Underwater Communication: A Detailed Review

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Abstract
The research in underwater wireless communication is attracting and leading to increased attention due to its numerous applications mainly for military & commercial fields. There exists enormous major challenges in the field of submerged communication or communication in underwater namely: Finite bandwidth, delay in propagation, less data rate, more BER (Bit Error Rate), Doppler spreading, High ambient noise etc. Underwater wireless communication is based on three types of waves, these are EM wave, acoustic wave & optical wave. Each type of wave propagation has its advantage & disadvantage. In the present review paper, mechanism of RF communication, acoustic communication & optical communication has been discussed in details & also differentiated the three communication based on various parameters such as attenuation, bandwidth, distance, propagation speed, latency, frequency etc. The mechanism of acoustic modem & its components has also been presented. The study will help the researchers to focus on the research gaps & undertake research in the field vigorously.

Keywords 1
Underwater communication, EM wave, RF communication, Acoustic communication, Optical communication, Acoustic Modem.

1. Introduction

The planet where water can be found is our earth & it nearly covered seventy percent with it. For monitoring the different activities such as marine life, environmental impact surveillance in an underwater, we have to communicate with them. Underwater oceanographic studies, oil exploration & defense activities are some examples of increasing demand to find water for the purpose of defense, scientific & industrial usage [1]. Electromagnetic, acoustic & optical wireless carriers considered in underwater communication applications. By deploying the techniques of underwater communication in water medium is more challenging than the terrestrial wireless communication. The deployment of network for communication includes fixed & variable sensing nodes, unmanned floating Autonomous Underwater Vehicle (AUV) signal receiving towers, ships, & submarines [2]. The most common way of communication is using hydrophone. Submerged communication is very tough as it involves variation in channel time, multi-path, strong signal attenuation & small signal bandwidth especially over the long range. If we compare it with terrestrial communication, underwater communication has data rates low because it uses acoustic waves instead of the electromagnetic wave. From the last few years, interest has been increased towards underwater wireless communication for space, terrestrial & submerged links.

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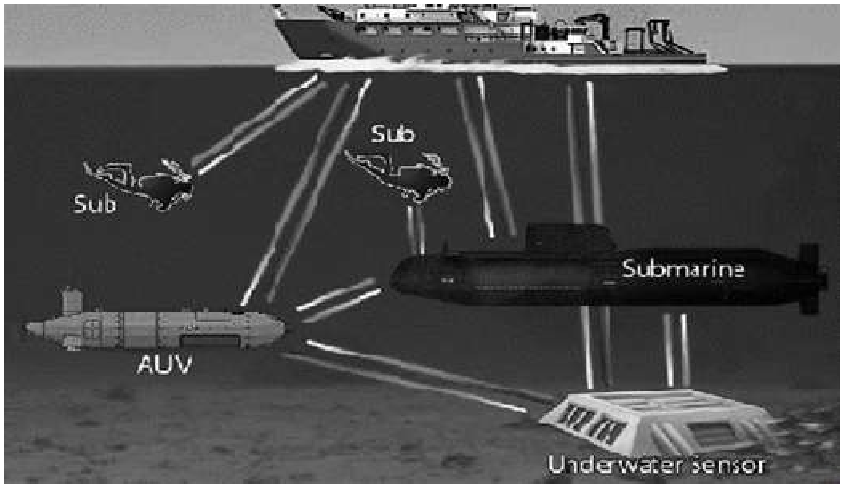

Figure 1: Underwater Optical Wireless Communication Scenario

This paper consists of seven sections. Section 2 includes different propagation waves, section 3 is about discussion of RF communication, Acoustic communication & Optical communication, section 4 brings out the major challenges, section 5 is recent advancements & applications, section 6 presents future scope & the last section 7 presents conclusion.

2. Types of Waves

Different types of waves present in underwater wireless means of communication. Each wave has its advantages & disadvantages.

2.1. Electromagnetic (EM) Wave

EM wave has a frequency range from 3Hz to 3 KHz in radio frequency & it is very much capable of high data transmission in water at short distances & it gets attenuated by the water. The speed mainly depends upon permittivity, permeability, volume charge density & conductivity & that varies to frequency used & underwater conditions. It is observed that if we increase the frequency then the attenuation of EM wave increases & gets heavily attenuated by the water. The propagation speed is very high with a range of 10^7 m/s, rate of transmitting data in the range of Mb/s. The communication range for EM wave is less than 10 m [2].

