A Review on Underwater Acoustic Sensor Networks: Perspective of Internet of Things

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Abstract: ***In the progressively used terrestrial and air-based Wireless Sensor Networks, Radiofrequency aids in the transmission of data and information. Nonetheless, from sensing followed by transmission in an underwater environment demands a completely contrasting technique to perform underwater communication. The oceans being the least unexploited, covering over 70% of the Earth's surface is a source of vast resources. Still, the underwater world is unaffected less by the recent progressions in this field of WSN and their impact on the research and development. Growing practical difficulties burden the shifting of the many terrestrial and aerial WSNs state-of-the-art to the aquatic world advancements. Acoustics with sensors forms the key for many underwater deployments to tackle with the stringent environmental conditions of the oceans. However, different underwater environment demands different communication approaches for sensing and transmission. This paper emphases in broadening the scope of sensing in acoustic sensing incorporated multimodal sensors, paving the way to the progress of robust Internet of Things (IoT) applications and the key idea of this detailed review is to see UW-ASN from the perspective of IoT. A detailed overview and niche future research openings in UW-ASN and its deployments is presented aiming for novel architectures and protocols in the future, covering the bigger picture of Underwater Acoustic Sensor Network through better research and industrial advancements.***

Index Terms: Wireless Sensor Network (WSN), Acoustics, Internet of Things Underwater Acoustic Sensor Network (UW-ASN)

I. INTRODUCTION

Due to urbanization, there has been a hasty growing trend in developing smart cities. More than 70% of the Earth's surface is covered by oceans of which more than 90% of the underwater areas are still unexplored. Climatic conditions and wind patterns that affect life on land are determined by the ocean temperature. Moreover, 1% of fresh water in lakes and rivers is contaminated seriously damaging the ecosystem.[1] This fact has drawn the attention of many researchers towards the underwater communications and networking and a need has a raised to explore what is hidden in the unfathomed world that lies under the seas by network communication on wireless links.

To enable practical applications towards developing smart cities, a technique to be used is 'Internet of Things'(IOT) which is defined as the infrastructure of Information Technology invented in 1985. [2] The Internet of Underwater Things (IoUT) which is a new class of IOT, that is a technological revolution in computing and communication. It is defined as a network of smart interconnected underwater objects such as underwater sensors, autonomous underwater vehicles (AUV), Autonomous Surface Vehicle (ASV), Remotely Operated Vehicle (ROV), Surface buoys, ships etc.

Underwater applications are used for monitoring scientific applications (Live aquarium), industrial applications (fish farms and pipeline monitoring), military and home safety applications (harbor security). Also, it is used for offshore oil and gas extraction, oil spills, military surveillance, reconnaissance, mine deduction, pollution monitoring, natural calamities like Tsunami and hurricane forecast, coral reef, habituate monitoring of marine life and fish farming.

The major challenges of IoUT are the quality of radio signals which are subjected to reduction and absorption in underwater environments at higher frequencies[3]. The Electromagnetic waves suffer poor propagation underwater, whereas the radio and optical signals can propagate for longer distance but require antennae and huge transmission power which is impracticable and therefore provide limited transmission rate due to its drastic scattering effect; Thus communication by means of acoustic signals was found out befitting to perform underwater wireless communications.[4] On the contrary, acoustic signals can propagate with lower attenuation and absorption much longer distance in underwater environments depending on the design of communication protocol.[5]

To overcome this challenge, the self-management process is required to operate without human intervention. For this purpose, self-configuration, self-healing, self-optimization and self-protection capabilities are required. Underwater communication is seriously limited by the harsh conditions of the underwater channel resulting in high error rates due to refraction of signals based on depth. Another important challenge is the improvement of the tracking technique applied to marine animals for their safety.[6] Energy efficiency is also challenging for acoustic communication which is power hungry by harvesting energy with supercapacitors that can replace batteries when they run out of operating. IoUT is a powerful tool for fish control to ensure food safety. Fish farms in aquaculture adopt five steps namely, production, transportation, processing, storage and distribution for quality control of fishery products by using wireless sensor networks to detect and reduce large scale fish diseases and enhance fish growth rates.

Revised Manuscript Received on April 18, 2019.

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A sophisticated coastal security system consisting of cameras and acoustic sensor network is required for harbor security to Underwater Acoustic Sensor Network (UW-ASN) is a network system of numerous stationery or mobile sensor nodes wirelessly connected to acoustic communication modules deployed underwater. It consists of underwater sensor nodes whose acoustic modems can sense water quality, pressure, temperature, presence of any metal, chemical and biological elements, relay and forward data to sinks located on the seashore. It has numerous applications, such as Environmental Monitoring, Underwater Exploration, Disaster Prevention, and many other miscellaneous applications, which are dealt in detail in the following section. Mobile Autonomous devices aid in the aquatic exploration with its self-adapting and organizing nature.[7] Despite the varied applications, the communications underwater suffer from some research challenges that are yet to be addressed.[8] which has formed the base for numerous expectational research work in this field. Despite its challenges, it is noticeable that the man-made/artificial UAN is a mimicked model of the natural acoustic systems. Many cetacean mammals like dolphins, Manatees, and Dugongs communicate underwater using sounds, echolocation, and foraging.[9] maintain trade and growth and alert potential security risks.

