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Review of Key Underwater Wireless Communication Mediums

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***Abstract*— Global warming is a phenomenon where frozen water in the poles will slowly dissolve resulting in rising ocean levels. Subsequently, it is important to monitor maritime activity. The purpose of this paper is to explore different underwater communication mediums which are reliable and sustainable in underwater environment. In the course of recent years, earthbound wireless communication is evolving due to the fact that deep sea ecological conditions are mostly unexplored. Hence, underwater communication has been affiliated with high bandwidth and data speeds. In addition, the analysis between techniques leading to an arrangement of communication in underwater is addressed. Furthermore, the effect of various parameters is documented along with future research directions.**

***Index Terms*— Underwater Wireless Communication, Magnetic Induction Communication, Optical Communication, Acoustics**

I. INTRODUCTION

GLOBAL warming has been an earlier issue for quite a few years. An analysis of the (UWC) strategy is an understanding of the maritime environment inquiry, which relates to the technique of transmission of information in unexplored water [1]. UWC is an imaginative technique for present-day underwater communication that has been selected to investigate and interpret knowledge in the under-water climate [2]. In addition, UWC is also used to hand-off simple tremor data, seismic and structural plate production data, and early discovery of a wave alarm from a under-water field. Remote internetworking developments have previously been a piece of human everyday life and are a significant area of study to imagine as of late. As of now, remote transporters of magnetic induction (MI), Radio Frequency (RF), optical, and acoustic frequency waves are used to simulate UWC strategies in underwater applications. Acoustic waves are the most effective method for concentrating on under-water signals over large distances with low inactivity and high spreading latency. Throughout the entire history of acoustic communications, acoustic waves were seen in the fifteenth century through an exploratory work by Leonardo da Vinci. In the late nineteenth century, acoustic waves were proposed with data rates of 8 kbps under-water at a depth of 20 m and 13 km above the surface of the water [3]. In 2005, a fast underwater acoustic communication system was proposed which recorded an information rate of 125 kbp/s using methods of 32-quadrature amplitude modulation [4].

In comparison to the earthbound environment, EM waves are distinctly produced in the under-water climate. The electromagnetic waves disperse with rapid submergence and speed during short separations [5]. The rapid and minimal limits of EM waves are based on the physical requirements of the water medium to which frameworks must be sent. Radio frequency (RF) EM waves are able to secure high data rates and shift over short separations in shallow water.

A critical technique is an optical network is that it offers high-transfer speed information rate with low inertness and less delay in a sea-going medium due to reduced transmission capability and low information packets of acoustic and EM waves. The old Greeks and Romans used optical remote communication via the cleaned shield in battle fields for occasions in 800 BC to relay messages [6]. Renowned researcher Alexander Graham Bell invented the remote phone in the 1880s to send and get sound based on optical waves up to 212 m. In the late nineteenth century, heliographs based on optical flagging were used for occupied defense internetworking [6]. LASER and signal propagation for large distances were developed during the 1960s [1]. Owing to the enormous dissimilarity of laser radiation, fiber optics is studied in the 1970s [7].

In comparison to other studies, the nature of the transmission and reliability of information may be

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dependent on the physical-chemical characteristics of the water climate and the actual attributes of optical signals [8]. Under-water internetworking involves more complex sophisticated gadgets to typically achieve high data transmission speeds over small region of separation. In relation to earthbound remote internetworking [9], it has several basic highlights that make it correspondingly unique. The under-water internetworking framework is a problematic sending cycle that is influenced by channel characteristics, such as the convergence of salt in water, the pressure in the remote ocean, the variance of temperature, the degree of light, the winds and their implications for under-water waves [10].

Due to the broad range of uses of UWSN underwater sensor networks, the most critical challenge is to supply power in a reduced medium. In order to boost the quality of service (QoS) and energy quality (QoE) of the framework over substantial distances, the key activities and commitments of recent wireless communication plans have been under-water [12].

