios to monitor the event in oceans. The network architecture has a significant impact on the network performance by improving scalability, reliability, stability, and energy efficiency of the network. The ill desired networks fail to maintain the network performance so the network structure play the fundamental role in UWSN communication. Thus, we adopt a multilayer network architecture [24] and developed a new scheme to deal with the network deployment. The base model of layered architecture is depicted in below given figure 2.

Figure 2. Multi-layered network architecture

In this scenario of underwater WSN, deployment of sensor nodes is a challenging task thus main idea of multilayer network architecture is to place the sin nodes at appropriate position so that the data collection can be carried out efficiently. The sensor network consists of five layer where each layer is equipped with multiple sensor nodes as $S = S_n \cup S_s$ where S_n is the sensor nodes and S_s denotes the sink nodes. These node sensors are deployed arbitrarily in the given area of underwater. These nodes utilize acoustic model to establish the communication via broadcasting the required information to establish the communication.

Initially, the energy of every sensor node is E_0, thus, the overall sum energy of network is expressed as $n \times E_0$, where n is the overall number of nodes. During communication, the neighbouring node is identified based on transmission range i.e. the range of transmission is compared with if the node's range of transmission is less than the Euclidean distance between nodes then the broadcasting node decides whether the next node is suitable for neighbouring node or not.

All the sensor nodes assumed here are homogenous in various aspects and parameters such as rate of exchange of data, battery capacity, energy consumption etc. We assume that the sink nodes are positioned in the centre of each layer. The location coordinates of primary sink node is expressed as:

$$\mathbb{S}_1(x, y) = x_c, y_0 \tag{1}$$

y_0 is the y^{th} coordinate of first sink node and x_c is the centre point of the x coordinate. Based on this, the location of other sinks can be obtained as:

$$\begin{aligned} \mathbb{S}_2(x, y) &= x_c, y_0 + h \\ \mathbb{S}_3(x, y) &= x_c, y_0 + 2h \\ \mathbb{S}_4(x, y) &= x_c, y_0 + 3h \\ \mathbb{S}_5(x, y) &= x_c, y_0 + 4h \end{aligned} \tag{2}$$

Where $h = 100$ which denotes the hierarchal order to sink node placement as depicted in figure 2. This method helps to obtain the location of the sink nodes. Further, these sink nodes communicate with base station for further processing of data.

CHANNEL MODELLING

Due to persistent complexities of underwater communication, an efficient channel modelling becomes a prime task to establish the communication. In this work, we consider several parameters for channel modelling such as underwater noise, attenuation, SNR, propagation delay.

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During data exchange when the signal is transmitted then it consumes some amount of energy and distorted by the noise present in the environment. For wireless scenario, the attenuation function is $A(d) \propto d^{\alpha}$ where α denotes the constant decay factor for the underwater scenario. However, the underwater communication links are affected due to distance and frequency. Moreover, the UWA channel loss is also affected due to spreading and absorption loss which leads to increase the attenuation. Let us consider as signal communicating between two nodes for d distance with frequency f and k denoting the Spreading Coefficient, the attenuation A(d, f) is given by:

$$\mathrm{A(d,f)} = A_0 d^k a(f)^d \tag{3}$$

A_0 denotes the normalize constant, (the value of k=1 in cylindrical and 2 in spherical space), and 'a ' is the Absorption Coefficient [13] can be presented as:

$$10\log \mathrm{a(f)} = \frac{0.11\, f^2}{1+f^2} + \frac{44 f^2}{4100+f^2} + \frac{2.75 f^2}{10000} + 0.003\left[\frac{db}{km}\right] \tag{4}$$

Similarly, the underwater communication is also affected due to different types of noise such as turbulence, thermal noise, waves etc. the power spectral density of this scenario is shown by Equation (5) as:

$$\mathrm{N(f)} = \mathrm{N_t(f)} + \mathrm{N_s(f)} + \mathrm{N_w(f)} + \mathrm{N_{th}(f)} \tag{5}$$

Here $N_t(f)$ denotes the turbulence noise, $N_s(f)$ noise generated due to shipping, $N_w(f)$ wave noise, and $N_{th}(f)$ is the thermal noise.