UW-ASN is a low power underwater wireless sensor network utilized globally for early warning against natural calamities like floods, Tsunamis, earthquakes, and hurricane. Also, it can measure seismic activity; variation in water turbulence, temperature and changes atmosphere density and incoming disaster a few days earlier.[10] UW-ASN is not at all viable with its hefty price tag and heavy power consumption susceptible to severe vibration during strong currents. UW-ASN with the help of robotic vehicles can observe and predict the quality of the ocean environment. It can perform pollution monitoring like chemical, biological and nuclear, undersea exploration for detecting underwater oil fields, laying of undersea cables and exploration of valuable minerals. Also, it can provide tsunami and earthquake warnings. The sensors can also be used to identify hazards on the seabed, locate dangerous rocks in shallow water and detect mine-like objects.[6]

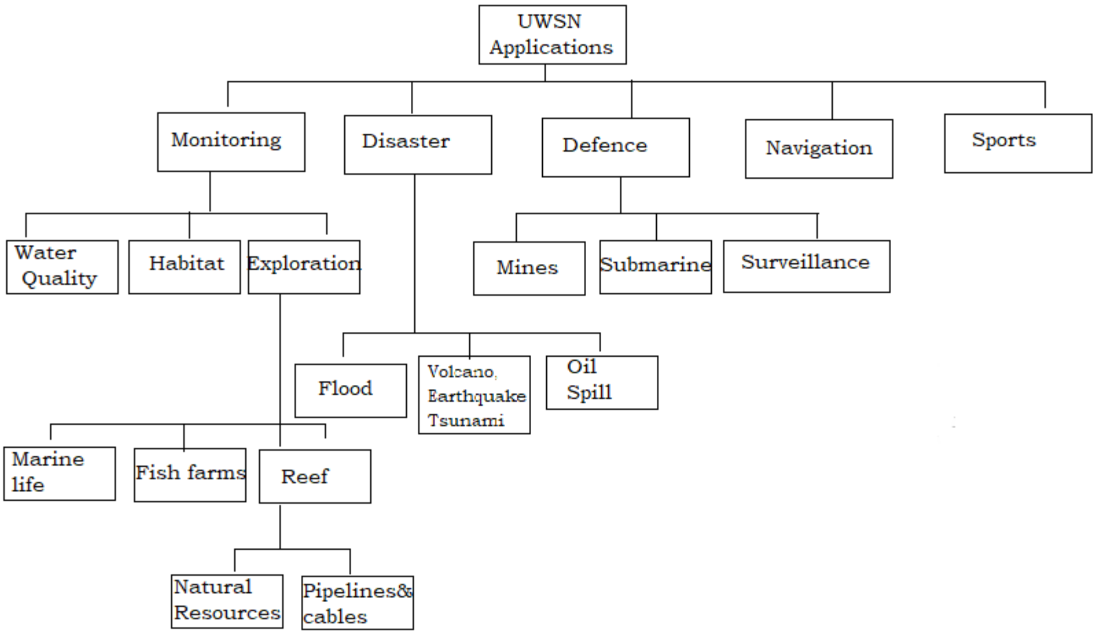

Fig 1: UWSN applications

A. CHALLENGES OF UW-ASN

Despite the fact that UW-ASN being a welcoming new field with numerous applications, like ocean environment monitoring, Disaster management, Assisted navigation and tracking, offshore exploration, oceanographic data collection and many other miscellaneous applications, the communications underwater suffer from some serious challenges that are yet to be addressed namely, reliable communication, low power design and efficient resource management, energy efficiency, etc.,[11] which has formed the base for numerous expectational research work in this field. Besides its challenges, it is noticeable that the man-made/artificial UAN is a mimicked model of the natural acoustic systems and suffer from many practical challenges like,

In underwater environment

1. Sensor Node deployment in 3D space
2. Passive Node Mobility
3. Time synchronization
4. Signal reflection, Multipath and Fading
5. Failure prone environment

In underwater acoustic channel

1. Variable sound speed
2. Low bandwidth and Bit rate
3. Variable propagation delay
4. High error probability

5. Asymmetric power consumption

The paper is prioritized as follows; Section II covers the background of WSN and a concise history of underwater sensing so far. Section III is a detailed literature review and the next section discusses the architecture of UW-ASN. Followed by the challenging research scope in UW-ASN in Section IV, Section V finally ends with the conclusion.

B. IoUT ARCHITECTURE

IoUT architecture with its functionalities are divided into three prominent layers which are,
(a) Perception Layer- It gathers information by identifying objects with the help of static underwater sensors, mobile underwater vehicles, surface and monitoring stations like PC, smartphones, data storage radio and receiver tags.
(b) Network layer- With the help of a privately-owned network, internet, network administrative system, cloud computing platforms, the data from the perception layer is processed and transmitted to the other layer.
(c) Application layer- Is a set consisting of intelligent solutions obtained through IoUT technology to effectively meet the user’s need.

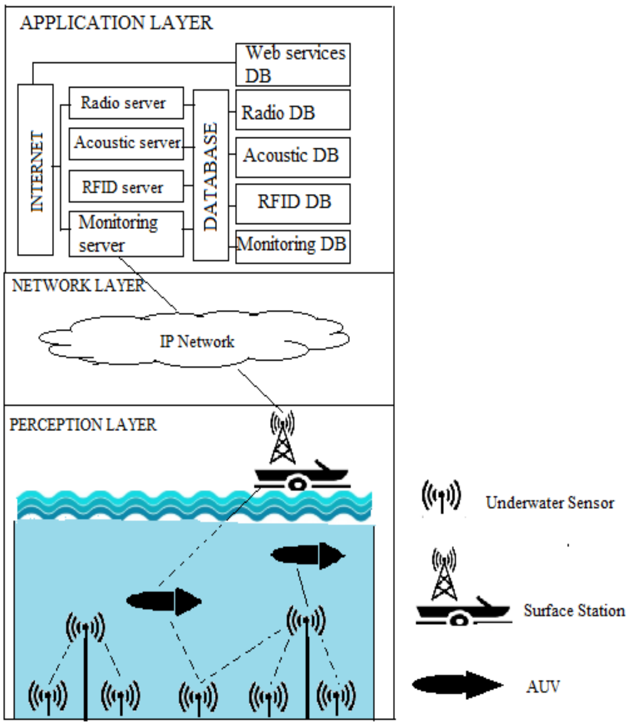

Fig2: IoUT Architecture

C. UW-ASN COMMUNICATION ARCHITECTURE

With reference to Fig 5, we discuss the different dimensional architectures of UW-ASN

