Energy Efficient 4-Dimensional Heterogeneous Communication Architecture For Underwater Acoustic Wireless Sensor Networks

M. Saranya Nair, K. Suganthi

Abstract: The oceans define our home planet, dominating the major portion of Earth's surface and significantly affecting the world's economy. But, only 4% of the ocean is protected in some way compared to 15% of the land which motivates the researchers to explore the ocean in-order to conserve it. Underwater sensor network technologies fetched us with innovative ways to monitor and sense marine environments. In spite of severe technical challenges, Underwater Wireless Sensor Networks (UWSNs) have proven its strength with a myriad of applications in the areas of monitoring, disaster, military, navigation, surveillance, archaeology and so on. To make ocean sensor network applications viable, efficient UWSN communication paradigms among the networking components is crucial. This paper summarizes the challenging characteristics and existing communication architectures of underwater sensor networks, hence propose an energy efficient design for an UWSN topology. First of all, the motivation for the development and deployment of UWSNs is presented trailed by the basics of underwater acoustic communications. The protocol stack and the possible network architectures of UWSNs are then discussed. Efficient network designs are then proposed and analyzed for UWSNs. In addition, the article outlines the challenging, open and hot research topics in UWSNs.

Index Terms : Acoustic Communication, Architectures, Characteristics, Heterogeneous, Motivation, Protocol Stack, Research Topics, Underwater Sensor Networks.

1. INTRODUCTION

THE growing population on earth involves air, water, food, new medicines, a comfortable climate, beauty, inspiration and recreation. The ocean is the major ecosystem on Earth; it is the planet's life support system. Healthy oceans can support human's survival and prosper. Oceans generate half of the oxygen we breathe, impacts the weather all over the earth and, at any given moment, they comprise more than 97% of the world's water [1]. In spite of the major role of oceans in our daily life, it subjects to various attacks from natural sources and manmade pollution. But, oceanic exploration remains a mystery due to its harsh environment. Ocean exploration must be well-organized and systematized which involves severe observations and documentation of natural aspects of the ocean. Deep-oceanic information can help forecast disasters like earthquakes and tsunamis and also aid us appreciate the role of oceans in Earth's environment. The traditional oceanic systems using research vessels are of high cost, time consuming and provide low resolution both in time and space [2]. The challenges imposed by oceanographic vessels pave the way for a potentially talented oceanic technology, called underwater wireless sensor networks (UWSNs).

UWSNs are generally formed by using underwater sensor nodes with sensing, computing, memory and underwater communication capabilities. Since the cost of underwater gadgets quickly increase for deep water, mobility is convenient to exploit sensor coverage with restricted hardware. It can be accomplished either using a floating buoy or an autonomous underwater vehicle (AUV) positioned underwater for a specific period of time to sense information and then drift near the surface to transmit the sensed information to the control station [3]. Current UWSNs are designed using combination of underwater sensor nodes and mobile AUVs. In contrast to the terrestrial sensor networks, underwater networks pose severe technical challenges like deprived connectivity, shorter bandwidth, harsh transmission medium, mobility, variable propagation delays and high cost [4]. Alike terrestrial networks, UWSNs also possess a major challenge of limited battery resource, and it is difficult to use solar energy for recharging under the water. In spite of all these challenges, underwater sensor networks have the promise of revolutionizing many areas of science, industry, defense and so on. The communication architecture plays a crucial factor in defining the energy consumption, capacity and consistency of the network [5]. UWSN lifetime can be maximized by the development of either efficient deployment schemes, or an optimal network management, or both. Hence, the UWSN communication architecture should be wisely engineered according to the application requirements. Prevailing research on UWSNs is generally focused on communication, connectivity, energy efficiency, localization, synchronization, MAC and routing. Unfortunately, the existing research is constrained in terms of efficient UWSN architectures because the underwater atmospheres are much more unnatural while the network deployment is more of economic-based due to the particularities and underwater environments.

