A State of Art Concept in Contriving of Underwater Networks

[1]Divyanshu Gaur, [2]Deependra Sharma, [3]Kunal Bhardwaj, [4] Nidhish Tiwari
[1,2,3]Dept. of Electronics & Communication Engineering, Apex Institute of Engineering & Technology, Jaipur, India
[4]Dept. of Electronics & Communication Engineering, JNIT, Jaipur, India
[1]divyanshugr@gmail.com, [2]dependra.sharma@gmail.com, [3]aktis.kunal@gmail.com, [4]nidhish_ju@rediffmail.com,

Abstract*—the underwater ocean environment is widely considered as one of the most difficult communications channels. Underwater acoustic networks have recently emerged as a new area of research in wireless networking. Underwater networks are generally formed by acoustically connected ocean-bottom sensors, underwater gateways and a surface station, which provides a link to an on-shore control center. In recent years, there has been substantial work on protocol design for these networks with most efforts focusing on MAC and network layer protocols. Low communication bandwidth, large propagation delay, floating node mobility, and high error probability are the challenges of building mobile underwater wireless sensor networks (UWSN) for aquatic applications. Underwater sensor networks (UWSNs) are the enabling technology for wide range of applications like monitoring the strong influences and impact of climate regulation, nutrient production, oil retrieval and transportation, many scientific, environmental, commercial, safety, and military applications. This paper first introduces the concept of UWSN, operation, applications and then reviews some recent developments within this research area and proposes an adaptive push system for dissemination of data in underwater wireless sensor networks. The goal of this paper is to survey the existing network technology and its applicability to underwater acoustic channels. In this paper we provide an overview of recent medium access control, routing, transport, and cross-layer networking protocols. It examines the main approaches and challenges in the design and implementation of underwater wireless sensor networks. Finally, some suggestions and promising solutions are given for these issues.

***Index Terms*— Underwater communication, Underwater Acoustic networks, Energy Efficiency, Medium Access Control, Networking protocols, Gateways, Clusters.**

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INTRODUCTION

Underwater sensor network (UWSN) is a unusual technique that provides a encouraging solution for efficiently scrutinizing and observing the aqueous environments. UWSN consist of variable number of sensors that are extended to perform collaborative monitoring tasks over a given area. Indeed several acoustic applications under marine require a permanent use of this network, therefore an important consumption of energy; that limits the life of battery and therefore the robustness of the network. The anticipation of energy is a major obligation in underwater wireless systems. [1]

This anticipation is due to the difficulties encountered to change the batteries of underwater stations. The change of the underwater stations batteries needs the recovery of equipment; this operation takes a significant time to stall the system, and it is expensive.

A. *Differences between underwater sensor networks and terrestrial networks.*

Underwater sensor networks are quite different from terrestrial sensor networks which are given as follows.

- *Communication Method*: Terrestrial sensor networks employ electromagnetic wave but underwater network communication relied on physical means like acoustic sounds to transmit the signal.
- *Cost Issue*: Terrestrial networks are becoming inexpensive due to advancement in technology but underwater sensors are still expensive devices. This is due to the extra protection required for underwater environment and more complex transceivers needed.
- *Node Mobility*: In case of terrestrial networks nodes mobility can be predicted whereas in the underwater networks prediction of mobility of the node is difficult, because of the density and flow variation of the water.

B. *Unique characteristics of underwater acoustic sensor networks.*

- *Noise*: It can be distributed as man-made noise and ambient noise. The prior is mainly caused by machinery noise (pumps, reduction gears, power plants), and shipping activity (hull fouling, animal life on hull, cavitations), while the latter is related to hydrodynamics (movement of water including tides, current, storms, wind, and rain). [3]

- *Multipath Propagation:* Multipath propagation is responsible for severe degradation of the acoustic communication signal, because it generates Inter Symbol Interference (ISI) whereas the multipath geometry depends on the link configuration. [2]

C. Challenges in underwater acoustic sensor networks.

Major challenges encountered in the design of underwater acoustic networks are:

1. The available bandwidth is severely limited.
2. The underwater channel is deteriorated because of multi-path, fading, connection losses and propagation delay.
3. Underwater sensors are characterized by high cost because of extra protective sheaths needed for sensors.
4. Battery power is limited and underwater sensors are more prone to failures because of fouling and corrosion. [7][8]