A. One dimensional Architecture

In the 1D UW-ASN architecture, the sensors are set up which function individually. The sensor node is designed as a stand-alone network performing sensing and transmitting the processed signals to the surface station (SS). The nodes are deployed either as a floating buoy or temporarily deployed underwater and float post sensing to transmit signals to the surface station. Autonomous underwater vehicle (AUV) is also deployed that dives underwater and gathers the sensed data from the nodes and transmits it to the SS. Nodes Communication and signal transmission can be acoustic, optical or radio frequency. The signal transfer from the nodes to the SS happens in a single hop. 1D architecture is also known as the static architecture, where the position of the nodes is static and a single network topology is followed throughout, unlike the 2D and 3D architectures.

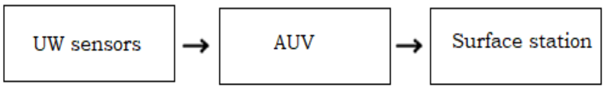

Fig 3: 1D Architecture

B. Two-dimensional architecture

2D architecture refers a network arrangement of a cluster of sensor nodes deployed on the sea bed with an anchor node. The underwater properties gathered by the sensor nodes are sent to anchor nodes, from there it is transmitted to the surface buoys. Communication here is two-phased, (i) Sensed data transmission from sensor nodes to anchor node via a horizontal link (ii) Signal relay as acoustic or optical form the anchor node to the surface buoys as a vertical link. Best sensing results and vast communication coverage is achieved in[12]. In [13] the performance of the nodes is enhanced using virtual sinks. Acoustic, optical and radio frequency links are used for relaying of signals but acoustics is most preferred when the distance between the anchor node and the surface buoy is predominantly high. The node cluster can follow any network topology like star, ring, mesh with respect to the design requirement. 2D UW-ASN is generally preferred for their delay tolerance and time deficiency.

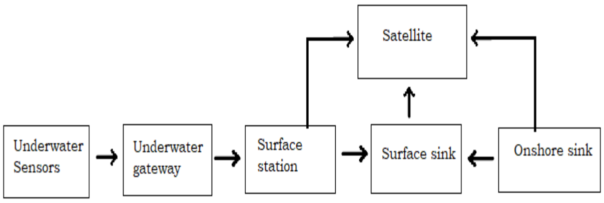

Fig 4: 2D Architecture

C. Three-dimensional architecture

Unlike 2D network, the sensor clusters are deployed and anchored at varying depths of the seabed. The positioning of sensors determines the nature of the communication, which takes place in three tiers namely, (i) Communication between the sensors at the varying depths- intercluster communication (ii) Sensor cluster to anchor node communication -intracluster communication (iii) Anchor node to surface buoy communication. [14] The information/signal relaying uses acoustic, optical and radio frequency links are used in a combination. 3D network favors assured network coverage with the use of a simple routing protocol but the cost of the aqueous sensors is a little expensive and the sensor density is low when compared to terrestrial communication.

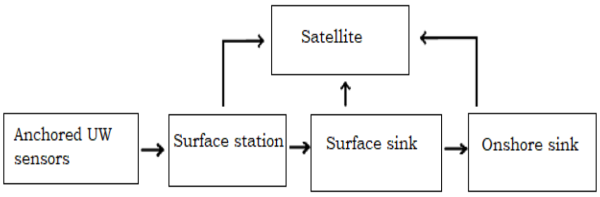

Fig 5: 3D Architecture

D. Hybrid Architecture

The hybrid network architecture is a hybrid combination of static (3D UW-ASN) and mobile sensors like AUVs, ROVs for signal transmission. The signal transmission is between the sensor nodes and the independently moving ROVs to the surface station. Data relay takes place independently with respect to the distance between the sensor node and the mobile node. The mobile node outperforms by performing an additional task of gathering data and boosting the network capacity. It functions as a super node with better energy and greater mobility. The choice of using radio or acoustic links depends on the distance and the quality of the data sensed by the sensor nodes. Nodes with large data OR can relay relatively shorter distance with ROV can relay signals using radio links whereas the nodes with lesser data OR longer distance with ROV uses acoustic links.

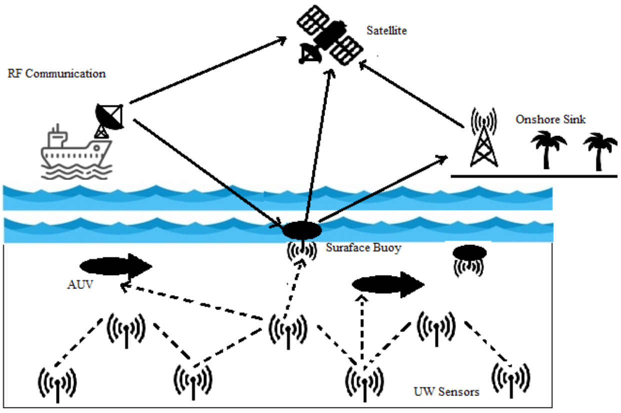

Fig 6: UW-ASN architecture

II. BACKGROUND

The history dates to cold war when hydrophones were used to oversee the movement of Soviet submarines. With the elapse of time, most sophisticated acoustic networks where developed for hostile ships and in detecting covert submarines. In the recent past, low-cost sensors were developed which operate on analogy circuitry to explore oceans.[15]

III. LITERATURE REVIEW

The authors in[16] have focused on one of the important challenges of IoUT, reliability. It is the key influencing challenge in IoUT affecting the performance. So, the author has used a concept called, channel modes to overcome this problem. The calculation of the delivery ration in channel models is performed as a two-step process as,

1.The relationship between the transmitter power and SNR.

