A Review of Underwater Communication Systems

1Dev Pratap Singh, 2Deepak Batham
1Student, 2Assistant Professor
1Madhav Institute of Technology and Science,
2Madhav Institute of Technology and Science

***Abstract* - Worldwide, 71% of the earth surface is covered by water, out of this 96.5% of water holds by the oceans and seas. These much water divides a large amount of non-livable land. These territories remain unexplored due to inability of machines to map a large area and the unique phenomenal activities in the underwater region. To communicate through this much distance, we started underwater communication. In recent times, we have upgraded our technology to underwater wireless or optical communication. It is crucial in marine activities like underwater exploration, monitoring of underwater environmental activities, scientific data collection, underwater pollution control, natural disaster surveillance, and naval tactical operations for coastal security. As a result of the growing interest in exploring underwater environments for various applications, the utilization of underwater communication has become critical and challenging field to aid numerous commercial, business, and military applications. Acoustic, optical, and electromagnetic wave carriers are helpful for data transmission in the underwater environment. In this work, we review and explore the past underwater communication techniques and unravel the benefits and limitations of each.**

***keywords* - Communications Wireless/Wired: Communication Theory and Systems; Wireless & Mobile Communications. Optical Communication and Networking: Optical Communications. RF theory: RF & Microwave Communications.**

I. INTRODUCTION

The first encounter with underwater communication dates back to the World War-II. Before that, marine life was explored using echo ranging, also called Fessenden Oscillator. In the year 1490, Leonardo Da Vinci developed the first underwater communication technique, which involved inserting a tube into the water and listen sound, using the human ears to detect vessels. This technique was developed during World War-I to combat the growing threat of submarine warfare. In 1918, an operational passive SONAR system has been used and became popular. The study of underwater communication techniques focuses attention towards the oceanic environment which refers the data transmission method used in the uncharted water medium [1].

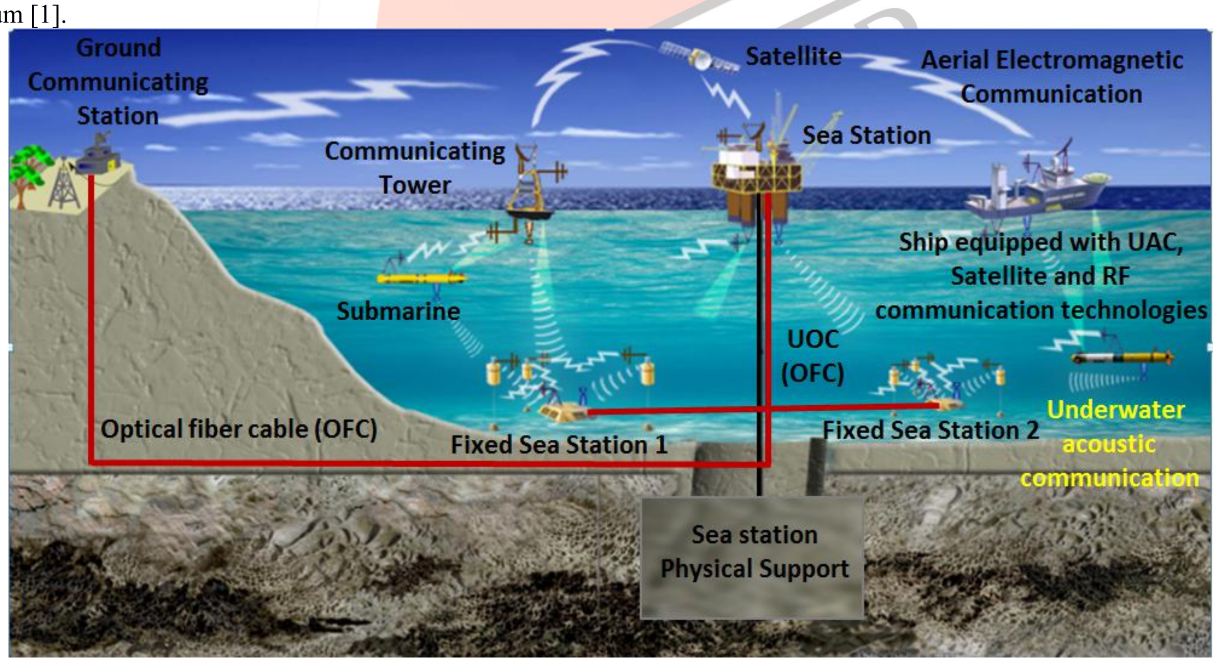

Fig. 1. Multiple communication technologies [6].