D. Applications of underwater acoustic sensor networks

1. Wireless underwater sensor networks are used for monitoring the health of river and marine environments.
2. A sensor network deployed underwater could monitor physical variables such as water temperature and pressure as well as variables such as conductivity, turbidity etc.
3. Wireless underwater sensor networks can provide tsunami warnings to coastal areas, study the effects of submarine earthquakes (seaquakes), monitors areas for surveillance, reconnaissance, targeting and intrusion detection systems.[1]

TOPOLOGIES FOR UNDERWATER SENSOR NETWORKS

Hierarchy Topology

Architecture for underwater sensor networks, shown in Fig. 1, consists of sensor nodes which are anchored to the bottom of the ocean and generic hardware to communicate acoustically in shallow water and send the data to the base station. As a network consisting of tens to hundreds of underwater sensors are deployed in a shallow water environment, they are organized in a cluster-based architecture and are interconnected by means of wireless acoustic that links to one or more underwater gateways (uw-gateways). A module consisting of uw-sink and uw-sensor, periodically samples their sensors, collecting physical indicator data such as temperature and salinity, which influence pollution levels in the water. After sampling their sensors, the nodes report their data to a surface node nearby. The gateways are in charge of relaying data from the ocean bottom network to a surface station. They are equipped with a long-range vertical transceiver and horizontal transceiver, where former transceiver is used to relay data to a surface station and latter one is used to communicate with the sensor nodes to send commands and configuration data, and to collect monitored data. The surface station is equipped with an acoustic transceiver, which is equipped with multi-user receiver capabilities to handle multiple parallel communications with the uw-gateways. It also consists of a long-range radio transmitter and/or satellite transmitter, which is needed to communicate with an onshore sink and/or to a surface sink. Onshore sink and/or surface sink manage the collected data which will be fed into a data repository that archives historical data from the monitored area. [3]

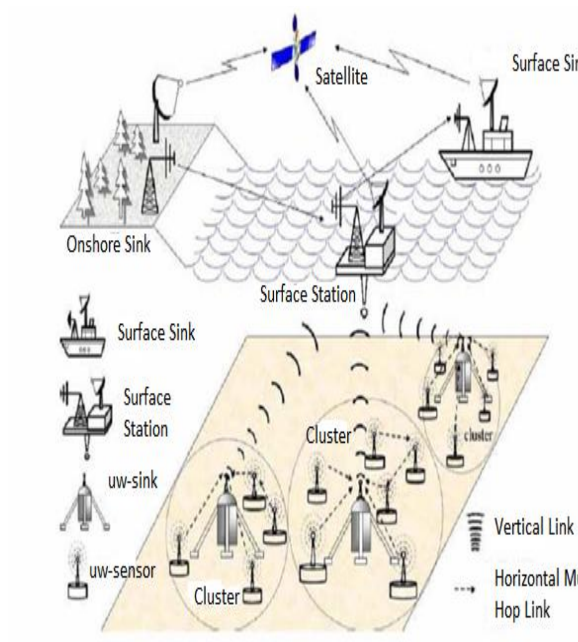

Figure 1. An example of Hierarchy topology.

Networks

Depending on the application, future underwater networks are likely to evolve in two directions: centralized (single hop) and decentralized (multi hops) networks [3]:

Centralized Network: Nodes are placed around of a central station that covers one cell. Larger area is covered by more cells whose base stations are connected over a separate communications infrastructure. The base stations can be on the surface and communicate using cable or acoustic links.

This topology presents several inconveniences:

- When the central node is in breakdown all the nodes is out network.
- This topology does not permit to cover big surfaces because of the limit of the range of the modem of the central station.

Decentralized Network: Nodes communicate via peer to-peer, multi-hop transmission of data packets. The signal passes from the nearest nodes of the emitter to the distant nodes in the direction of the receptor. Intelligent algorithms adapted to the different conditions manipulate the routing of information. This topology is able to cover height distances, on other hand the delay of propagation increases with the number of hops.