The contributions of this paper are as follows:

- In this paper, the special characteristics and constraints of UWSNs against terrestrial sensor networks are presented.
- The network architectures in UWSNs are classified and discussed in detail. Based on the analyses, efficient communication paradigms are proposed for UWSNs.
- In addition, the functional behavior and feasible countermeasures in each layer of the UWSN's protocol stack are analyzed.
- This article also outlines few research directions relating to efficient design and control of UWSN topologies.

The remainder of this paper is organized as follows. In Section 2, the basics of acoustic communication in UWSNs are detailed and the protocol stack of UWSNs is introduced in Section 3. Section 4 presents the peculiar characteristics and architectures of underwater networks followed by proposed

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network design in Section 5. Few research directions are outlined in Section 6 and Section 7 concludes the paper.

2 ACOUSTIC COMMUNICATION IN UWSN

Underwater sensor nodes are usually equipped with acoustic modems to wirelessly communicate with each other. This is because high-frequency radio waves are intensely absorbed in water medium and optical signals undergo heavy scattering and are restricted to low-range-LoS applications [6]. The sound speed in UWSNs is around 1500 m/s near the shallow ocean which is five times slower than the speed of light. Also, it depends on water temperature, depth and salinity [7]. The UWSN acoustic communication has a limited bandwidth and it depends on both signal range and water column depth. The acoustic bandwidth varies from 500 Hz to 10 kHz for wide-range communications, 10 to 100 kHz for mid-range and 100 to 500 kHz for short range communications [8]. The communication range also influences the data rate in UWSNs. The data rate varies from 10 kbps to 100 kbps respectively for long-range and short-range communications. Underwater acoustic communications are getting influenced by signal interference, noise, multipath, Doppler Effect and high propagation latency. All these factors establish the temporal and spatial variability of the acoustic channel. The path loss in UWSNs is mainly due to signal spreading and attenuation. During Spreading, the acoustic signal will spread over a wider surface area, and so the wave energy in each unit surface area becomes smaller. Attenuation causes the signal energy to transform into other forms like heat energy and get absorbed by the medium. Ocean noise is another factor that has a severe impact on the communication in underwater acoustic channel. The ambient noises in UWSNs can be categorized into turbulence noise, shipping noise, wind noise and thermal noise. In UWSNs, the multipath effect is predominant than that in WSNs. Multiple arrival of the same signal at a destination contributes to the changes in the channel's frequency response termed as Doppler effect. The effect of Doppler shift is proportional to the relative speed between source and destination of a particular signal [9]. Furthermore, the sharing of an underwater acoustic channel can passively intercept the attackers to disrupt the transmission.

3 PROTOCOL LAYERS OF UWSN

Due to expensive instruments and energy problems, UWSNs face a lot of difficulties in the construction and implementation of applications. The limited operating range and the challenges in global timing synchronization, motivate the researchers to propose new protocols for UWSNs. The different layers and functions of the UWSN's protocol stack is shown in Figure 1. The existing UWSNs' protocol stack constitutes - physical layer (data transfer), data link layer (ARQ and MAC), network layer (addressing and routing), transport layer (process to process communication), and application layer (data processing). The protocol stack should also consider network security, power efficiency, and distributed network protocols with efficient bandwidth utilization.

