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Prospects and Challenges of Underwater Acoustic Sensor Networking: A Review

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Abstract

This paper presents the important milestones in the development and applications of underwater wireless communications. The primary application areas are monitoring of environmental changes, collecting marine and oceanic data etc. Towards achieving these goals, research is being carried out for the evolution of methodical communications and signal processing algorithms, design of modulation and coding schemes, multiple access methods. In the related field of communication networking, design of protocols to take care of propagation delays and power requirements are important factors. Many problems are still unresolved in the design of acoustic communication system, recent research in this area serve as encouragement for future work.

Keywords: Acoustic, Communications, Networking, Sensor, Underwater

1. Introduction

Underwater Acoustic Sensing Networks (UWASNs) are widely used in many important applications such as coastal surveillance systems and AUV operations. On Comparing UWASNs with remote sensing, one can easily understand the space and time complexities of underwater environment by utilizing sensing and surveillance technology. The underwater wireless communication has drawn the attention of researches over the past one decade to monitor the oceanic environments for scientific, environment and military needs[1]. Wireless information transmission through the ocean plays a significant role in the future ocean observation system whose applications include detection of objects on the ocean floor, gathering scientific data, pollution control, climate monitoring and transmission of images from remote sites[2]. Underwater wireless communication also plays important role in surveillance and military applications, as well as control of AUVs under Deep Ocean. Existing underwater communication systems involve information transmission in the form of waves like sound, electromagnetic and optical. These methods have some constraints for use in underwater communication. The underwater communication is usually difficult to establish through acoustic techniques as communication fail after short distances. The velocity of sound underwater is 1500 m/sec. Underwater acoustic communication established using various numbers of sensors that are deployed at different locations under ocean to monitor over given area. Acoustic communication is mainly affected by the multipath propagation which varies with time, limited bandwidth and less speed of sound underwater. The multipath underwater propagation includes reflection and refraction principles. The reflections of signals result from top and bottom of the ocean's surface. Reflections of signals occur when wave front direction changes at an interface between two different mediums and the wave front returns into the original medium. In case of shallow water, due to reflection and refraction acoustic waves are adversely affected by factors like temperature gradient, surface ambient noise and multipath propagation. Refraction of signals occurs when the wave passes from one medium to another

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medium. These factors make underwater acoustic channel of poor quality and high latency which is quite different from terrestrial wireless networking. To overcome these effects development of several security mechanisms are discussed later in this paper. Application of EM waves in underwater environment is not possible due to conducting nature of medium. However, EM waves propagate over short distances underwater with faster speed with the advantage of faster and efficient communication between sensor nodes underwater.

2. Underwater Sensor Architecture

An underwater sensor consists of CPU controller which is connected to sensor interface circuitry shown in Figure 1. The CPU controller collects the data from the sensors and after processing it stores into the memory and transfers the data to others sensors with the help of acoustic modem[3].

2.1 Underwater Acoustic Sensor Network Architecture

These reference architectures are helpful in analyzing the future challenges of communication between the underwater sensors. Acoustic sensor networking technology is still an open research topic which is attracting various research communities. Underwater acoustic sensor networking architecture is classified in two categories. First architecture is a two dimensional architecture (covering floor of the ocean) and second is three dimensional architecture (including depth also).

2.2 Two Dimensional Underwater Acoustic Sensor Networking Architecture

The 2D architecture of underwater acoustic sensor network is depicted in Figure 2. The sensor nodes are connected to the ocean bed. These sensor nodes are small in size, operated through the battery and the communication between these nodes is established using acoustic modems. The sensor nodes are mostly connected to more than one sink present underwater. They have to send the data from bottom of the ocean to the ground station. To attain this, underwater sinks have horizontal and vertical transceivers. The horizontal transceiver makes the communication between the sensor nodes so that it sends commands or collects monitored data. The vertical transreceiver is used by underwater sensors to transmit information to the ground station. Vertical transceivers should be long range for deep water applications[4].

Sensors can be connected to underwater sinks through direct or by multi-hop links. In the former case, the gathered data can be sent directly to the selected underwater sink. This method is not complex but a lot of energy is lost, as the sink is at a distance from the node and the transmitting power reduces with distance. The direct links are not useful as they reduce the overall network throughput. While in multi-hop paths[4], the information gathered by a source sensor is re-transmitted by intermediate sensors till it reaches the sink. This yields saved energy and enhanced network capacity at the expense of increasing the complexity of the routing function.

