Underwater Wireless Sensor Network: A Review

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***Abstract*— The paper presents a review of Underwater Wireless Sensor network as it is emerging to be a promising technology in unveiling the mysteries of the marine life and other underwater applications. Taking that into account, we study the existing and the best possible technologies for underwater nodes to communicate in a network. The details about underwater channel have been mentioned with focus on both the acoustic and optical type communication. Furthermore, channel modulation and coding techniques have been discussed. Subsequently, the techniques for node localization and the corresponding Routing protocols which can be applied to the type of communication desired, have been briefly presented.**

***Index Terms*— Underwater Wireless Sensor Network, Underwater Optical Communication, Underwater Acoustic Communication, Underwater channel modeling, Multi-Hop Communication, Underwater node localization.**

I. INTRODUCTION

About 71 percent of the world's surface is covered by water and out of which oceans hold a share of approximately 97 percent. Exploration of oceans is not restricted to study of marine life or to observe the different biological changes underwater but it can also provide a great deal of information regarding climate change, natural disasters, and can provide significant data which can help us learn more about the history of our planet. An efficient and reliable communication system is, therefore, the need of the hour to unveil the unknown.

II. MOTIVATION

A. *Areas of Application of UWSN*

- Ocean biology: The health of the water bodies and of the marine life it sustains, is an accurate indicator of the level of pollution in the environment. To study this, we need a power efficient, self-sustained network to sense and analysis the required parameters.

- Disaster Management: Having the seabed under surveillance would help in disaster management as we could sense various disasters having their epicenter in the ocean or sea, at an early stage. From the information gathered, pre-warning can generated for the nearby terrestrial areas.

- Surveillance Systems: The world has seen large number of border issues between countries sharing boundaries, be it on land or in waters. So Wireless Sensor network can be used to keep the disputed water areas under surveillance to check for any enemy intrusion.
- AUV/ROV operation: The unmanned robots are used underwater for various data collection purposes. Unlike on the land, the communication between different robots cannot be done through RF. Therefore, the Autonomous Underwater Vehicles can form a sophisticated network if communication takes place using appropriate link.
- Aid in search and rescue operations: In case of any accident that happens in oceans and other water bodies, deployed networks can be of help in the search and the rescue operations conducted. Critical data can be gathered from these, which is really important in such scenarios.

B. *Types of Communiciation Links*

There are a few ways to communicate underwater due to external challenges posed by the its environment. They are discussed as below:

- ***RF Communication :*** Radio wave does not propagate well in underwater environment owing to the conducting nature of seawater. As we know, attenuation is higher for the high frequencies; therefore, most of the commercial radio equipment cannot be used underwater as they operate in MHz and GHz ranges. To avoid this if we use a very low frequency radio wave, then a large sized antenna would be required as it consumes a lot of power. The attenuation of electromagnetic wave in water for 2.4 GHz band is 1695 db/m in sea, and 189db/m for fresh water body. [1]

- ***Acoustic Communication:*** This is most mature technology in underwater communication. The speed of sound in water is 1.5 x 10^3 m/sec while in air it is just 340 m/sec. It is majorly used because of its far distance communication capability but along with this it also possesses limitations like large signal attenuation and low bandwidth. Moreover, the report of Natural Resources Defence Council, the rising ocean noise is having a grave impact on life of mammals like dolphin and whales, causing hearing loss or sometimes even turn fatal.

- ***Optical Communication:*** Light travels at a speed of 2.25 x 10^8 m/sec in water, which is very high as compared to speed of sound wave. Moreover, visible light communication does not harm the marine life in any way. Higher bandwidth, faster speed, power efficient and lesser interference with noises are the benefits of optical communication. But the major challenge faced by optical communication is that it can only work in a closer range. A study by Sullian and Dimtley et al. in 1963 found out that attenuation of 450-540 nm wavelength is much smaller than the other wavelengths of light in water (shown in Fig 1), thus making this band of wavelength best to be used for underwater light wave communication.