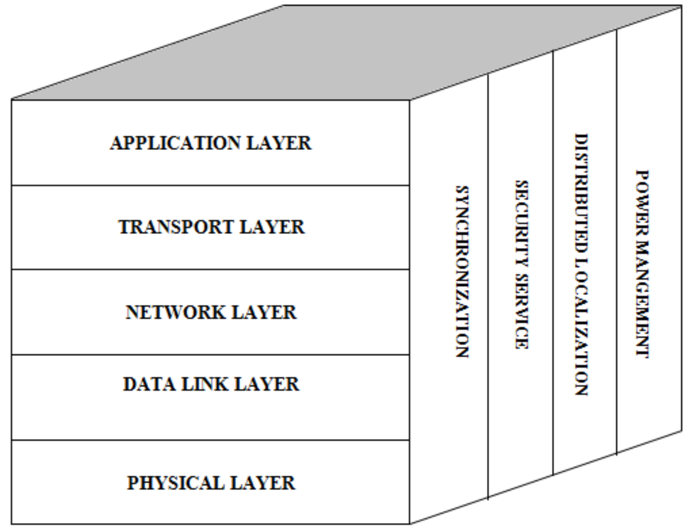

Figure 1. *Protocol Stack of UWSN*

3.1 Physical Layer

Physical layer handles the functions related to data communication in water medium. Acoustic signals are considered to be the most obvious choice for underwater communications. The UWSN physical layer supports half-duplex broadcast transmission in a shared medium [10]. UWSNs support star, tree and cluster based topologies. Distributed topology control approaches are preferable in UWSNs because centralized architectures lead to protocol overhead for large scale acoustic sensor networks.

3.2 Data Link Layer

The DLL is responsible for detecting the signal interference caused due to noise, multi path propagation and node battery failures which are major reasons that influence acoustic communication in UWSNs. In order to reduce signal loss, efficient ARQ and MAC protocols should be used. Due to the difficulties in achieving precise synchronization in UWSNS, setting the timer values in window based ARQ protocols becomes complex. The exclusive characteristics of an underwater communication, like attenuation, propagation delays, limited bandwidth, error rates, and energy consumption impose a wide variety of challenges for Medium Access Control (MAC) in UWSNs. Existing protocols are based on CSMA, FDMA or TDMA. CSMA based protocols are subject to increased overhead of RTS/CTS packets which in turn increases the energy consumption of underwater networks. FDMA approaches were found to be not suitable due to narrow bandwidth available from acoustic channels and TDMA based MAC schemes are proved to be the efficient in UWSNs when being done with accurate synchronization and limited bandwidth. Various MAC protocols like MACA [11], FAMA [12], etc. have been proposed for UWSNs and some are under process.

3.3 Network Layer

Network layer enables routing of data packets arrived from transport layer to the destination. In UWSNs, the routing involves multi-hop communication, for which a routing protocol is required. Network layer is responsible for finding an optimum path for data travel. In underwater networks, proactive and reactive routing protocols cannot be used since they incur increased signaling overhead and latency. Due to the limitations of GPS reachability under water, geographic routing methods have also not shown good performance in UWSNs. Hence, protocols involving distributed localization methods need to be incorporated for routing in UWSNs and they must be power conscious with enhanced time synchronization.

3.4 Transport Layer

Reliable data delivery is required in underwater communication. The transport layer is liable for process to process communication over acoustic network, congestion control and flow control. It establishes a virtual communication among processes. Traditional TCP mechanisms are not suitable for underwater networks because of the following reasons – (i) UWSNs exhibit very low propagation speed, which along with TCP encounters more delay, (ii) the flow control and congestion control in wireless networks depends on window based mechanisms which can be done efficiently with the accurate estimation of Round Trip Delay (RTD), however, in case of UWSNs it is difficult to fix a RTD value as it is variable. Suitable transport layer protocols are vital for challenging environment of UWSN. Existing protocols in WSNs can be used to resolve these issues [13] but they are based on spatial correlation among devices. In UWSN, nodes are sparsely deployed and hence it is challenging to correlate the sensor readings.

3.5 Application Layer

The application layer protocol could be developed with the deep knowledge of the UWSN applications. It provides network management by utilizing the hardware and software facts of the lower layers. It keeps an interface to query the sensor network completely. It also takes care of task-assignment and promotion of data and events.

4 CHARACTERISTICS AND ARCHITECTURES

This section briefs about the peculiar characteristics and the associated constraints in UWSNs. Also, the existing communication architectures are detailed.

4.1 Characteristics & Constraints

UWSNs provide accurate detection and monitoring of oceanic events comparing to traditional sonar/radar systems. In order to efficiently develop the protocols for UWSNs, the researchers need to have a depth understanding about the unique characteristics of UWSNs [14]. The comparison of UWSN characteristics in relation to WSNs is provided in Table 1 which helps the research community on how to modify the WSN protocols for underwater environment.