An underwater narrowband signal which requires P power, operates at frequency f and bandwidth is $B[Hz]$ for a distance d, then the SNR characteristics can be expressed as:

$$SNR(d,f) = \frac{P}{A(d,f)\, N(f) B'} + \rho(d,f) \tag{6}$$

Here, $N(f)$ denotes the spectrum density of noise power, and $A(d,f)$ is the attenuation of signal.

Here, we assume that the generated noise follows the Gaussian distribution and communicating channel remains stable for some duration. During successful transmission of the data over a channel, the capacity of channel may be expressed as:

$$C(d,f) = B\log_2\big(1+\rho(d,f)\big) \tag{7}$$

Thus, the channel capacity $C(d,f)$(bits/sec) depends on the frequency and distance [13]. Based on these assumptions and computations, the radio channel for underwater communication can be modelled as:

$$T_d = 10\log_{10} d + 10^{-3}\, a(f) d \tag{8}$$

FORMATION OF CLUSTER AND SELECTION OF CLUSTER HEAD (CH)

The formation of Cluster and cluster head selection has a main key role in this field. As described in previous section, we have divided the network into multiple stages or layers. Each layer has a sink node which collects the data from other nodes of that layer. Direct communication to that sink node causes over consumption of energy due to distance and attenuation factor. Thus, CH selection is an important task.

Once the nodes are dispersed randomly in underwater scenario, the sink node initializes the broadcast message to all sensor nodes in the given region. After receiving the broadcast signal, each node s_i calculates the distance length between the node(si) and sink as $d(s_i, sink)$. This distance is computed based on the signal strength and a threshold distance is assigned for each node as $T(s_i)$, computed as:

$$T(s_i) = \begin{cases} T_1, d(s, sink) < d_{hot} \\ T_2, d_{hot} \le d(s_i, sink) \le 2d_{hot} \\ T_3, d\,(s_i, sink) \ge 2d_{hot} \end{cases} \tag{9}$$

d_{hot} is the radius of node where any event is occurring, T_1, T_2 and T_3 denotes the threshold values based on distance and event occurrence radius.

Each node produces a random number $r(s_i)$ ranging between the values of 0 and 1, and this value will be compared with threshold value or reference. If the generated value is smaller than the reference value then the sensor node s_i is eligible for temporary cluster head. This node is included in the list of temporary cluster head nodes $P(P = \{p_1, p_2, .., p_{n1}\} = \{s_i | r\,(s_i) < T(s_i), s_i \in S\}$ where p_i denotes the i^{th} temporary cluster head. On the

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other hand, if the node is not selected for this list then that node is discarded from cluster competition.

The temporary cluster heads define competition radius as $R(p_i)$ and broadcast the message which contains information such as node ID, distance and communication radius as $msg = \{node\ ID, d(p_i, Sink), R(p_i)\}$. After becoming the temporary cluster head node p_i receives the message and computes the distance $d(p_i, p_j)$ to the node p_j from where it is receiving the signal and defines the neighbour node $S_{CH}(p_i)$ in its competition radius $R(p_i)$ as:

$$R(p_i) = \left(1 - \frac{d_{max} - d(p_i, sink)}{d_{max}}\right) R_0 \qquad (10)$$

Where d_{max} denotes the farthest distance between any point in water and target area, R_0 is the maximum value of competition radius. Based on this, the competition neighbour node as CH can be expressed as:

$$S_{CH}(p_i) = \left\{p_j | d(p_i, p_j) \le \max\left(R(p_i), R(p_j)\right), d(p_i, p_j) \le R_0\right\} \qquad (11)$$

During the phase of competition for cluster head, all temporary cluster head nodes are assigned the same waiting time to participate in communication. During this period, each temporary cluster head compares its distance to the sink with the nodes which are present in the list of cluster head $S_{CH}(p_i)$ and it also determines whether the temporary cluster head is suitable to be assigned as cluster head (F_{CH}) or not. In order to make decision for this, we follow the conditions which are mentioned below:

