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Underwater Wireless Sensor Networks (UWSNs) Centric Acoustic Communication: Potential Applications and Research Challenges

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Abstract: Underwater communication remains a challenge until nowadays due to limit in deployment of underwater wireless communication. Acoustic communication suffers from several losses due to its dependency on environmental properties like temperature, pressure, salinity, depth and geometric configuration. As the advancement in technology the application of interest nowadays comprises of underwater wireless sensor networks (UWSNs). These networks have a number of sensors deployed in a particular acoustic area between different nodes and ground base stations to perform data collection and monitoring. Presently, UWSNs possess several constraints like cost of deployment, limited battery source, limited bandwidth, propagation delay, routing, topology, security, resource utilization etc. Several methodologies have been introduced to overcome these issues and challenges in last few decades. In this paper a comprehensive review of potential application areas along with research challenges is carried out by comparing several aspects of presently available methods in the field of UWSNs and a new research direction is identified indicating future aspects for further improvements in Underwater Wireless Sensor Networks.
Keywords: Underwater Wireless Sensor Networks (UWSNs), Acoustic Communication, Acoustic Area

I. INTRODUCTION

Transmission and reception of information utilizing sound as a means of propagation in underwater environment is termed as acoustic communication. A large number sensors and vehicles are deployed in a particular area of interest to perform huge number of applications for example: oceanographic data monitoring and collection [1], surveillance of aquatic life, pollution discovery, monitoring fisheries for commercial exploitation, extraction of oil and minerals etc [3]. These wide ranging applications poses a lot of challenges like bandwidth limitation, path loss, routing issues, power barriers, continuously changing underwater environment etc. [2] Usage of optical and radio waves is considered non-feasible for underwater communication at every point in the ocean. Acoustic waves are considered as an effective means of communication in underwater environment. Still the acoustic spectrum is partially utilized [6] because of various challenges in the way of fully utilizing the channel for example: sound speed, propagation delays and noise observed underwater. Underwater communication involves dynamically changing sensor nodes. The main reason behind this is underwater activities and scenarios due to water currents. Efficient consumption of energy is another major constraint for successful deployment of UWSNs.

UWSN Architecture:

Acoustic Technology is used by underwater networks physical layer. Due to limitations in capacity, bandwidth and propagation delays, the design network topologies, routing protocols and communication techniques requires utmost significance and devotion from designers. UWSNs architecture are defined as follows: [14-16]

- **UWSN Architecture in 2D:** In 2D architecture deep underwater anchored nodes are used. Acoustic links are used as a means of communication within nodes or with the sinks. Nodes transmit data to which sinks are responsible for further communicating it to the control stations. Horizontal and vertical transceivers are also utilized to collect data from sensors and send it to the command stations.
- **UWSN Architecture in 3D:** In 3D architecture sensor nodes are deployed in such a way that they float at different ocean depths for the purpose of monitoring certain activities in 3D environment.