- ***Hybrid Optical Acoustic Communication***: The limitations of both the individual technologies can be overcome by combining the two. An optimal network can be devised to appropriately use required technology at the right point of time. In J.Wang et al[1], depending upon the SNR value of signal at the receiver ends determines that which technology will be used to transmit the data. High, medium and low SNR allows the optical communication while the below threshold SNR requires acoustic communication. Other than this, multi-hop technique is also employed to transfer the data from source to sink node. For this purpose different layer protocols have also been devised.

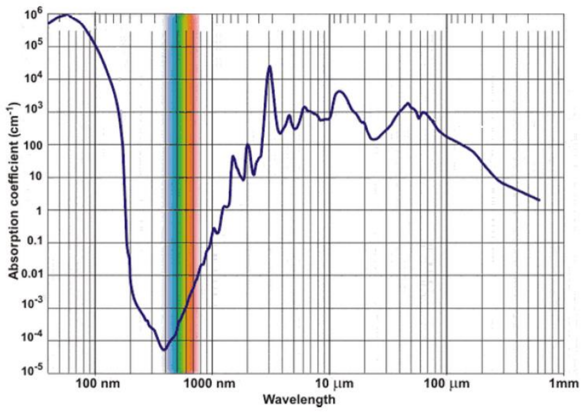

Fig 1. Light absorbtion vs wavelength curve

III. CHANNEL MODELLNG

To improve any type of communication significantly, we first need to study the channel of communication along with transmitter and receiver. The received signal can be accurately obtained for the transmitter signal if we can accurately model the channel between the nodes. The channel modelling is dependent on the following signal characteristics as it travels from transmitter to receiver:

- Location of the two nodes.
- Signal attenuation as it travels along the medium.
- Noise present in the channel.
- Reflection, Refraction and diffraction of signal due to any obstacles present in the path.
- Relative motion of the nodes.

A. *Acoustic Signal Attenuation*

The performance of a wireless communication system is majorly dependent on the attenuation of its signals under the conditions offered by the channel. Stefanov et al. in [3], gives the equation to model the attenuation associated with acoustic underwater communication:

$$A(d, f) = A_0\, d^k\, a(f)^d \qquad (1)$$

where $A(d,f)$ is the amount of attenuation at frequency f and over a distance d, while A_0 is the Normalizing constant and k (spreading factor) has a value of 1.5. The absorption coefficient $a(f)$ is used to find the loss due to absorption in the total path loss in underwater wireless communication and can be obtained empirically by using Thorp's formula [3]. It shows the relationship between absorption coefficient and frequency which comes out to be approximately linear.

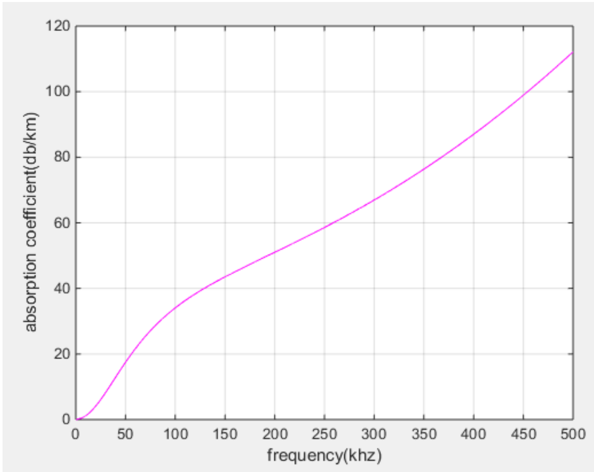

Fig 1. Absorption coefficient versus frequency: Implementation with Thorps' formula

B. *Optical Signal Attenuation*

Optical signals have higher attenuation for larger distances. Anguita et al.[4] modelled the power of optical signals received at the destination node in the following formula:

$$P = \frac{2P_0 A_r \cos\beta}{\pi L^2(1-\cos\theta)+2A_t}\cdot e^{-\alpha t} \qquad (2)$$

with receiver area (A_r), distance from the receiver (L), inclination angle to receiver (β), transmitter light beam divergence angle (θ), transmitter area (A_t), attenuation coefficient (α), and distance from the sender (d). To enhance the receiving power, the optical communications relies on a direct line-of-sight and narrower field-of-view.

