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Research paper

A technical survey on underwater communication

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Abstract

The world's pace has elevated technology to a higher pinnacle in the field of communication, yet the research in underwater communication is progressing in a slow traverse due to its compound barriers. Underwater communication is one of the unique and challenging fields in communication engineering in the case of both designing and communication. It is limited by several factors like the multipath channel and frequency which is limiting the application of underwater communication. An appropriate choice of modulation will enable the device to give better data rates. As every communication needs higher data rates, appropriate devices must be coupled with multiple access methods to make it efficient and reliable. The paper is a plot of the data surveyed on underwater communication which combines of major challenges associated with underwater applications and the approaches to mitigate some of these challenges is data.

Keywords: *Underwater Communication; Acoustic; Noise; Doppler Effect; Network Layers; Modems.*

1. Introduction

A huge number of years prior sea-going creatures used to speak with the assistance of sounds they made and its in 1490 the ascent of Underwater Acoustic Communication occurred with the assistance of Leonardo Da Vinci expressing that, "Using a tube of longer length we can hear the ships which are at farther distance from us when one end of the tube is immersed in water and the other end in closer proximity to ear".

Treatment of Sound Waves using mathematical equation was first done by Isaac Newton in his "Mathematical Principles of Natural Philosophy" in 1687. In 1826 at Lake Geneva, the significant improvement occurred on Underwater Acoustics by the assistance of Daniel Colladon and Charles Sturm, who were Swiss physicist and French mathematician, by measuring how the flash of light brought about ringer of underwater listening horn contrasted in time and the modern acoustic came to presence by Lord Rayleigh in 1877 after he composed the book on "Theory of Sound". The law of hearing by which people can translate a mind-boggling sound by separating them into set of basic tones inquire about led by George S. Ohm with the assistance of resistors fortified many researchers.

In the mid twentieth century the Underwater Communication got pace because of the events like TITANIC and World war where the outlining for frameworks that can identify ice shelves and underwater crafts were executed and European nations began their advances in this field and on a huge scale the submarines and acoustic mines are produced. Around 1960-1970 numerous trial examination were done on fluctuations in propagation and the effectiveness of the framework for dynamic and static sonar gadgets were completed.

Briefing the refraction of sound waves in water and on their qualities the primary logical paper was distributed on Underwater Acoustics, in 1919 and from the next decades huge advancements in this viewpoint were brought out like innovation of Sonar Systems , Fathometer and introduction of Optical Wave Communication rather than Acoustic waves and their attributes , prompt new pattern in underwater communication and critical changes to change in information rates, transmission capacity and parcel more numerical enhancements in this particular space of research were seen.

Underwater acoustic communication is unpredictable. It has time variation and is restricted by a few physical wonders putting obliges on the limit and dependability of the channel the most genuine confinement on underwater communication which is the accessible transmission capacity. [7] [8] Recurrence subordinate ingestion put requirements on the accessible transfer speed, along these lines restricting the information rate. [9] Multipath propagation, which causes time spread and fading, is another critical contributor to distortion of the acoustic signal. Time spread is caused by multipath parts arriving at various times at the beneficiary.

As of late, there have been broad research exercises in underwater communications and underwater sensor systems. The principle inquire about destinations on one hand is to accomplish high information rates, expanded limit and accomplish high spectral proficiency. From one viewpoint is the endeavor to build the communication separate and to control the vitality utilization. Underwater remote communication Networks (UWCN) or underwater remote sensor systems (UWSN) is made of accumulation of a few individual sensor systems gadgets, for example, underwater acoustic sensors, Autonomous Underwater or Unmanned Underwater Vehicles (AUV or UUV) and Remotely Operated Vehicle (ROV) furnished with detecting, handling, and communication capacities [12]. In most existing underwater sensor sending situations, the Buoy station (BS) and the gadgets are furnished with single electro-acoustic transducer. Accordingly, it depends on Single- Information Single-Output (SISO) communication. In any case, due to the persistent increment of information movement in current underwater applications, MIMO frameworks have attracted much intrigue late years which now assumes an overwhelming part in numerous advanced remote and underwater communication frameworks.