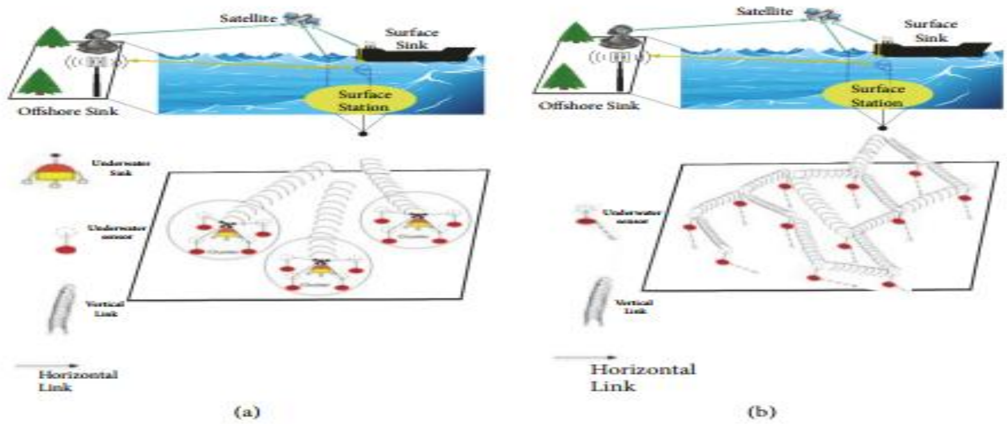

Fig. 1: (a) 2D-Architecture (b) 3D- Architecture

For the efficient and improved use of resources example: energy and network lifetime in underwater communication, techniques should be proposed to overcome challenges posed for the successful deployment and functioning of UWSNs. The paper is further organized as illustrated. Section II presents review of the existing literature, section III highlights the potential application areas, section IV identifies the challenges faced, section V comprises of proposed techniques for overcoming the challenges and enhancing the working of UWSNs, section VI concludes the paper and gives a future direction for further research.

II. REVIEW OF EXISTING LITERATURE

Several techniques are suggested and utilized in underwater wireless sensor network acoustic communication. In this paper we review various researches going on in this field and try to identify the best approach to deal with the challenges posed. Lv-et-al [17] aim to find a solution for issues like synchronization of time for channel access, delay, efficient utilization of channel etc. by proposing a technique called UA-MAC based on TDMA. The main contribution of this work is reduction in energy usage and rate of utilization. Sehgal-et-al [18] has identified that at shorter range the capacity of acoustic channels along with throughput increases with increasing temperature and depth. Luo-et-al [6] presents a technique to sense whether the spectrum is engaged or is free named as Cognitive Acoustic (CA). This technique has the ability to change the frequency and use the idle one avoiding the interference with other networks making the underwater communication error free. Guo-et-al [20] provides a technique for localization AFLA (Anchor-free localization algorithm). It can be used in both the network cases i.e. static and dynamic and has the ability of self-localization. Huang-et-al [22] has presented a fuzzy logic based routing protocol with an aim to utilize the energy efficiently. The main contribution is that the protocol has proven beneficial in reducing the usage of energy and payload. Basagni-et-al [9] have identified that fragmentation of large data packets into smaller ones can reduce the data collision rate. Faheem-et-al [12] has proposed QERP which has been successful by reducing the packet loss probability. Harris-et-al [19] has carried out the comparison of three techniques involving packet size and packet train size adaptation and FEC to overcome issues like long delays, channel usage and large BERs. Ayaz-et-al [11] has proposed a 2-hop ACK based algorithm for increasing data transfer reliability by identifying suitable packet size.

III. POTENTIAL APPLICATIONS

There are tremendous numbers of applications of Underwater Wireless Sensor Networks:

- **Monitoring of Environment:**

Monitoring of soil salinity, water, mineral content and temperature comes under this application. Apart from this disaster monitoring and pollution monitoring can also be done using UWSNs.

- **Monitoring of Security:**

It is also used by defense forces to monitor any foreign intrusions in their zones. For example: submarines can detect any alien object approaching them.

- **Monitoring of Infrastructure:**

During the process of underwater mining and extraction of minerals it is used to detect any faults in the pipelines and other components deployed underwater e.g. dam and minefields.

- **Seismic Monitoring:**

This application is mainly concerned with extraction of oil i.e. the functioning and performance of oil fields can be judged by continuous seismic monitoring.

- **Commercial Use:**

Monitoring Fisheries for commercial exploitation can be done using UWSNs.

IV. CHALLENGES

Underwater sensor networks face several challenges which make underwater communication tough and problematic in comparison to sensor network communication on land. In the following section these challenges are discussed.

4.1. Environmental Effect: The sound waves emitted in underwater environment are anthropogenic in nature and can affect the marine life in various ways, from hearing disability to even becoming the cause of their death [23]. Due to the characteristics like less attenuation and low absorption in sea water the acoustic communication becomes the most suitable method [5].
The speed of sound is also variable in the ocean. Speed of sound is directly proportional to the temperature of the water. It has been seen that speed is increased by 4m/s with increase in 1°C temperature, also1 unit of increased salinity increases speed of sound by approximately 1.4m/s. Depth also plays role in change in speed due to change in pressure for every 1km the speed enhances by 17m/s[4].
Temperature, depth and salinity are the factors which play significant role in changing the speed of sound in water. The following figure (Fig.2) the variation for these factors is shown. This variation can be observed in three parts, in first the temperature is dominating but in second depth also plays an equivalent role. In third the depth is the dominating factor. Salinity also plays role directly in changing the speed of sound.
Such sound waves should be used in underwater communication which has no affect on marine life.