. To calculate the optical path loss, Beer-Lambert's law, a simple exponential attenuation model, is applied.

$$I(z) = I_0 \exp(-c(\lambda)\cdot z) \qquad (3)$$

Equation 3 gives the Beer-Lambert's Law [3] which gives an expression for light received at a distance of z from the transmitter in a channel when the transmitted light is I_0 and attenuation coefficient is $c(\lambda)$.The attenuation coefficient is dependent on the water types and the typical values, from [6], are given below.

Table I Attenuation Coefficient of Different Water Conditions

S.No.	Water Type	Attenuation Coefficient (m^{-1})
1.	Pure Seawater	0.043
2.	Clean Ocean	0.141
3.	Coastal Ocean	0.398
4.	Turbid Harbor	2.190

IV. CHANNEL MODULATION

To establish wireless communicating links between nodes, the data needs to be modulated first and then transmitted for minimal losses. Most of the underwater optical systems are based on intensity modulation schemes, such as on-off keying and PPM (Pulse position modulation). Jingjing Wang et al.[1] gives a model of how adaptive modulation technique can be used to communication over different ranges.

Table II Various types of modulation for underwater communication

Type of Modulation	Advantages	Limitations
OOK (On-off Keying)	Simple technique. Used for Low Speed optical communication.	Low energy and power efficiency
PPM (Pulse Position Modulation)	Higher energy Efficiency. Suitable for medium speed optical communication mode	Lower bandwidth utilization rate and complex transreceivers
QAM (Quadrature Amplitude Modulation)	1. Higher spectral Efficiency by phase and amplitude control 2. Higher data rate transmission within a defined frequency band, therefore used for high speed optical communication.	
PSK (Phase Shift Keying)	1. Higher Energy transfer Efficiency 2. Strong anti-interference ability. 3. Used for transmitting over longer distances, therefore used with acoustic communication.	Acoustic signal has very low bandwidth, therefore cannot be used for sending multimedia.

V. CODING TECHNIQUES

Like the acoustic signals, the optical signals also experience attenuation in underwater environment due to scattering of light and significant absorption too. This degrades the Bit Error Rate of the system. Therefore, to reduce the impact of this attenuation, Forward Error Correction (FEC) channel coding techniques are employed.

These techniques add redundant bits to the transmitted message in order to aid the receiver to correct the received message in case of errors. Though these codes improve the power efficiency of the system, but at the same time they decrease the bandwidth efficiency.

FECs have two categories : block codes and covolution codes.

Block codes are used in underwater optical systems due to their simplicity and robustness. The RS(Reed Solomon) code is generally used to avoid difficulty of system implementation and hardware resource consumption.[1]

Although the block codes are easy to implement but in the harsh environments like oceans and other turbulent waters with high interference, they do not give the desired performance. Therefore, we require more powerful and complex channel coding schemes like Turbo Codes.

Turbo Code is similar to random code and is particularly suitable for long distance communication. It is not much affected by interference and attenuation, therefore is employed in rough environments. As during higher attenuation environment and for long distance communication, we donot prefer optical communication in a hybrid medium, thus we use this code in an acoustic link.

Table III Various channel codes for underwater communication

Channel Codes	Comments
Reed Solomon Codes	Simple, robust block code
BCH (Bose–Chaudhuri–Hocquenghem Codes)	Simple, robust block code
CRC (Cyclic Redundancy Check)	Simple Error Detecting code
LDPC (Low Density Parity Check)	Complex linear block code.
Turbo Codes	Complex convolution code.

VI. NODE LOCALIZATION

All neighbouring nodes need to know each other's location in order to form an efficient communication network. There are two type of nodes in any network- first the ones which need to be located, and the others which are the reference/anchor nodes. The latter ones assist in the localization process. Since the techniques of GPS does not work inside water due to inability of RF waves to travel inside water, therefore the node localization techniques are broadly classified into two categories.

1. Range Based Schemes: These schemes are based on bearing information to estimate their location relative to other nodes in the network.