- Deployment Method: Since UWSN nodes are more expensive it will be cost effective to build a sparse rather than a dense sensor network.
- Network Topology: The network topology indicates the type of interconnection between nodes. In UWSNs, the topology changes habitually because of automatic mobility of underwater nodes and time-varying acoustic links.
- Spatial correlation: Since underwater nodes are placed at a larger distance of separation and also due to continuous movements, it is difficult to provide spatial correlation among them as in terrestrial WSNs.
- Communication method: The communication relies on acoustic signals mainly due to the relatively low absorption in underwater medium. But, underwater acoustic transmission poses certain challenges like temporary path losses, high bit error rate, small bandwidth and large propagation delays.
- Propagation Latency: The sound velocity is in the range of 1200 to about 1500 m/s which is five times slower than the speed of light and hence delay becomes high. Also, the acoustic velocity is frequently getting affected by water temperature, depth and salinity which make the delay varying. The accurate estimation of the propagation latency is a major challenge in UWSNs.
- Power: The transmission power of UWSNs is very high as compared to terrestrial networks. Also, recharging is a challenging task in underwater networks.
- Memory: The signal connectivity is usually interrupted in UWSNs due to shadow zones. Therefore, underwater sensor nodes need to reserve more data to prevent the loss of vital information.

4.2 Communication Architectures

The communication architecture of UWSNs has to be engineered carefully according to the application's specifications so that it will enable high energy efficiency at an acceptable throughput. Generally, the UWSN applications are classified into two major categories [15]:

TABLE 1

COMPARISON OF UWSN VS WSN

Characteristic Feature	Terrestrial WSN	Underwater WSN
Deployment Strategy	Dense / Sparse as per Application Requirements	Sparse
Spatial Correlation	Likely to happen	Not possible due to Sparse Deployment
Communication Method	Radio Frequency	Acoustic Signal
Propagation Speed	3×10^8 m/s	1500 m/s
Mobility	Optional	Continuous Mobility due to Water Currents
Power Consumption	Low	Very high
Bandwidth	20 kHz – 300 GHz	(0-400) kHz
Environmental Interference	Less	High Interference
Cost	Less	Expensive
Memory	Limited	Needs more storage

(i) Long-term, Non-Time-Critical Applications: The nodes have to be self-organized, to cover the given area of interest. Energy optimization is the primary concern in these networks, as the nodes lose their energies more quickly and it is difficult to harvest energy from underwater environment. Underwater monitoring, Resource exploration are some of the practical applications with such networks.

(ii) Short-term, Time-Critical Applications: On-time data delivery is mandatory in such network, and hence synchronization and localization are of much concern here. Such types of network are used in military and defense operations for detection of submarines, disaster detection, etc.

The UWSN wireless communication architectures are broadly classified into three categories [16]: (i) Static 2D UWSN, (ii) Static 3D UWSN and (iii) Mobile UWSN.

(i) Static 2D UWSN Architecture: In this architecture, the sensor nodes are deployed at the ocean floor with the help of anchors. The sensors can be arranged in the form of clusters and connected to underwater gateway nodes / cluster heads using acoustic links. The gateway nodes are responsible for relaying data to the surface sink and then to the surface station. The surface sinks will be equipped with acoustic transceivers to communicate with gateways, and RF/satellite transceiver to communicate with an onshore sink.

(ii) Static 3D UWSN Architecture: These networks are used for ocean column monitoring cannot be adequately observed by means of 2D networks. In this architecture, sensors are made to glide at different depths to observe a given phenomenon. The earlier networks surface buoys, to adjust the depth of each sensor node. However, as many surface buoys as the number of nodes buoys may obstruct the regular shipping activities and they can be easily attacked by enemy warfare. Furthermore, surface buoys are vulnerable to changes in weather conditions. So, modern networks use winch based sensor devices to be placed on the bottom of the ocean, as in static 2D structures. The buoy attached to the sensors wrenches the nodes towards the ocean surface. The height of the sensor can then be controlled by fine-tuning the length of the wire that connects the sensor to the anchor.

