

An Extensive Research on Acoustic Underwater Wireless Sensor Networks (AUWSN)

P. P. Joby

Professor and Head, Department of Computer Science and Engineering, St. Joseph's College of Engineering and Technology, Kerala

E-mail: jobypcse@gmail.com

Abstract

It is a well-known fact that water covers nearly 71% of the total earth's surface. This makes the extraction of most valuable information from the seafloor and underwater resources extremely difficult for humans. As a result, in order to meet the requirements of underwater exploration, researchers have focused their efforts on developing new technologies for establishing underwater communication. The recent advancements in wireless acoustic underwater sensing and communication technology has resulted in an upsurge in the exploration of abundant underwater natural resources. This research study intends to provide a comprehensive overview of acoustic underwater sensor networks, including their implementation techniques, routing algorithms and applications. This study also provides a comparative analysis on various acoustic wireless sensor networks deployment in order to find the existing research gaps. Furthermore, some real-time AUWSN applications were reviewed, providing diverse and insightful information about the AUWSN approach. Finally, the study discusses about some potential future research directions for designing the next-generation AUWSNs.

Keywords: Acoustic networks, underwater communication, autonomous underwater vehicle, network analysis, underwater sensors

1. Introduction

Over the last decades, wireless sensor networks (WSNs) has shown a huge potential in the areas of military, healthcare, disaster management, and so on. With the sensors deployed on the particular region of interest, the data will be collected, analyzed and transferred to the base station (BS), which will be usually placed at long distance [1]. Due to

its capability of deploying sensor nodes in a random manner, in the real-time applications like search and rescue operations, WSNs play a highly beneficial role by broadcasting the emergency messages among the clustered nodes before transmitting it to the base station for further analysis [2]. Communication autonomously with the local peer, dynamic adaptability to the sudden network topology changes, and reduced energy consumption are the potential advantages of WSNs.

As a recent advancement of WSNs, the underwater networks are gaining a significant research interest. However, dissimilar to WSNs, which mainly use the optical or electromagnetic signals to transmit data in any medium, the high absorption coefficient renders the conventional data transmission technologies incapable for performing underwater communication. Alternatively, the acoustic signals can be effectively used to transmit signals over a long distance underwater. As a result, the wireless underwater sensor networks [3] that rely on acoustic communication are frequently referred to as Acoustic Underwater Wireless Sensor Networks (AUWSNs).

AUWSN is typically composed of two different systems, they are 1) Surface System: ocean surface trawl and floating data center. These systems can transfer the signal to the base station by utilizing the global positioning system technology. 2. Underwater System: This system is usually composed of three elements they are seafloor sensors, floating sensing elements, and unmanned underwater vehicles [4].

The preceding part of the article is focused on exploring the state-of-the-art Acoustic Underwater Wireless Sensor Networks (AUWSN)

2. Acoustic Underwater Wireless Sensor Networks (AUWSN)

The Acoustic Underwater Wireless Sensor Networks (AUWSN) framework distributes the miniaturized sensor nodes with different characteristics in different water levels to continuously monitor the activities happening underwater. The underwater sensor nodes poses the ability to record and transfer the acoustic signals via underwater acoustic communication to the surface node, which then transmits the information to base station for further analysis. The Autonomous Underwater Vehicle (AUV) is the commonly used surface node/sink to sense the acoustic signals and perform the related operations. AUVs are generally used to monitor the underwater environment by sensing the acoustic signals [5]. The general block diagram of different AUWSN operations are depicted in Fig 1.

