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Underwater Transmission Techniques for Subsea Data Acquisition

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***Abstract*—** This paper presents a detailed study of problems arising in underwater communication and also presents the application and challenges of underwater sensor networks (UWSNs). Over the past few decades, ocean exploration activities have been steadily increasing. We work on RF propagation to a larger distance using cross-medium communication but, in this paper, we only present the research challenges on UWSNs in long-distance transmission of RF waves. The data transfer rate, network coverage, impact on marine life, and propagation speed all these factors play a major role in communication carriers for UWSNs. Navigation, military purposes, fishing, ecology, weather influence and support for petroleum offshore exploration are some of the applications of UWSNs.

***Index Terms*— Underwater Sensor Networks (UWSNs), RF waves, Underwater Communication, Cross medium communication.**

I. INTRODUCTION

In today's time, research on Underwater wireless Communication is getting its pace. As the water covers more than 70% of the Earth's surface so it's become requisite to explore mysterious parts of the Deep Ocean, although it's very difficult to retrieve oceanographic data from the deep ocean because of some limitations such as water depth, attenuation of the transmitted signal, bandwidth, data transmission rate and transmission range, propagation delay and many more such things. Water is itself a major challenge for underwater communication Electromagnetic waves, Optical Waves and Acoustic Waves can be considered as transmission waves for Underwater wireless communication. Electromagnetic waves can be preferred over acoustic and optical waves. Optical waves need clear water to propagate and line-of-sight alignment of communicating nodes and it also encounters the difficulty in crossing the water-air boundary. While Acoustic waves can travel long distances up to 20km and there is no requirement of line-of-sight alignment for propagation. Acoustic waves can travel in deep water and have low propagation speeds. Electromagnetic – Radio frequency (EM-RF) waves. They can meet the limitations of crossing the water-air boundary it also doesn't require line of sight alignment of nodes for propagation can have high data rates but there is a major drawback for RF waves in underwater communication, i.e., they attenuate rapidly in seawater because of some EM properties of seawater. The propagation of EM in water is different from the air because of the water's high permittivity, permeability, electrical conductivity, and volume charge density [1]. These three transmission waves have their advantages and disadvantages it is less likely to overcome all the limitations of these waves. The transmission of waves underwater can be done by underwater sensor networks (UWSNs) and different modulation techniques with wireless standards will help the signals reach their destination node [2]. Navigation, fishing, ecology, weather influence and support for petroleum offshore exploration are some examples of this importance.

The necessity of Underwater wireless communication has increased now days in this paper we will focus on different modes of data transmission in UWC, Its applications and challenges, wave modulation techniques, underwater wireless sensor networks (UWSNs), and an overview of cross-medium communication.

II. MODES OF UNDERWATER COMMUNICATION

A. Review of Underwater Optical Communication

Optical transmission in seawater provides very high data rates (in Gbps) and very low power consumption but for a short-distance transmission. Absorption, strong backscattering, and turbidity are dominant factors that degrade underwater optical transmission performance [9]. A precise alignment is needed between the transmitter and receiver to get efficient communication. Underwater Optical communication is carried through Ultraviolet, Visible or Infrared waves in an unguided propagation medium. Path loss is also a disadvantage for optical communication in seawater, Absorption and scattering are the two phenomena impairing the propagation of light in water. These effects lead to the loss and deviation of light photons, respectively [10]. According to the conservation of balancing, the absorption & scattering phenomena can be expressed as:

$$P_o(\lambda) = P_a(\lambda) + P_s(\lambda) + P_c(\lambda)$$

$P_o(\lambda)$ = Strength of input beam of light
$P_a(\lambda)$ = Small fraction of incident beam absorbed
$P_s(\lambda)$ = Fraction scattered by the water element
$P_c(\lambda)$ = Unaffected result passes through the element of Water
Combined attenuation in underwater coefficient c(λ) is given by:

$$c(\lambda) = \alpha(\lambda) + b(\lambda)$$

The values of α (λ) and b (λ), in addition to the wavelength, vary with the water type.
Orthogonal frequency division multiplexing (OFDM) is used in multiple sub-carrier modulation (MSM) techniques. Different such as QPSK and QAM for UWOC and the FPGA complete Ethernet data packet processing, channel coding, modulation and demodulation tasks for efficient data transmission.
UWOC has various applications, mainly in military applications Submarine detections, underwater mine detections, underwater surveillance systems, video data transmission etc. [11].