2. The relationship between the SNR and the delivery ratio.

Four important parameters are considered for calculations namely, Source level, Transmission loss, Noise level, and directivity index.

The simulations are performed in C++ and the results prove that when transmitter power is high, the corresponding SNR is high but BER is lowered and thereby the delivery ratio is higher. The obtained results prove channel modes are practical and applicable for different power and distance ranges.

SUNRISE GATE[17] is an interface offered by the sunrise federation to its users to access their varied resources from sea trials to perform their experiments.

A. Underwater Cognitive Acoustic Network (UCAN)

In[18], it is found out that the artificial acoustic signals from the acoustic modems overlap heavily with the cetacean frequencies, causing fatal impacts. To overcome this frequency clashes, the authors have proposed a dolphin aware data transmission scheme (DAD-Tx), where transmission is performed in a multi-hop acoustic network. The aim of the paper is to formulate an environment-friendly transmission scheme to achieve maximum end-to-end throughput. To aid the implementation the activities of the dolphins are recorded and presented mathematically as a probabilistic constraint. The results proved DAD-Tx algorithm to be effective for dolphin awareness and maximum end-to-end throughput is achieved. The research gap is to design more environment friendly sophisticated transmissions schemes for more severe scenarios e.g., Dynamic scenarios.

A complete overview of cognitive acoustic networks with its different applications and research challenges is detailed in [19],[20]Cognitive acoustic networks aids in performing environmentally friendly safe underwater communication and proper spectrum usage. The authors have emphasized on the spectrum usage for underwater acoustic communication and it is noted that even though acoustic communication, natural and artificial use acoustic signals heavily, but the spectrum is still underutilized. [21]The challenges and opportunities of UWAN are dealt with in detail in this paper.

Military operations underwater necessitate stealthy operations. To aid this, authors in[22] have designed a Low Probability Detection (LPD) approach that performs transmission and reception in a low Signal-to-Noise Power Ratio(SNPR). The authors have designed real-time implementation and tested LPD with varied transmission power and carrier frequencies. The results claim that LPD performs well in shallow warm water with a low carrier frequency range.

A detailed review of Low probability of detection is presented in [23]. The importance of LPD in military activities to evade the detection of the communication signal underwater and in civilian applications for its reduced environmental impact are highlighted. Efforts to design a suitable transmitter to decode packets in SNPR and to hide the transmission noise from the transmitter to the receiver has also been taken. Low probability Detection (LPD) intents in performing a low power and low spectral density mean of transmission aiming to reduce the impact of artificial acoustic modem interference with natural acoustic signals.

An improved bionic covert UAC approach is presented in[24] to camouflage acoustic communication. The inceptor here deceives the received signal regarding it as the original sound. The original signal is used for synchronization and the mimicked whistle is used for communication. Both simulations and sea trail experiment are performed.

Increase in oceanic activities has resulted in a rise in the acoustic noises, which can affect marine life badly. Statistically, profiling of the acoustic sources needs to be done to improve the performance of acoustic communication in harsh environmental conditions. A blind technique is employed to perform noise separation from acoustic sources. The noises are then classified and analyzed. A grey box model and a BSS based algorithm are used for separating the dominant noise sources. The experiment was performed for various scenarios with different multipath. A pilot-aided probing method was exploited, and a correlation-based characterization, as well as a PSD-based classification, were studied in [25]

The paper [26]aims to reduce the impact of acoustic signals on the marine life by source level reduction by redesigning the waveforms. High ratio speed spectrum transmission is attached to products exceeding 1000. The data reception with extremely low SNR has performed far away from the discomfort radius of the marine life. Consistent communication with low SNR is achieved.

The identified research challenges are-

*To design more bio-friendly modems to operate in subtle fauna regions and stricter with environmental controls.

* To work on an optimum error correction coding with the coherent combination of multipath signal energy, the performance, and channel capacity utilization could be increased further.

The authors of [27] have designed bionic sonar signal waveforms mimicking the original whistle sound of whales and the constructed bionic sonar signal waveforms are embed with the true whale call trains to mask the real sonar signal waveforms. In accordance to the time-frequency (TF) structure of the real whale whistle, a bionic sonar signal model is ascertained to generate the proposed sonar signal waveforms. The range of the target is measured using a single sonar signal and a combination of two sonar signals is utilized for measuring its speed. The authors have also proposed an efficient algorithm to estimate the target range and speed of the waveforms. A camouflage application strategy is designed based on the constructed signal waveforms and the characteristics of false killer whale call trains to improve the disguise ability of the sonar signal sequence. The simulation results prove that the covertness of the system is substantially achieved.

B. Underwater Localization

The authors in [28] have proposed an efficient localization algorithm. Localization techniques like GPS and traditional in-direct methods using Ad hoc networks are not fully applicable for positioning in underwater, therefore, an improved algorithm is proposed that works efficiently in underwater localization based on the maximum likelihood estimation method to improve the accuracy and reduce the errors caused due to measurements. The redundancy of the model is reduced by using a basic algorithm. The data is processed before proceeding with the localization with improved accuracy and reduced redundancy.