2. Major means of communication

The concept of underwater communication which has immense depth in its applications and wide use for marine archaeology and oceanography. The first telephone that was made for underwater has a frequency range of 2 to 25 KHz. The prime means of communication through underwater are acoustic waves, EM waves and optical signals. The acoustic waves have ability to travel long distance, while the optical means are limited to shorter distance. As the temperature increases the sound increases in acoustic medium. It even applies with the proportionality increase of depth leading to increase in sound speed. The EM waves have random attenuation in water, while the optic signals have overcome this factor. The bandwidth is limited by a factor in acoustic waves and optical signals carry more information nut get absorbed in water.

The radio frequency waves that function in a frequency band of 30-300 GHz are electromagnetic waves that have a frequency which proliferates in the electromagnetic field as disturbed due to oscillation of electric charges. The dissolves salt in the water will make the water a slight conducting, which causes it to be functional for attenuation. Conductivity and frequency play a key role to increase the attenuation. The fact of refraction loss caused due to change of medium from air to water at the transmitter and receiver majorly effects the RF communication. SeaText was the first underwater modem made which gave a data rate of 100bps for 10 meters.

Table 1: RF Underwater Communication Characteristics

Range	<1m	<10Km
RF (Data rate)	100Mbps	1bps
Application	Underwater Vehicle docking	Underwater telemetry

The optical wave travel at with speed of light but leads to have short wavelength due to scattering and absorption in underwater communication. These waves have wavelength of range 390nm to 700nm. The organic and inorganic matter accords major scattering factor in underwater communication. The optical modems are now combined with the acoustic to give better characteristics. The hybrid approach uses laser beam in underwater communication.

Table 2: Comparison of Different Communication Models for Underwater Communication

Communication Models	Range	Channel Dependency Factors
EM	< 20m	Conductivity, Multipath attenuation
Acoustic	~km	Doppler effect, Multipath Propagation, Temperature, Fading losses
Optical	10-100m	Light scattering, Line of sight communication

A sound wave is combination of compressions and rarefactions which is detected with the help of device called hydrophone. Generally, the frequency range in underwater communication is between 10 Hz to 1 MHz. But the problem arrives with increase in frequency, which leads to absorbing of signal. The commonly used means which is the acoustic waves has high propagation delay and low data rate caused by multipath fading and Doppler effects due to variation in temperature and salinity in water.

Inferable from the saline nature of the water medium, the high frequency EM waves are influenced by extreme attenuation. Along these lines, these high frequency waves are not reasonable for underwater environments. Then again, low-frequency waves extending from 30-300 Hz can spread over long spaces in such a powerfully evolving condition. Nonetheless, for transmission of such low frequency signals, an extensive measured radio wire with high transmission capacity is required, which is unreasonable. Conversely, optical waves don't experience the ill effects of the issue of attenuation; they require a high accuracy pointing bars which for the most part are influenced by scattering. Then again, for underwater medium; acoustic waves are less lossy and support long range signal transmission. In this way, acoustic signals are significantly utilized in underwater communication. In any case, underwater acoustic waves are likewise restricted by multipath propagation, Doppler Effect, and low data rates [3], [4].

The rate of transmission of data (Data rate) is an important characteristic of a channel, though it varies from medium to another. It majorly depends on channel bandwidth (B), channel SNR (Signal to Noise ratio) and number of levels in a transmitted signal. The Nyquist bit rate for an L level signal is given as:

$$r_b = 2B\log_2(L) \quad (1)$$

$$C = B\log_2(1+SNR) \quad (2)$$

The capacity of information transmitted in a channel varies with bandwidth and signal to noise ratio of the signal, which is called Shannon's Channel Capacity:
Where C = channel capacity, B = Bandwidth of the channel,
S = Average received signal power, N = Average noise power, S/N = signal to noise ratio.
We can see that the more interference leads to decrease of signal power in comparison to noise power, which proportionally leads to decrease of channel capacity.