CHOICE OF ACCESS TECHNIQUE SCHEMES FOR UNDERWATER COMMUNICATION

Underwater wireless sensor networks (UWSN) prosecute a large mutation resulting of limited bandwidth, especially when multiple users split a common channel. The major objectives underwater communication system is to maximize the channel capacity and to minimize latency time between a station deciding to transmit and able to transmit. In this subsection, we present comparative study between typical multiple access schemes in order to adapt the best technical access for underwater channel communication. The most important access techniques are Frequency Multiplexing (FDMA, Frequency Division Multiple Access) Temporal Multiplexing (TDMA, Time Division Multiple Access), Code Multiplexing (CDMA, Code Division Multiple Access). [4]

FDMA /TDMA Multiple Access

Both frequency divisions multiple access (FDMA) and time division multiple access (TDMA) are the most signifying access schema, usually used in radio communication. The frequency division multiple access (FDMA) channel-access scheme is based on the frequency division multiplex (FDM) scheme, which provides different frequency bands to different data-streams. The time division multiple access (TDMA) channel access scheme is based on the time division multiplex (TDM) scheme, which provides different time-slots to different data-streams (in the TDMA case to different transmitters) in a cyclically repetitive frame structure.The main advantages of both FDMA and TDMA for under water communication are: FDMA and TDMA insure that each transmission is successful and no control messages are required. FDMA does not require synchronization between the nodes. In other side, FDMA and TDMA are inefficient, when the load is uneven. In addition, these two techniques are not flexible; adding a new node to the network requires equipment or software modification in every other node. Frequency division multiple access (FDMA) divides the available band into sub-bands. Afterwards, it assigns each sub-band to a device. Due to the narrow bandwidth in underwater acoustic channels and to the vulnerability of limited band systems to fading, FDMA is not suitable for UWSNs. Time division multiple access (TDMA) divides time into slots, providing time guards to limit packet collisions from adjacent time slots. These time guards are designed accounting for the propagation delay of the channel. Due to the characteristics of the underwater environment it is very challenging to realize a precise synchronization, with a common timing reference, which is required for a proper utilization of time slots in TDMA. Additionally, due to the high delay and delay variance of the underwater acoustic channel, TDMA efficiency is limited because of the high time guards required to implement it. Due to the limitations to the acoustic propagation speed and the limited bandwidth, protocols based on time or frequency scheduling alone are severely restricted in terms of coverage.

Code Division Multiple Access

Code division multiple access (CDMA) allows multiple devices to transmit simultaneously over the entire frequency band. Signals from different devices are distinguished by means of pseudo-noise codes that are used for spreading the user signal over the entire available band. This makes the signal resistant to frequency selective fading caused by multi-paths. In conclusion, although the high delay spread which characterizes the horizontal link in underwater channels makes it difficult to maintain synchronization among the stations, especially when orthogonal code techniques are used, CDMA is a promising multiple access technique for underwater acoustic networks. There are several mode of CDMA, notably the direct sequence CDMA, noted DSCDMA, and hopping frequency CDMA, noted FHCDMA. Code division multiple access (CDMA) implemented with direct sequence spread spectrum (DSSS) signaling is among the most promising multiplexing technologies for underwater sensor networks (UWSNs). Compared to TDMA and FDMA the advantages of CDMA for underwater channel include:

- CDMA allows multiple users to operate simultaneously over the entire frequency band.
- The large bandwidth of CDMA channels provides resistance to frequency-selective fading.
- Flexibility in the allocation of channels; increasing channel reuse by decreasing packet retransmissions.
- High Capacity
- The ability to operate asynchronously
- Strong Security
- Less sensitivity to noises
- Better diversity on frequency
- Energy Efficiency

FDMA and TDMA schemes do not utilize the shared channel very efficiency, for thus they are not suitable for the underwater environment. CDMA is conflict free multiple access method which is promising for future underwater networks.