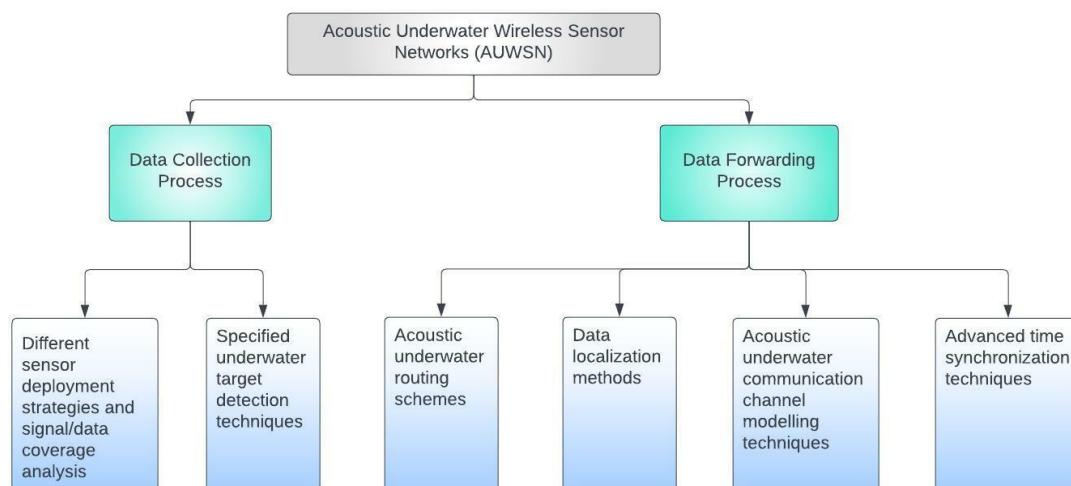


Figure 1. Different Operations involved in AUSWN

2.1 Data Collection Process

In the segment, the primary focus was given to the deployment of sensor nodes at random places within the region of interest and then the detection of target objects and observe the acoustic signals for monitoring purpose [9]. Even though acoustic signals and communication perform better when compared to radio waves in underwater communication, it also faces some challenges such as error rate, propagation delay and path loss.

Generally, two different types of noise are observed in the underwater communication, one will be the naturally generated noise and the other will be the human-generated noise. The human-generated noise will usually occur by the movement of any objects like (Ship, boat) in the water surface.

2.2 Data Forwarding Process

In this segment, the two main data forwarding concepts were discussed.

2.2.1 Acoustic Underwater Communication Channels

AUWSN is primarily used for establishing real-time long-term underwater monitoring tasks. The negative aspects of underwater environment, such as corrosion due to increased salinity, structural destruction, and so on must also be taken into consideration [6].

Potential research efforts have been initiated to design the characteristic features of underwater acoustic signal propagation for successfully implementing a much more accurate

simulation. The main factors that affect acoustic propagation are attenuation and multipath loss [7].

Path loss is generally defined by using the distance (r) and frequency (f) as follows:

$$Path\ Loss\ P(r, f) = PtLoss_0 r^n \alpha(f)'$$

Here, n denotes the spreading factor, $PtLoss_0$ referred as a constant, $\alpha(f)$ indicates the absorption coefficient.

The signal-to-noise ratio denoted as $\delta(r, f)$ of the transmitted acoustic at frequency f after spreading within a distance r is derived as follows:

$$\delta(r, f) = \frac{S_{pd}(f)}{P(r, f) \cdot N_s(f)}$$

Here, the $S_{pd}(f)$ represents the power spectral density and $N_s(f)$ denotes the noise power density [8].

2.2.2 Acoustic Underwater Routing Protocols

Table 1. State-of-the-art AUWSN Techniques & Applications

Reference	Technique	Application	Outcome	Advantage
Ali et al [1]	Multilayer algorithm (MuLSi-Co)	Acoustic Underwater Wireless Sensor Networks (AUWSN)	- Reduced the multiple hops - Increased the reliable data exchanging - Better Performance valuable	- Less energy cost - Efficient - Minimize energy consumption
Ali et al [2]	Elliptical shaped data collection mechanism (ESEDG)	Autonomous Underwater Vehicles	- Maximum data gather GNs - Balanced energy consumption and network delay	- high reliability - validity - reduces the time
Mohan et al [3]	IMCMR-UWSN	Multi hop routing in AUWSN	- Maximized the energy efficiency - Longevity - Performance improved	- boost the energy efficiency - lifetime - Increased coverage - Reduced deployment cost
Menon et al [4]	Location driven opportunistic routing	Internet of Underwater Things (IoUTs)	- improved the QoS - Energy Efficiency - Reduced delay - Better performance	- Easy-to-implement - Highest coverage of node - Better energy and throughput

Sivakumar et al [5]	Vector driven Forwarding	Markov probability and voltage profile approach	- Improved throughput - distributed load evenly - Equal load sharing	- Simplicity - accuracy - Fast convergence - very limited redundancy
Chen et al [6]	Backoff tolerant Opportunistic protocol (BTBO)	Acoustic Underwater Wireless Sensor Networks (AUWSN)	- Effectively - Improved performance - Better throughput	- Independent timeline - Stable state increase in coverage range
Günther et al [7]	Utility Estimation using microphone	Machine Learning driven AUWSN	- Excellent performance - learned an optimal feature set - Improved accuracy	- Efficiency data managing - Time-consuming
Lowes et al [8]	Envelope modulation based noise detection - DEMON.	Passive Device: Acoustic Surface Vessel Detector	- Reduced power consumption - Improved performance - increased detection radius	- Improved sensitivity - power efficient - Reliability - Increased processing power
Goutham et al [9]	Space coded non-OMA (STBC-NOMA)	Acoustic Underwater Wireless Sensor Networks (AUWSN)	- Improved performance of bandwidth-limited - Improvements in ergodic sum rate - Energy efficiency	- Improve reliability - Enhance the performance - Higher spectral Efficiency - Lower latency
Zhao et al [10]	Time domain based Interference Arrangement scheduling	Deep Reinforcement Learning based Acoustic Underwater Wireless Sensor Networks (AUWSN)	- Increase network throughput - Reduce collisions - Improved network throughput - Improved network performance	- Better performance - highly dynamic - no computational restriction - large propagation delays