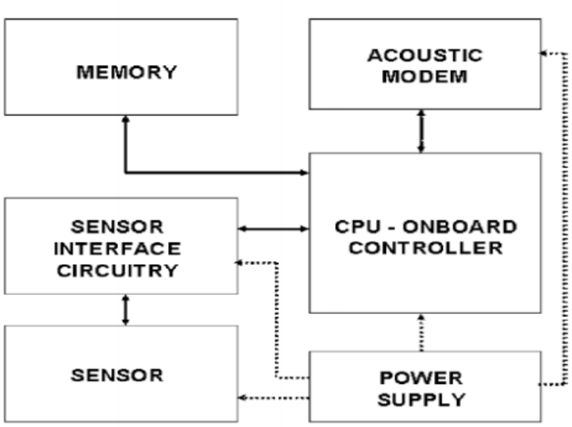

Figure 1. Internal architecture of underwater sensor[3].

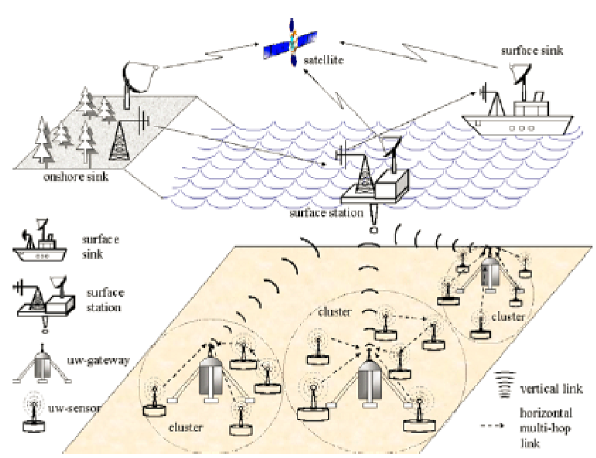

Figure 2. Two dimensional UWAS network architecture[4].

2.3 Three Dimensional Underwater Acoustic Sensor Networking Architecture

The 3D architecture of underwater acoustic sensor network is shown in Figure 3. This architecture can perform the 3D sampling of ocean environment i.e., it is used to observe the characteristics of ocean that cannot be observed by sensor nodes present on bottom of ocean floor. In this architecture, sensor nodes which are underwater can float at different depths using buoys. This set-up of large set of buoys may hinder navigation process. Thus, different methodology has to be employed to use sensor nodes underwater. There are many issues which should be taken care of before using three dimensional architecture like sensing coverage and communication coverage.

3. Underwater Sensor Network Protocols

3.1 Routing Protocols

3.1.1 *Flooding based Routing Protocols*[5]

In this approach, the node transmitting the packet to the other nodes lies in the transmission range.

3.1.2 *Multipath based Routing Protocols*

In this type of routing protocols, multiple paths are established from source to destination.

3.2 MAC Protocols

The communication underwater is established with the help of large number of sensors deployed at different levels of the ocean floor. There are two common MAC protocols are:

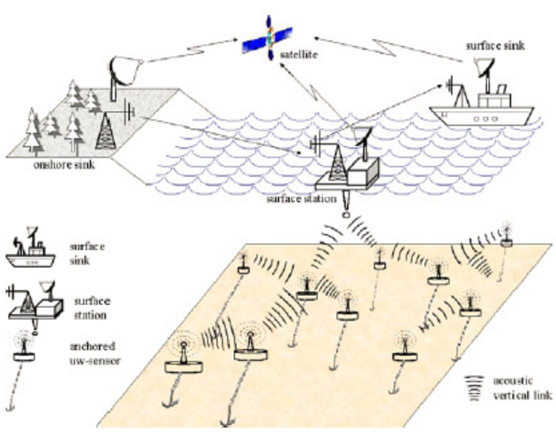

Figure 3. Three dimensional UWAS network architecture[4].

3.2.1 *Sensor MAC*

The sensor MAC protocol enables the synchronization of underwater sensor nodes and various sleep listen schedules deployed at the ocean floor. The S-MAC also has the feature of breaking the long messages into small frames and sends them in a burst[6]. Advantages of sensor MAC protocols are reduction in energy wastage and simple implementation.

