MARINE INFORMATION TECHNOLOGY

CURRICULUM REPORT

On

CURRENT EMERGING TECHNOLOGY IN THE FIELD OF UNDERWATER WIRELESS COMMUNICATION
Focus: Internet of Underwater Things (IoUTs)

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DECLARATION

I declare that the assignment here submitted is original except for source material explicitly acknowledged and that the same or related material has not been previously submitted for another course. I also acknowledge that I am aware of University policy and regulations on honesty in academic work, and of the disciplinary guidelines and procedures applicable to breaches of such policy and regulations.

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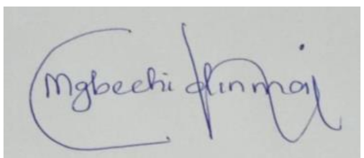

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ABSTRACT

The ocean makes up about 70% of the earth's surface. Yet the exploration rate of the ocean is limited when compared with other parts of the earth including the moon. This can be attributed to the large depth of the ocean and some distinct phenomenal activities in the underwater environment. Nevertheless, the need for an underwater study has increased over time. Hence, igniting the development of many technological advances in the field of environmental monitoring, water pollution, surveillance of natural disasters, oil and gas exploration, warfare, among others. Underwater wireless communications have played a significant role in the above-mentioned fields and the available technologies depend on electromagnetic, optical, and acoustic transmission. In this regard, the underwater wireless communications are supported by current emerging technologies such as Energy Harvesting System for WSNs, Massive MIMO System Aided Underwater Communication, Non-orthogonal Multiple Access (NOMA) Assisted Underwater Communication, mm-Waves Enabled in Underwater Communication and Internet of Underwater Things (IoUTs). Internet of Underwater Things (IoUTs) is a promising and current technology in the Internet of Things. It has contributed to the advancement of underwater wireless communication mainly through the improvement of the data rate, connectivity, energy efficiency, and more. This report presents a concise overview of the existing underwater wireless communications techniques and technical issues. The current emerging technologies in the field of underwater wireless communication with a major focus on the Internet of Underwater Things (IoUTs). The characteristics, applications, and recent works using the Internet of Underwater Things (IoUTs) for underwater wireless communication are described. However, the contributions of the Internet of Underwater Things (IoUTs) to underwater wireless communication by improving the quality of service and energy of the system over a border range are also mentioned.

1.0 INTRODUCTION

In recent times there has been significant attention in the study and exploration of the marine environment by monitoring and investigations. This has enhanced the innovation and current emerges of technologies in the area of underwater wireless communication for data transmission (Zeng *et al.,* 2017; Jouhari *et al*., 2019). According to Ali *et al.* (2019), this is attributed to the possible assessment of data through the water column, oceanographic data analysis, observation of water pollution, environment monitoring, early warning of natural disasters such as floods and tsunamis as well as the study of the rising water levels in the ocean which is a significant effect of climate change and global warming. Therefore, underwater wireless carriers or signal transmitters such as acoustic, optical, and electromagnetic waves are used to enable underwater wireless communication techniques in underwater applications (Su *et al*., 2020).

In underwater wireless communication, technologies that utilize electromagnetic waves in the form of radio frequencies enable features of high data rates over short ranges (Singh and Kumar, 2020). The optical signal transmission technique obtains high bandwidth and data rate, which requires a line attenuating position during signal propagation over moderate distances (Spagnolo *et al*., 2020). Meanwhile, the acoustic wave is the most widely employed technology because it can be used for the longest range of communication (Cao *et al.,* 2020). However, the acoustic transmission technique is affected by large delay spread and severe inter-symbol interference (ISI). In practice, an important factor that determines the use of any of the above-discussed technologies is their cost of implementation. The cost of implementation is related to the required data throughput for a specific communication range and the relative transmission power that might lead to environmental impacts such as interference with marine life. Figure 1 and 2 shows the hybrid transmission in underwater wireless communication which is a cluster of underwater sensor networks (UWSNs). However, in an underwater environment, several signals exchanging devices or communication nodes which comprise of the autonomous underwater vehicle (AUVs) and remotely operated vehicle (ROVs) can be deployed.

In current projects on underwater wireless communication, a novel technology known as the **Internet of underwater things (IoUT)** is been applied in the exploration of the marine environment (Coutinho *et al*., 2020). This is to solve the limitation in the use of the acoustic, optical, and electromagnetic (in RF ranges) waves wireless carriers. Most of the IoUT are referred to as Figures 1 and 2. For better efficiency of the IoUT concept, an Underwater Wireless Sensor Network (UWSN) which is a real-world network has also been considered appropriate (Liou *et al*., 2018). Figure 3 shows the network architecture of UWSN used mainly with the acoustic wave.