The acoustic transmission range can be lengthy, wherein establishing an end-to-end communication link for any two sensor nodes present underwater cannot be assured. This necessitates the need to implement Acoustic Underwater Routing Protocols (AURP) [10]. Generally, vector driven forwarding [15] is the common routing protocol followed in underwater communication but due to the scattered deployment of AUWSN with unstable mobility the routing protocols need to be more relied on the location information. This increases the computational complexity of the AUWSN system. Currently the opportunistic routing protocol is preferred in order to select the forwarding operation by selecting the suitable hop. Further, to avoid the localization challenges in opportunistic routing protocol [14], the depth driven routing protocol is preferred since it only requires the information about the depth to select the next forwarding node.

3. State-of-the-art AUWSN Techniques and Applications:

Researchers have recently developed a novel collaborative multilayer sink algorithm and an elliptical structured data collection technique for AUWSNs in order to reduce the multi-path loss, increase data reliability, and optimize the energy consumption [11, 12]. An improved metaheuristics driven clustering algorithm is proposed to enhance the communication lifetime and network coverage [13]. As an advancement of vector driven forwarding, the Backoff-tolerant-opportunistic network protocol [16] is proposed to enhance the network throughput. The microphone utility has been estimated with the incorporation of recent machine learning technology in order to deliver an optimal feature set, reduce time consumption and incorporate effective data processing strategies [17]. In order to avoid the spectral noise and white noise generated from AWGN, an envelope modulation based noise detection approach and non-orthogonal multiple access technique [18, 19] has been proposed to enhance the processing power, sensitivity, and reliability. The recent technological innovations like deep reinforcement learning has been applied in order to establish an effective time synchronization to make AUWSN network more dynamic and reduce the network collisions.

4. Conclusion

AUWSNs have received a significant research attention in recent years. This article has summarized some of the important attributes of underwater acoustic signal transmission and also proposed a comparative analysis on the state-of-the-art approaches for AUWSNs. The study has successfully presented a general overview on AUWSNs and also showcased the related works in different categories such as: i) Underwater sensor based data collection; ii) Acoustic channel modelling; iii) Network coverage schemes; iv) Localization & time synchronization schemes; and v) Underwater routing protocols. Moreover, each section has also stated the challenges faced by the traditional WSNs and AUWSNs and also discussed about the recent research works proposed in such domain. Finally, the research directions for the design and development of real-time and efficient AUWSNs are outlined.

References

- [1] Li, Jianzhong, Huadong Ma, Keqiu Li, Li Cui, Limin Sun, Zenghua Zhao, and Xiaofei Wang, eds. Wireless sensor networks. Springer Singapore, 2018.