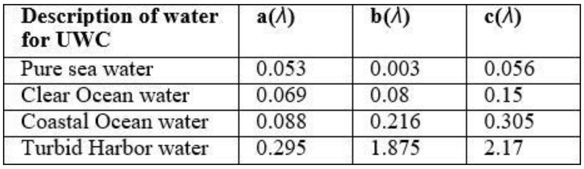
Throughout recent years, Under-water communication has been chosen as a preferred system to become more familiar with bandwidth and data rates using complex remote processes due to the limitation of terrestrial ecological climate conditions.

II. UNDERWATER WIRELESS COMMUNICATION OVERVIEW

The deployables are used in oceanographic information investigation, noticing water contamination, climate observing, and early admonition of cataclysmic events, for example, floods and tidal waves. Electromagnetic waves (in the form of radio frequencies) that empower a high information rate portion over short ranges are the primary innovation. The cost of execution is correlated with the necessary data throughput for an authorized internetworking range and the total transmission power that may cause ecological effects, such as marine life impedance.

RF is generally utilized for terrestrial applications. The electromagnetic waves have high-recurrence, high data transmission, quick response, and performance is exemplary among network hubs which are talked about in [14]. As a result of the impact of water permittivity and electrical conductivity [15], EM waves propagate like the speed of light and proliferate in water different than air in a number of ways. The suspended particles in the water channel diffract, hold and dissipate optical waves. The wave energy converts into heat energy. Optical waves do not propagate in water at a rate close to vacuum but have significant less wavelength in the water medium due to attenuation. Acoustic waves proliferation rely upon actual channel properties, for example, weight, temperature, and pH values. The group of UWSNs are discussed in *Fig. 1*, and *Fig. 2*. Absorption coefficients are given in Table I in a division of water into 5 standardized classifications mostly attributed to optical intrinsic properties.

TABLE I
TYPICAL VALUES OF ABSORPTION AND SCATTERING



Description of water for UWC	**a(λ)**	**b(λ)**	**c(λ)**
Pure sea water	0.053	0.003	0.056
Clear Ocean water	0.069	0.08	0.15
Coastal Ocean water	0.088	0.216	0.305
Turbid Harbor water	0.295	1.875	2.17

COEFFICIENT IN DIFFERENT WATER MEDIUMS [12] [23]

A. *Channel Medium Classification*

As per Jerlov [10], the water can be classified into topographical condition for example transparent, medium dense and opaque. As indicated in [17] [18] because of optical intrinsic properties, sea water has been separated into four types. These are classified as pure sea water, transparent ocean water, coastal ocean water and turbid wharf water type.

- Clear ocean water: Due to the major process of disintegration of natural salts, and mineral segments is clear sea water. Because of its properties and geological specifications, clear sea water was discussed in [12] [19].
- Pure sea water: Less effective optical signals as compared to turbid and coastal waters in pure seawater. The preservation of optical properties is the volume of absorption in transparent water and salt substantially due to the expansion within the optical frequency. The bandwidth of interest, which is approximately 400 - 700 nm, is as seen in *Fig. 2*.
- Coastal sea water: In contrast to pure sea water, the sea water at the land edge is of importance. Coasts having seawater having a high rate of turbidity to spread and assimilate [4] [20]. In this category, the dissipating and retention coefficient is higher [12].
- Turbid harbor water: Suspended particles have a hostile and elevated focus intensity. When compared to beachfront sea water, a high degree of retention and dissipation occurs in it [4].

TABLE II
SUMMARY AND COMPARISON OF VARIOUS UWC COMM. CHANNELS WITH BW, BIT ENERGY [37].

