A Comprehensive Study on the Existing Technologies in Underwater Wireless Communication

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Introduction

Underwater wireless communication involves transmitting data through water without physical connections. It utilizes acoustic, optical, or electromagnetic methods to overcome challenges like signal attenuation and multipath propagation. This technology is vital for underwater exploration, environmental monitoring, and communication in marine industries, including offshore energy, fisheries, and oceanographic research. Innovations in underwater wireless networks enable real-time data transfer, remote control of underwater devices, and collaborative underwater robotics, fostering advancements in ocean exploration and resource management.

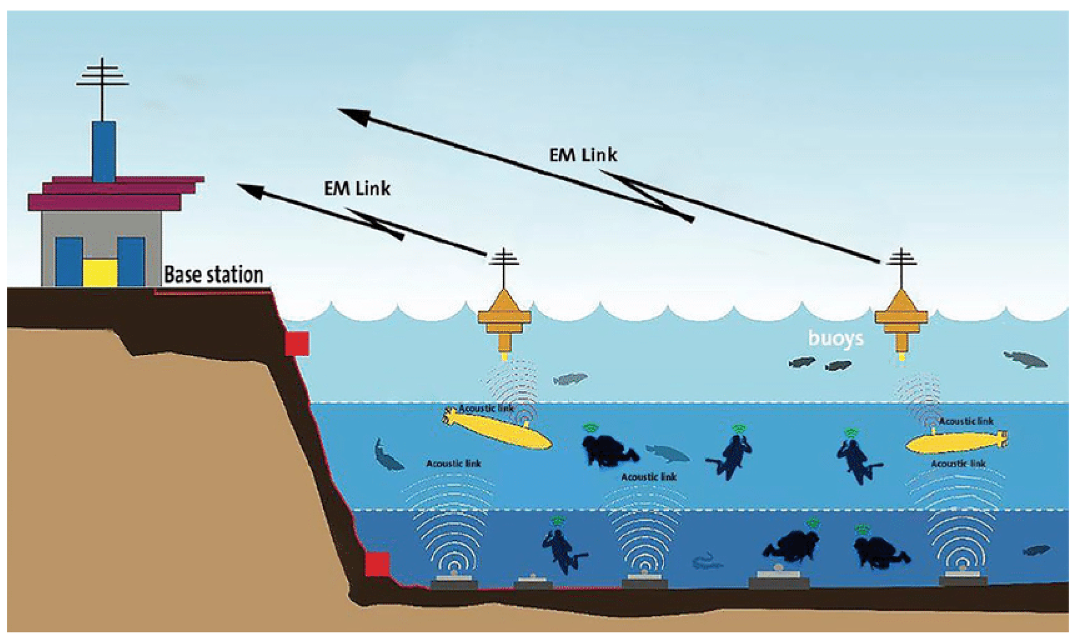

Figure 1. Data transmission in underwater environment

Radio Frequency Communication

Radio frequency (RF) underwater communication utilizes electromagnetic waves to transmit data through water. It offers a promising avenue for short-range underwater data transmission. RF signals propagate via direct paths and reflections, though they experience attenuation and signal loss due to water's absorption and scattering properties.

It can smoothly progress in air-water channel over short distances (Up to 100 m) and is also unaffected by pressure gradient as well as it can propagate in dirty and high turbid water.

Benefits and Limitations

RF signals propagate in a relatively directional manner, which can pose challenges for establishing reliable communication links, especially in dynamic underwater environments. It also shows tolerance with natural properties of water i.e. salinity, pressure and turbidity. It has moderate latency.

It requires costly, bulky and high energy consuming transceiver. It is susceptible to interference from natural and man-made sources such as electromagnetic noise and other RF devices. This interference can degrade signal quality and reduce communication reliability.