The localization technique proposed in the paper [29] is based on prior-computed acoustic communication parameters between the transceiver and the receiver by mapping the area from a grid of points. The idea is close to matched field processing. The transceivers transmit a group of pilot signals, and the receiver on the other end receives the signals using hydrophone and processes the signal to estimate the Channel State of Information (CSI). The processed signal is matched with the grid to find the best match to find the localized area. This localization technique has an inherited property of informing the transceiver about the available CSI at the receiver and the receiver must only inform the grid point index for matching to avoid overhead. Accurate results are fetched from the simulations and the method is applicable for multiple detections to achieve good performance.

In[30] the authors have proposed a novel mobile localization method that takes into consideration the time alignment and range bending compensation to localize the mobile nodes. This method proved that the localization error is only 1.44m (when compared to GPS).

Authors of [31] have proposed an algebraic localization approach to overcome the challenges of underwater localization of uncertainty in sensor parameter, Doppler effect and low-computational complexity due to energy efficient techniques. The authors claim that the localization approach outperforms the prevailing approaches equal to Cramér–Rao lower bounds (CRLBs).

The paper[32] deals with localization issue with respect to node mobility and clock synchronization. The authors have proposed a hybrid model with AUV and active and passive sensor nodes to perform localization. The node mobility and clock synchronization issues are dealt with two localized optimization problems and the future position of AUV is predicted using a mobile prediction strategy. The simulation results prove that the localization technique reduces its time and solve node mobility and clock synchronization effectively.

Finally in [33], the authors have proposed a novel concept of introducing localization with underwater cognitive acoustic network to develop an environment-friendly spectrum decision strategy to improve spectrum-efficiency on the condition of avoiding interference on marine mammals and the position prediction of the marine mammals is achieved with the combination of location and velocity measurement of the cetaceans. The simulation result show that the proposed localization algorithm fetches a success rate of about 92% accurate localization and a negligible error of less than 10m.

The environment friendly allocation scheme is found to work effectively with the changing location of the marine animals. The typical allocation scheme can be designed significantly for any other marine species.

C. Underwater Acoustics in Shallow Water

In[34] a study on underwater channel estimation based on different node placement in shallow water is done. An idle UW-ASN should be reliable with maximum connectivity, minimum multipath, low cost, and energy efficient. The authors claim that the data used is from a genuine source, and the experiment is performed in three distinct scenarios namely, ground-based, buoys-based and horizontal point-to-point. Real-time implementation on sea-trial and simulations on MATLAB along with Acoustics BELLHOP toolbox is performed and the various influencing parameters of UW-ASN are tested. The results show that ground-based scenario has achieved better results in terms of low coherence bandwidth and BER and high time delay and transmission loss.

The authors in[35] have proposed a passive short-range localization technique in shallow water using a mobile short horizontal array of fewer than ten meters. The intended localization is designed based on match field-based techniques. The performance of the localization is enhanced using broadband processing and inter-position processing in terms of stability and ocean-environment mismatch. The proposed technique is aimed at source detection and localization. The nodes are arranged in a multi-horizontal fashion to support short-range transmission.

In [36] the authors have studied as to how the wave dynamics affects the frequency of the broadband. Underwater acoustic communication in shallow water highly necessitates an understanding of broadband acoustic transmission as the transmission in shallow water is highly affected by wind dynamics. The paper aims to cover the co-relation of high-speed wind on broadband (low to -high fz) acoustic transmission. 2D rough parabolic equations fetched show the interlinking between the high wind speed and the pressure associated with it. The results conclude that roughness caused by high wind drove surface is the major influencing factor in inflicting the surface-reflected paths and high-speed winds are the cause for surface reflected paths. The proposed model is found to be adaptable to the time-varying surface conditions but lags inaccurate acoustic modeling that needs to consider 3-D, bubble, and Doppler effects.

The scattering caused on the surface of the sea that results in surface waves and bubbles due to wind is a notable problem in acoustic swallow water networks. Of the frequency ranging from 1 to 4 kHz, the bubbles caused by wind can cause refraction. This can be changed using the sound-speed profile (SSP) accounting for the bubble void fraction at the surface layer. For greater frequency from 4 to 8 kHz, the bubbles are extinct causing absorption and scattering. Experiments are performed to generate rough-sea evolutions. The difference in scattering effect between static and mobile node is examined and studied in [37]. A practical simulation framework called IRsim is created. The simulation results showed a better outcome considering the real-time environmental surface conditions.

D. Optical communication

In [38]an efficient hybrid UOWC model is developed combining both acoustic and optical wireless communication to achieve higher bandwidth with less latency for a moderate distance. The developed model will also help in the advancement of terrestrial communication. The performance of UOWC is said to be better than other communication modes like RF, Optical fiber and acoustic communication. Underwater optical wireless communication is preferred than the traditional acoustic communication for its higher data transfer rates, energy efficiency, and low computational needs.

UOWC suits both deep and shallow coastal regions. The paper touches on the overview of UOWC and aims in developing a hybrid form of acoustic-optical communication complementing the acoustic communication to fetch low latency, energy efficiency, and high data rates. The future work of the paper is

To develop a more robust, cheap, highly scalable and adaptive optical sensors need to be developed for underwater monitoring effectively. Research emphasis should be given to laser beam propagation, modeling of the solar penetration model, multi scattering techniques and reflections from the sea surface.

*To achieve energy efficiency and communication efficiency

*To avoid the intermediate obstacles during communication, spatial diversity techniques and routing protocols need to be considered.

* UOWC with acoustic communication is a growing field of research.

The authors of [39] have proposed a hybrid model of acoustic and optical communication to effectively perform fine quality real-time video streaming from AUVs to aid in better underwater examination. The proposed hybrid model favors communication without optical cables and the acoustic communication is designed as a backup to optical communication in the case of a failure. Image processing technique is used to compress the size of the images to achieve good quality video streaming. The following are the future research directions from the authors,

* Better computation time and power constraints can be addressed.

* An efficient protocol design can be designed for the hybrid model.