(iii) Mobile UWSN Architecture: Mobile UWSNs are constructed using static 3D sensor nodes and mobile underwater vehicles. The mobile nodes can be AUVs, UUVs or low-power gliders. They tour over the region of interest and emit signals at defined locations. The locations are decided in such a way that all sensor nodes should receive the signals from AUVs. Beaconing using mobile nodes can help to reduce the number of ordinary sensor nodes thereby saving cost and energy. For monitoring applications, data can be stored at internal memory of sensor nodes and be delivered to mobile nodes when they come in the vicinity.

5 PROPOSED 4-D HETEROGENEOUS ARCHITECTURE

Literatures reveal that UWSN deployment is very challenging as it is a key factor in determining the energy consumption and coverage of the network. The main challenges of network deployment are the cost, the computational power, the memory, the communication range and, most of all, the limited battery capacity. In this paper, we have proposed an efficient heterogeneous 4-dimensional acoustic communication architecture for UWSNs considering the energy and delay as the main factors.

5.1 Components of the Proposed Architecture:

Heterogeneous sensor networks consist of sensor nodes with different communication, sensing and transmission abilities. The proposed architecture comprises a collection of sensor nodes in static 3D model along with a mobile AUV. The components of the proposed network architecture are listed as follows:

- Elementary Sensor Nodes (ESNs): They are the ordinary sensor nodes, which will be deployed in static three dimensions with the help of floating buoys. The ESNs equipped with acoustic modems will sense or monitor the events and forward the collected data to the nearby MSNs or SSNs if any in their vicinity. In the proposed system, the ESNs are assumed to be organized in clusters, providing each cluster has at least one MSN.
- Master Sensor Nodes (MSNs): The main function of MSNs is to collect the data from ESNs and relay them to the next hop MSNs or to the SSNs. The MSNs are responsible for routing the data using an optimum path.
- Super Sensor Nodes (SSNs): These nodes implement the function of delivering the collected data from the MSNs or ESNs to the on shore sink. The SSNs in our architecture is an Autonomous Underwater Vehicles, which are assumed to have large battery storage and they will be enabled with acoustic and RF modems. This implies that SSNs have a higher communication capability.