The behavior of EM wave can be described using (1)

$$\gamma = \alpha + j\beta \qquad (1)$$

where α represents attenuation constant & β represents phase constant.

In dissipative medium γ is given by

$$\gamma = \sqrt{j\omega\mu}\sqrt{j\omega\varepsilon' + \sigma_{eff}} \qquad (2)$$

where ω is angular frequency, ε' is electrical permittivity & σ_{eff} is effective conductivity [3].

The important term that affects EM wave the most is α and it is given by:

$$\alpha = \omega \sqrt{\mu\varepsilon'} (\sqrt{0.5} \sqrt{1 + (\sigma_{eff}/\omega\varepsilon')^2} - 1 \qquad (3)$$

where ω represents frequency in radians, σ_{eff} represents effective conductivity & μ is permeability.

Effective conductivity (σ_{eff}) is the sum of conductivity with real and imaginary values as shown in (4)

$$\sigma_{eff} = \sigma + \omega\varepsilon'' \quad , \qquad \varepsilon'' = \varepsilon_0 \varepsilon''_r \qquad (4)$$

Similarly, the complex relative permittivity is [4] shown in (5)

$$\varepsilon''_r = \varepsilon'_r - j\varepsilon''_r \qquad (5)$$

2.2. Acoustic Wave

For underwater communication, present technology uses acoustic wave as its operating performance is restricted by high transmission losses, Doppler spread, less bandwidth, more latency, and multipath propagation. The factor gives spatial & temporal variation in channel of acoustic which restricts system bandwidth. The current UWAC (Underwater Acoustic Communication) supports the rate of transmitting data in hundreds of kilo bps for few meters (short distance) & in tens of kilo bps for large range mainly in KM. depending upon the distance of transmission, the acoustic link can be classified as short, very short, very long, long and medium. Table 1 provides Bandwidth & transmission ranges for different UWAC links/services.

Table 1: Bandwidth & transmission ranges for different UWAC links

Distance	Bandwidth (kHz)	Range (KM)	Data Rate
Very short	>100	< 0.1	500 kbps
Short	20-50	0.1 - 1	30 kbps
Medium	10-12	1 – 10	10 kbps
Long	2-5	10 - 100	5 kbps
Very long	< 1	1000	600 bps

Underwater vehicles will require a link for communication for different data rates. If we use stationary & large system, optic fiber or copper cable is used for achieving more rates of transmitting data as this requires proper maintenance & engineering problems. If the platform is moving then the alternative is wireless link [5].

2.3. Optical Wave

Optical wave has high bandwidth that will leads to low wavelength in the range of 390nm to 700 nm & it gets affected by scattering, absorption, fluctuations due to temperature, beam steering & line of sight communication [6]. The propagation speed & date rates is approximately same as of EM wave but the communication distance is increased from 10-100 m. The most important difference between RF & optical propagation of wave is medium behavior as for optical, water is seen as dielectric & for RF, water is seen as conductor. Seawater behaves as a conductor & a dielectric at different frequencies.

3. Modes of Communication

3.1. RF Communication

The frequency ranges that are employed for satellite communication, mobile services, radio & TV, seawater is very highly conductive in nature thus it will affect the propagation seriously of electromagnetic waves. This results in the ocean, beyond 10 m of distance it's very difficult to establish the link of communication in high frequencies or even in ultra-high frequency (UHF) & very high frequency (VHF). At lower frequencies, attenuation of EM wave is low enough for reliable communication over various kilometers. In RF communication, the range of frequency if from 3 Hz to 3KHz & it's not wide enough that will enable transmission at very high rate. Despite being used in environmental & naval applications, it performs communication at low range of frequency has financial & operational difficulties as the equipment are expensive & large that will require high power [7]. Underwater RF signal can travel through various paths is another characteristic. There is a possibility that in the shallow water to increase the propagating distance of signal it uses multiple paths. The signal traversing the air might suffer attenuation lower than signal propagates in the water only. There is no need for surface repeater. The signal can cross the water-air boundary for large distance with no help of repeater at surface [8].