UWC Techniques	Range	Bandwidth (KBit/s)	Bit per energy (bit/J)
Acoustic	350	17.8	≈ 8900
	1000	35.7	≈ 6000
	10000	5	≈ 125
Optical	40	10^4	≈ 280000
	100	10^3	30000
EM	10	156	≈ 9850
MF	180	6-10	4 × 10^8 −
	2000	2-4	2 × 10^9
			300-400

In summary, communication may be possible for transmitting signals to underwater vehicle or submarine. Furthermore, it is conceivable to transport various types of internetworking hubs consisting of autonomous underwater vehicles (AUVs) and remote-operated vehicles (ROVs) [8] [11]-[13].

III. UNDERWATER RF COMMUNICATIONS

Electromagnetic waves in RF range rely upon water imperatives, for example, wireless conductivity, and permittivity and water porousness of water way. Electromagnetic waves effectively lessen via seawater on expanding of the speed range [5] [11]. Table I-III portray the various terminologies in various water mediums [22].

Radio waves will disperse for a considerable distance in conductive seawater in the influence of mixed under-water electromagnetic on frequency (30Hz - 300Hz) requiring high transmission and an enormous receiving station [23]. Electromagnetic waves are used in under-water and terrestrial areas for internetworking with limited range and frequency bandwidths. The connection between speed and frequency in a vacuum appears in the accompanying method (1).

$$c = f\lambda \quad (1)$$

In the under-water environment with super moderate speed, high speed ranges (VHF and UHF) or even in high frequencies as shown in Table III, less conceivable findings are available to build up RF communication for substantial distance. Indeed, the weakening of electromagnetic waves in terrestrial communication may be considered low enough to consider prediction. It is a generally known fact that 3 Hz to 3 kHz and from 3 kHz to 30 kHz are not sufficiently wide enough to allow transmissions at high rates of information used for maritime and natural internetworking applications [25][26]. The standard conductivity estimate for seawater is around 4 mhos/m, which is multiplied by the magnitude of conductivity in new water [12]. (2) shows that it has a description of the penetration of water into transparent seawater.

$$\alpha(f) =\sqrt{\ }\, p\, \pi\sigma\mu 0f \quad (2)$$

A remote channel model for Radio Frequency in sea water portrayed by a regular channel model exchange work [11] [28].

$$H(f) = H0 \exp(-\alpha(f)d) \exp(-j)\theta(f) \quad (3)$$

Where,

H0 = DC channel gain

θ (f) = Phase of the channel,

d = Distance between transmitter and receiver.

Yet, because of the high conductivity, the diminished models are more perceptible and signal spread is possible if we consider the circular wave model.

A. Radio Frequency Receiver-Transmitter

Transducer is such apparatus that are able to change over simple information into electrical signs or the other way around in outdoors wireless internetworking through a receiving wire [11]. In Electromagnetic waves, if speed range changes Extremely Low Frequency to Very Low Frequency, there is a prerequisite for receiver for appropriately inserted activity for UWC.

B. Impacting electromagnetic contact variables in the underwater world

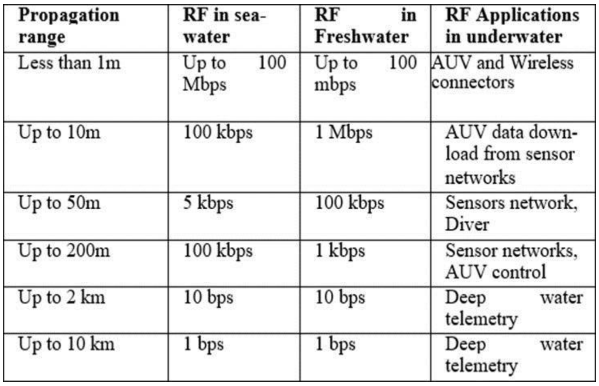
EM communication potentially affects the properties of the water channel or the marine environment by a few de-forthcoming factors, such as fixed minimal data transmission, power assets, unforgiving conditions of the water channel, turbidity and various forms of commotions, in under-water surrounding conditions.