3. Challenges in Underwater communication

The major challenges associated with underwater applications are as follows:

i) The propagation delay is quite high in underwater medium in comparison with terrestrial environment.
ii) The dynamic nature of the channel due to multipath fading problem.
iii) Temporary losses of connectivity and high error in bit rates can be experienced in the channel characteristics.
iv) The power factor of the batteries is a major drawback due to its high-power requirement.
v) Pollution and corrosion have played a key role to cause failure for underwater sensors [1], [2].

4. Factors affecting Underwater communication

The main factors which alter underwater communication are:

a) Ambient noise

It is a background source level in each point, which is used to study invasive sound source. It varies with the effect of turbulence which is seen at low frequency points where it is less than 10 Hz. The motion of the waves causes surface motion which leads a frequency ranging 100 Hz to 100 kHz. The high frequency factor is the thermal noise which effects at a frequency greater than 100 kHz. [10] [11]

b) Doppler effect

An effect which is considered to have key role in affecting underwater communication. As the Doppler frequencies are greater than carrier frequency and the speed of the sound is low it leads to play that key role. The motion between the transmitter and receiver due to movement of the sea surface the Doppler shift completely distorts the frequency of the transmitted signal.

c) Multipath channel

The propagation speed of acoustic network is around one kilometer per second, which is quite low compared to other modems. The water medium is comprised of many scattering parameters and the reflection caused from the surface adds up to the occurrence of multipath in underwater acoustic channel. From the Rayleigh fading model we can see that,

$$R(t) = M(t) \times S(t) + N(t) \quad (3)$$

Where,

R (t) = Received Signal, M (t) = Message Signal, S (t) = Modulated Signal, N (t) = Additive white Gaussian noise.

It is a major factor to cause inters symbol interference (ISI); inter channel interference (ICI) and fading of the signal. The signal flow gets majorly disrupted through these factors, which leads to time and frequency spreading causing high attenuation in a signal.

5. Underwater communication network model

Unlike the TCP/IP, the underwater network lacks with the ability to provide a high data rate network and a smooth connection. It even cannot be reconfigured once the underwater modems are deployed. The challenges they are combined are solitary, as the medium acts an obstruction to the functionality of wireless sensor network. The TCP/IP is not familiar with the long propagation delays; hence the underwater network protocols need to be designed with an aspect to tolerate the delay caused in the underwater communication. From paper [13], we see that the underwater modems, energy consumption factor is very high in comparison with RF devices. The factor that the energy consumption during transmission is greater than receiving, leads us on an importance property which must be included, that is, as the batteries are non-rechargeable the energy saving must be given high priority.

The proposed protocols in recent years have converged in varying the algorithms of the data link layer without considering the alterations for the whole stack. As we know that protocols proposed are not made general for all applications, they are quite application specific, hence it leads to a problem for designing protocols for every application required for underwater communication. This can be seen in tectonic plate movement system, where it is specific to the speed of the moment of water, while the delays are considered insensitive. In paper [14], the author has proposed a low power wireless personal area network architecture that brings IPv6 to 802.15.4 networks. This helps in compression and fragmentation method to make the frame format more converged to underwater scenario. In Paper [15], the author discusses the experimental deployment of underwater networks called SEAWEB. The system needs mediator ship of humans to setup and monitor the systems.

The layered architecture defines interface standards between layers of the communication protocol used and does not allow interaction of non-neighboring layers. An underwater communication network basically comprises various protocols as MAC, DLC (Data Link Control) and routing protocols [5] apart from the communication stack. The protocol stack of an underwater acoustic network is shown in Figure 2. The underwater acoustic network model consists of 5 layers [6].