* A cross layer design of the network protocols can be designed to achieve the QoS goals.

The research paper[40] proposes a hybrid system formed of both acoustic and optical medium for achieving high bandwidth underwater. The acoustic modem works well for small data transmission over a long distance, whereas the simulation results prove that the hybrid system outperforms the acoustic modem and helps in achieving maximum throughput and energy -efficiency. The drawback of an optical modem is the oceanic noise. In such cases, the need for acoustic modem persists.

The authors in [41] aim at assessing the performance of the underwater wireless optical communication based on the size and the density of the bubbles caused by sea waves. The obtained signal intensity results claim that the bubble size hinders the optical beams causing a deep fade. Likewise, the performance was evaluated for varied bubble sizes. Beam expansion is found as a solution to this problem. Improved transmitter systems can be designed to aid optical communication.

The authors of[42] aim to find a mutual relationship between the short-range (acoustic communication) and long-range (Optical communication) and the optical communication link is predicted with its signal noise ratio (SNR). A 100% accuracy is achieved in predicting the quality of SNR with RDF classifier. Challenges figured in this paper are,

*Difficulty in deriving the mathematical relation between acoustic and optical communication encountered is left for future work.

*An idea of adding an initial unsupervised phase to perform tasks for many supervised tasks; and to use unsupervised learning methods for pattern discovery in the data as part of the future work.

E. Data transmission

The paper [43]presents an overview of MAC protocol its types and it uses in UW-ASN. MAC protocols help in increasing the overall performance of underwater communication. Earlier, the emphasis was given to delay and throughput but now energy efficiency is of key concern as many underwater sensor nodes are powered by an external battery source and frequent recharging is a problem. The paper then discusses the research gap as,

*To design an ideal QoS-aware solution for MAC protocols;

*To design an adaptive MAC protocol to offer different levels of QoS;

*To design MAC protocols keeping in mind the mobility of the sensors due to ocean currents which result in topology changes.

*To design a CDMA based MAC protocol to control the transmission power at all the sensor nodes and to counter the near-far effects;

*To develop handshaking protocol with multiple channels needed for increased network throughput;

* To work on underwater localization technique based on MAC protocols; and

*To investigate the various MAC protocols and their algorithms and the cross-layer design of MAC protocols.

In [44] an acoustic sensor network is designed with a single mobile surface node and few nodes underwater to facilitate data collection. The destination mobile node requests for retransmission to each node individually using the ARQ (Automatic Repeat Request) protocol. A practical node co-operation protocol for data transmission from the underwater nodes to the mobile sensor node is developed and deployed to facilitate data collection efficiency. The proposed protocol provides better numerical results and energy efficiency compared to the conventional ARC protocol. The research gap found out is to perform real-time processing of the acoustic underwater network data. The proposed protocol can avoid the nodes overhearing the other nodes transmission and fetch better numerical results and energy efficiency compared to the conventional ARC protocol. The challenge is to perform real-time processing of the acoustic underwater network data.

The research paper [45] aims to study the propagation model of acoustic communication. The experiments are performed in a short vertical link to study the properties affecting acoustic communication. The fetched information can aid in the transmission between the buoys and the data acquisition system underwater. The simulation results reveal that the encoded signals can be detected in adverse conditions of channel absorption and low SNR.

F. Acoustic modem

The paper [46] provides an overall review of the prevailing underwater acoustic modems. The acoustic communication underwater is highly influenced by the environmental conditions of the water like, temperature, pressure and salinity. To adapt to these conditions, modems need to be designed and an in-depth study of the simulator NS2 is done.

In[47] the authors have aimed in designing a software aided underwater acoustic modem (SDAM) adaptable to the real-time environmental conditions to which new physical layers adaptations are introduced. Drawbacks in the earlier proposed works like achieving attainable data rates and the property to change the protocol stack in real-time can be overcome with SDAM. The modem was tested on real-time both in an indoor setup and in an outdoor environment.

*The designed software aided modem achieves high rate and is highly reconfigurable.

*The SDRAM also supports real-time video streaming in the acoustic channels.

*The introduced real-time physical layer facilitates the SDAM for real-time environmental adaptations.

*The modem fetched optimal results in both deep and shallow water and finally a robust chirp-based feedback link is introduced.

Modern acoustics communication can provide the signal propagation time and the distance for transmission from the sender to the receiver. This quality can be utilized in the synchronization of the acoustic networks. The authors of research paper [48] have introduced a precise propagation time calculation in a resonating environment and the payload data exchange is found out to be the desirable method for clock skew and synchronizing the acoustic networks. In the previous work, the synchronization of clocks was not possible during the data payload exchange. To overcome this challenge a novel S2C series is combined with the acoustic networks to perform clock synchronization possible even during data payload.

*High accuracy is achieved using S2C series of synchronization.

*Time and energy efficient procedure are achieved.

*Increased network throughput

*The need to develop complex clock synchronization protocol is eliminated

Real-time experiments were performed in different resonating environments with dissimilar node positions.

The aim of the research work in [49] is to design a cost effective modem for underwater acoustic communication. The cost of the transducer contributes to being high;

hence it is replaced with a low-cost homemade transducer to aid short range and low data rate UW-ASN. Future Work in this field is aimed at working with electromagnetic waves and comparing it with the other contrasting different acoustic communication modem and sensors.