Multi-way proliferation: It was thought that the most convincing wonders of electromagnetic waves generating from air to water affected the displays of sign spread. Similarly, the refraction point and misfortunes are seen as in RF flagging [27]. The uncaring refractive point allows for high permittivity to dispatch signals that would correspond to the water surface about *Fig. 5*.

Antenna: The huge radio wires size needed for RF engendering earthly to under-water internetworking. The attractive sorts of receiving wires are the most minimal reasonable arrangement that has been talked about in [27]. RF communication offers incredible imminent viewpoints for UWC that grant to investigate the prohibited field of sea and under-water climate. EM flagging enables the proliferation of the bottom distance signal that was untouched by brutal surface water conditions and noise. In addition to the potential results, the purpose of sending RF internetworking to secure high transmission speed information rates is to remove the difficulties of clogged water.

EM waves used for a small degree of reduced internetworking that could be improved and completed by express wiring plan in Substantial Ocean to long distance. Electromagnetic internetworking mechanical plan in under-water would be considered of reception apparatus configuration, communicating force, transmission capacity, and commotion as central point to determine. RF-put together internetworking utilized with respect to actual layer since they offer particular utilities when contrasted with optical and acoustic sort internetworking.

TABLE III:
TRANSFER SPEED SCENARIO OF RADIO FREQUENCY SIGNAL PROLIFERATION OVER PARTICULAR RANGES IN DIFFERENT WATER MEDIUMS



Propagation range	**RF in sea-water**	**RF in Freshwater**	**RF Applications in underwater**
Less than 1m	Up to 100 Mbps	Up to 100 mbps	AUV and Wireless connectors
Up to 10m	100 kbps	1 Mbps	AUV data down-load from sensor networks
Up to 50m	5 kbps	100 kbps	Sensors network, Diver
Up to 200m	100 kbps	1 kbps	Sensor networks, AUV control
Up to 2 km	10 bps	10 bps	Deep water telemetry
Up to 10 km	1 bps	1 bps	Deep water telemetry

IV. OPTICAL UNDERWATER COMMUNICATIONS

The seawater provides a transmitter property for EM spread and allows enormous receiving wire size and energy-devouring handsets to suffer a high decrease in seawater, while the seawater provides dielectric properties for transmission of optical characteristic [6][11]. In this way, optical internetworking pushes creativity to establish a under-water correspondence interface, but it may very well be affected by dissipation, dispersion, loss of vision, temperature change, and physical chemical properties changes of the channel. The amount of creation of human exercises to investigate the under-water environment by UWSNs, ROVs, and AUVs. The wide benefit of VLC is that it provides simple communications with respect to beacons and signals [31]. In under-water secure high information volume, the use execution of VLC than under-water acoustic communication. In comparison to RF communication via a dielectric medium where the scope of engendering was limited to several meters, the UWOC strategy allows high data rates [34] and LOS in optical communication link [35].

A. State of the art - Underwater Optical

Graham Bell developed a picture phone in the late nineteenth century that was used to transmit voice signals about 200 m via optical give-up. A review work on lasers as communication was scattered during the 1960s where the laser He-Ne implemented more than 30-40 km at 632.8 nm of speed [7]. In the late nineteenth century, the advancement of free-space optical communication (FSO) was introduced where fibre optical associations were not conceivable. The FSO system is used to transfer high data rates between two linked centers in excess of a few kilometers. A detailed discussion of FSO has been summarized in the most recent review article [1] [2]. Since the last decade, the basic tests have been implemented and enhanced for FSO device execution and current desire expects the modern use of FSO to increase to twice by 2018. FSO links are used for particularly high data transmission speeds, whereas natural optical remote communication can be used for data rates of 10 Gbps [2].