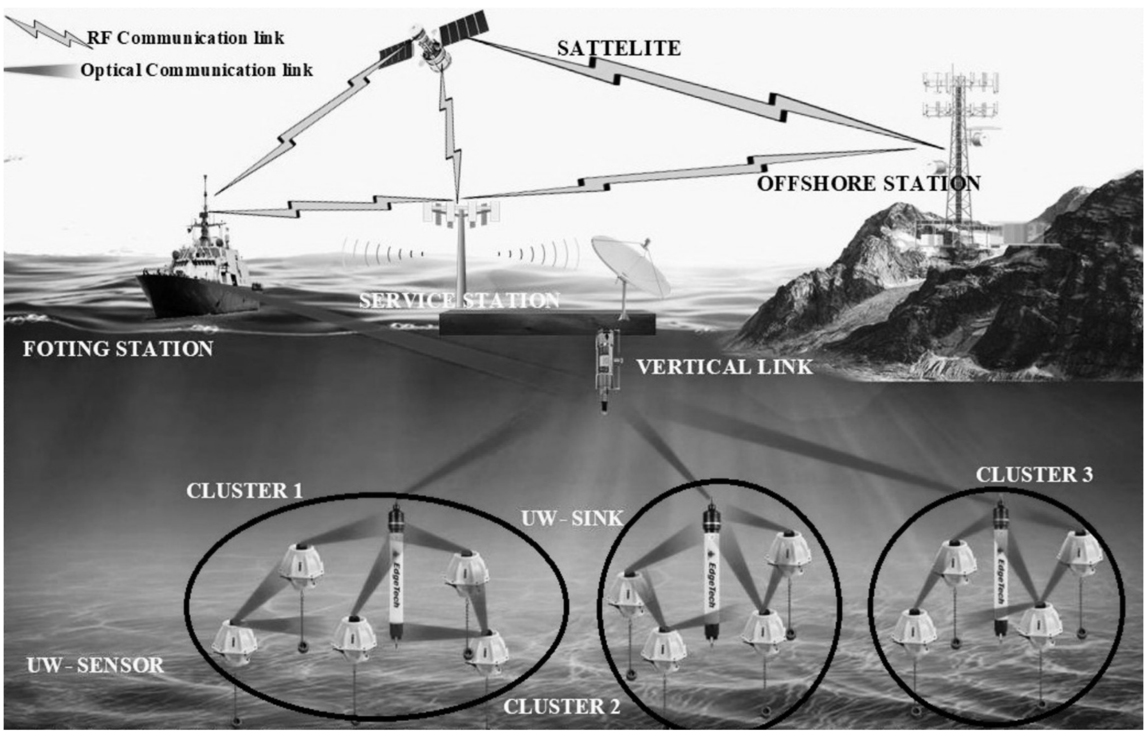

Figure 2: Illustration of Underwater optical sensor network clusters with terrestrial RF based station

Acoustic modems introduced for low power, short range acoustic communication for monitoring seismic. An underwater modem consists of the 3 components mainly that is an analog transceiver, an underwater transducer & hardware digital platform for signal processing & controlling. The expensive component is an underwater transducer [16]. Most of the acoustic modems will offers only low data rates. Acoustic modem also have some problems such as propagation delay, transmission loss, Doppler Effect, & multipath & frequency attenuation [17].

The RF signal propagation depends upon various conditions of environment such as temperature & salinity. It is frequency dependent. α(f0) Represents the absorption coefficient or channel attenuation per meter in sea water is given by:

$$\alpha(f_0) = \sqrt{\pi\sigma\mu_0}\sqrt{f_0} = d\sqrt{f_0} \qquad (6)$$

where f0 represents the RF signal frequency (Hz), σ represents the conductivity of water (S/m), μ0 represents vacuum permeability= 4π * 10-7 H/m. The conductivity for seawater is 4.3 S/m whereas for fresh water it's in the range of .001 to .01 S/m & conductivity is the function of temperature & salinity. The permeability of fresh & sea water is approximately same. As a result, attenuation in sea water is higher than fresh water for RF signal [9].