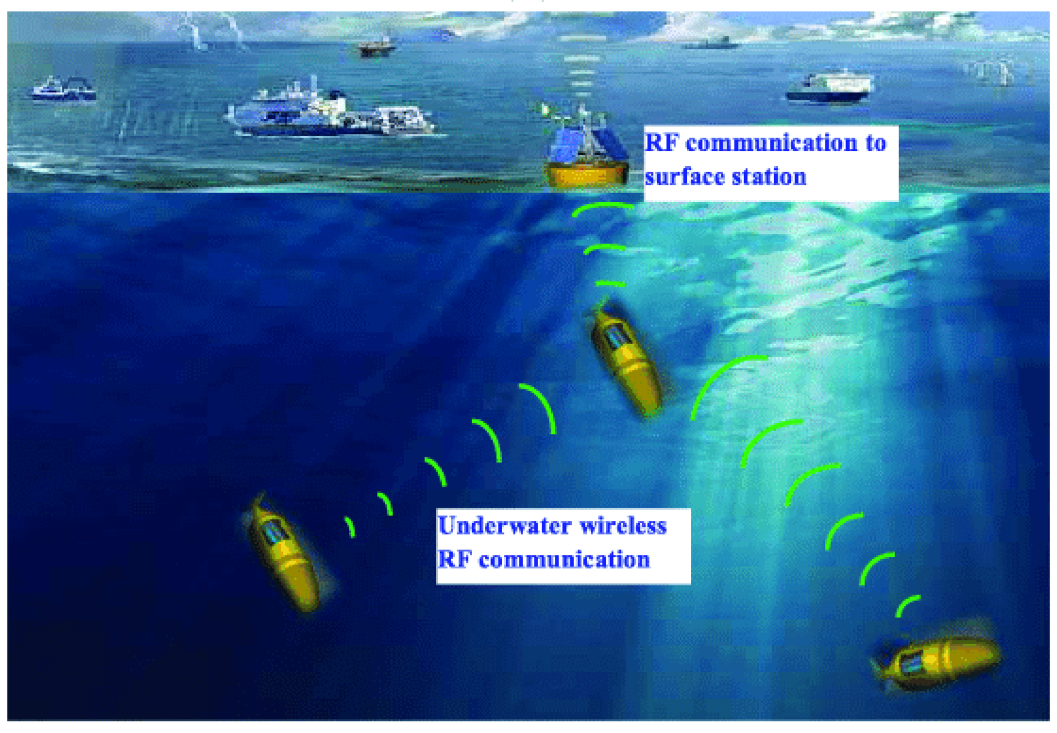

Figure 2. Direct Radio Frequency (RF) Communication

We can create multi-hop relay network using RF technology. The first layer would be stationary and below layers would be moving ones. The below layers can communicate with their upper layers which will relay the information to server node above water.

Electromagnetic waves effortlessly attenuate by way of seawater on increasing of the frequency variety. We can use RF to communicate in air and acoustic or optical to communicate in water as they can travel longer distances as seen in Fig. 3

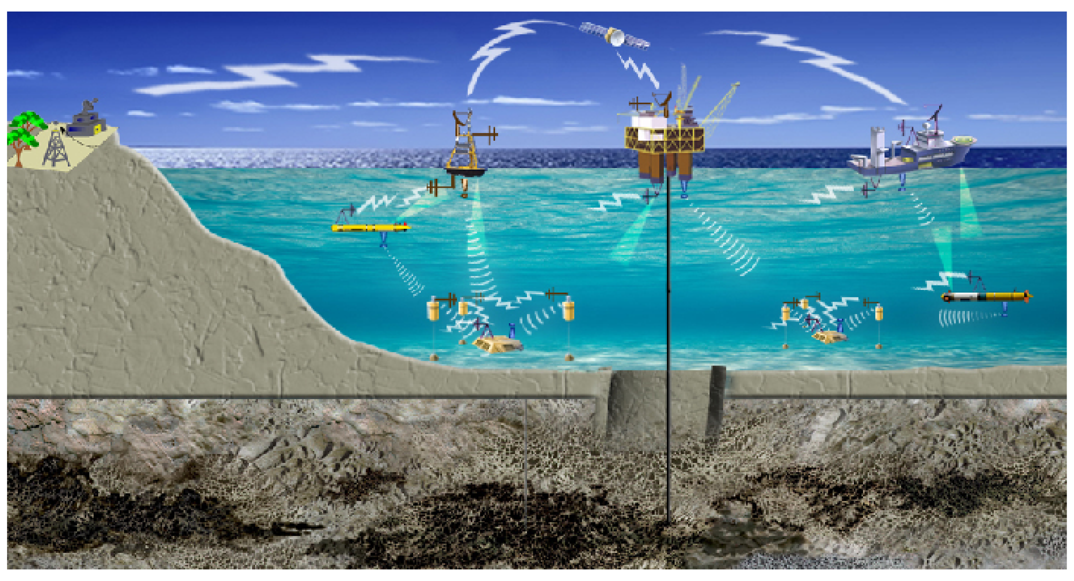

Figure 3. Scenarios of multiple communication technologies

Acoustic Communication

Acoustic waves are produced through the vibration of molecules in an elastic medium. Unlike radio frequency (RF) or optical communication, which face significant attenuation and scattering underwater, sound waves can travel long distances with minimal loss. Acoustic communication systems typically use specialized underwater modems to encode digital data onto acoustic signals for transmission and decode received signals at the receiving end.