B. Optical Signal Propagation in Underwater Communication

It is important to express UWOC innovation in under-water scenarios and to measure according to the water condition requirement (shallow to deep water). With different geological conditions and break-up criteria, the channel properties fluctuate based on the propagation. As the natural conditions suggest, the seawater can be categorized into two explicit classifications that affect the optical generation in the water channel. Such highlighted categories are the inherent optical properties (IOP) and apparent optical properties (AOP). The medium word is IOP, while AOP is subordinate to the light source [66]. For under-water remote interconnection, IOP is more essential. In IOP, the two fundamental components to be considered are the absorptive coefficient and volume dissipating power, the explanation for assimilation and dispersing marvels [17]. The optical communication can also be converted into heat energy after being absorbed by suspended particles. The phytoplankton with chlorophyll at colored dissolve organic matter, results in water atoms end up breaking up salts in water [36]. The photons alter their course because of dispersing. The chance of dispersion begins by salt- particles in unadulterated water or by particulate issue [36]. The absorption a(λ) and scattering b(λ) boundaries are referenced in Table I. [37]. Because of th energy attenuation in retention and dispersing characterized as a weakening of the optical sign which has been portrayed as [38] [39].

$$I = Io \exp{-c(\lambda)d} \quad (4)$$

Where the light intensities at the ends of the transmitter and receiver are I0 and I. The distance between the transmitter and receiver is denoted by d. As described in [17] [38], the whole procedure. Via (4), Table I denotes and numerically lists the spectral absorption coefficient a(λ) and the dispersion coefficient b(λ).

V. UNDERWATER ACOUSTIC COMMUNICATIONS

Acoustic waves produce approximately 1500 m/s with low speed, data transfer capability and low velocity. In general, the velocity of acoustic waves increases by approximately 4 m/s when the water temperature increases by 1◦C [8] [14].

However, acoustic waves are not sufficiently used for significant distance interconnection to achieve high data transmission capability signals in under-water use. Acoustic waves sorted on the basis of communication proliferation distance as small, short, medium, long and very large distances referred to in Table II [12]. There has been discussion of an acoustic proliferation model and static representation. The mechanical and electromagnetic properties of the channel [41] depend on the speed of proliferation. The EM waves are several times greater in amplitude than the transmission velocity of acoustic waves in water. In underwater communication conditions with depths of up to 1000 meters, an acoustic model was discussed based on sound velocity profile [41]. The two groups are distinctly hypsometric and acoustic. Before their detection by the collector, the waves encountered as a reflection from the ocean depths to the water surface in acoustic sign transmission, while in profound water it isn't really an impression of a wave from the ocean depths.

Lost signal is the main concern in acoustic wave propagation. In acoustic wave proliferation, there are different forms of strength losses, such as spreading loss, dispersing, and separate assimilation. Spreading data loss is considered and shown as round and hollow for large distances where the limits of proliferation through the ocean surface and floor can be considered as circular or barrel shapes due to distance increases in the wave surface model. Acoustic waves spread reach calculations are time, signal strength and point subordinate as in [43] [44]. The initial two terms in (11) are a commitment by boric corrosive and magnesium sulfate [8] and the last term is the commitment of clean water. Further, deterrents via ocean surface or ocean bottom and existing articles in the water either fixed or adaptable are known to impact the underwater communications as in [43] [46].

A. Acoustic Transducer

The acoustic transducers were usually considered as transmitters and modems as receivers.

B. Frequency shift

The proliferation speed of acoustic waves in the UWAC channel is many times lower than in RF communication in high latency and delayed amplitudes. The speed and variations are time dependent especially in comparison of the relation and q(t) also depend on time which is known as the Doppler factor [11][47].

The point's φ and θ are the signal spreads on transmitter and collector as shown in *Fig. 1*, and *Fig. 2*.

Most recently, the latest reports have identified that under-water communication in an emerging paradigm. The exceptional and most commonly used remote transporter with low communication constriction of sound is under-water acoustic communication (UAC). As of late, UAC has become a large subject of research in various fields and exploration companies. Related problems and applications are implemented in UAC as a diagram basically used by military, maritime, and mechanical fields. By proper fixing of UWSNs, the difficulties of under-water communication can be reduced.