A typical transfer function of channel model represented by:

$$H\,(f0) = H0e\text{-}\alpha(f0)de\text{-}j\theta(f0) \qquad (7)$$

where H0 is DC channel gain, ϑ(f0) = channel phase & d = distance between transmitter & receiver. If the frequency is fixed then channel magnitude Response will decreases exponentially with distance.

$$\lambda = 1/\sqrt{f\sigma} * 10^{-7} \qquad (8)$$

$$V = \sqrt{f} * 10^{7}/\sigma \qquad (9)$$

$$\delta_{Depth} = 1/\,(2\pi\ \sqrt{f\sigma} * 10^{-7}) \qquad (10)$$

where λ is the wavelength, v represents velocity of propagation, σ represents conductivity, δ depth represents skin depth. The main issues in the RF communication is it gets affected heavily by propagation loss & environmental noises [10].

3.2. Acoustic Communication

UWAC is method of receiving & sending messages under water. Optical & RF transmission have propagation range limited. The former transmission is affected severely by strong attenuation that will lead to small distance of propagation. For reaching the higher distance, acoustic communication is alternate technology & it is currently the dominant technology for underwater wireless communication. Doppler Effect & multipath propagation are challenges recognized for underwater networking but computational & realistic model of physical layer is very difficult to realize. Due to rise in 10C in water, the speed of acoustic wave increases by 4m/s. An acoustic model for sound speed profile (SSP) has been discussed for underwater communication environments with 1 km of water depth.

$$c = 0.016z + 4.6T + 1449.2 + 0.00029T^3 - 0.055T^2 + (S_a\,\text{-}35)\,(1.34 - 0.01T) \qquad (11)$$

where c represents acoustic wave speed, T is temperature of channel, Sa is salinity of water & z is water depth.

Scattering loss can be considered as an obstacle caused by disturbance at sea level. Absorption & spreading losses will contribute to loss of path which is described by a simple model described below:

$$10\,logA\,(l0, f0) = 10\,log\,(A0) + (l0) * 10\,log\,a\,(f0, Sa, Tc, c, p, Hd, z) + 10kt\,log\,(l0) \qquad (12)$$

where l0 denotes distance between receiver & transmitter in meter, f0 represents range of frequency (Kilo Hz), & kt represents factor of spreading. For cylindrical kt=1 & for spherical kt =2. A0 is normalizing factor, d represents separation range between receiver & transmitter, Sa is salinity (ppt), Tc represents temperature (0C), and Hd represents depth of water in meters [11].

In the existing system we are using at-least wideband or ultra wideband with large bandwidth. The absolute bandwidth of underwater acoustic communication is very small in comparison with terrestrial because of the absorption in the seawater. The attenuation will increase with the increase in range & frequency. The popular b& of frequency for acoustic is 8 – 14 KHz with few Km range [12].

3.2.1. MIMO Technique

A system of wireless which employs multiple receivers & multiple transmitters represents Multiple Input Multiple Output (MIMO) system. MIMO can be applied for both single & multi-carrier transmission.

3.2.2. Multicarrier Modulation

Main idea of the modulation of multicarrier is that it divides the available bandwidth into huge number of sub bands which are overlapping in nature due to which symbol duration of waveform is long. ISI can be neglected in each b&. Due to this advantage, multicarrier modulation form of Orthogonal Frequency division Multiplexing (OFDM) been adopted in recent wireless broadband applications [13].