3.2.2 *Wise MAC*

In W-MAC, the idle listening time is reduced with the help of preamble sample technique. This precedes each data packet for altering the receiving node. If the medium is busy, it continues to listen until the medium becomes idle again[6]. It gives better performance under congested traffic conditions and less power is consumed also.

4. Attacks on Underwater Communication Network and Countermeasures[7,8]

4.1 Jamming

Jamming attacks interfere with the medium by using carriers of neighboring frequency nodes. Underwater communications networks are vulnerable to narrow-band jamming. The attacker can jam the communication between a sender and a receiver and later replays the same message posing as the sender.

4.2 Wormhole Attack

A wormhole is created by the intruder between two physical locations in a network. In this case, the malicious node transfers some selected packets and injects them into the network. Due to this, false neighbor relationships are created, as two nodes out of each other's range can erroneously conclude that they are in proximity with one another due to the wormhole's presence.

4.3 Sinkhole Attack

A malicious node attempts to attract traffic from a particular area in a sinkhole attack. Geographic routing and authentication of nodes using routing information are possible defenses against this attack, but it is an unexplored area so far.

4.4 Hello Flood Attack

A node receiving a "Hello" packet from a malicious node may interpret that it is from some neighbor. Bidirectional link verification can provide some defense.

4.5 Sybil Attack

An attacker with multiple identities can pretend to be in many places at once. Authentication and position verification can be helpful but difficult to check due to mobility.

5. Security Requirements for Underwater Acoustic Communication[7]

5.1 Authentication

Authentication shows that the data was sent by a legitimate sender. It is usually essential in military and safety-critical applications of UWCNs.

5.2 Confidentiality

This shows that information is not accessible to unauthorized intruders. Thus, confidentiality in critical applications like maritime surveillance should be prioritized.

5.3 Integrity

Any intruder should not be able to modify the information. Many underwater sensor applications like water quality monitoring require highly reliable information.

5.4 Availability

It implies that the information could be retrieved easily when required by an authorized user. Any lag would affect time-critical aquatic exploration applications such as prediction of sea quakes.

6. Research and Issues for Underwater Acoustic Communication

6.1 Secure Time Synchronization

Time synchronization is a must in underwater applications. Time division multiple access requires precise timing between nodes to adjust their sleep-wake up schedules for power saving. Achieving precise time synchronization is especially difficult in underwater environments due to the characteristics of underwater communication network. Thus, the synchronization techniques used for ground based sensor networks cannot be applied on underwater acoustic communication[7].

6.2 Secure Routing

Routing is a main problem in under water communication networks due to the large propagation delays, the low bandwidth, the difficulty of battery refills of underwater sensors and the dynamic topologies. Thus, routing protocols should be designed to be energy-efficient, robust, scalable and adaptive[9].

6.3 Secure Localization

Localization plays a significant role in underwater sensors. It is an also important issue for data tagging and making routing decisions. Localization techniques employed for ground-based sensor networks cannot be used for underwater communication because of long propagation delays, Doppler Effect, multipath etc[10].

7. Communication Channel

The most common way of employing underwater communication channel is through hydrophones. As the data rates is small as compared to other types of communication, so acoustic waves are preferred. Also, the RF signals cannot carry digital information through an underwater channel; to resolve this issue acoustic waves are used, which can propagate over long distances. The three distinguishing characteristics of this channel are frequency-dependent propagation loss, severe multipath, and low speed of sound propagation. None of these characteristics are difficult to tackle in ground-based radio channels, but in underwater wireless communication they are extremely difficult to handle[11].

7.1 Wave Propagation

Path loss of acoustic communication channel over a distance d is given by A = dka(f)d, where k is the path loss exponent whose value is usually between 1 and 2, and a (f) is the absorption factor that depends on the frequency[11].

Within limited bandwidth, the signal is subjected to multipath propagation, which is particularly pronounced on horizontal channels. Multipath occurs in shallow water due to signal reflection from the surface and bottom, shown in Figure 4. Multipath propagation occurs in deep waters due to ray bending.

The nominal speed of sound underwater is 1500 m/s; it varies with depth and also depends on the environment. There are two important implications of sound's speed underwater. First is long signal delay and second is Doppler distortion in a mobile acoustic system.

8. Underwater Networks

There is vast advancement in acoustic communications, sensor and vehicular technology. Oceanic engineering is heading towards the integration of these components into autonomous underwater networks. The present applications include monitoring of AUVs, and telemetry of oceanographic data. The future vision is that of a "digital ocean" in which integrated networks of instruments, sensors, robots and vehicles will operate together. Some applications like fleets of AUVs deployed on collaborative search missions and ad hoc deployable sensor networks for environmental monitoring[11].