Noise, frequency, and multi-way propagation delays, Doppler frequency, high and variable propagation delay are the fundamental issues that affect the communication link. It has low latency and transmission capacity in correlation with RF and optical under-water interconnection, but provides the most stable channel capacity to motivate under-water interlink.

VI. MAGNETIC INDUCTION

MI communication is an emerging communication paradigm proposed as a substitute for complex applications, such as the Internet of Underwater Things (IoUT) [54], [55], and Wireless Body Area Networks (WBANs). The importance of using MI communication is because of lesser interference occurred between transceivers. UWSN has been considered as a promising sensor network to support the development of IoUT [54].

It is consisting of multiple underwater nodes interconnected with one another through MI used for monitoring of the large unexplored sea and enables applications for smart cities development [1]. Magnetic Induction (MI) is preferably used in Underground Wireless Communication Networks [55], [57]. In such case the propagation medium can have implications for disaster management security and surveillance [58]. The application of Magneto Inductive wireless communication for under water applications is demonstrated in [59],[60].

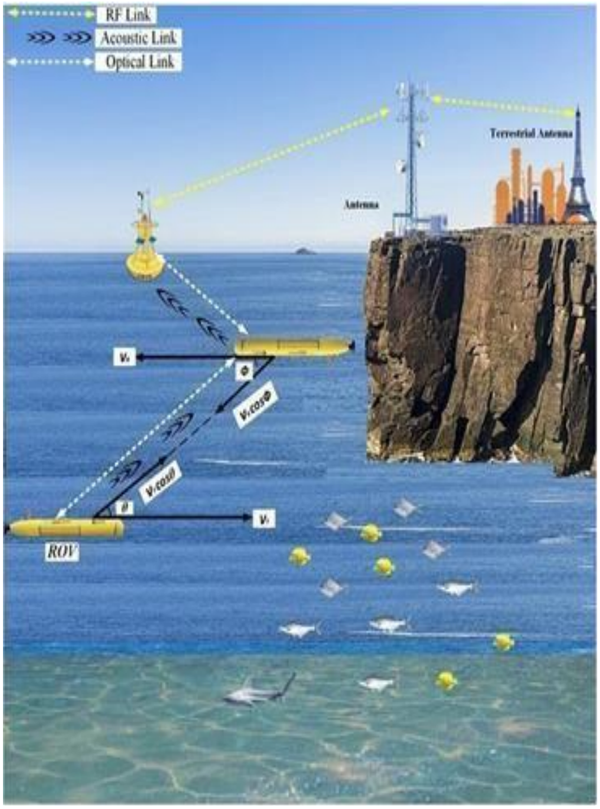


Fig. 1. Tx and Rx moving with respect to proliferation medium for RF, Acoustic and Optical Links

TABLE IV
RANGE, BANDWIDTH AND DATA RATE OVER VARIOUS PROPAGATION DISTANCES [12]

Classified Propagation distance	Possible range (km)	Maximum bandwidth (kHz)	Possible data rate (kbps)
Very Sort	< 0.1	> 100	500
short	0.1 - 1	20 to 50	30
Medium	1 - 10	Up to 10	10
Long	10 - 100	2 - 5	5
Very long	> 1000	< 1	600

TABLE V
SUMMARY AND CORRELATION OF VARIOUS UWC TECHNOLOGIES INCLUDING LATENCY, TRANSMISSION POWER AND QUALITY OF TRANSMISSIONS