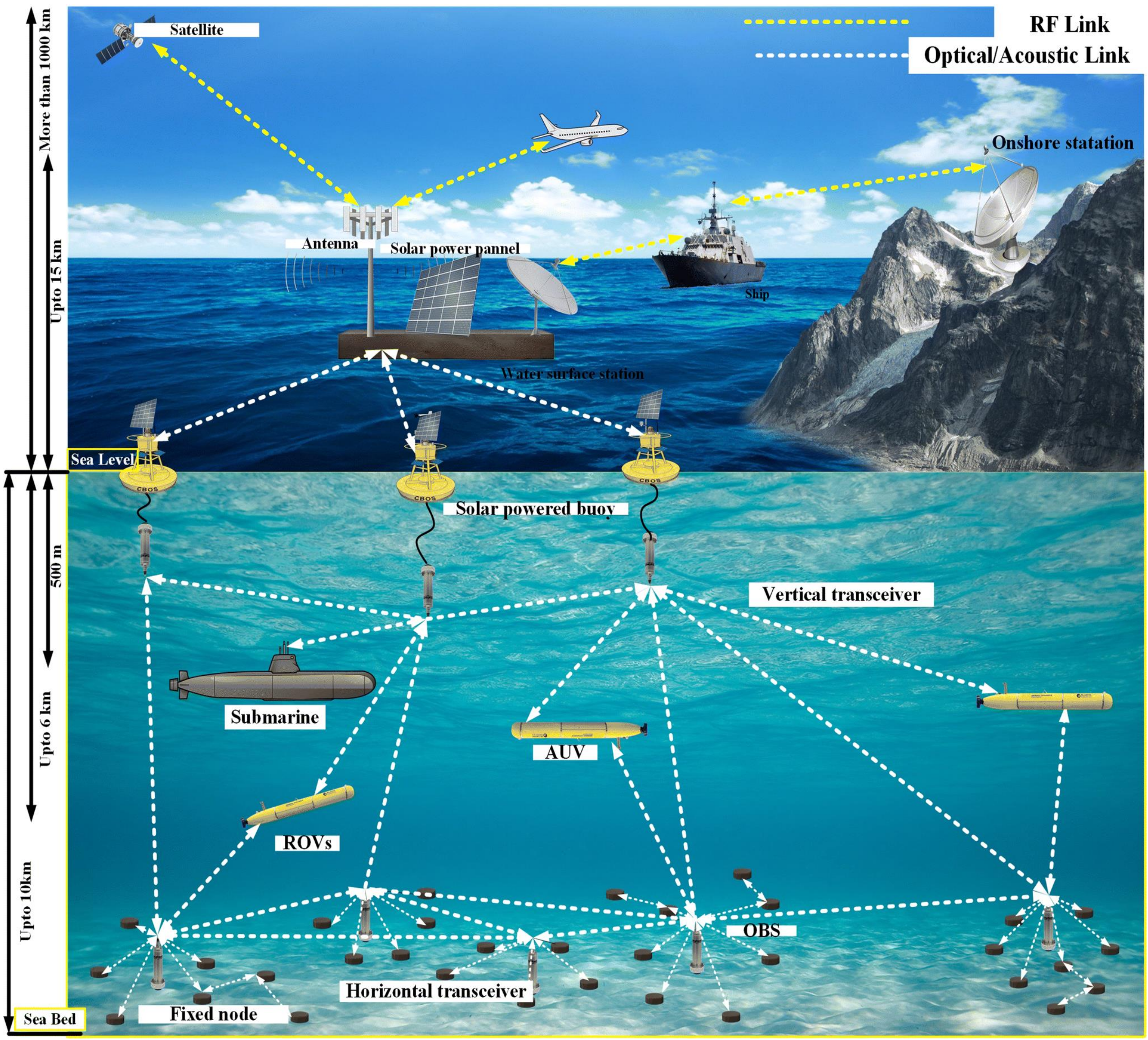

Figure 1: Demonstration of hybrid RF-Optical Underwater wireless communication systems

Source: (Ali *et al*., 2019)