To start data/information communication in water, three techniques have been developed. The first-ever technology used the sound waves to transport information/data which was earlier used in submarine systems for calculating the distance between ocean-bed and other machines. Later on, the technology has been upgraded and the electromagnetic waves were used in underwater imaging. The same technology is also used in the advanced submarine systems. Since last decade, high and heterogeneous bandwidth demand, and reliable data transfer increased due to the advances in the 4G, 5G, data store and forward, cloud and fog computing applications/services [2-4]. To fulfill the pressing need of huge bandwidth capacity, the optical fiber cable based backbone optical networks are used [4-5]. The intricate system of sensor networks and subsea fiber cable networks can be used in oil and gas industries/plant monitoring. These techniques helped in underwater transportation not only for data but some important materials also. The overall development of underwater communication systems is shown in the Fig. 1. The figure explains multiple communication technologies used so far. Remaining manuscript is arranged in the following manner. Section-II describes the methods/techniques of underwater communication systems, highlighted with their advantages and limitations. Current development in the existing technologies and future scope has mentioned in Section-III. Section-IV presents conclusion of the study.

II. Method of Underwater Communication

The present section deals with the underwater communication techniques. In literature the underwater communication has been possible in three ways. These are underwater acoustic communication (UAC), underwater electromagnetic communication (UEC), and underwater optical communication (UOC). Each techniques is explained on by one with their pros and cons.

A. Underwater Acoustic Communication (UAC)

For millions of years, marine species have used underwater sound communication techniques. The Leonardo Da Vinci in the year 1490 used underwater acoustics as a science to detect the vessels [7]. He wrote, "If you cause your ship to stop and place the head of a long tube in the water, and place another end outer extremity to your ear, you will hear ships at a great distance from you." In 1877, Lord Rayleigh published "The Theory of Sound" which explains the modern acoustic theory. The basic acoustic communication model is explained below.

(i) Basic Acoustic Communication Model

As innovation has progressed, a lot of gadgets to support information transmission have arisen. One of them is a modem (Modulator-Demodulator). It sends information remotely and is a fundamental for distant correspondence. For quite a while, it has been and keeps on being a practical technique for submerged correspondence. Fig. 2 portrays the design of a fundamental acoustic correspondence model.

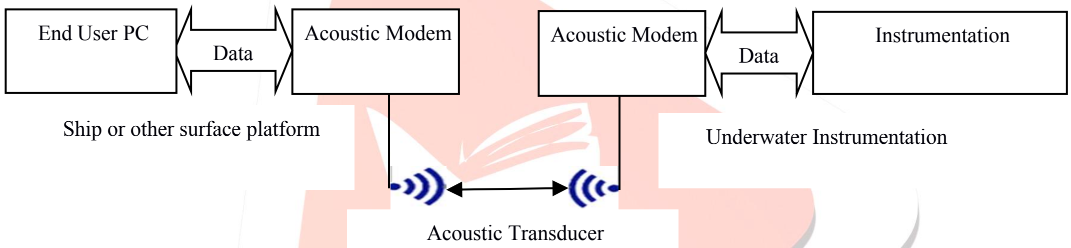

Fig. 2. Schematic diagram of basic acoustic communication model

We can understand the working of acoustic modem with the help of Fig. 2, which is used to transmit data underwater in the same way that the telephone modems transmit data over the wired copper/optical cable lines. The acoustic modem transforms digital information/data into unique underwater sound signals. Here, the acoustic transducer receives and converts the sound signals and used further for analysis. The transducers for acoustic signals are mainly used in this technology. These signals are converted back into digital data using another acoustic modem. This model can be used as underwater monitoring, diver communication systems, and self-driving underwater vehicles.

(ii) Transmission loss in acoustic communication model

Transmission loss is one of the prime parameter to analyze the performance of the selected technology. There is some loss with every piece of machinery. We may experience these loss during data transmission. Transmission loss is due to an influenced of non-environmental factors. These factors are transmission range, transmission frequency, and the transmitter and receiver depth. As a result, the theoretical process that regulates transmission loss indexes the transmission distance, receiver depth, and transmission range implicitly [8]. While choosing or implementing any technique, the transmission loss should be zero or minimum as possible.