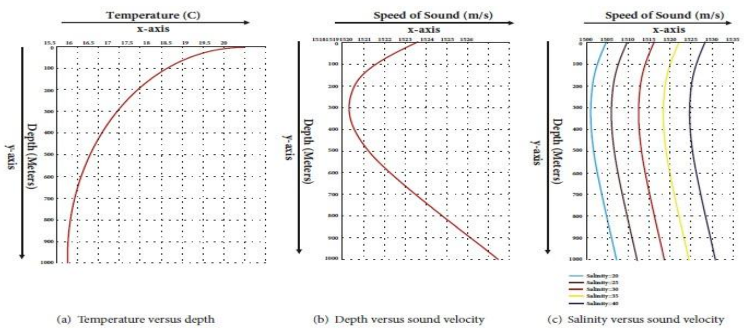

Fig.2: Variation of environmental factors (depth, temperature, and salinity).

4.2. Cognitive Communication: For underwater communication the frequencies are limited due to the attenuation. Generally the natural and artificial acoustic systems work in the range of 1 kHz to 100 Khz which increases the crowd in channel. In the figure below (Fig.3) the underwater acoustic spectrum is represented with overlapping frequencies, heavily shared at medium range frequencies. A very few acoustic system take other acoustic activities into account in the working area. The frequency spectrum is also underutilized because of mobility and idle listening characteristics of system.

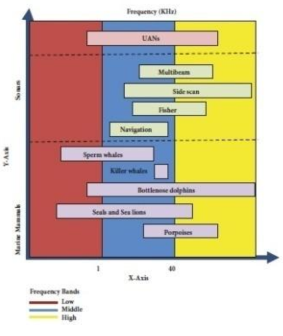

Fig.3: The acoustic spectrum usage in underwater environment.

4.3. Media Access Control (MAC) Issues: MAC is an exclusive challenge faced by acoustic channel. MAC protocols are categorized into two types, scheduled protocol and contention based protocol. Use of protocol is dependent on the environment. Frequency Division Multiple Access (FDMA) is not suitable because of limited bandwidth underwater. Time Division Multiple Access (TDMA) suffers from propagation delay problem. Spatial Division Multiple Access (SDMA) is also used where at some satisfactory positions antenna elements are used [8]. Underwater sensor network system has long propagation delay and low data rates as its attributes.

4.4. Channel Utilization: Due to different factors of the underwater environment affecting the system, to design a channel which can be used to high extent is a tough task, for example fading and phase fluctuations occur because of multipath propagation. Also due to movement of the nodes in the underwater environment problem of Doppler Effect arises. Speed of sound and underwater noise also plays part in the performance of the acoustic channel [7].

4.5. Localization: Sensor nodes are not localized in the acoustic network as they are either fixed with anchors or are being tied up with the buoys with the help of GPS. Due to dynamic movement of sensor nodes localization is the problem of great significance [8]. Since GPS signals cannot propagate with efficiency in the underwater environment. All localization techniques whether range based and range free techniques, static reference nodes and dynamic reference nodes, and single stage and multistage schemes when analyzed in the simulated environment works well but are not analyzed in practical environment [24]. The main problems faced in the routing of nodes are limited bandwidth range, consumption of energy; delay in the propagation, and short of memory [25].

4.6. Routing Issues: Energy saving is the other significant issue faced by the underwater sensor network. The rapidly varying network topology and mobility of nodes make the terrestrial based protocols unsuitable for underwater application area. Proactive and Reactive are the two groups of land based protocols but they do not work well in underwater environment. Whenever the topology is changed for the application a large signal overhead is created by the proactive protocol and because of large acoustic delay and asymmetrical links the reactive protocols are also not suitable for underwater environment.

4.7. Optical Packet Size Selection and Energy Efficiency: Offered load and Bit rate are the attributes on which the packet size depends for optimization. Performance of the network decreases if the proper packet size is not selected [10]. Large area is covered by multi-hop networks and its efficiency can be increased by using the suitable packet size. Throughput efficiency, latency, and energy consumption these parameters can be changed to a very significant value in multi-hop underwater networks by selecting a proper packet size. Network performance directly depends on the packet size.