Type of Technology	Ranges	Latency	Transmission Power	Affecting factors determine channel quality	Key References
Underwater Optical Wireless Communication (UWOC)	Up to 100 m	Low	mW - W	Absorption, scattering, turbidity, suspended and organic matter of channel link	[1] [2] [12] [4] [38]
Underwater Wireless Acoustic Communication (UWAC)	Up to 20 km	High	> 10 W	Absorption, Scattering, Pressure, Temperature and salinity of water channel	[11] [23] [13]
Underwater Wireless Electromagnetic Communication (UWRF)	Few meters (Up to 10 m)	Moderate	mW - W	Conductivity and permittivity of channel	[11] [13] [15] [22]

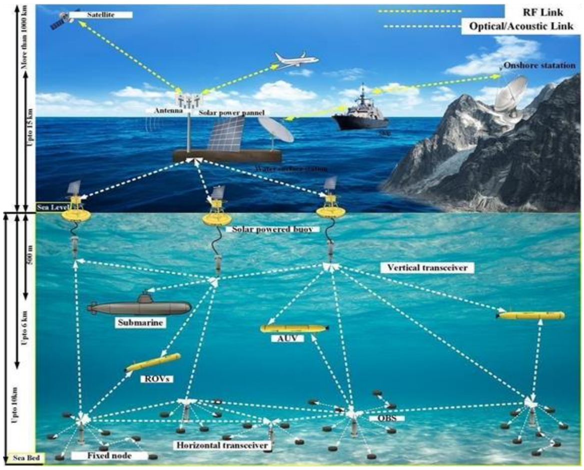


Fig. 2. Exhibit of Blend RF/optical/acoustic UWC Systems

As per *Fig. 3*, light emission has a wavelength power of Pi with λ. The small portion of episode shaft assimilated (Pa) by the water component and dispersed bar indicated by (Ps). The unaffected result is that Pc passes through the water component whose volume is respectively δV and thickness δr. According to the law on the conservation of energy, it can be described as,

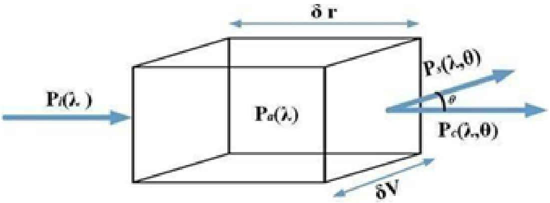


Fig. 3, Innate optical properties cause dispersing and assimilation during UWOC [4] [12]