(iii) Disadvantages of acoustic communication model

This technology allows for fairly low data rates over medium distances and do not provide any link security. It is an old technology which only establishes low-speed transmissions over long ranges. Furthermore, a significant amount of marine life communicates through an acoustic medium. This may cause the multipath or signal fading problems.

B. Underwater Electromagnetic Communication (UEC)

In UEC electromagnetic waves are used in the radio frequency (RF) spectrum. In this method, the transmitter emits electromagnetic waves, which are produced by the acceleration of an electric charge and propagated by the periodic variation of intensities of, usually perpendicular, electric and magnetic fields. It has been observed that the attenuation of RF waves increases with the increase in frequency and that they are heavily attenuated by sea water. Understanding the limitations of UEC, RF brought to work in order to achieve the fast wireless transmission. RF waves are not affected by temperature and depth. Due to the absorption and scattering, attenuation of electromagnetic waves in water is a prime concern. The seawater is a high-loss medium and the behavior of electromagnetic waves in normal and seawater is considerably different. Electromagnetic waves in water are strongly frequency defendant and proportional to frequency squared. Low-frequency, very low frequency, and extremely low frequency bands may penetrate hundreds of meters of ocean, making them extremely valuable for submarine communications [9].

UEC is an advanced technology used in underwater communication, but it still has some loopholes. The main drawback of electromagnetic wave is it requires large size antenna and signal attenuation in seawater. The commercially available underwater radio frequency solutions may attain 100 bps bit rates across the distance of decade meters. For 1 m distance/range, 1–10 Mbps data rate is used [7, 9].

TABLE I. LIST OF LASER USED IN UOC SYSTEM

Types of Laser	Wave-length (nm)	Advantages	Limitations
Ar-ion laser	455–529	High output power Less lifetime	Low efficiency. Required high input power. Required cooling mechanism.
Diode-pumped solid-state laser	532 (green) 493 (blue)	Increased output power Longer lifetime Small size	Low efficiency Expensive
$Ti:Al_2O_3$	455	Faster output pulses Adjustable frequency	Expensive Vibration sensitive.
Flash lamp-pumped, frequency doubled laser	532	Higher power	Difficult to modulate
Semiconductor laser	450–470 (InGaN) 375–473 (GaN)	Most efficient. Compact	Expensive Stop overcurrent damage
Fiber laser	518	Smaller size Higher efficiency Higher output power	Expensive External modulator required

C. Underwater Optical Communication (UOC)

To overcome the limitations of UAC and UEC, and to fulfill high bandwidth demand of Internet, due the recent boom in the data consumption, we needed to upgrade our existing systems. For on-the-ground and underwater wired communication, presently we are using the optical fibers cables as a fastest and efficient medium for data transfer. UOC was first proposed in the year 1990. Since, last three decades, the use of UOC technology has significantly increased. Some researchers use Photomultiplier Tubes (PMTs) as UOC receivers to reduce the pointing requirements of UOC systems. The PMTs have large lenses with wide range (i.e., 10 to 500 mm range) and a wide field of view (FOV). But PMT is costly, bulky, and easily to damage, also incompatible with multi-user environments. Currently, the electronic switches are used in UOC system, aiming to allow the optical front end of the receiver to change FOV based on the angle of beam arrival [8]. Lately, Lasers are being used for this kind of communication due to their monochromatic behavior, high intensity and low dispersion quality. Some commonly used lasers in UOC systems are reported in Table I with their wavelength range, advantages and disadvantages.

To find the efficiency and usability of optical signals underwater, a few places with different type of water quality was chosen and done a study on that [6]. The authors were found that due to less concentration of marine life and other manipulating factors, the seawater had the least signal attenuation. While, in the oceans near the coast and in clear oceans a mild attenuation was observed. But the places near the harbor with a tidal behavior had the most attenuation in their signal. Fig. 3 shows the attenuation or propagation loss factor (in db) curve for pure seawater, clear -ocean, coastal ocean, and turbid harbor.