Table 1: An overall comparative analysis

CITATION	AUTHOR	EXPERIMENT	ENVIRONMENT	SENSORS & OTHER DEPLOYMENTS	TECHNIQUE/ APPROACH
[16]	Chien-Kao, Yi-Shan L, Geng-De Wu, and CJ Huang, 2017	Deep sea	C++ Simulator	BPSK modulation and Rayleigh fading channel	A reliable communication channel model.
[17]	Chiara Petrioli et al, 2014	Different underwater environments-lakes, canals, sea	Real-time	gateways, underwater nodes, vehicles, buoys	SUNRISE GATE-Underwater testing interface
[18]	Xuanheng Li, Yi Sun et al, 2017	Deep sea	Simulation	Cognitive Acoustic Modem (CAM)	Dolphin Aware Data Transmission (DAD-Tx)
[20]	Nicola Baldo, Paolo Casari and Michele Zorzi, 2008	Deep sea	Simulation	Cognitive Radio device	Channel allocation Scheme
[21]	Qiu Wang et al, 2017	Deep sea	Extensive Simulations	Natural acoustic systems, Artificial acoustic systems	Analytical Model
[22]	Roee Diamant et al, 2018	Deep sea	Sea experiment	Transmitter, Receiver, Interceptor	Secure Low Probability of Detection
[23]	Roee Diamant, L Lampe, and E Gamroth, 2016	shallow and warm water	Sea trail at the Saanich Inlet (outdoor) and Ocean Technology Test Bed (Indoor) - a 100m testbed	Hydrophones, buoys	Low probability of Detection (LPD)
[24]	Songzuo Liu, Tianlong Ma, Gang Qiao , Lu Ma, Yanling Yin, 2017	Yellow Sea (50m depth)	Simulation and sea experiment	--	Camouflage underwater acoustic communication approach
[25]	Mehdi Rahmati, and Dario Pompili, 2018	Deep ocean	Simulation	Hydrophones, Buoys	Grey box model and BSS based algorithm
[26]	Benjamin Sherlock et al, 2018	Stonewall marina with floating pontoons with an approx. depth of 10m	Simulation	Transmitter: Acoustic power amplifier, Weighted transducer Receiver: Hydrophone, Bandpass filter, and amplifier	High ratio speed spectrum transmission
[27]	Jiajia Jiang et al, 2018	Deep sea	Simulation	Underwater acoustic channel (WATTCH) model	Disguised sonar signal waveform design approach with Camouflage application strategy
[28]	WU Zhehao, LI Xia, 2015	Deep sea	MATLAB Simulator	Sensor nodes, gateway buoys	An improved algorithm with a strategy like the greedy algorithm

[29]	Li Liao, Yuriy V. Zakharov, And Paul D. Mitchell,2018	Sea depth of 220m	Waymark Simulator	One hydrophone, many transducers	Location technique based on CSI
[30]	Cuie zheng Dajun sun, Lin Cai, And Xiang Li1,2018	Shallow and deep-sea experiments	Deep Sea trial	Anchor nodes, mobile nodes	TA-PCCP-RT localization algorithm
[31]	Bingbing Zhang and team, 2018	Deeper sea	Numerical simulation	----	Algebraic source localization approach
[32]	Jing Yan et al,2018	Deep sea	MATLAB 2016b simulator	Sensor nodes (active, passive), AUV	Hybrid localization technique
[34]	Bahrami, N et al, 2016	Shallow water	Real-time implementation on sea-trial and simulations	Ground-based sensors, Surface Buoys	Localization of sensors
[35]	Dexin Zhao, Woojae Seong, Keunhwa Lee, and Zhiping Huang,2013	Shallow water	Real-time	6 hydrophones	A passive localization technique
[36]	Zheguang Zou and Mohsen Badiey,2017	Shallow water and estuaries -Delaware Bay	Numerical simulation	Acoustic tripods, transducer, Hydrophones	A new empirical prediction method
[37]	Henry S. Dol, Mathieu E. G. D. Colin and team, 2013	Shallow water	Matlab simulator and Real-time implementation	Transmitter, receiver	Simulation framework IRsim
[37]	Mohammed Ali Khalighi et al, 2014	Deep and shallow water	---	---	Performance study od UOWC
[38]	Seongwon Han et al, 2014	Sea bottom	Artificial sea bottom setup and simulations	AquaSeNT acoustic modems	The hybrid solution with acoustic optical communication for real-time video streaming
[39]	S. Han et al,2014	Medium depth	QualNet simulator	Depth sensor, Hybrid solution- acoustic transmitter, receiver, optical modem	A Hybrid system with optical & acoustic modem
[40]	Hassan Makine Oubei et al, 2017	A water tank of size 50cm × 34cm × 34 cm	Indoor experiment	Hardware setup for generating bubbles	Beam expansion technique for performance enhancement
[41]	Roee Diamant et al 2017	Shallow water and deep water	Simulation	Projectors, hydrophones	The relationship between AC and OC
[43]	Yougan Chen, Xiaoting Jin, Xiaomei Xu, 2017	Shallow water environment	Simulation	14 underwater sensor nodes	Node co-operation Protocol
[45]	J. Pires, M. Colombo, J. Gallardo, 2013	San Jorge gulf-coasts	Simulation	Data acquisition system, buoys	Propagation model
[47]	Emrecan Demirors, 2018	A very low shallow lake	Real-time implementation in water tank(indoor) and lake environments (outdoor)	SDAM prototype with hardware components	High-rate software-defined acoustic modem (SDAM)

[48]	A J Zaji and team 2013	Deep sea	Real-time experiments in different resonating environments	---	A novel S2C series-based synchronization
[49]	Bridget Benson et al 2010	---	---	Cost efficient transducer	Cost effective underwater acoustic modem

IV. CHALLENGING RESEARCH AREAS/SCOPE IN UW-ASN

A.Extending the lifetime of the sensors[50], [51]

Sensors play a vital role in UW-ASN, Dynamics of Networks is not focused much in the previous work. The harsh environmental conditions intensely affect the functioning of the underwater sensors causing malfunctioning, battery power depletion and sometimes getting lost. Therefore, a scheduling scheme finds utmost purpose here to extend the battery life of the sensors. Each sensor should be so designed that it decides on its own work and sleep pattern with respect to the surrounding environmental conditions. Improving lifetime, computational and robustness of the sensors are the challenges and the scope for research is abundant in this area.