- If $d(p_i, sink) \le \min\left(d(p_j, sink)\right), p_j \in S_{CH}(p_i)$ i.e. the distance between the node p_i and sink is smaller than the minimum distance from nodes which are in that of temporary cluster head list, then the node p_i becomes the Cluster Head(CH). After becoming the CH, it broadcast the information of it being the "successful cluster head" to other nodes and updates its communication radius.
- If $d(p_i, sink) > \min\left(d(p_j, sink)\right), p_j \in S_{CH}(p_i)$ i.e., if the distance between that of the node p_i and sink is not in the range of communication, then it waits for message from other nodes from the competition list. At this stage, if node p_i receives the message of "successful cluster" of p_j then the node p_i quits the competition for cluster head and broadcast this message. After quitting, it becomes the normal node as cluster member. The overall flow of the method employed is mentioned in the following Figure 3.

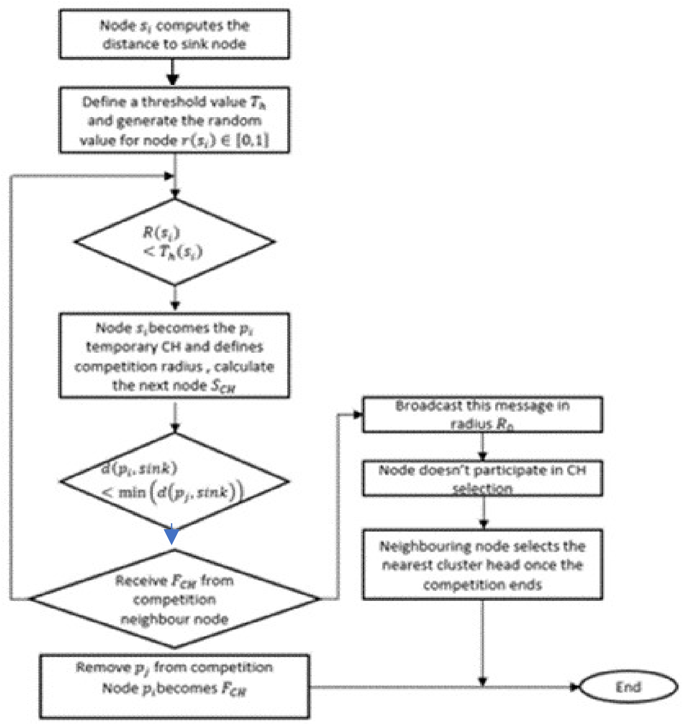

Figure 3. Flowchart of CH selection

4. RESULTS AND DISCUSSION

The experimental analysis shows the results and comparative analysis by using approach proposed. The Comparison of performance is done with existing protocols such as UDAR, BTM, EBR, and IEBR as mentioned in [14]. Below given table 1 displays values of the parameters that are used in this experiment.

Table.1. Simulation parameters

Parameter name	Value
Radius on network	1-5 km
Number of nodes	500
Initial energy	300 J
Frequency	20 kHz
Receiving constant	0.2×10^4

Transmission speed (underwater)	300 bits/sec
Standard competition radius	80m
Data packet length	1000 bits
Number of taps	200

In this work, we have considered total 500 nodes which are deployed in underwater scenario where each node has initial energy as 300J. The radius of network is considered as 1-5km. In this range, the nodes communicate with a data speed of 300bits/sec in a CH competition range of 80meters. The data packet length is 100bits. For this scenario, we simulate the proposed approach and perform the clustering. Once the clusters are formed, they communicate with the nodes sink which are placed at the centre of each layer. The behaviour of method proposed is expressed in terms of network lifetime, transmission loss, network throughput corresponding to network radius and varied number of nodes, network lifetime corresponding to network