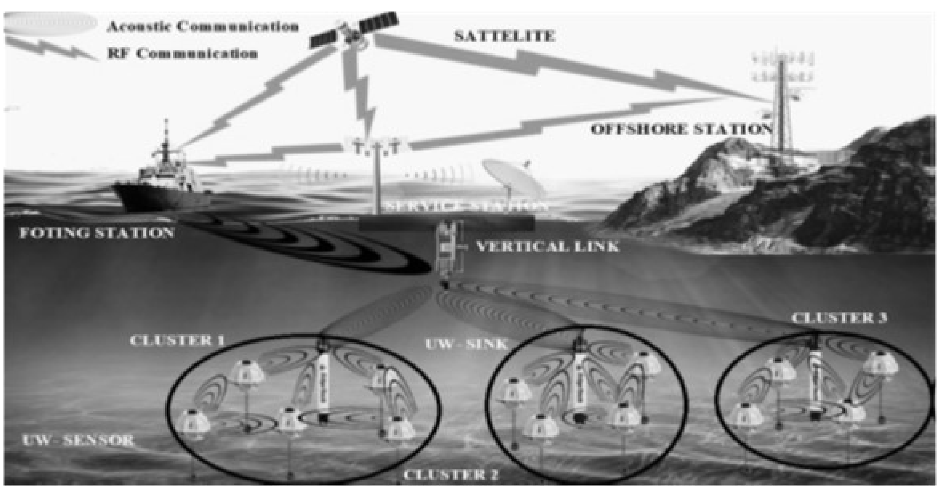

Figure 3: RF signal & Acoustic Communication between terrestrial offshore station & underwater sensor nodes

The increasing demand for efficiency, bandwidth, & performance of UWAC can be improved by using mixture of OFDM & MIMO that provides promising answers for many scenario in the UWA communication. [14]. In underwater communication, acoustic technique is widely used the typical velocity of sound near ocean surface is around 1520 m/s & loss is around .67s/km. This is affected severely by multi-path propagation [15].

3.3. Optical Communication

The main difference between optical & RF communication is behavior of the medium. This technology can provide high data rates in comparison with RF. The EM wave has lower attenuation in dielectric medium than in conducting medium. It has a propagation range of tens of meters. Doppler spread is negligible in optical communication. According to conditions of environmental, sea water categorized into two specific categories i.e. (IOP) inherent optical properties & (AOP) apparent optical properties with respect to optical propagation. IOP relies on transmission channel only, while AOP relies on both the transmission channel & geometrical structure of optical field also. In underwater optical communication (UWOC) propagation, the beam attenuation coefficient is directly related to the intensity & separation distance of light sources. The light intensity at receiver end which is given by:

$$I_t = I_{t0}\, e^{-dc(\lambda)} \quad (13)$$

where It & It0 are intensity of light at receiver & transmitter end & d represents distance between receiver and transmitter [18]. For finding the propagation loss factor, put z=d

$$L(z) = e\text{-}cz \quad (14)$$

is the propagation loss factor [19].

Scattering & absorption are two factors or effects which affect optical propagation in submerged. This phenomena can be understood by these two effects or factors & by geometrical model of element of water as shown in Figure 4. If strength of input beam of light Pi (λ), small fraction of incident beam Pa (λ) absorbed & fraction Ps (λ) scattered by water element. The unaffected result Pc (λ) passing through element of water whose thickness is δr & volume is δV respectively. According to conservation of conservation balancing, the absorption & scattering phenomena can be expressed as

$$P_i(\lambda) = P_a(\lambda) + P_s(\lambda) + P_c(\lambda) \quad (15)$$

Combined attenuation in underwater coefficient c (λ) is given by

$$c(\lambda) = a(\lambda) + b(\lambda) \quad (16)$$

The values of scattering & absorption parameters are different for different water medium [20].

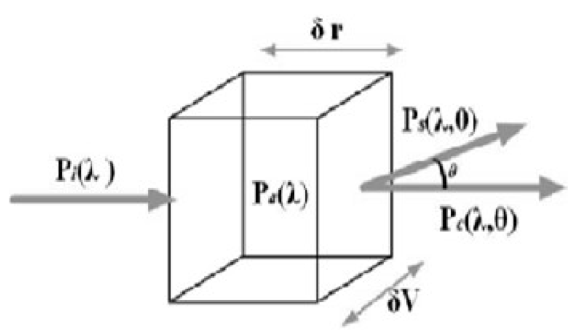

Figure 4: Optical wave scattering & absorption phenomena in underwater

Underwater LED based communication has various applications in military fields, AUV drivers & marine. Spatial modes has interest growing in optical communication & free space [21]. In UWOC, sources of optical such as LED & laser, it is a viable substitute against the present system which is based on the RF frequencies from the EM spectrum [22]. There are various works which are devoted in the underwater optical communication such as LoS (Line of Sight) underwater optical communication, LoS underwater optical communication through water – air interface [23].