B.Energy efficiency/ Green protocol design[52], [53],[54]

Charging underwater sensors is tedious work and practically problematic. To overcome this, an energy efficient acoustic node powered by a renewable source of energy needs to be designed.

C.Performance evaluation of UW-ASN[55]

D.Environmental monitoring, Target tracking-UW-ASN applications[56]

Underwater acoustic sensor networks have numerous applications with challenges. Detail research of these applications is needed to attain an in-depth analysis.

E.Data collection from Acoustic sensors [57]

Testing a technique in underwater acoustic communication is both costly and difficult. Hence the use of simulators is expanded to perform computer network analysis. A mobile simulator for both static and mobile data gathering and that is compatible with both terrestrial and underwater communication is needed.

F.Collision avoidance MAC protocol[58]

The medium Access Control protocol is used to share the common channel between the nodes in the networks. The primary task of the MAC protocol in UW-ASN is collision avoidance. The MAC protocol in UW-ASN is inappropriate for UWSN, because of the harsh underwater channel. Therefore, the scope to develop an efficient collision reduction method and the overall performance of the UWSN system.

G. Path finding[59]

The mobile AUVs collects the sensed data from the nodes through optical technology and synchronizes using underwater acoustic communication. The data sensed is connected with a time-delayed value. In such a case, pathfinding problem is addressed to maximize the vol of the delivered data from the AUV to the surface sink.

H. Secure communication in UW-ASN[60], [61], [62]

Unlike any other network, UW-ASN is equally vulnerable to security attacks. Studies conducted so far prove that UW-ASN is deployed in many applications, but very little importance is given to their security aspect. Prominent differences between air-borne WSN and UW-ASN urge the need for a secure mechanism for underwater communication.

I. Cognitive acoustic sensor network/ Spectrum Management

Most recent works in this field are emphasized in creating an environmentally safe UACs to perform reliable discovery underwater. In most cases, the frequency of the man-made acoustic modem strongly overlaps with the natural cetacean communicating frequency causing behavioral and even fatal impact on the cetaceans. The frequency band of cetacean communication is highly disturbed by artificial acoustic activities. Hence to design a low interference modem with a high network performance is the need of the hour.

J. Time synchronization[63]

Some of the important challenges of time synchronization like messaging timestamping, the mobility of the nodes and Doppler scale effect are vital and demanding problems of the underwater acoustic sensor network. An efficient acoustic time-synchronization algorithm needs to be designed to overcome these challenges.

K. Routing[64],[65],[66]

Focusing on the design of UW-ASN routing protocols is a hopeful solution to deal with some of the prominent challenges of the underwater like restricted sensor node battery life, high noise, and interference, shorter bandwidth, extended multipath delay.

L. Underwater Acoustic communication in fresh water[67]

Salinity plays a major role in acoustic communication, higher saline water favors greater speed of sound. And the speed propagation and absorption coefficient in a freshwater environment is not dependent of the working frequency range of the signals transmitted. Hence, designing fresh water compatible UW-ASN is a challenging problem.

M. Software-defined acoustic networks[68],[69]

In the world of hardware and application-based architectures, which suffer inflexibility, reconfiguration, and reprogramming. The next gene UW-ASN is slowly finding its pace. The want of a flexible, robust, programmable and an adaptive software defined acoustic network is drawing research to this field.

N. Underwater optical communication

Various influencing properties of underwater wireless optical communication like exceptionally high data transmission rate with huge distance coverage, better attenuation has drawn the interest of many researchers recently.

O. Bionic Covert / Camouflage underwater acoustic Communication[70], [71]

Covert means non-detectable; the idea is to deceive the interceptor to actively exclude the communication signal as it resembles the original signal. Highly finds purpose in marine defense related activities, e.g. submarine.

P. Multi-user communication [72]

Distinct features and hardware constraints of UW-ASN cause multi-user cooperative transmission improbable. Multi-user cooperative transmission is an inviting architecture for underwater acoustic sensor networks (UW-ASNs) where the appropriate allocation of resources is the key.

Q. Underwater Localization[73], [74]

Unlike GPS receivers in terrestrial WSN, UW-ASNs do not favor the propagation of GPS signals through the water. The strident nature of the physical layers with its challenges hinder the acoustic channels underwater. Factors like the variable speed of sound and node mobility caused by the harsh ocean currents are some of the challenges in undersea localization.

R. Underwater Acoustic Communication in Shallow water

Many shallow water applications of UW-ASN that use underwater acoustics are recently gaining the attention of many researchers.

S. Topology Control in UW-ASN[75]

Topology control is the key for enhancing Wireless ad hoc sensor network performance wise and in UW-ASN it aids in efficient ocean monitoring and exploration.

V. CONCLUSION

In this paper, we have given a detailed review of the underwater acoustic sensor network from the perspective of Internet of Things. It is quite evident from all the research done so far in UW-ASN that numerous challenges with research and development is in the antecedent stage and therefore demand a wide-spread contribution to overcome the prominent challenges with special emphasis to physical deployments of the systems on a larger scale. UW-ASN is slowly gaining importance and if the challenges are appropriately addressed can aid in the drastic exploration of the aquatic world. The paper also discussed some of the least explored promising domains of the UW-ASN and their future research openings have been highlighted. The literature review of this paper has surveyed the existing works and they are open for extensive future investigation to unveil the interesting part of the oceans. The paper aims to provide a deep root basics for future novel advancements in underwater sensor network.

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