V. PROPOSED WORK

In this section we discuss the techniques and improvisations done by the researchers to overcome the challenges faced in underwater communication.

5.1. Using an appropriate frequency: To overcome the effect of underwater communication on the marine creatures. Frequency of the sound waves used for communication should be selected considering the natural acoustic communication and life of the marine creatures in the application area. Though it is still an open area of research, different creatures use different frequency and are affected in different way by the acoustic communication.

5.2. Cognitive Acoustic (CA) Technique: CA technique is capable of modifying its working parameters like, frequency, power, and other operational parameters after detecting the parts of spectrum engaged by other communication system. And use the frequencies free for communication without interfering with the other communication networks. The transfer of signals takes place after sensing the spectrum according to the surrounding environment and if any idle frequency is detected. Therefore CA techniques prevent the use of frequencies used by marine creatures and when they get detached from the spectrum the system use these frequencies. Although the CA technique faces difficulties of underwater communication like long propagation delays, long preamble embedded by acoustic modems, severe busy terminal problem of acoustic modems, and highly dynamic underwater channel. Also some attributes make the designing of CA network a tough task, these are namely spectrum sensing, dynamic power control, spectrum sensing strategy, spectrum sharing, and spectrum decision [6].

5.3. Underwater Acoustic Channel Access Control method (UA-MAC): UA-MAC enables us to enhance the utilization of channel in mobile UWSN. Time schedule to access the channel, hidden terminal problem, and end-to-end delay are the problems solved by the UA-MAC method, it also avoids the collision and lower downs the energy consumption. Although an area which is the matter of concern in the field of information gathering in underwater environment is reliable data delivery, for which suitable solution still needs to be found [17].

5.4. Enhancing the channel utilization using multiple techniques: The techniques used for the enhancement of the channel utilization are adaptation of packet size, forward error correction and adaptation of packet train size. The simulation results after implementing these techniques in the protocol increases the utilization of the communication channel in presence of the acoustic channel constraints. Long delays in acoustic channel are overcome by using the adaptation of packet size; the forward error correction overcomes the high bit error rate problem. The optimal use of these techniques depends on the distance between the source and destination nodes, which is an important affecting factor in propagation delays and bandwidth. And in presence of challenges like Doppler Effect, underwater noise these all depends on the distance, to curb these we require a better solution.

5.5. Anchor Free Localization Algorithm (AFLA): Use of predefined location maps, anchor nodes, surface buoys or AUVs is very costly and not efficient in performance. To restrict the unwanted movement of the underwater nodes due to ocean current, AFLA works for the nodes which are bound to some known anchor using cables. It has capability of localizing the nodes without requiring the anchor node assistance and gives the efficient results in the underwater network [20]. Though localization of free nodes is still area of research

5.6. Level-Based Adaptive Geo-Routing (LB-AGR) protocol: This protocol has four different categories defined as upstream to the sink, downstream to sensor nodes in elected area, downstream to specific node not considering of where the node is locating, and downstream to all the sensor nodes. LB-AGR transfers the packet from upstream to sink to the best hop node instead of every neighboring node. To determine the best hop neighbor from all the suitable neighbors the LB-AGR considers the energy, density, location, and level-difference as parameters. The following table (Table 1) compares the performance of LB-AGR with other protocols used for routing [21]. The discovery of new paths for the network depends on the routing protocols. Network layer is the area of research though in the routing protocols [26].

Table 1 : Performance evaluation of LB-AGR with existing protocols of UWSNs.

Factors	LB-AGR	VBF	VBVA
Energy Consumption	Low	High	High
Successful packet received	High	Low	Low
End-to-End interruption	Low	High	High
Delivery percentage	High	Low	Low

5.7. Techniques for packet size selection and energy efficiency: Different routing protocols have been advised in the recent years to optimize packet size selection and energy efficiency. We have used the comparison on various parameters to find the most suitable one among the group using the plot between energy consumption and number of packets and number of nodes (Fig.4).