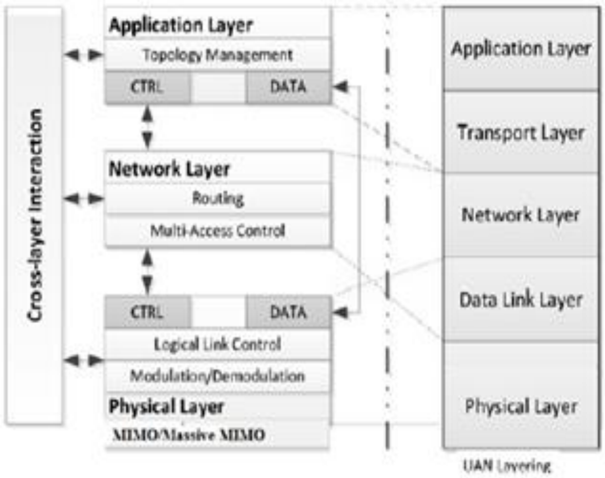

Fig. 1: Underwater Acoustic Layers.

Physical Layer: The first layer is the physical layer. This layer characterizes every electrical level in computer networks or acoustic signal transmission in underwater communication networks. The physical layer also deals with the propagation methods for communication. Many modulation techniques have been developed, the coherent modulation techniques were developed to provide high-throughput systems with long-range communication ability. Some planar coherent modulation schemes e.g. phase shift keying (PSK) Binary Phase Shift Keying (BPSK) and quadrature amplitude modulation (QAM) [20].

Data Link (DL) Layer: This layer works bit-stream formatting into frames, network topology, stream or flow control physical addressing, and error notification. The data link has two sub layers viz. Data Link control (DLC) protocol and Media Access Control (MAC).

The OSI model works around the system architecture while the cross-layer approach concentrates on performance of the communication system over architecture. This allows transports of feedback through the boundaries of the layers dynamically to facilitate the compensation for the constraints of underwater communication such as high latency, overload, signal fading due to absorption and multipath, it also tackles the issues of Doppler Shifts and other mismatch of resources and requirements by any input control to other layers which are directly affected by the issues of that specific layer.

While many researchers have proposed and presented several protocols and algorithms in different areas of UWASNs, these protocols are based on the OSI communication model. Cross-layer design is a modern design approach/technique to improve the performance of underwater wireless sensor network communication by optimizing cross boundary/layer communication function.

6. Underwater Acoustic modems

There is a major emphasis given the communication model for the underwater communication system. The major components in any communication network are nodes. The network relies on the ability of these nodes to transmit and receive information, thus the major component in underwater communication is the modem used. There is a major effort being put into development of underwater communication networks. The research is focused towards developing communications systems for underwater networks to overcome the limitations and constraints of underwater environment such as channel latency, the available bandwidth, and maximum communication distance (range). The major component of an underwater communication system is the modem. A generic underwater communication modem has the following components:

i) A power supply equipped with battery, power management unit, and DC to DC converters.
ii) A control unit, which is usually a processor and memory unit (this can also be a FPGA).
iii) A modulating and demodulating circuitry equipped with, digital to analog converter and analog-digital converter to facilitate the transitional change between the medium and the electric circuit (a DSP can perform these functions).
iv) Peripheral connectivity ports (USB and RS232 are few of the useful ports).
v) Finally, a physical hydrophone and loudspeaker. [16], [17].

Due of the unavailability of wired connectivity in underwater environmental conditions; underwater communication equipment is solely dependent of battery power supply. Because of this the power consumption of underwater equipment has to be minimum in order to make underwater oceanographic equipment suitable for long term deployment. On the other hand, static underwater communication nodes do not have this constraint as power to the nodes can be supplied via wired medium.