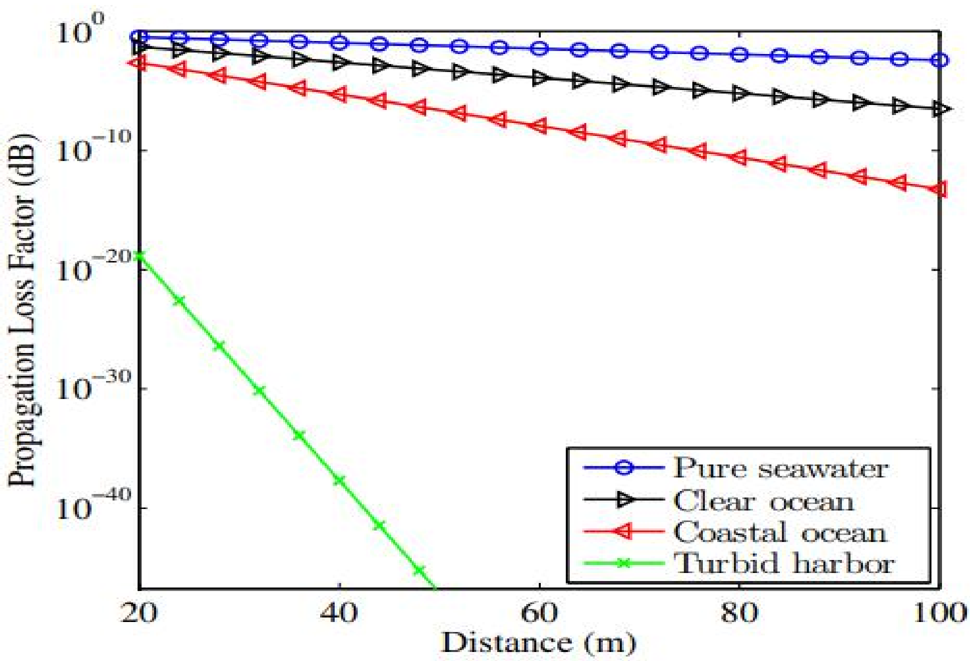

Fig. 3. Attenuation of the optical signal [6]

III. Current Development and Future Scope

While talking about the past and the present of underwater communication, we must also care about its future. In 21st century, to support various online services/activities, and fulfill the present demand of huge bandwidth and high speed connectivity, we observe massive upgrade to our machinery. The journey of UOC started with the fixed grid wavelength division multiplexing technology (WDM) which is now been upgraded with the orthogonal frequency division multiplexing technology with flexible spectrum bandwidth facility [2-5, 9-11]. In this communication technology optical fiber cables are used for data transfer who is laid down underwater. The initial installation and maintenance cost of such large capacity subsea optical fiber lines are high. The free space optical communication (FSOC) technology used to be, which introduced in late 19th century. When fiber optical links/cables were not viable, copper cables were used to transfer data. FSOC technique was used to transmit high data rate signals over long distances between two corresponding points. These two points are linked with high bandwidth optical fiber cable which is an upgrade of copper cables. In [1], authors summarized a broad discussion of FSOC. Since, last decade, significant research has been introduced and improved for FSOC system performance. The commercial use of FSOC is doubled by 2018. FSOC links are used for high data transmission rates, whereas, traditional wireless communication is capable to support data rates up to 10 Gbps.

Apart from UOC, UEC has also developed a lot. Electromagnetic waves are currently used for a limited range of underwater communication, but this could be improved and implemented to a long range in the deep ocean by using a specific antenna design. UEC schemes have various challenging issues such as antenna design, transmitting power, bandwidth, and noise as major factors need to resolve in the future research.

Lastly, UAC is a first-generation or broadly used wireless carrier with low sound signal attenuation. UAC has still many challenges which need to be investigated further. This opens lot of opportunity for the research community to make this as more industry oriented. UAC offers a high overview of related issues and applications primarily used by the military, naval, and industrial domains. By properly repairing underwater sensor networks, the challenges of underwater communication can be addressed more precisely.

We all have been using these technologies for quite a long time; they have been found useful and also complicated sometimes. Each technology and machinery has its advantages but also has some limitations. After this detailed study we have concluded the following which is shown in Table II which highlights the benefits and limitations of underwater communication technologies.