Benefits and Limitations

Acoustic communication systems can transmit data over longer distances underwater compared to RF and optical methods. These are less affected by environmental factors such as water turbidity, salinity, and temperature variations compared to optical signals. It can penetrate through obstacles such as underwater structures, marine life, and underwater terrain more effectively than optical signals so as to maintain connectivity in complex underwater environments where LOS communication may be obstructed.

Acoustic communication generally offers lower data rates compared to RF and optical communication. The bandwidth available for acoustic signals is narrower, restricting the amount of data that can be transmitted within a given time frame. It has high communication latency and provides limited data rate.

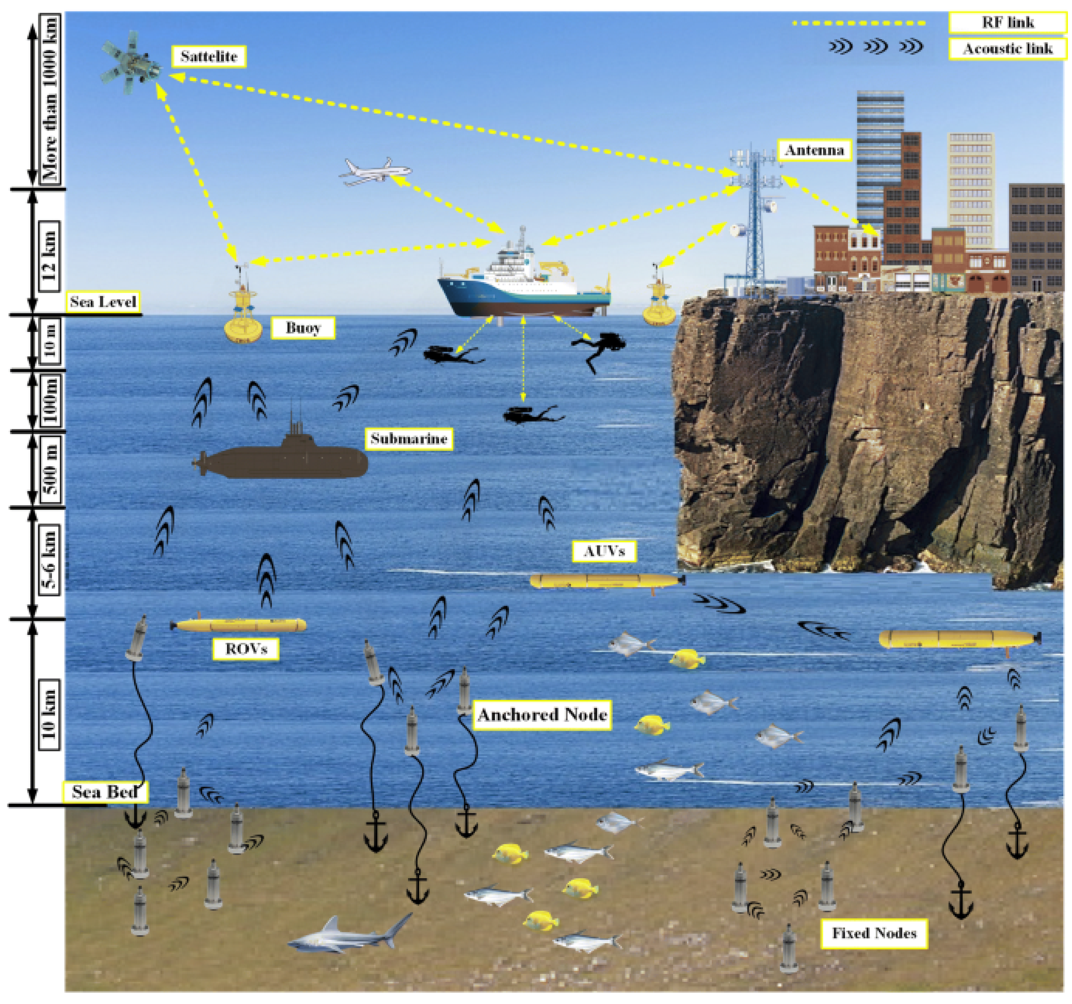

Figure 4. Scenario of existing hybrid dual-hop RF-Acoustic underwater wireless communication link

It is harmful for marine life as it may cause noise pollution which may affect marine organisms. Doppler shifts can distort the received signal frequency, affecting demodulation and data recovery, especially in high-mobility scenarios such as with moving underwater vehicles.
Speed of propagation depends on temperature, salinity and water depth. Acoustic communication can be affected by factors like pressure, temperature, salinity of water channel and turbidity. Earthquakes, rain, bubbles, etc. can affect noise in communication channel.