B. Review of Underwater Acoustic Communication

Underwater Acoustic communication is generally meant for long-distance data transmission up to the distance of 20km but the achievable data rate will be low and the low propagation speed with the frequencies vary from 10Hz to 1MHz. The speed of the acoustic wave underwater depends on water pressure, temperature and composition. The acoustic wave can be affected by the water temperature, turbidity, path loss, noise, limited acoustic link capacity, multi-path effect, and Doppler spread. Which may cause a communication delay from the acoustic source to the acoustic receiver [11]. Acoustic waves are generally mechanical and longitudinal waves created by UWSNs as pressure waves. Underwater acoustic communication implies sending and receiving sound messages underwater. The sound is travelled as a pressure wave or as an acoustic wave with limited bandwidth this is also its disadvantage. The speed of sound in water is around 1500 m/s [3], and it varies significantly with temperature, density and salinity, causing acoustic waves to travel on curved paths Underwater acoustic communication is vulnerable to malicious attacks. The underwater acoustic communication has attenuation in the form of path loss or transmission loss and is caused by energy spreading and sound loss [12]. It will create strong attenuation and reflection while crossing the water-air boundary. Acoustic propagation under water's primary disadvantages i.e., transmission loss, noise, reverberation and temporal and spatial variability of the channel Transmission loss and noise are the principal factors determining the available bandwidth range and signal-to-noise ratio. Both radio waves and acoustic waves experience $1/R^2$ attenuation due to spherical spreading The main disadvantage of acoustic communication is, it travels in a vertical path either horizontally, vertically or diagonally [4].
The impact of the environment on acoustic signals is high and it also affects marine life. Ambient ocean acoustic noise is caused by shrimp, fish, and various mammals. Near Harbors, there is also man-made acoustic noise in addition to ambient noise.

An underwater acoustic channel is characterized as a multipath channel due to signal reflections from the surface and the bottom of the sea. Because of wave motion, the signal multipath components undergo time-varying propagation delays that result in signal fading [6]. Acoustic Sensors senses and receives the data, the data can be audio, video or image. The hydrophones are used as acoustic sensors to receive or send the data. The hydrophone is generally a microphone based on a piezoelectric transducer and these piezoelectric transducers converts pressure waves into electric signal. It consumes more power as it requires high-power transmission of acoustic signals.

C. Review of Underwater EM-RF communication.

Radio Frequency waves are forms of electromagnetic radiation with related radio frequencies that range from 3 kHz to 300 GHz. Radio waves have a different mechanism of propagation than acoustic waves. Electromagnetic propagation through water is very different from propagation through air. RF waves have a higher data rate, consumes less power, can cross the water-air boundary, can't affect by turbidity/bubbles, have no need for line-of-sight alignment, and can't be affected by multipath and acoustic noise. The propagation velocity of RF waves is 100 times more than acoustic ones for frequencies above 10 kHz. But it travels for a short range due to path loss or propagation loss. EM waves attenuate rapidly in seawater because of their high permittivity and electrical conductivity nature. Water has a higher permittivity than any other material with a relative permittivity of 80. The conductivity of seawater is almost 4 S/m. Freshwater has the same permittivity as seawater and relative permeability is 1 so there is a slight effect on the magnetic field component but the conductivity of fresh water is around 0.01 S/m. The RF wave propagation is affected by various conditions of the environment such as temperature and salinity of water. Most of the loss is due to the effect of conduction on the electric field component [1]. The attenuation of RF waves underwater can be expressed in terms of Skin Depth. It's the depth where the EM signal weakens to 1/e, or around one-third. Skin depth(δ) for seawater will be $250/\sqrt{f}$. Where f is in Hz and δ is in meter [6].

The propagation of Electromagnetic waves over long distances is not possible except at Extremely Low Frequencies, yet the signal transmission of these low frequencies is expensive as the transmission requires large and powerful transmitters.

Table 1: Comparison of Modes of Underwater Communication technology

TRANSMISSION WAVE	ADVANTAGES	DISADVANTAGES
ACOUSTIC WAVE	1.For Long range transmission. 2. Proven technology	1. Low Propagation Speed. 2. Impact of Environment is high & impacts Marine Life. 3. Strong signal attenuation 4. Low data rates
OPTICAL WAVE	1. High propagation speed. 2. Very high data rates	1. Requires line of sight alignment. 2. Strong backscattering due to the turbidity & water particles. 3. For short range transmission
RF WAVE	1. High data rates. 2. Not affected by the turbidity and acoustic noise. 3. High propagation speed.	1. High attenuation 2. For short range transmission 3. Susceptible to electromagnetic interference

III. Modulation Techniques

- On-off keying (OOK) or 2ASK is the most popular optical communications modulation technique used for free-space optical links. The number of discrete signal amplitude levels used to carry a digital signal is OOK which is the special case of Amplitude Shift Keying. This modulation scheme is easy to implement so it is usually adopted in underwater optical communication. Here the '1' bit or logic High represented the presence of light and the '0' bit or logic Low is represented the absence of light and we can consider it the non-return-to-zero OOK modulation.