Table 1. FDMA-TDMA-CDMA Performance in Underwater Channel

	FDMA	TDMA	CDMA
Scalability			×
Complexity		×	
Security			×
synchronization		×	
Throughput	×		×

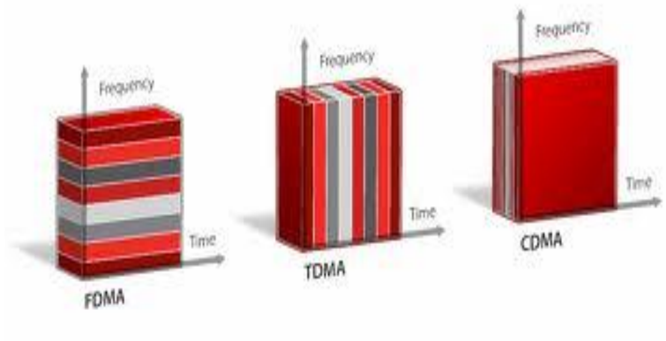

Figure 2. FDMA, CDMA & TDMA

MEDIA ACCESS CONTROL PROTOCOLS FOR UNDERWATER COMMUNICATIONS

Selection of suitable MAC protocol has a great effect on the system efficiency and is especially important for channels with low quality and high latency, such as underwater channel. The main task of MAC protocols is to provide efficient and reliable access to the shared physical medium in terms of throughput, delay, error rates and energy consumption. Many protocols have been developed in order to provide the sharing of underwater channel. In this section, a family of medium access control protocols for underwater communication is specified and analyzed to ensure best underwater communication. Existing MAC solutions are mainly focused on Carrier Sense Multiple Access (CSMA) or Code Division Multiple Access (CDMA). [6]

ALOHA Protocol

The ALOHA protocol is a random access protocol used for data transfer .The ALOHA protocols do not listen to the channel before transmission and therefore do not exploit the information about the other users. The protocol provides free access to the channel when user has data to transmit. In these conditions, it is clear that collisions occur. By listening to the channel before engaging in transmission, great efficiencies may be achieved and listening to the channel during the transmission, the user can know if a collision took place and broadcast data. The drawback of this protocol is that the probability of collisions increases when the system is too busy or loaded. [6]

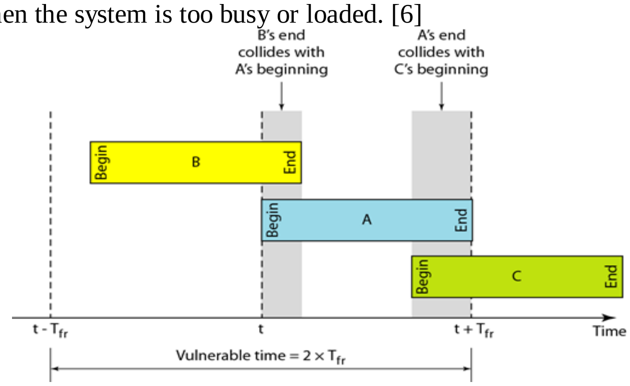

Figure 3. Pure ALOHA

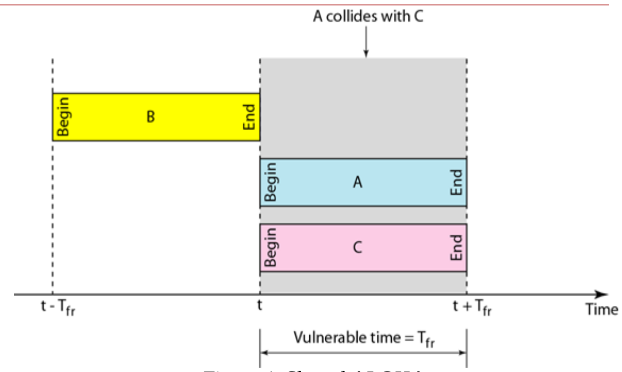

Figure 4. Slotted ALOHA

CSMA Protocol

Carrier Sense Multiple Access (CSMA) is a probabilistic media access control (MAC) protocol in which a node verifies the absence of other traffic before transmitting on a shared transmission medium, such as an electrical bus, or a band of the electromagnetic spectrum. "Carrier sense" means that a transmitter uses feedback from a receiver to determine whether another transmission is in progress before trying to send. That is, it tries to detect the presence of a carrier wave from another station before attempting to transmit. If a carrier is sensed, the station waits for the transmission in progress to finish before initiating its own transmission. In other words, CSMA is based on the principle "sense before transmit" or "listen before talk".