$$Pi(\lambda) = Pa(\lambda) + Ps(\lambda) + Pc(\lambda) \tag{5}$$

$$A(\lambda) = Pa(\lambda)/Pi(\lambda) \tag{6}$$

$$B(\lambda) = Ps(\lambda)/Pi(\lambda) \tag{7}$$

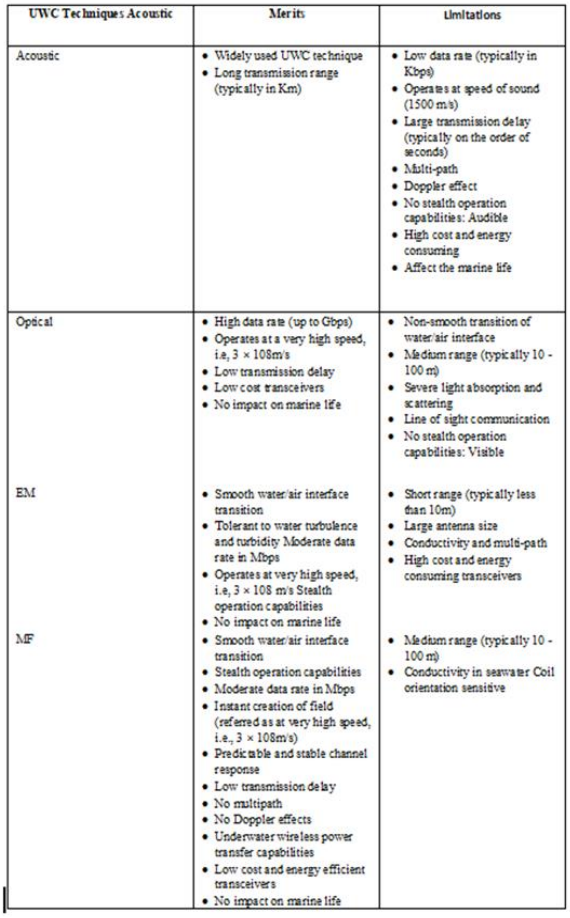
C. *Future Directions*

Use of Optical Wireless Networking technique open with high frequencies. Speed is a predominant factor. The implementation and capacity of the structure could be strengthened by extending the UWOC approach. Compared to AUVs, the UWSNs are highly recommended. Subsequently, the huge degree of promising evaluation needed for the creation of light-emanating tolerating sources of additionally generated and negligible exertion. Similarly fitting to the FSO structure, a few uses with a high data transfer rate of about 10 Gbps are open for the terrestrial association. In a heterogeneous association scheme, applications are found due to ease, low restriction of power use and substantially feasible optical association. Via assisted computerized sensor associations, an acoustic-optic blend interconnection structure is able to provide high data transmission.

Here high data rates with low dormancy over a moderate distance. In either case, the maritime medium puts various problems for underwater optical communication. UWOC perseveres in the lowered channel by specific occurrences and diffraction. Scattering and ingestion as a result of postponed particles are the most countable disasters. The temperature and weight are water's physical chemical properties. Different structures to boost delivery and application have been extensively inspected and linked to the references [4] [12].

A summary of the proposed underwater wireless techniques is given in table below:

TABLE VI
SUMMARY OF PROPOSED UNDERWATER WIRELESS TECHNIQUES [61]



UWC Techniques Acoustic	**Merits**	**Limitations**
Acoustic	• Widely used UWC technique • Long transmission range (typically in Km)	• Low data rate (typically in Kbps) • Operates at speed of sound (1500 m/s) • Large transmission delay (typically on the order of seconds) • Multi-path • Doppler effect • No stealth operation capabilities: Audible • High cost and energy consuming • Affect the marine life
Optical	• High data rate (up to Gbps) • Operates at a very high speed, i.e, 3 × 108m/s • Low transmission delay • Low cost transceivers • No impact on marine life	• Non-smooth transition of water/air interface • Medium range (typically 10 - 100 m) • Severe light absorption and scattering • Line of sight communication • No stealth operation capabilities: Visible
EM	• Smooth water/air interface transition • Tolerant to water turbulence and turbidity Moderate data rate in Mbps • Operates at very high speed, i.e, 3 × 108 m/s Stealth operation capabilities • No impact on marine life	• Short range (typically less than 10m) • Large antenna size • Conductivity and multi-path • High cost and energy consuming transceivers
MF	• Smooth water/air interface transition • Stealth operation capabilities • Moderate data rate in Mbps • Instant creation of field (referred as at very high speed, i.e., 3 × 108m/s) • Predictable and stable channel response • Low transmission delay • No multipath • No Doppler effects • Underwater wireless power transfer capabilities • Low cost and energy efficient transceivers • No impact on marine life	• Medium range (typically 10 - 100 m) • Conductivity in seawater Coil orientation sensitive

VI. CONCLUSION

This review paper aims to show that underwater communications can be classified into wireless with techniques in comparison with acoustic, optical, RF and EMF. RF speeds were highlighted whereas physical properties related to optical characteristics is detailed as well as stable channel capacity for underwater interlink. The underwater communication empowers under-water gadgets where the channel and climate have pivotal properties. Method of 5G remote systems administration is proposed to be with RF, acoustic and optical design mediums. The emerging technologies, like UWSN are testing signal generation, with correct configuration of organization hubs being an essential key to understanding and determining effective information inspection between source and collector with the required information rates. We propose a comparison using standard feature. To sum up, in the context of under-water environmental communications this paper proposed specialized problems, difficulties and possible research directions.

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