Comparision Table

Parameters	RF	Acoustic	Optical
Range	< 100 m	< 20 Km	100-200 m
Attenuation Factors	Frequency & Conductivity	Conductivity	Distance and inherent optical properties
Speed	2.25×10^8 m/s	1500 m/s	2.25×10^8 m/s
Tx. Power	≈ 100 W	≈ 10 W	≈ 1 W
Cost	High	High	Low
Data rate	< 0.1 Gbps	< 10 Kbps	< 10 Gbps
Antenna size	0.5 m	0.1 m	0.1 m
Latency	Moderate	High	Low

Figure 5. Table-1

Parameters	RF	Acoustic	Optical
Types of Water	Fresh/Sea	Shallow/Deep	Pure coastal/Turbid
Efficiency	Medium at short ranges	Medium (non-multipath)	Highest (non-turbid)
Requirements	High Attenuation over short distances	Doppler estimation and existence of shadow zones	LOS, receiver direction tracking

Figure 6. Table-2

Optical Communication

Optical underwater communication involves transmitting data through light signals in water. It utilizes the optical spectrum, typically blue or green light as it suffers less attenuation and travels further in water than other wavelengths. Light pulses encode data which are then transmitted through the water medium.

Benefits and Limitations

Optical communication is less susceptible to interference from natural sources like marine life and ambient noise compared to acoustic signals. This can lead to more reliable and accurate data transmission , especially in environments with high levels of background noise.

Optical signals are more difficult to intercept or eavesdrop on compared to acoustic signals, providing a higher level of security for sensitive data transmission underwater. It requires low cost and small volume transceiver. As light travels faster through water than sound, it enables faster communication speeds over longer distances.

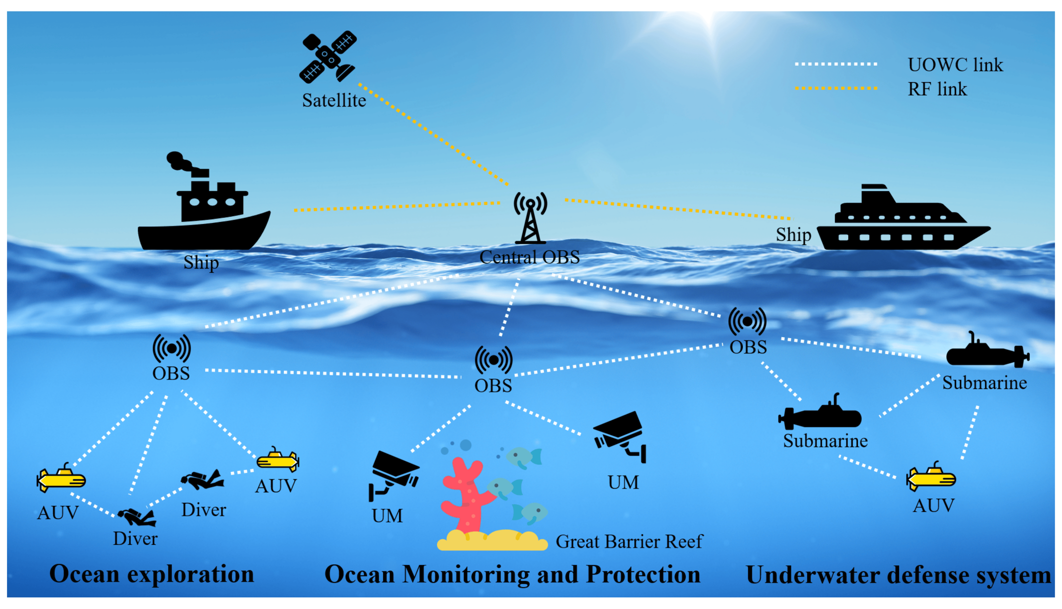

Figure 7. Optical Communication Network Architecture

Generating and detecting optical signals underwater require significant energy, which can be challenging for battery-operated devices, particularly for long-duration deployments. Optical signals can be susceptible to interference from ambient light sources, such as sunlight, artificial lighting, which can degrade signal quality and reliability. It requires LOS,as if any obstruction is present it can disrupt communication. It has low latency. It cannot cross air-water boundary. Optical communication is leading technology to build a communication link in underwater but it might be affected by scattering, dispersion, lack of line of sight (LOS), changing in temperature, and by physiochemical properties of the channel.

Conclusions

- Despite much development in this area, there is still an immense scope for more research as major part of ocean bottom is still unexplored. The main objective is to implement advance technology to overcome the present limitations such as environmental effects on the noise performance etc.
- Each of the technologies discussed here has it's own limitations,so, we can combine them to gain more benefits. Along with this,there are recent advances such as 5G interaction and internet of underwater things.

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