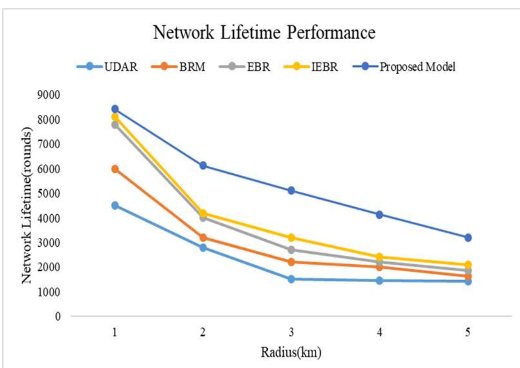

Fig.4. Network Lifetime Performance

radius and varied number of nodes.Above given figure 4 depicts the network lifetime performance in terms of total number of communication round. One communication round includes on entire communication from collection of data to delivery to base station. In this experiment, the average number of rounds are obtained as 2336,3004, 3710, 4000, and 5395 by using UDAR, BRM, EBR, IEBR, and Proposed Model.

This study shows that the increasing the network radius requires extra efforts to deliver the packets and demand for increased communication radius. Due to this, the network lifetime decreases. However, proposed approach outperforms when compared with existing techniques. In figure 5, we have measured the performance in terms of transmission loss for varied network radius. The average transmission loss is obtained as 30.62 dB, 24.8dB, 19.46dB, 14.8dB, and 10dB 5395 by using UDAR, BRM, EBR, IEBR, and Proposed Model.

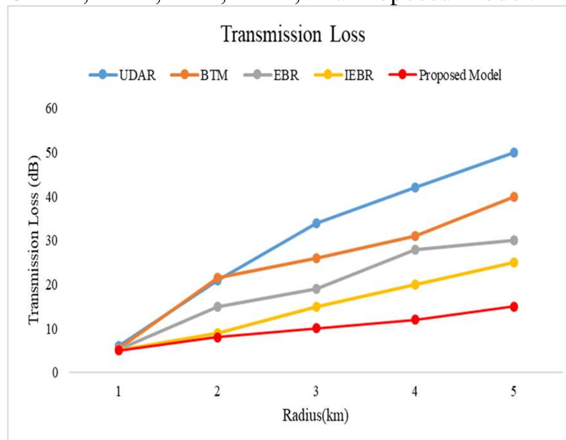

Figure 5. Transmission Loss

For the same simulation scenario where the network radius is varying, we also measure the network throughput in terms of total packet delivered to the destination, below given figure 6 shows the comparative analysis in terms of throughput. Based on this study, we observed that the average network throughput is obtained as 1548, 1371, 2290, 4140, and 4930 by using UDAR, BRM, EBR, IEBR, and Proposed Model.

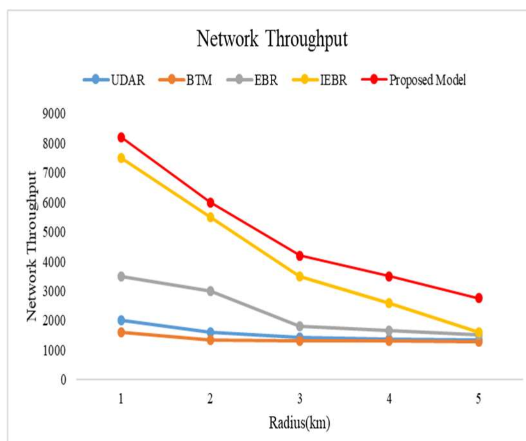

Figure 6. Network Throughput

The increased radius leads to increase in packet drop thus the network throughput decreases. In figure 7, we measure the performance relating to the throughput and lifetime of the network. For this experiment, we have considered 2km and 5km radius. For 7(a), the average network lifetime performance is obtained as 4760, 6400, 7600, 8140, and 8440 rounds, for 7(b) the average lifetime performance is achieved as 4240, 5080, 5800, 7040,