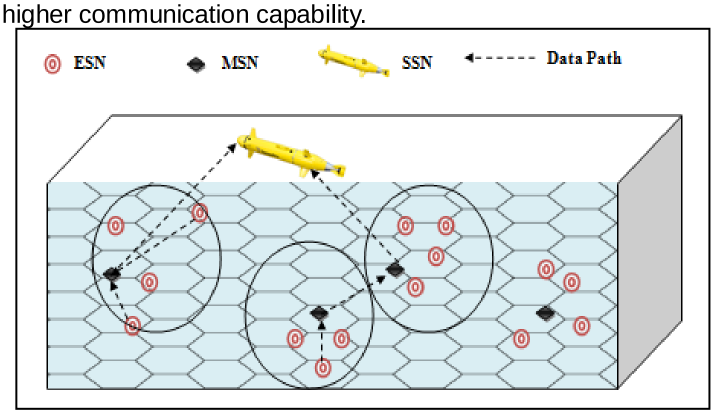

***Figure 2**. Components of the Proposed Architecture*

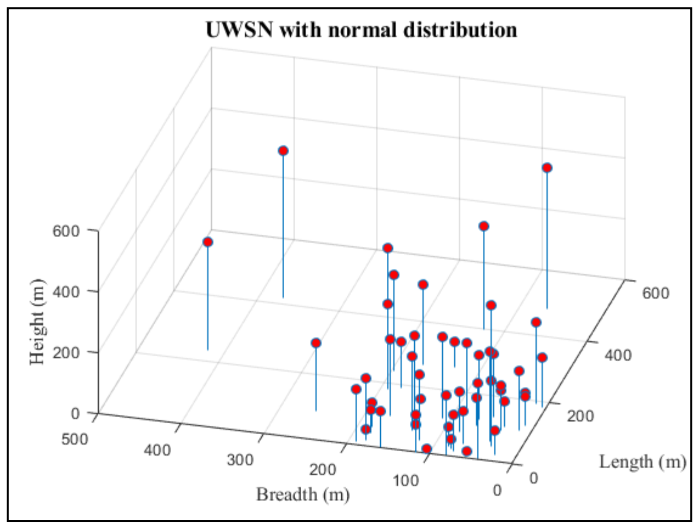

***Figure 4**. UWSN with normal distribution*

In the proposed architecture, the static ESNs are deployed in 3D using hexagonal grids depending upon the application and target area. The sensor nodes are placed with uniform distribution initially, and then organized themselves towards the application's area of interest with Gaussian distribution. Each sensor is assumed to have Omni directional antenna. The components of the proposed architecture are depicted in Figure 2.

5.2 Localization & Data Collection Scheme:

In the proposed architecture, the SSNs are assumed to be equipped with GPS and they made to float on the ocean surface. They will acquire the time and location using the GPS signals, then dive into the water and move along the predefined trajectory while updating their information in both

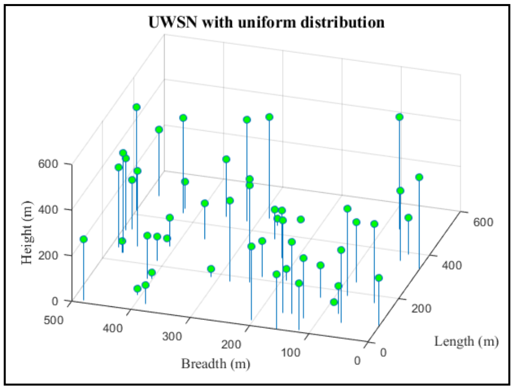

Figure 3. *UWSN with uniform distribution*

time and space. The SSNs will do beaconing of their information at predefined locations which will be received by MSNs. The MSNs using distributed localization methods update their location. The MSNs will disseminate the information to its ESN members, and then using the MSNs' data, the ESNs will determine their location. The data transfer also follows the same strategy as in localization. Since the SSNs and MSNs alone taking care of the relaying process, the energy of the ESNs could be saved to a larger extent. The ESNs will spend energy once for receiving, processing and transmission will be done only to closer MSNs which will not consume more power as in existing schemes.

5.3 Analysis of the Proposed Architecture:

We have simulated a 3D area of 500 x 500 x 500 m. We vary the node density from 0 to 500 with interval of 50. The region of interest is assumed as the center of the deployment area. We have analyzed the proposed architecture with uniform and Gaussian distribution and the results are depicted in Figure 3 and 4 respectively. The network lifetime is analyzed for both the distributions and the results in Figure 5 shows that the network lifetime increased significantly in a normal distribution. Lifetime increased due to more no of sensors around the region of interest in a normal distribution. In a uniform distribution, the lifetime can extend up to some extent, but after that even we increased the no of sensor node still network lifetime remain same. The network lifetime of the proposed architecture is also compared against the existing static 3D architecture and the results show that our proposed saves more energy.

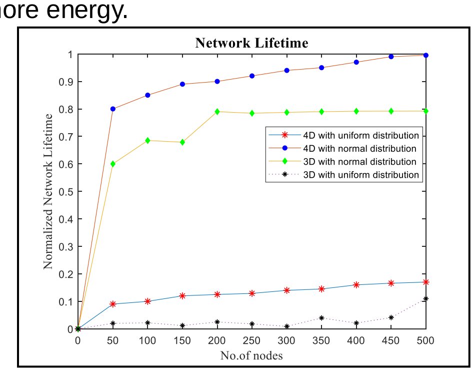

Figure 5*. Network Lifetime*

The delay and throughput for the proposed architecture with VBF [17] is also analyzed for uniform and normal distribution of nodes. The results in Figures 6 and 7 prove that the uniform distribution provides better performance in all aspects.