Future underwater communication networks are likely to evolve in two directions: centralized and decentralized networks. The two types of network topologies are shown in Figure 5 and Figure 6. In a centralized network, nodes communicate through a base 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 radio links. In a decentralized network, nodes communicate via multi-hop transmission of data packets. The packets must be transmitted to reach the destination[11].

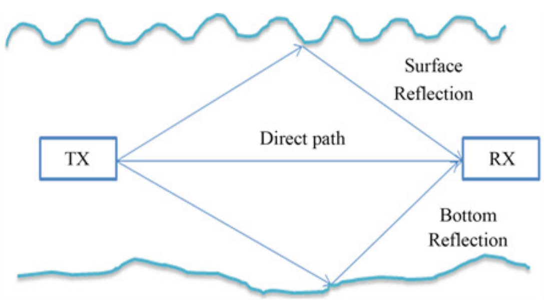

Figure 4. Shallow water multipath propagation[11].

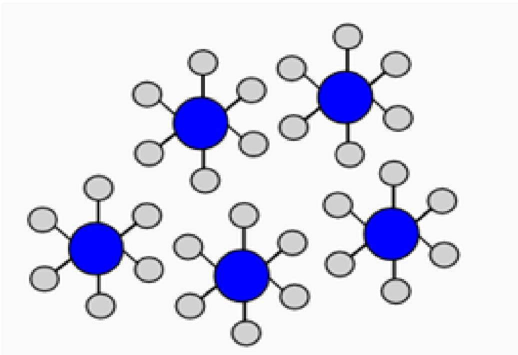

Figure 5. Centralized network topology.

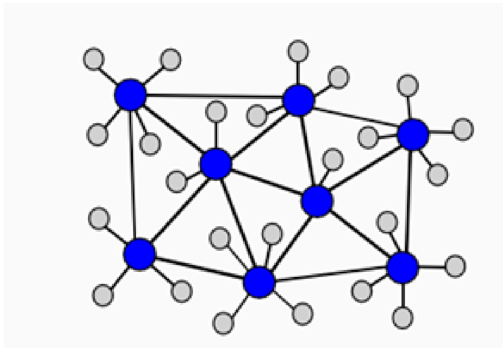

Figure 6. Decentralized network topology.

9. Conclusion

Extensive research is going on across the world in underwater communication networks[12–29]: From fundamental capacity analyses to the design of practical network architecture. It is a very promising area which has applications in more complex and sophisticated systems for oceanic engineering.

10. References

1. Heidemann J. Guest editorial– Underwater wireless communication networks. IEEE Journal on Selected Areas in Communications. 2008; 26(9):1617–9.
2. Stojanovic M. Acoustic (underwater) communications. In: Proakis JG, editor. Encyclopedia of Telecommunications. USA: John Wiley and Sons; 2003.
3. Proakis JG, Sozer EM, Rice JA, Stojanovic M. Shallow water acoustic networks. IEEE Communications Magazine. 2001; 39(11):114–9.
4. Akyildiz IF, Pompili D, Melodia T. Three-dimensional and two-dimensional deployment analysis for underwater acoustic sensor networks. Ad Hoc Networks. 2009; 7(4):778–90.
5. Subbu K, Li X. SFRP: A selective flooding-based routing protocol for clustered wireless sensor networks. Proc IEEE Radio and Wireless Symposium; 2010.
6. Wood AD, Stankovic JA. A taxonomy for denial-of-service attacks in wireless sensor networks. Chapter in Handbook

of Sensor Networks: Compact Wireless and Wired Sensing Systems. CRC Press; 2004. p. 1–18.