- [2] Tseng, Yu-Chee, Meng-Shiuan Pan, and Yuen-Yung Tsai. "Wireless sensor networks for emergency navigation." *Computer* 39, no. 7 (2006): 55-62.
- [3] Davis, Almir, and Hwa Chang. "Underwater wireless sensor networks." In *2012 Oceans*, pp. 1-5. IEEE, 2012.
- [4] Jouhari, Mohammed, Khalil Ibrahimi, Hamidou Tembine, and Jalel Ben-Othman. "Underwater wireless sensor networks: A survey on enabling technologies, localization protocols, and internet of underwater things." *IEEE Access* 7 (2019): 96879-96899.
- [5] Sahoo, Avilash, Santosha K. Dwivedy, and P. S. Robi. "Advancements in the field of autonomous underwater vehicle." *Ocean Engineering* 181 (2019): 145-160.
- [6] Wang, Chao, Xiaohong Shen, Haiyan Wang, and Haodi Mei. "Energy-efficient collection scheme based on compressive sensing in underwater wireless sensor networks for environment monitoring over fading channels." *Digital Signal Processing* 127 (2022): 103530.
- [7] Wang, Chao, Xiaohong Shen, Haiyan Wang, and Haodi Mei. "Energy-efficient collection scheme based on compressive sensing in underwater wireless sensor networks for environment monitoring over fading channels." *Digital Signal Processing* 127 (2022): 103530.
- [8] Coutinho, Rodolfo WL, Azzedine Boukerche, Luiz FM Vieira, and Antonio AF Loureiro. "Geographic and opportunistic routing for underwater sensor networks." *IEEE Transactions on Computers* 65, no. 2 (2015): 548-561.
- [9] Sun, Peng, and Azzedine Boukerche. "Integrated connectivity and coverage techniques for wireless sensor networks." In *Proceedings of the 14th ACM International Symposium on Mobility Management and Wireless Access*, pp. 75-82. 2016.
- [10] Khan, Hashim, Syed Ali Hassan, and Haejoon Jung. "On underwater wireless sensor networks routing protocols: A review." *IEEE Sensors Journal* 20, no. 18 (2020): 10371-10386.
- [11] Ali, Munsif, Sahar Shah, Mahnoor Khan, Ihsan Ali, Roobaea Alroobaea, Abdullah M. Baqasah, and Muneer Ahmad. "MuLSi-Co: Multilayer Sinks and Cooperation-Based Data Routing Techniques for Underwater Acoustic Wireless Sensor Networks (UA-WSNs)." *Wireless Communications and Mobile Computing* 2022 (2022).
- [12] Ali, Ghulam, Tariq Ali, Insha Ul Hassan, Ahmad Shaf, Muhammad Irfan, Grzegorz Nowakowski, Kazimierz Kielkowicz, Adam Glowacz, and Samar M. Alqhtani. "A Novel Routing Protocol Based on Elliptical Shaped Movement of Autonomous

- Underwater Vehicles in Data Gathering Process for Underwater Wireless Sensor Network." *Sensors* 22, no. 14 (2022): 5269.
- [13] Mohan, Prakash, Neelakandan Subramani, Youseef Alotaibi, Saleh Alghamdi, Osamah Ibrahim Khalaf, and Sakthi Ulaganathan. "Improved metaheuristics-based clustering with multihop routing protocol for underwater wireless sensor networks." *Sensors* 22, no. 4 (2022): 1618.
- [14] Menon, Varun G., Divya Midhunchakkaravarthy, Aaromal Sujith, Sonali John, Xingwang Li, and Mohammad R. Khosravi. "Towards Energy-Efficient and Delay-Optimized Opportunistic Routing in Underwater Acoustic Sensor Networks for IoUT Platforms: An Overview and New Suggestions." *Computational Intelligence and Neuroscience* 2022 (2022).
- [15] Sivakumar, V., G. R. Kanagachidambaresan, Muhammad Arif, Christy Jackson, and G. Arulkumaran. "Energy-Efficient Markov-Based Lifetime Enhancement Approach for Underwater Acoustic Sensor Network." *Journal of Sensors* 2022 (2022).
- [16] Chen, Keyu. "Backoff- toleration- based opportunistic MAC protocol for underwater acoustic sensor networks." *IET Communications* (2022).
- [17] Günther, Michael, Andreas Brendel, and Walter Kellermann. "Microphone Utility Estimation in Acoustic Sensor Networks using Single-Channel Signal Features." *arXiv preprint arXiv:2201.09946* (2022).
- [18] Lowes, Gavin James, Jeffrey Neasham, Richie Burnett, Benjamin Sherlock, and Charalampos Tsimenidis. "Passive Acoustic Detection of Vessel Activity by Low-Energy Wireless Sensors." *Journal of Marine Science and Engineering* 10, no. 2 (2022): 248.
- [19] Goutham, Veerapu, and V. P. Harigovindan. "Space–time block coded non-orthogonal multiple access for performance enhancement of underwater acoustic sensor networks." *ICT Express* 8, no. 1 (2022): 117-123.
- [20] Zhao, Nan, Nianmin Yao, Zhenguo Gao, and Zhimao Lu. "Deep Reinforcement Learning Based Time-Domain Interference Alignment Scheduling for Underwater Acoustic Networks." *Journal of Marine Science and Engineering* 10, no. 7 (2022): 903.

Author's biography

P. P. Joby is currently a Professor and Head, in Department of Computer Science and Engineering. St. Joseph's College of Engineering and Technology, Kerala. His research area includes Machine Perception, Robotics, Cyber-Physical Systems, Internet of Things,

Complex Networks, Quantitative Network-based modelling, Complex and Intelligent Systems, Networks, Recommendation System, Human-Computer Interface, and Knowledge Representation.