TABLE II. Benefits and Limitations of Underwater Communication Technologies

Underwater Communication technologies	**Benefits/Advantages**	**Limitations**
UAC	• Easy to construct. • Operating range: Few KM to 20 KM.	• Low data rate. • Large communication latency. • Bulky, costly, and energy consuming transceivers. • Harmful for marine life.
UEC	• Smooth transition to cross sea surface. • More tolerant to water turbulence. • Moderate data transmission rate at short distance. • Loose pointing requirements	• Short link range. • Bulky, costly, and energy consuming transceivers.
UOC	• Ultra-high data rate capacity. • Ultra-low latency. • Transceivers used are low-cost and compact in size. • Low attenuation.	• Sophisticated processing required to cross sea surface • Moderate link range • Signal absorption and scattering losses

IV. Conclusion

Lately, UOC has come up as a reliable source for data transmission due to its capability of travelling to long distances with minimal loss of data and provide huge bandwidth capacity, but still they are quit costly and moderate coverage. In future we might need to ramp up our technologies and finding out cheaper ways like optical sensor clusters or finding out new types of laser. We would also require to enhance the communication distance to kilometers for seamless data transfer and also manufacture a way to connect remotely to the system. A hybrid communication system with an optical transceiver and an acoustic transceiver could improve network availability. A hybrid communication system can provide high-data-rate transmission by utilizing an optical transceiver. When the turbidity of the water is high or the distance between the terminals is great, the system can use the acoustic transceiver to switch to a low data rate, increasing the average data rate and availability. The systems complexity and cost, however, increase. In this type of system, smart buffering and prioritization could help to mitigate short-term data rate reduction. Many aspects of the studied systems need to be researched further.

References

[1] Z. Zeng, S. Fu, H. Zhang, Y. Dong and J. Cheng, "A survey of underwater optical wireless communications," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 1, pp. 204-238, Firstquarter 2017, doi: 10.1109/COMST.2016.2618841.

[2] J. Yuefeng, J. Zhang, Y. Xiao and Z. Liu, "5G flexible optical transport networks with large-capacity, low-latency and high-efficiency," *IEEE China Commun.*, vol. 16, pp. 19-32, 2019.

[3] R. Zhu, S. Li, P. Wang, Y. Tan and J. Yuan, "Gradual migration of co-existing fixed/flexible optical networks for cloud-fog computing," *IEEE Access*, vol. 8, pp. 50637-50647, 2020.

[4] D. Batham, S.K. Pathak, D.S. Yadav and S. Prakash, "A traffic scheduling strategy based on cost function for differentiated class of service in multi-domain optical networks," Optical Fiber Technology, vol. 60, pp. 102337, Dec. 2020. DOI: https://doi.org/10.1016/j.yofte.2020.102337.

[5] D. Batham, D.S. Yadav and S. Prakash, "Survivability using traffic balancing and backup resource reservation in multi-domain optical networks," *International Journal of Communication Systems*, vol. 31, no. 15, pp. 1-22, July 2018, DOI:10.1002/dac.3786.

[6] C.M.G. Gussen, P.S.R. Diniz, M.L.R. Campos, W.A. Martins, F.M. Costa and J.N. Gois, "A survey of underwater wireless communication technologies," *Journal of Communication and Information Systems*, vol. 31, no. 1, pp. 242-255, 2016.

[7] Yi Lou and Niaz Ahmed, "Underwater communication and networks," *Springer*, Switzerland AG, 2022.

[8] T.D. Burnett. "The characterization of variability in transmission loss in the ocean," *Naval Postgraduate School*, California, 1971.

[9] P. Lv, J. He, R. Zhou and H. Liu, "The application of underwater optics and its development," In Proc. *Information Optics and Photonics Technologies II*, Photonics Asia, Beijing, China, vol. 6837, pp. 7–8, Jan. 2008. DOI: https://doi.org/10.1117/12.756919.

[10] S.K. Pathak, D. Batham and S. Prakash, "Time and bandwidth aware traffic balancing in elastic optical networks-a two dimensional approach," *Optical Fiber Technology*, vol. 64, pp. 102585, July 2021. DOI: https://doi.org/10.1016/j.yofte.2021.102585.

[11] S. Dixit, D. Batham and R. P. Narwaria, "Cost function-based class of service provisioning strategy in elastic optical networks," *International Journal of Communication Systems*, vol. 33, no. 18, pp. 1-12, Dec. 2020. DOI: https://doi.org/10.1002/dac.4634.