They rely on the following approaches to make measurements:

- Time of Arrival (ToA)
- Time Difference of Arrival (TDoA)
- Angle of Arrival (AoA)
- Received Signal Strength Indicator (RSSI)

V. Chandrasekhar et al. 2006 surveyed various methods adopted in UWSN and found out that while RSSI based schemes only provided a ranging accuracy of a few meters while with ToA based schemes an accuracy of a few centimeters could be achieved. With RSSI the problems of large variances in reading, multi-path fading, irregular signal propagation patterns and interference from background noises are to be tackled with. Therefore it is advisable to use ToA/TDoA over RSSI for underwater scenario as the mode of communication is acoustics.

2. Range Free Schemes:

These schemes donot uses the approaches like ToA, TDoA, RSSI to estimate the distances to other nodes.They are broadly classified into:

- Hopcount based schemes
- Area Based schemes

Theses schemes are fairly simple as compared to the formerly discussed ones. However, they provide only a coarse estimation of the location of a node. Due to this limitation, they are primarily employed in terrestrial WSN not in Underwater WSN.

VII. Routing Techniques

The UWSNs consists of significant number of sensor nodes arranged at different depths throughout the region of interest. The nodes located at the sea/ocean bed cannot communicate with the surface buoys directly, thus multi-hop communication is needed which is then assisted by a routing algorithm. An efficient routing scheme should provide optimal route between the source and the sink.

Designing a routing protocol depends on the requirements of the application of the network, as well as the desired level of precision and optimization, which furthermore depends on availability of the resources.

G. Han et al.[8] provide the comparison between various routing protocols used for Underwater WSN. They have classified the protocols into the following categories:

- Energy-based routing [9-10] : It is an Energy Optimized Path Unaware Layered Routing Protocol (E-PULRP). The whole network is divided into layers with each node of a layer allowed to communicate to sink via equal number of hops. In the communication through multihopping, the choice of relay nodes is based on the later's distance from the sink node i.e node, more closer to the sink and significantly away from source, becomes the next hop. The lifetime of network increases by allowing non active nodes to sleep. But in this protocol the mobile nature of nodes is not considered, therefore making it unsuitable for real time underwater applications. Another energy based protocol is QELAR which has been discussed in [10] which is specifically suitable for mobile UWSNs. However, this demands the nodes to keep a lot of information in store due to the Q-Learning algorithm it uses, therefore, it is not possible to apply QELAR on a large scale UWSNs.
- Geographic information-based routing : The position or location based routing approach is also used in various protocols which continuously updation of the location of the neighbouring nodes is done to communicate data. Different protcols like Hop-by-Hop Dynamic Addressing Based (H2-DAB), Depth-Based Routing (DBR) and DelaySensitive Depth-Based Routing (DSDBR) protocol have been discussed in [11-12].

Majorily for underwater acoustic sensor network, various routing protocols have been studied by Qadri and Shah, 2010 [13]. They compared the following protocols:

- DSR (Dynamic Source Routing)
- AODV (Ad-hoc On Demand Distance Vector Routing protocol)
- DSDV (Destination-Sequenced Distance-Vector Routing protocol)
- OLSR (Optimized Link State Routing protocol)

In DSR, the routing path is carried by data from node to node. Therefore, as the network size grows, the length of path also increases which leads to unnecessary consumption of bandwidth. To overcome limitations of DSR, AODV is used where each node maintain its own routing table to keep record of its neighbours.

The results from the above mentioned work showed that DSR is not suitable to be used due to lower throughput and OLSR due to its high energy consumption characteristic. Futhermore, it inferred that AODV and DSDV have better performances in underwater WSN but the former is primarily used for denser network with lesser traffic while the latter is used for higher traffic with regular traffic.

VIII. Conclusion

WSN is one of the major areas of interests of this century. Underwater environment in WSN poses additional challenges as compared to terrestrial WSN, thereby the network needs to be modelled more carefully. Different aspects like allowable communication links for UWSN, channel modelling factors, modulation and coding techniques, node localization and the Routing protocols have been discussed in the paper.

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