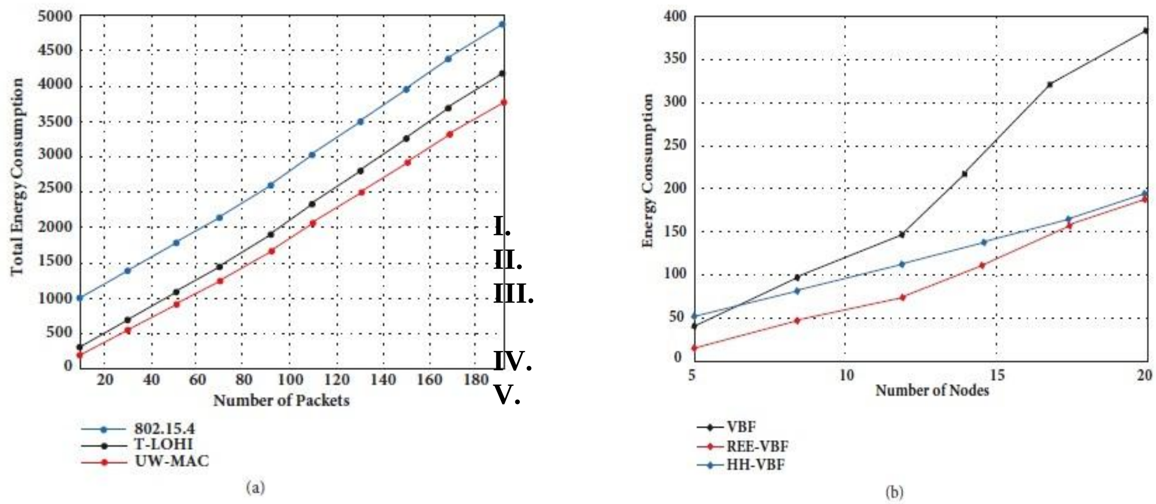

Fig.4: (a) Energy consumption of T-Lohi and MACUWASN [13]. (b) Energy consumption of VBF, REE-VBF, and HH-VBF [13].

In Fig.4 (a) Energy consumption of different MAC protocols is plotted and it is seen that UW-MAC has better energy consumption that the others. In Fig.4 (b) we can see that REE-VBF is more suitable.
Different MAC and contention based protocols are being compared in the table below (Table.2).

Table 2: Comparison between MCA Protocols.

Protocol	Based	Topology	Advantages	Disadvantages
T-Lohi	Contention	Not fixed/Distributed	It is used to solve the space time & uncertain data reservation problem while using short wake up time to reduce energy consumption.	Node is required to be idle and listen to the channel each in contention round.
R-MAC	Contention	Multi-hop	TC & data packets are scheduled to the both sender and receiver side.	There is No technique to join for new nodes when node dies or left.
H-MAC	Hybrid	Centralized	It accepts the benefits from both contentions based &contention-free protocols while low power consumption/energy reservation.	Not Optimal for dense & heavily loaded network.
UWAN-MAC	Hybrid	Dense network	It achieves synchronized locally schedule even when long propagation delay is present because it required small duty cycle.	Difficult to achieve high throughput due to small duty cycle feature.
P-MAC	Hybrid	Centralized	According to information of VDL it works dynamically & adaptively.	The addition of P-MAC with multichannel& ad-hoc mechanisms.
MFAMA	Contention	Mobile UWASN	A greedy approach intends to maximize throughput.	pay compensation to the Fairness.

From the above plots and table we can say that for the packet size selection and energy efficiency UW-MAC and REE-VBF are better protocols.

VI. CONCLUSION AND FUTURE WORK

Underwater Wireless Sensor Networks is one of the promising areas of research having a set of wide range of opportunities as well as challenges. In this paper we have presented a comprehensive research based study of potential applications of UWSNs in the field of acoustic communication along with highlighting the challenges posed during their deployment and implementation. We have also indentified and have proposed various techniques to overcome these issues leading to the enhancement of UWSNs. This inclusive review is beneficial for giving a new direction to the researchers by identifying the best approach as per there area of interest. According to the given perspective future directions can be identified comprising of areas like nonlinear acoustic communication, developing techniques for utilizing the underwater spectrum completely without any compromise, investigating research area of localization properly for enhancing the monitoring application using

UWSNs as GPS localization is not effective for underwater environment. Therefore, the future aim is to identify novel techniques for further improvement of acoustic communication using underwater wireless sensor networks.

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