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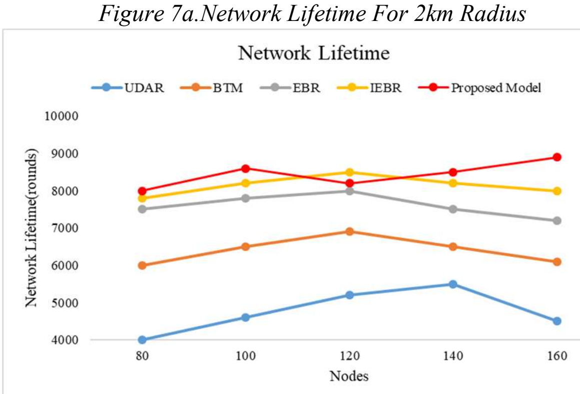
and 7460 by using UDAR, BRM, EBR, IEBR, and Proposed Model, respectively. This experiment shows the increased transmission radius reduces the network lifetime performance. Similarly, we measured the network throughput performance for 2km and 5km radius scenarios. Figure 7(c) displays that the mean throughput obtained performance is as 4860, 5540, 6260, 7220, and 7780 for 2km radius, and figure 8(d) shows the network through is obtained as 4580, 5410, 5680, 6126, and 6460, by using UDAR, BRM, EBR, IEBR, and Proposed Model, respectively.

Figure 7a.Network Lifetime For 2km Radius



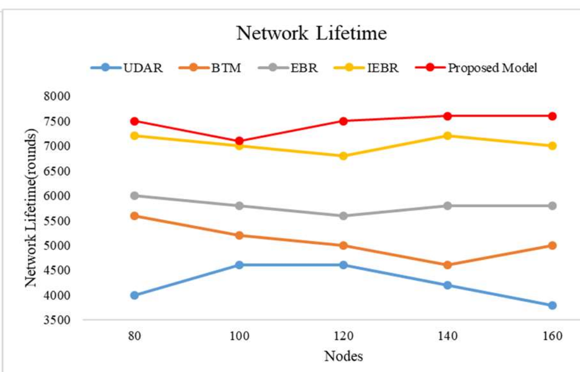


Figure 7b. Network Lifetime For 5km Radius

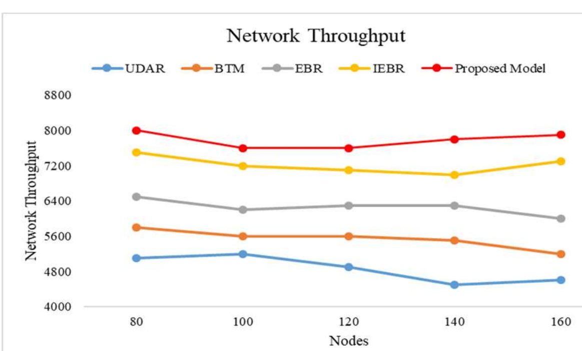


Figure7c.Network Throughput For 2km Radius

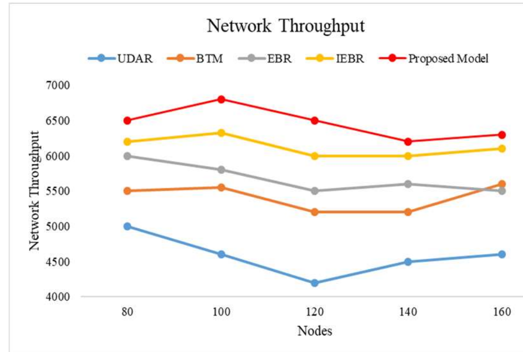


Figure7d.Network Throughput For 5km Radius

5. CONCLUSION

The demand of underwater sensor network is increasing drastically, however, there are several challenges present in this field of communication. This article mainly focusses on the improving the performance of wireless sensor networks underwater by addressing the consumption of energy as well as channel modelling results. First section presents a brief introduction about underwater communication and role of WSN in Underwater communication. Moreover, challenges faced by these communication systems are also discussed. In next section, a brief literature review is presented which describes the current status of ongoing research in this field of UWSN. The challenges are identified and a novel mechanism for channel modelling and CH selection is presented to improve the communication performance. The comparative study shows the robustness of proposed approach by achieving significant improvement with respect to the throughput and lifetime performance of the network.

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