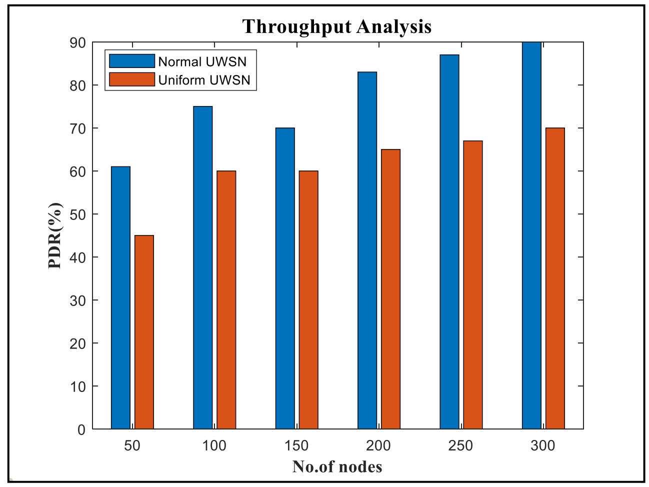

Figure 6*. End to End Delay between ESN & SSN*

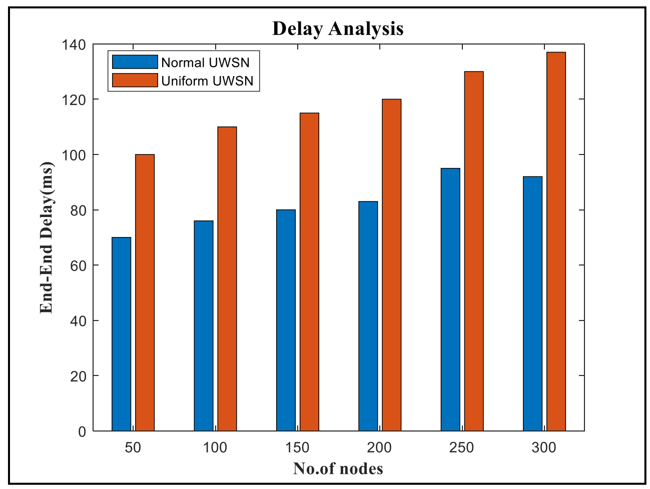

Figure 7*. Packet Delivery Ratio between ESN & SSN*

6 IMMINENT RESEARCH DIRECTIONS

The restricted battery of the UWSN nodes is a major challenge for prolonged lifetime with acceptable performance. Therefore, novel protocols developed for UWSNs should be energy efficient irrespective of the layers in which they operate. A good communication channel can be designed by considering the effects of depth, water temperature, and salinity. The inclusion of underwater vehicles in static 3D architectures has drawn much attention recently. The path planning of AUVs is an interesting research area. The optimum path should be short, and provides maximum coverage. All UWSN nodes exhibit passive mobility, and hence designing of mobility patterns in UWSNs becomes unavoidable while proposing networking protocols for mobile UWSNs. Algorithms that consider mobility in UWSNs only can provide reliable networking solutions. The existing communication architectures of UWSNs assumes reliable environment, but in real time, the underwater environment is susceptible to a lot of safety issues. Therefore, networking algorithms should also consider failure detection or redundancy mechanisms in order to get interrupted network service.

7 CONCLUSIONS

It is understood from the literatures that most of the static deployment algorithms in UWSNs follow uniform distribution and hence provides lesser energy efficiency. Static deployment algorithms in general intend at maximizing network coverage with less number of nodes. But the results will not be accurate in such cases whereas sensor nodes deployed using normal distribution will provide better results about the target. Also, mobility caused by water current cannot be neglected in UWSN. The proposed architecture considers mobile AUVs along with sensor nodes deployed with normal distribution and the results prove that the proposed method outperforms well in energy, PDR and end to end delay. Considering the costs, fewer SSNs need to be deployed in a UWSN.

