Acoustic Wireless Sensor Network: A Detailed Review

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Abstract— The paper presents understanding of Underwater Wireless Sensor network, as it is emerging to be a promising technology in unveiling the mysteries of the marine life, ocean monitoring, underwater mineral extraction, and other underwater applications. The work also covers dynamic structure, route discovery, route maintenance and data forwarding mechanism of routing protocol based on protocol operations. 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.

Keywords: 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, etc. the sensor device collects the information from bottom of sea water and transfer that information to the sink nodes deployed on the water surface and sink nodes further transfer that data to the onshore data center for further rectification. RF signal is not feasible for underwater wireless sensor network due to attenuation. The acoustic signaling is a better solution for underwater environment because acoustic signaling speed is 1500 m/s. However, underwater wireless sensor network faces more challenges like: acoustic signaling has the limited bandwidth due to the water current, dynamic network topology due to the node movement on water pressure, effect on acoustic channel due to path loss; noise and Doppler spread and link between sensor nodes remain highly prone.

II. BACKGROUND AND LITERATURE REVIEW

The design of routing protocol in underwater environment is the complicated task because the static topology is not valid due to continues movement of water. Hence dynamic topology is used but it has issue due to water current and limited bandwidth. This paper focus on issues of routing protocols based on protocol operations; whish is further classified into source initiated, table driven and data aggregations. The classification is listed below:

A. *Information Carrying Routing Protocol (ICRP):*

It is a source initiated and table driven routing protocol. It is an energy efficient, scalable and real time routing protocol which carries the control packets for information sharing through data packets. It is a location free routing protocol and consist small no. of sensor nodes. The source node is responsible for route discovery, if the route is not established the source node will carry the data packets with route discovery message. When all the node receive this message then these nodes will also establish the reverse route for the acknowledgement, when source node will receive the acknowledgement then the successful packets delivery will be considered. The use of routes depends on time priority and if the route is not used for transmission is called the route lifetime. If the route lifetime remains larger means it is valid or even remain unused. Route lifetime validity is depending upon TIMEOUT; if the threshold exceeds the TIMEOUT the route will become invalid [16].

ICRP faces issues like: 1) In underwater environment the architecture is not valid due to continuous movement of water. 2) If the intermediate nodes didn't have route information then these nodes will transfer the data packets to destination and in resultant the destination will not accept the data packets and in resultant the drop of the packets will occur and also the energy of these nodes will also be wasted. 3) Due to water pressure in underwater environment the route may be broken within 2-3 sec.

B. *Location Aware Routing (LASR):*

It is a location based protocol and revised form of DSR protocol. It is a source initiated and based on protocol operation. It uses two extra methods; location awareness and link quality metric. In location awareness method; local network topology was designed which uses the information for transmission. The local network topology consists tracking system and time-of-flight for range and transmission process. TDMA technique is used for medium access control. The link quality metric uses DSR for hop count and powerful computational methods are adapted for the improvement of link quality [15].

LASR uses five protocol options for node forwarding; the functionality is described below:

1) Explicit acknowledge: when LASR sent a message or protocol option that must be acknowledged this is called explicit acknowledgement.
2) Route request: on arrival of packets the route request option will carries a route along with link quality and time stamp from originator to the last hop.
3) Route advice: it removes the route errors and carries the updated information about individual links.
4) Source route: analogous to DSR. Its route carries link quality and time stamp.

In LASR every route is recalculated on every hop count, the route principally serves to spread the network topology, the link cache mechanism is updated with the new data and then the route but not the option is discarded. The route can be replaced when the implicit information appears to build the link cache. LASR uses dijkstra's algorithm for updating the network graph. Route handling mechanism will use the protocol options to develop the route link, these options are acknowledgement, route selection and route reply. The link could be cast-off before the departure of option.

LASR uses three features when transmits the no. of packets on routes, these features are acknowledgement delay guarantee, hello message and option packing. The LASR features will increase the packets delivery ratio, will reduce the end-to-end delay and will provide the updated information. Description of LASR features:

1) Acknowledgement delay guarantee: It is the guarantee of LASR that within time span the acknowledgement of all the messages will be received to the sender nodes.
2) Hello message: if sender node wants to transmit the data but it has no option like ready to send, it can send a route advice option as a hello message when this message enters in the route link it will update the route for data sending from sender node to neighbor/destination node.
3) Option packing: it consists piggyback outgoing as a sub option. The piggyback option will separate the route and user data message from source route. These options also take the responsibility for the acknowledgement from multiple neighbors on a single route transmission.

The LASR tracking system is recursive state estimation filter that uses the range estimates to predict the network topology. Its performance is modeled.