7. Kasture S, Gudpelliwar N. Securing underwater wireless communication networks-literature. International Journal of Scientific and Engineering Research. 2013; 4(12):73–8.
8. Raju KG, Kumar AV, Kumar GA, Kiran VR. Attacks and securing under water wireless communication networks. International Journal of Research in Advent Technology. 2014; 2(5):12–5.
9. Domingo MC. An overview of the internet of underwater things. Journal of Network and Computer Applications. 2012; 35(6):1879–90.
10. Domingo MC. Securing underwater wireless communication networks. IEEE Wireless Communications. 2011; 18(1):22–8.
11. Stojanovic M. Underwater wireless communications: Current achievements and research challenges. IEEE Oceanic Engineering Society Newsletter. 2006; 41(2):10–3.
12. Demirkol I, Ersoy C, Alagoz F. MAC protocols for wireless sensor networks: A survey. IEEE Communications Magazine. 2006; 44(4):115–21.
13. Wood AD, Stankovic JA. A taxonomy for denial-of-service attacks in wireless sensor networks. Chapter in Handbook of Sensor Networks: Compact Wireless and Wired Sensing Systems. CRC Press; 2004. p. 1–18.
14. Wang W, Kong J, Bhargave B. Visualization of wormholes in underwater sensor networks: A distributed approach. Int'l J Security Net. 2008; 3(1):10–23.
15. Stojanovic M, Catipovic J, Proakis J. Phase coherent digital communications for underwater acoustic channels. IEEE Journal of Oceanic Engineering. 1994; 19(1):100–11.
16. Jurdak R, Lopes CV, Baldi P. A survey, classification and comparative analysis of medium access control protocols for ad hoc networks. IEEE Communications Surveys and Tutorials, 2004; 6(1):2–16.
17. Kalofonos DN, Stojanovic M, Proakis JG. Performance of adaptive MC-CDMA detectors in rapidly fading rayleigh channels. IEEE Transactions on Wireless Communications. 2003; 2(2):229–39.
18. Ye W, Heidemann J, Estrin D. An energy-efficient MAC protocol for wireless sensor networks. Proceedings of IEEE 21st Annual Joint Conference of the IEEE Computer and Communications Societies. INFOCOM 2002; New York, USA. 2002. p. 1567–76.
19. Abolhasan M, Wysocki T, Dutkiewicz E. A review of routing protocols for mobile ad hoc networks. Ad Hoc Networks. 2004; 2(1):1–22.
20. Melodia T, Pompili D, Akyildiz IF. Optimal local topology knowledge for energy efficient geographical routing in sensor networks. Proceedings of IEEE 23rd Annual Joint Conference of the IEEE Computer and Communications Societies INFOCOM 2004; Hong Kong. 2004. p. 1705–16.
21. Sankarasubramaniam Y, Akan OB, Akyildiz IF. ESRT: Event to-sink reliable transport for wireless sensor networks. Proceedings of ACM MOBIHOC; Annapolis, MD, USA. 2003. p. 177–88.
22. Jagan BOL, Rao SK, Jawahar A, Karishma SKB. Application of bar-shalom and fortmann's input estimation for underwater target tracking. Indian Journal of Science and Technology. 2016 Jun; 9(21). DOI: 10.17485/ijst/2016/v9i21/85451.
23. Santhosh MN, Rao SK, Das RP, Raju KL. Underwater target tracking using unscented kalmanfilter. Indian Journal of Science and Technology. 2015 Nov; 8(31). DOI: 10.17485/ijst/2015/v8i31/77054.
24. Goel G, Dutta M, Goswami S. An approach for shallow underwater images visibility and color improvement. Indian Journal of Science and Technology. 2015 Dec; 8(35). DOI: 10.17485/ijst/2015/v8i35/72210.
25. Annabattula J, Rao SK, Murthy ASF, Srikanth KS, Das RP. Underwater passive target tracking in constrained environment. Indian Journal of Science and Technology. 2015 Dec; 8(35). DOI: 10.17485/ijst/2015/v8i35/82264.
26. Raj SMA, Supriya MH. FPGA implementation of underwater image enhancement using nonlinear filtering. Indian Journal of Science and Technology. 2015 Dec; 8(35). DOI: 10.17485/ijst/2015/v8i35/79110.
27. Karthik SS. Underwater vehicle for surveillance with navigation and swarm network communication. Indian Journal of Science and Technology. 2014 Oct; 7(S6). DOI: 10.17485/ijst/2014/v7iS6/54589.
28. Kalpana G, Rajendran V. Development of adaptive denoising algorithm using wavelet technique for a linear fm acoustic signal. Indian Journal of Science and Technology. 2015 Dec; 8(35). DOI: 10.17485/ijst/2015/v8i35/82273.
29. Chitre M, Shahabudeen S, Stojanovic M. Underwater acoustic communication and networks: Recent advances and future challenges. Marine Technol Soc Journal. 2008; 42(1):103–16.