ASK (Amplitude Shift Keying) and PPM (Pulse Position Modulation) are also used in direct detection techniques for underwater optical communication because of their easy implementation of the system [13].

- Some underwater acoustic communication modulation techniques are MPSK (BPSK, QPSK, and 8PSK) and MQAM. From MPSK and MQAM, MPSK is the most frequently used modulation technique. MPSK is M-ary phase shift keying it represents the set of M equal energy signals to represent M equiprobable symbols, phase of the carrier wave varies while amplitude and frequency remain constant.

$$A_{MPSK}(t) = cos(\omega_c t + \theta_m)$$

A= Amplitude of the carrier signal
ω_c = Angular Frequency of the carrier wave
θ_m = Phase

While the MQAM technique is different from MPSK, in this modulation technique the digital data is sent by varying both the phase and envelope. In M-ary QAM energy per symbol and distance between possible symbol state is not a constant.

$$A_{QAM}(t) = cos(\omega_c t + \theta_m) + A_i \cos(\omega_c t + \theta_m) + B_i \cos(\omega_c t + \theta_m),$$

Where i =1, 2…M.
$A_i = a_i \cos(\varphi_i)$

$B_i = b_i \cos(\varphi_i)$

- For the transmission of EM-RF wave Pulse modulation and Continuous-Wave modulation technique is used but continuous wave modulation is a frequently used method. The carrier can be analog or digital depending on the transmission. In continuous wave modulation, we used phase shift keying and complementary code modulation. The amplitude of the carrier is constant in PSK modulation, while the carrier's phase changes. Because of this, the phase has discontinuities that can be seen at the start and end of each symbol interval T. We may choose either conventional PSK or Differential PSK, both have several subtypes the common ones are BPSK, QPSK, 8PSK, 16PSK, OQPSK (Offset Quaternary PSK) and SOQPSK (Shaped OQPSK).

IV. Cross Medium Communication

Cross Medium Communication helps to combine two different Waves having different characteristics In future work we will discuss, how cross-medium communication helps the RF and Acoustic waves to communicate underwater and be able to cross the water-air boundary effectively.

VI. Applications And Issues Of Underwater Communication

Applications:

- Ocean Exploring – There are many such things inside the sea, which have not been detected yet, for that underwater technology has been used for ocean exploring including marine life monitoring, climate study, Oil and gas mining, pollution controlling etc.
- Military Purpose – Underwater technology is beneficial in many ways for surveillance work of military and defence. Every country needs to defend itself from underwater or through underwater attacks. So underwater communication is required for military purposes. Communication to submarines from the ground, threat detections, detection of hostile attacks,
- Data Collection & Transmission – The sensors deployed underwater helps in sending and receiving data. The data collected in sensors is transmitted to relays or buoys on the water surface and then again transmitted to the satellite or base station. The underwater technique for data collection and transmission is very helpful in the detection of any harmful object, damaged object, foreign substances etc.
- Disaster Detection – Some natural disasters cannot be detected by satellites or are detected late such as earthquakes, cyclones, and tsunamis. Tsunamis are generally caused by earthquakes. The sensors deployed underwater will be able to detect the natural disaster and transmit the information to the base station as soon as possible.

Issues:

- EM Waves – The achievable data rate for EM wave transmission is high up to 100 Mbps but for a very short distance. EM waves got attenuated rapidly in seawater because of their conducting nature that's why EM wave can't travel long distance as it attenuates with distance. Requires large antennas and high power for ELF transmission for long-distance transmission.
- Acoustic Waves – It provides low data rates and high transmission loss because of scattering loss, absorption loss and spreading loss. The propagation speed of acoustic waves is low i.e., 1500 m/s and results in multipath propagation. It is also affected by high ambient noise.
- Optical Waves – Needs the proper alignment of nodes for receiving and transmitting the signal. Strong backscattering occurs due to the suspended particles and is also affected by the turbidity of water. Travels for the short range and can't cross the water-air boundary.

VII. Conclusion

This paper provides an overview of underwater communication transmission modes and their modulation techniques for subsea data acquisition. The data collection and transmission can be through EM waves, Acoustic waves or Optical waves. We can conclude from this paper that the EM and Acoustic technologies can be preferred over optical, with the help of these two technologies we will be able to cross the water-air boundary and their combination will refer as cross-medium communication. This paper highlights the application and issues of underwater communication.

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