C. Hop-by-hop Dynamic Address Based (H2-DAB):

H2-DAB is based on multi-sink architecture. It is a scalable, robust and energy efficient. It is based on dynamic address mechanism. In architecture of H2-DAB; the dynamic addressing mechanism has been used till the depth of water to solve the easy movements of nodes in water current. Depth level was set from water surface to bottom level. The surface level buoys are collecting the information and will transfer to the bottom level. The addressing mechanism of H2-DAB is based from smaller depth to the large depth of water dynamically. The dynamic addresses are generated by the surface sink with the addition of hello packet. H2-DAB uses two packet formats: hello packet and data packet; both packets are generated by sink surface nodes. Any node which receives the data packets will transfer the data packets to the upper level with greedy method algorithm. When data packets are received by surface sinks the delivery is considered as successful and the entire surface sinks are linked with each other with the radio communication link and surface sinks will transfer that data to the onshore center [14].

H2-DAB faces some issues like; 1) no hop count mechanism is properly defined and no greedy method is defined. 2) Due to improper hop count mechanism the definition of energy efficiency is baseless.

D. Multi-Sink:

The protocol uses mesh network structure with 2D quasi-stationary for shallow water. The underwater sensor nodes are deployed like a tired architecture and the surface buoys are directly connected through wires with the UW-sink nodes. The mesh nodes are deployed and the neighbors to the sensor nodes, mesh nodes have a high memory power with the longer transmission range and sophisticated with high processing power. Surface buoys are placed and are directly connected through RF signals with the monitoring center. Mesh nodes can be recharged with the help of water control vehicles.

The mesh nodes are used for the data aggregation purpose; when sensor nodes transfer the data to the mesh nodes. It first aggregate the data then by using acoustic multi-hop channel will transfer to the UW-sink nodes; the UW-sink nodes which are directly connected to the surface buoys sends data to monitoring center through surface buoys. This protocol transfers the data in a smooth way towards destination. The protocol also enhances the packet delivery ratio due to simultaneous transmission of sensor nodes.

But the protocol has some issues like: 1) mesh nodes store the information like node ID and geographic area of all nodes of entire network, 2) quasi-stationary architecture doesn’t mean the mobile nodes it means static node according to architecture structure so in underwater environment the structure cannot response well and 3) packets duplication will increase the no. of hops.

III. MOTIVATION

A. Areas of Application of UWSN

1) 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.
2) Disaster Management: Having the seabed under surveillance would help in disaster management as we could sense various disasters having their epicentre in the ocean or sea, at an early stage. From the information gathered, pre-warning can generate for the nearby terrestrial areas.
3) 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.
4) 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.
5) Therefore, the Autonomous Underwater Vehicles can form a sophisticated network if communication takes place using appropriate link.
6) 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 Communication Links

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

1) 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]

2) 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. According to the report of Natural Resources Defense Council, the rising ocean noise have a great impact on life of mammals like dolphin and whales, causing hearing loss or sometimes even turn fatal.
3) 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.
4) 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.

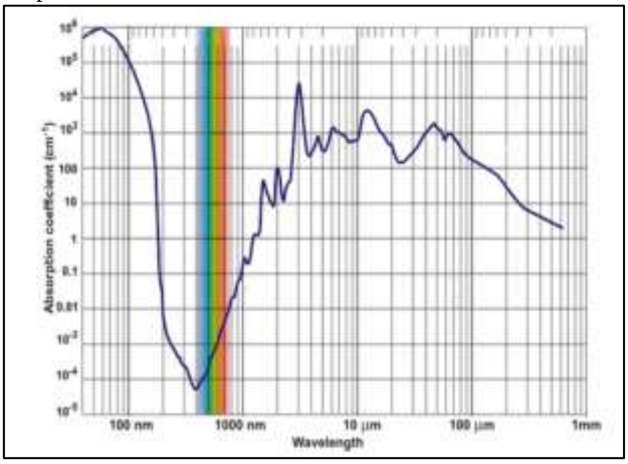

Fig. 1: Light Absorption vs Wavelength curve

IV. 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.

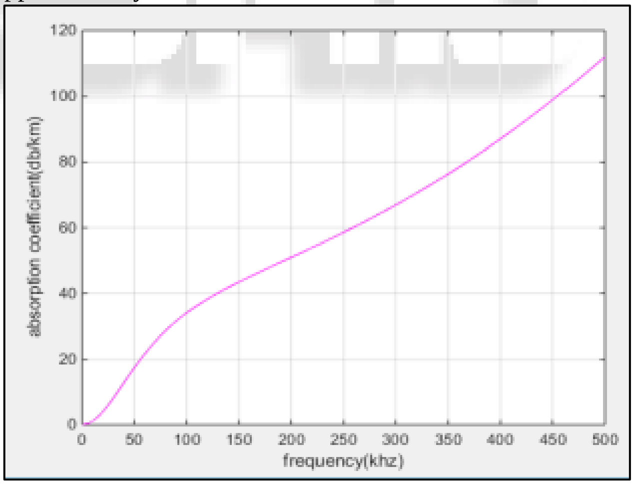

Fig. 2: Absorption coefficient versus frequency: Implementation with Thorps' formula

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.

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

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.

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

Table 1: Attenuation Coefficient of Different Water Conditions

V. 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.

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 transceivers
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.

Table 2: Various types of modulation for underwater communication

VI. 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 convolution 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 gives 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 do not prefer optical communication in a hybrid medium, thus we use this code in an acoustic link.