REFERENCES

[1] https://theoceanpreneur.com/sail-green/seven-reasons-ocean-important/, accessed on 09.11.2019
[2] Brandt, A., Gutt, J., Hildebrandt, M., Pawlowski, J.,Schwendner, J., Soltwedel, T., Thomsen, L., "Cutting the Umbilical: New Technological Perspectives in Benthic Deep-Sea Research", J. Mar. Sci. Eng. 2016, 4, 36.
[3] Nasir Saeed, Abdulkadir Celik, Tareq Y. Al-Naffouri, Mohamed-Slim Alouini, "Underwater optical wireless communications, networking, and localization: A survey", Ad Hoc Networks, Vol. 94, 2019.
[4] Ian F. Akyildiz, Dario Pompili, and Tommaso Melodia, "Challenges for efficient communication in underwater acoustic sensor networks", SIGBED Rev. 1, 2 (July 2004), 3-8.
[5] Djedouboum, A.C., Abba Ari, A.A., Gueroui, A.M., Mohamadou, A., Aliouat, Z., "Big Data Collection in Large-Scale Wireless Sensor Networks", Sensors 2018, 18, 4474.
[6] Qureshi, U. M., Shaikh, F. K., Aziz, Z., Shah, S. M., Sheikh, A. A., Felemban, E., & Qaisar, S. B., "RF Path and Absorption Loss Estimation for Underwater Wireless Sensor Networks in Different Water Environments", Sensors (Basel, Switzerland), 16(6), 890.
[7] https://dosits.org/tutorials/science/tutorial-speed/, accessed on 09.11.2019
[8] Gunilla Burrowes and Jamil Y. Khan, "Short-Range Underwater Acoustic Communication Networks, Autonomous Underwater Vehicles", Nuno A. Cruz, IntechOpen, DOI: 10.5772/24098.
[9] M. Stojanovic and J. Preisig, "Underwater acoustic communication channels: Propagation models and statistical char-acterization," IEEE Communications Magazine, vol. 47, no. 1, pp. 84-89, 2009.
[10] Khalid Mahmood Awan, Peer Azmat Shah, Khalid Iqbal, Saira Gillani, Waqas Ahmad, and Yunyoung Nam, "Underwater Wireless Sensor Networks: A Review of Recent Issues and Challenges," Wireless Communications and Mobile Computing, vol. 2019, Article ID 6470359, 20 pages, 2019.
[11] L. Qian, S. Zhang, M. Liu and Q. Zhang, "A MACA-based power control MAC protocol for Underwater Wireless Sensor Networks," IEEE/OES China Ocean Acoustics (COA), Harbin, 2016, pp. 1-8.
[12] Wang, J., Shen, J., Shi, W., Qiao, G., Wu, S., & Wang, X., "A Novel Energy-Efficient Contention-Based MAC Protocol Used for OA-UWSN", Sensors (Basel, Switzerland), 19(1), 183.
[13] Kumar, S. , Feng, Z. , Hu, F. and Xiao, Y., "E^2SRT: enhanced event-to-sink reliable transport for wireless sensor networks", Wirel. Commun. Mob. Comput., 9: 1301-1311.
[14] Gkikopouli, G. Nikolakopoulos and S. Manesis, "A survey on Underwater Wireless Sensor Networks and applications," 20th Mediterranean Conference on Control & Automation (MED), Barcelona, 2012, pp. 1147-1154.
[15] Felemban, E., Shaikh, F. K., Qureshi, U. M., Sheikh, A. A., & Qaisar, S. B., "Underwater Sensor Network Applications: A Comprehensive Survey", International Journal of Distributed Sensor Networks.
[16] El-Rabaie, El-Sayed & Nabil, R. & Alsharqawy, Mohammed, "Underwater Wireless Sensor Networks (UWSN), Architecture, Routing Protocols, Simulation and Modeling Tools, Localization, Security Issues and Some Novel Trends", CiiT International Journal of Networking and Communication Engineering, vol. 7, no. 8, pp. 335-354, 2015.
[17] Xie P., Cui JH., Lao L., "VBF: Vector-Based Forwarding Protocol for Underwater Sensor Networks", In: Boavida F., Plagemann T., Stiller B., Westphal C., Monteiro E. (eds) NETWORKING 2006. Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks; Mobile and Wireless Communications Systems, Lecture Notes in Computer Science, vol 3976. Springer, Berlin, Heidelberg