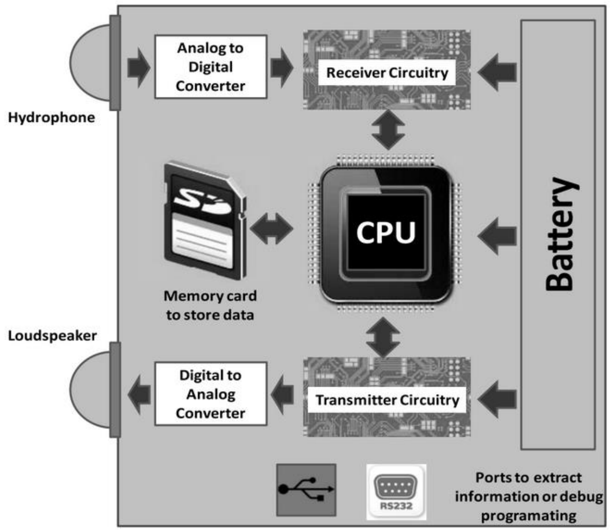

Fig. 2: Components of Underwater Acoustic Modem.

S. Blanc presented a proposed prototype for underwater acoustic communication modem in [18], the authors designed and underwater acoustic modem whose main distinguishing feature of this prototype modem is its low cost and low energy consumption design. In the paper the authors describe the basic modem architecture which is similar to figure 2. They utilized an 8-bit microcontroller to facilitate the control and synchronization between different circuit components of the modem. The authors' major focus was to transmit and receive acoustic signal. They made use of a commercially available device for the role of a transducer, which is based on the properties of piezoelectric materials, usually present in sonar. Different modulation algorithms were compared to obtain low energy consumption. Finally, authors arrived at Coherent-FSK algorithm as the most power efficient, capable to transmit information at a speed of 1 kbps. The proposed energy consumption and the quoted price of their proposed modem are similar to the typical terrestrial wireless communication nodes. The energy consumed by the modem when put into standby mode is 3 μW (as claimed by the authors) and the proposed modem consumes close to 12 mW in transmission mode and about 24 mW in reception mode. The modem has a range of 100m, with the test parameter being the goodness of the received packets when compared to the transmitted packets, along with the packet transmission range. The maximum communication range of the prototype in the performed tests was 100 m.

Wu et al., the author [19] presented the design of an underwater modem utilizing the acoustic mode of communication. The proposed modem provides energy efficient communication summed up with reliable information exchange in underwater communication networks. The author's work was tested with a host of experiments and in field sea tests which helped in quantifying the benefits given by different types of channel estimation techniques, different modulations algorithms, and symbol synchronization. The results obtained show that using communication rate adaptation could lead to substantial energy saving. The proposed modem clocked communication rates of 1900 bps with a reliable communication range of 200m.

Benson et al. [16] conducted a survey on major design components of the authors' low cost underwater communication modem prototype and described different components of their prototype. The designed modem was intended for close range acoustic communication with applications that require low data rate for simple sensor networks. The designed hardware platform was tested with a conclusion that the prototype can transmit information with data rates of up to 200 bps with a SNR (signal to noise ratio) of about 10 dB for error free transmission. The author also developed a power management board equipped with batteries. In water tests on the transducer and analog transmitter and receiver confirmed that the designed acoustic modem can detect a signal with 350m distance between the transmitter and receiver.

C. Benson and the coauthors have described and evaluated the performance of an acoustic underwater communication modem in [22]. The modem prototype developed is a FPGA based design using, Cyclone III EP3C25. The modem operates at high frequencies providing higher data rates for underwater communication. The major improvement this designed modem over the existing commercially available modes is that the prototype uses DSP processor. All of the processing tasks are performed in a digital domain; this makes the modem less complex and more cost effective with its operation. Utilizing the DSP processor enables the modem to be highly flexible by offering the ability to change parameters of the modem as required. This ensures that the rework costs are minimum.