"Multiple access" means that multiple stations send and receive on the medium. Transmissions by one node are generally received by all other stations using the medium.

- *Persistent CSMA:* The terminal listens to the channel and waits for transmission until it finds the channel idle. As soon as it finds the channel is idle, the terminal transmits its message.
- *Non persistent CSMA:* Non persistent CSMA is less aggressive compared to P persistent protocol. In this protocol, before sending the data, the station senses the channel and if the channel is idle it starts transmitting the data. But if the channel is busy, the station does not continuously sense it but instead of that it waits for random amount of time and repeats the algorithm. Here the algorithm leads to better channel utilization but also results in longer delay compared, to 1 –persistent (with probability 1). [6]
- *P-Persistent CSMA:* This is a sort of trade-off between 1 and non-persistent CSMA access modes. When the sender is ready to send data, it checks continually if the medium is busy. If the medium becomes idle, the sender transmits a frame with a probability *p*. If the station chooses not to transmit (the probability of this event is *1-p*), the sender waits until the next available time slot and transmits again with the same probability *p*. This process repeats until the frame is sent or some other sender

starts transmitting. In the latter case, the sender monitors the channel, and when idle, transmits with a probability *p*, and so on.

- *CSMA/CD*: Persistent and non persistent CSMA protocols are an improvement over ALOHA, but another improvement is for terminals to abort their transmission as soon as they detect a collision. In order to decrease the probability of collision the improvement consists in stopping immediately the emission when a station detects a collision, in order to free the channel and to win of the time. It permits the reemission of the lost message. This algorithm is known as CSMA/CD (Carrier Sense Multiple Access with Collision Detection) used by Ethernet 802.3. CSMA/CD is used to improve CSMA performance by terminating transmission as soon as a collision is detected, and reducing the probability of a second collision on retry. Indeed in underwater wireless sensors networks, CSMA-based protocols are vulnerable to both hidden and exposed terminal problems.

  In order to reduce the effects of hidden terminals, MAC proposals should include techniques similar to the ones used in terrestrial networks like MACA, that uses RTS/CTS/DATA packets to reduce the hidden terminal problem, and MACAW which adds to the previous one an ACK packet at the link-layer, which can be helpful in an unreliable underwater channel. FAMA extends the duration of RTS and CTS packets in order to avoid data packet collisions, and so contention is managed at both sender and receiver sides before sending data packets. The efficiency of these protocols is heavily influenced by propagation delays due to their multiple handshakes. Hence, we choose to seek another approach based on MACA, which we describe below. [6]

MACA Protocol

Multiple Access with Collision Avoidance (MACA) is a slotted media access control protocol used in wireless LAN data transmission to avoid collisions caused by the hidden station problem and to simplify exposed station problem. [6] The basic idea of MACA is a wireless network node makes an announcement before it sends the data frame to inform other nodes to keep silent. When a node wants to transmit, it sends a signal called Request-To-Send (RTS) with the length of the data frame to send. If the receiver allows the transmission, it replies the sender a signal called Clear-To-Send (CTS) with the length of the frame that is about to receive. Meanwhile, a node that hears RTS should remain silent to avoid conflict with CTS; a node that hears CTS should keep silent until the data transmission is complete. The problem of hidden terminals and exposed terminals arises in ad-hoc networks due to the lack of connectivity between certain nodes. A situation of a hidden terminal occurs when one station cannot sense one or more nodes that can interfere with its transmission. A situation of an exposed terminal occurs when a station delays transmission because of another overheard transmission that would not collide with it.