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.

Table 3: Various channel codes for underwater communication

VII. 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.

A. 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 centimetres 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.

B. *Range Free Schemes:*

These schemes do not uses the approaches like ToA, TDoA, and RSSI to estimate the distances to other nodes. They are broadly classified into:

1) Hop-count based schemes
2) Area Based schemes

These 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.

VIII. 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] provides the comparison between various routing protocols used for Underwater WSN. They have classified the protocols into the following categories:

A. *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 multi-hopping, the choice of relay nodes is based on the latter's distance from the sink node i.e. node, 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.

B. *Geographic Information-based Routing:*

The position or location based routing approach is also used in various protocols which continuously updating of the location of the neighbouring nodes is done to communicate data. Different protocols like Hop-by-Hop Dynamic Addressing Based (H2-DAB), Depth-Based Routing (DBR) and Delay Sensitive Depth-Based Routing (DSDBR) protocol have been discussed in [11-12].

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

1) DSR (Dynamic Source Routing)
2) AODV (Ad-hoc On Demand Distance Vector Routing protocol)
3) DSDV (Destination-Sequenced Distance-Vector Routing protocol)
4) 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. Furthermore, 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.

IX. 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.

REFERENCES

[1] Jingjing Wanga, Wei Shia, Lingwei Xua, Liya Zhoua, Qiuna Niua, Ju liu, Design of optical-acoustic hybrid underwater wireless sensor network, Journal of Network and Computer Applications, Elsevier, 2017.
[2] Stefanov, A.; Stojanovic, M.;, "Design and Performance Analysis of Underwater Acoustic Networks," Selected Areas in Communications, IEEE Journal on , vol.29, no.10, pp.2012-2021, December 2011.
[3] P. L. L.M. Brekhovskikh, Yu, "Fundamentals of Ocean Acoustics" 3rdEdition. Springer, 2003.
[4] Anguita, D.; Brizzolara, D.; Parodi, G.; Qilong Hu, "Optical wireless underwater communication for AUV: Preliminary simulation and experimental results," OCEANS, 2011 IEEE - Spain, vol., no., pp.1-5, 6-9 June 2011.
[5] Giles, J.W.; Bankman, I.N.;, "Underwater optical communications systems. Part 2: basic design considerations," Military Communications Conference,

2005.MILCOM 2005.IEEE, vol., no., pp.1700-1705 Vol. 3, 17-20 Oct 2005.
[6] Seongwon Han, Youngtae Noh, Richard Liang, Roy Chen,Yung-Ju Cheng, and Mario Gerla, "Evaluation of Underwater Optical-Acoustic Hybrid Network," IEEE China Communications, 11(5): 49-59, May,2014.
[7] V. Chandrasekhar, W. K. Seah, Y. S. Choo, H. V. Ee, “Localization in underwater sensor networks: survey and challenges”, Workshop on Underwater networks (WuWNet), pp. 33-40, 2006.
[8] G. Han, J. Jiang, N. Bao, L. Wan, and M. Guizani, “Routing protocols for underwater wireless sensor networks,” IEEE Commun. Mag., Vol.53, no.11, pp.72–78, 2015.
[9] S. Gopi et al., “E-PULRP: Energy Optimized Path Unaware Layered Routing Protocol for Underwater Sensor Networks,” IEEE Trans. Wireless Commun., vol. 9, no. 11, pp. 3391–401, 2010.
[10] T. Hu and Y. Fei, “QELAR: A Machine-Learning-Based Adaptive Routing Protocol for Energy-Efficient and Lifetime-Extended Underwater Sensor Networks,” IEEE Trans. Mobile Comp., vol. 9, no. 6, pp. 796–809, 2010.
[11] M. Ayaz et al., “An Efficient Dynamic Addressing Based Routing Protocol for Underwater Wireless Sensor Networks,” Comput. Commun., vol. 35, no. 4, pp. 475–86, 2012.
[12] H. Yan et al., “DBR: Depth-Based Routing for Underwater Sensor Networks,” Proc. Net., vol. 4982, pp. 72–86, 2008.
[13] Qadri, N.B.; Shah, G.A.;, “Performance evaluation of ad-hoc routing protocols in underwater acoustic sensor networks,” Wireless and Optical Communications Conference (WOCC), 19th Annual , vol., no., 14-15, pp.1-6, May 2010.
[14] Ayaz M, Abdullah A, Hop-by-Hop Dynamic Addressing Based (H2 DAB) Routing Protocol for Underwater Wireless Sensor Network, 2009 ICIMT, Proceedings 2009, pp 436-441.
[15] Carlson EA, Beaujean P-P, An E, Location Aware Routing Protocol for Underwater Acoustic Network, OCEANS 2006; 1-6.
[16] Liang W, Yu H, Liu L, Li B, Che C, Information Carrying Based Routing Protocol for Underwater Acoustic Sensor Network, Mechatron Automat, 2007, ICMA 2007, International Conference 2007: 729-34.