The designed modem communicates using BPSK modulation as BPSK modulation scheme is more insensitive to noise. The BPSK modulation is process utilizes BPSK with Costas loop. Authors tested the prototype in a real outdoor environment, such as a lake. Their focus of these tests was the performance of the modem while transmitting from different location across the test lake. The tests were conducted at a depth of 3 m where the transmitter and receiver were deployed. The underwater acoustic modem designed by the authors operated at amid-frequency of 800 kHz producing a data rate of 80 kbps and reached a maximum communication distance of 50 m in the test conducted on the prototype modem.

Table 3: Comparison of Commercial and Developed Modems Based on Their Operating Parameters

Underwater acoustic modem	Modulation	Carrier frequency	Bandwidth	Data rate	TX power consumption	RX power consumption	Ideal power consumption	Max. distance
RESEARCH MODEMS								
[18]	FSK	10 kHz	1 kHz	1000 bps	12 mW	24 mW	3 μW	100 m
[19]	FSK	9 kHz	N/A	1900 bps	N/A	N/A	N/A	200 m
[16]	FSK	35 kHz	6 kHz	200 bps	750Mw	N/A	35 mW	350 m
[22]	BPSK	80 kHz	N/A	80 kbps	N/A	N/A	N/A	50 m
COMMERCIAL MODEMS								
LinkQuest UWM2000	N/A	35695 kHz	17.85 kHz	17800 bps	2W	0.8W	8 mW	1500 m
LinkQuest UWM10000	N/A	10 kHz	5 kHz	5000 bps	40W	0.8 W	9 mW	1000 m
TriTech Micron-Modem	N/A	44 kHz	4 kHz	40 bps	7.92 W	0.72 W	N/A	500 m
Desert Star Systems SAM-1	N/A	37.5 kHz	9 kHz	154 bps	32 W	0.168 W	N/A	1000 m

The comparison of different research modems and commercially available modems based on the data rates, communication distance, power consumption and other parameters has been done in Table 3.

7. Future scope and Conclusion

Presently there is possibility only for the Half-Duplex communication between Acoustic Transducers, the problem here is that it cannot be separated spatially far enough for the happening of full duplex communication and the main reason for this is that wavelength which is proportional to transducer size. So, the better way for future development here is to use the concept of Equalizing PSK for much better Spatial Diversity.

Due to less available bandwidth the main techniques for better efficiency are the use of Cross Layer Optimization and to overcome the longer latency the Adaptive parameter setting can be used, and for better efficiency of the system we can use Lower-frequency transducer for longer range, Lower bandwidth and vice-versa. For Security purposes we can use different methods of available coding techniques, and we can use OFDM techniques [21] for better usage of available bandwidth with low interference levels.

To overcome the challenges of underwater communication we should precise and regulate the sensors properly and make the signal resilient against frequency selective fading. Various CDMA spectrums are available and for better approach, we can go with routing schemes and multiplexing methods like wavelength multiplexing can be used. The multipath effects and absorption losses can be avoided in the system design by increasing the accuracy.

Cross-layer approach may offer improved performance and efficiency to overcome the challenges in the underwater networking. The major challenge with this technique is it requires a joint design of different network functionalities. Systematic investigation of cross-layer approach for underwater communications is still unexplored. The supports for richer interaction facilitate a better coordination among the communication layers and distributed decisions. Richer interactions aim to provide improved inter-layer communication or interaction within a node to improve its performance in a sensor network, with the objective to overcome the drawbacks of a layered design approach that prohibits information sharing across boundaries of protocol layers.

The paper deals with basics to the communication end of underwater medium. The contrivance side in UWC has been slow; perhaps we can see that the underwater medium is complex and tougher to caper with the characteristics of underwater communication. To conclude, the Underwater Communication is the domain where we can see lot of opportunities and creative ideas to be developed for better communication within the available bandwidth using multiple accessing schemes and energy efficiently methods for a planet filled with two-thirds of water.

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