Table 2: Comparison among Various Underwater Wireless Technologies based on the Parameters given

Parameters	Acoustic	RF	Optical
Attenuation	Dependency on frequency & distance (0.1-4 dB/m)	Dependency on conductivity & frequency (3.5-5 dB/m)	11 dB/m (Turbid water) & 0.39 dB/m (Ocean)
Rate of transmitting data	Kilo bps	Mega bps	Giga bps
Bandwidth	1 Kilo Hz – 100 Kilo Hz	Mega Hz	10 – 150 Mega Hz
Frequency	10-15 kilo Hz	30-300 Hz	10^12 – 10^15 Hz
Propagation Speed(m/s)	1500	2.255x10^8	Almost same as RF
Distance	Long distance (<20 km)	Very short distance (< 10 meter)	Short distances (< 100 meter)
Affecting factors determine channel quality	Absorption, scattering, Temperature, pressure & salinity of water medium	Conductivity & permittivity of channel	Turbidity, Scattering, Absorption, suspended & organic matter of link of channel
Latency	High	Moderate	Low
Size of Antenna	.1 meter	.5 meter	.1 meter

4. Recent Advancements & Applications

The author in [24] proposes a mathematical model for studying the node movement due to movement of ship in underwater network. Author in [25] design the Viterbi decoder which is implemented on Field Programming Gate Array (FPGA) & found out that it can operate up to 188Mbps data rate by consuming less than 680mW power. The author in [26] presents a reliable data delivery system AEDG (AUV aided Efficient Data Gathering Routing Protocol). SPT (Shortest Path Tree) algorithm is used for minimizing energy consumption, it also increases throughput of network & prevents data loss. The author in [27] uses the Blind detection technique to determine whether the signal is communication signal or ambient noise. UWC plays vital or significant role that will serve the most relevant applications in different areas such as Surveillance system & low noise environment, for military purposes, for pollution monitoring, for collection of data under the ocean, for monitoring the effects of change in climate, for water quality monitoring, for assisted navigation, for offshore engineering monitoring, for fish farm monitoring, for searching areas for mining, for research about abyssal habitat, for monitoring population changes, in detection of .oil, gas & mineral resources, for seismic monitoring, for equipment monitoring & control [28].

5. Major Challenges in Underwater Communication

There are some major challenges in underwater communication, delay is one of them. The delay of propagation in underwater medium is quite large in comparison with environment of terrestrial.

There is high error bit rate & temporary connectivity can be experienced with the channel. Corrosion & pollution played a vital role that will cause failure for underwater sensor. Channel utilization, environmental effect, routing issues are other challenges [29].

Ambient noise: It is source background level. At low frequency points for less than 10 Hz, it varies with the turbulence. Due to motion of waves that will cause surface motion in frequency range of 100 Hz to 100 Kilo Hz. The factor of high frequency is thermal noise.

Doppler Effect: It has vital role in affecting the communication. If Doppler frequency is higher than frequency of carrier then the speed of sound is less that will play the vital role. Due to movement, Doppler shift distorts completely the transmitted signal frequency.

Multipath channel: from the Rayleigh fading model

$$R(t) = N(t) + M(t) * S(t) \quad (17)$$

where N (t) represents Additive White Gaussian Noise, M (t) represents message signal, S (t) represents modulated signal & R (t) represents received signal. It is the major factor that will cause inter symbol interference, inter channel interference & fading of signal. This will leads to high attenuation of transmitted signal [30].

6. Future Scope

The future of the networking technique in underwater wireless communication is 5G wireless network because it has high data rates, extremely low latency rate & improves quality of service. In underwater communication, latest techniques for 5G applications are FBMC (Filter Bank Multicarrier) & GFDM (Generalized Frequency Division Multiplexing). 5G wireless networking method proposed to support acoustic, optical & RF signal carrier that will improve the probabilities of communication.

7. Conclusion

UWC technology enables a platform to build up connection of network between offshore based stations with underwater devices. This paper provides an overview of the underwater communication. If we have to decide which technology is best among RF, acoustic & optical for transporting the information then environmental conditions must be known in which system has to operate & what are the requirements for communication. The various communication technologies are discussed & grasp to deploy the underwater technologies. Main outline of this paper is to encourage the development of recent communication methods & research efforts. This paper contributes & provides a survey of technical aspects, communication of entire technologies towards wireless networking system & research challenges in wireless underwater communication.

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