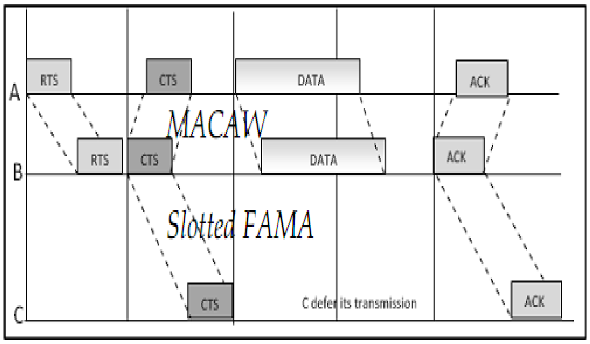

Figure 5. The use of virtual channel sensing
(MACAW and Slotted FAMA protocols)

As showing in figure (5) upon receiving the CTS, station A immediately sends its data. MACA protocol can eliminate problem of hidden and exposed terminal, in fact in the hidden problem station C would not hear the RTS from station A, but would hear the CTS from station B and therefore would defer from transmitting during A's data transmission. In the exposed problem, station C would hear the RTS from station B, but not the CTS from station A, and thus would be free to transmit during B's data transmission. [6]

MACAW Protocol

Multiple Access with Collision Avoidance for Wireless (MACAW) is a slotted Medium Access Control (MAC) and a modified version of MACA. The IEEE 802.11 RTS/CTS mechanism is adopted from this protocol. Unlike MACA, which uses RTS-CTS-DATA, MACAW uses RTS-CTS-DS-DATA-ACK message exchange and had a better backoff algorithm. To enable better congestion detection, MACAW shares backoff timers among stations by putting this info in headers. Further, to provide better synchronization among stations, the station sent a 30 byte Data-Sending packet (DS) before sending a DATA packet. For increased fairness MACAW uses separate queues for each stream in each node. Also, each queue is capable of running independent backoff algorithms. [5][9]

[As showing in figure (6) in MACAW protocol when a node A wants to send a packet to node B, it sends a small packet called Request-to-Send (RTS) in starting. Upon correctly receiving the RTS, node B wants to respond with another small packet called Clear to-Send (CTS). After receiving the CTS, node A sends the DS packet followed by DATA packet to node B. If node B receives the DS and DATA packet correctly, it sends an Acknowledgment (ACK) back to node A. Both the RTS and CTS frames contain information about the length of the DATA frame. Any node overhearing an RTS frame (for example node F or node E in the illustration) refrains from sending anything until CTS is received, or after waiting a certain time. If the captured RTS is not followed by CTS, the maximum waiting time is the RTS propagation time and the destination node turnaround time. Any node (node C and node E) overhearing a CTS frame refrains from sending anything for the time until the data frame and ACK should have been received (solving the hidden terminal problem), plus a random time. Both the RTS and CTS frames contain information about the length of the DATA frame. Hence a node uses that information to estimate the time for the data transmission completion. An overhearing station (node F), which might have received RTS and DS but not CTS, defers its transmissions until after the ACK frame should have been received plus a random time.][9][10]

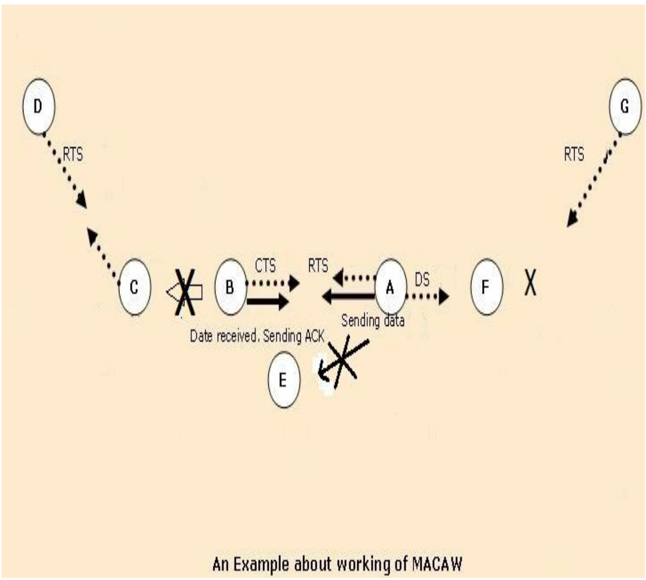

Figure 6. An example to illustrate the principle of MACAW. [10]

CONCLUSION AND FUTURE ASPECTS OF UNDERWATER NETWORKS SYSTEM

Underwater networks of sensors have the potential to enable unexplored applications. These potential applications will be made viable by enabling communications among underwater devices. .Most proposals have focused on random access techniques, but some have used a fully synchronized approach. So the real application of the aquatic networks, use FDMA as an access technique which is not efficient because of the selectivity in frequency and the limited underwater bandwidth. Underwater Acoustic Sensor Networks will consist of sensors and vehicles deployed underwater and networked via acoustic links to perform collaborative monitoring tasks. UWSN bandwidth is constrained by the physical properties of the medium, for thus the existing terrestrial MAC solutions are unsuitable for underwater communication. In this paper a distributed Medium Access Control (MAC) protocols and access techniques for UW-ASNs are analyzed. Our contribution consists on presenting a flexible solution suitable for different network sizes and architectures. Several MAC protocols have been proposed recently that attempt to provide sufficient operation. In near future underwater sensor networks will have significant advancement but numbers of challenges still remain to be solved. With the flurry of new approaches to communication, medium access, networking and applications. Effective analysis, integration and testing of these ideas of the field must be done and it should be understand in pratical manner.

Integration and testing of current ideas will stress the seams that are more focused in laboratory research, such as total system cost, energy requirements and overall robustness in different conditions. In accumulation, we are encouraged by a broadening of the field to consider different options, covering high-performance, cost to low-cost but has lower performance.

REFERENCES

[1] J.Hong Cui, “The Challenges of Building scalable Mobile Underwater wireless sensor Network for Aquatic Applications”, IEEE Network,2006.
[2] G. John and all, “Shallow water acoustic sensor Networks,” IEEE Communication Magazine 2001.
[3] F. Akyildiz and all, "Underwater acoustic sensor networks: research challenges", Elsevier January 2005.
[4] G.Xie and John Gibson, "A Networking Protocol for Underwater Acoustic Networks “December 2000.
[5] A. Demers, S. Shenker, and L. Zhang, “MACAW: a media access protocol for wireless LAN’s”, In SIGCOMM ’94, pages 212–225, 1994.
[6] E.M. Sozer, “Underwater Acoustic Networks” IEEE Journal of Oceanic Engineering, 25(1), 2000.
[7] J.Partan, J.Kurose1 and B.Neil Levine, “A Survey of Practical Issues in Underwater Networks”, WUWNet’06, September 25, 2006, Los Angeles, California, USA.
[8] J. Hong Cui, "The Challenges of Building Scalable Mobile Underwater Wireless Sensor Networks for Aquatic Applications", IEEE Network • May/June 2006.
[9] Vaduvur Bharghavan et al. (1994-08-01).” MACAW: A Medium Access Protocol for Wireless LAN's”. In the Proc. ACM SIGCOMM Conference (SIGCOMM '94), August 1994, pages 212-225. Retrieved 2007-01-18
[10] "Multiple Access with Collision Avoidance for Wireless". [Online] .Available: http://en.wikipedia.org/wiki/Multiple_Access_with_Collision_Avoidance_for_Wireless
[11] “Multiple Access” [Online]. Available. http://cclab.kw.ac.kr/lecture2013/spring/chap12.pdf
[12] Raja Jurdak , Antonio G. Ruzzelli , Gregory M. P. O’hare , Cristina Videira Lopes “Design Considerations for Deploying Underwater Sensor Networks” Sensor Technologies and Applications, 2007. SensorComm 2007, 227 – 232.
[13] John Heidemann, Milica Stojanovic and Michele Zorzi “Underwater sensor networks: applications, advances and challenges” Royal Society, 2012, Philos Transact A Math Phys Eng Sci. 2012 Jan 13;370(1958):158-75. doi: 10.1098/rsta.2011.0214.
[14] Ethem M. Sozer, Milica Stojanovic “Underwater acoustic networks - Oceanic Engineering” IEEE Journal Of Oceanic Engineering, Vol. 25, NO. 1, JANUARY 2000.
[15] Z. Guan, T. Melodia, D. Yuan, "Stochastic Channel Access for Underwater Acoustic Networks with Spatial and Temporal Interference Uncertainty," in Proc. of ACM Intl. Conf. on UnderWater Networks and Systems (WUWNet), Los Angeles, CA, USA, November 2012.

*** Corresponding Author:** Divyanshu Gaur
Tel.: +919460108150 E-mail: divyanshugr@gmail.com