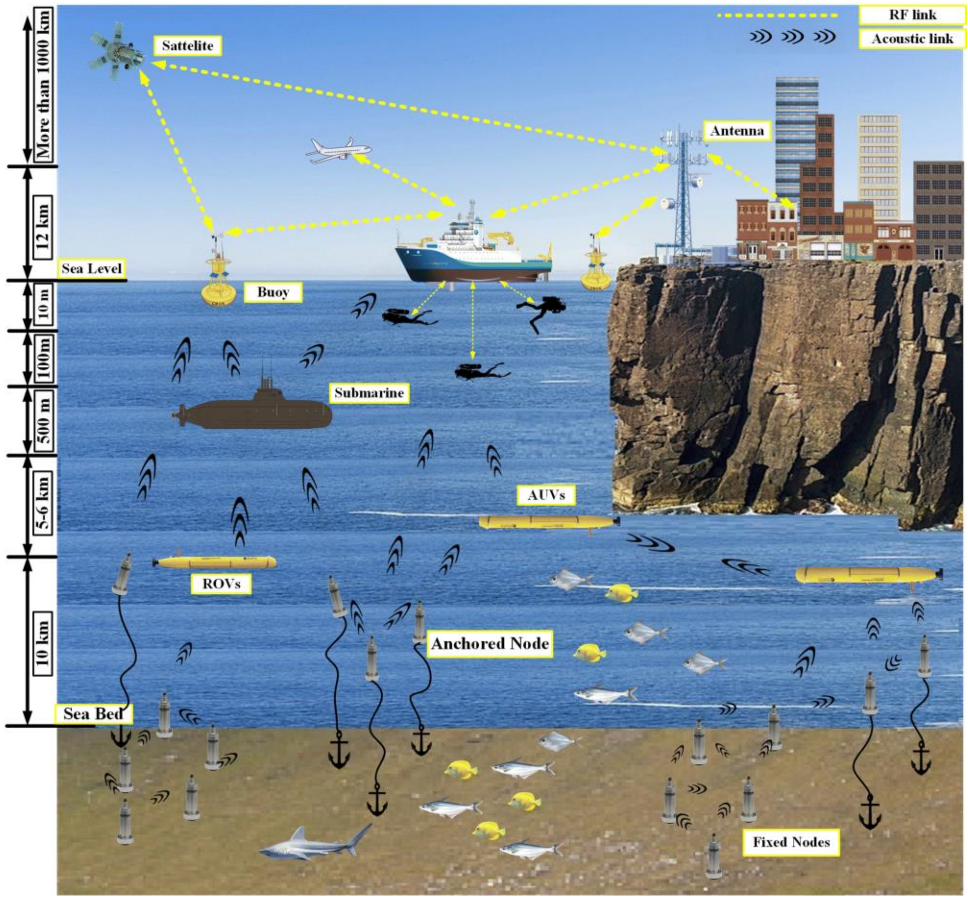

Figure 2: Scenario of existing hybrid dual-hop RF-Acoustic underwater wireless communication link Source: (Ali *et al.*, 2019)

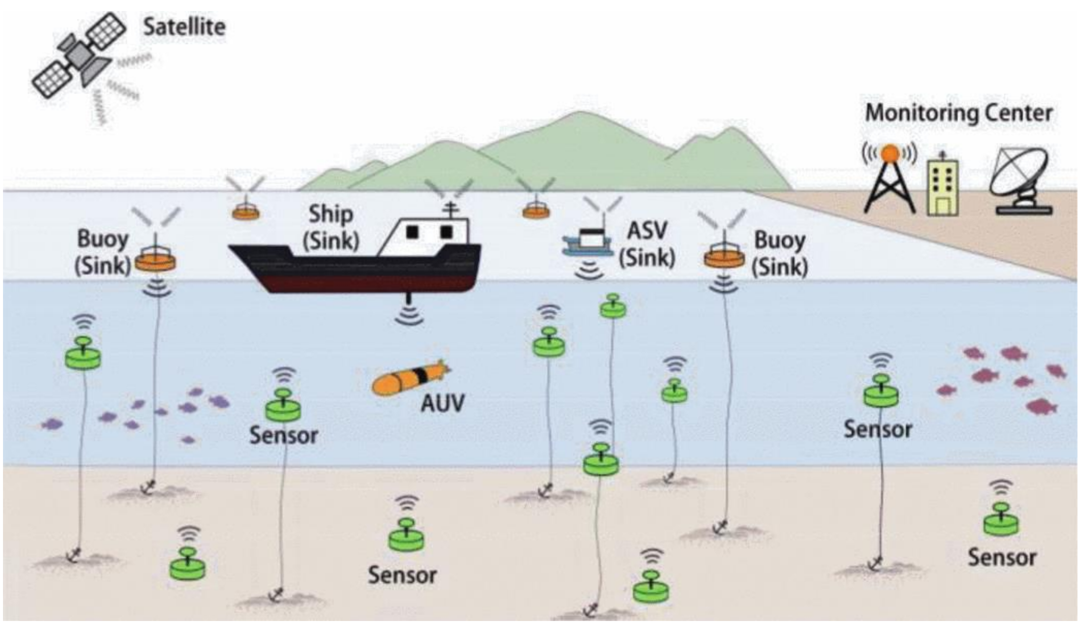

Figure 3: Network architecture of IoUT/UWSNs Source: (Liou *et al.*, 2018)

2.0 TECHNICAL ISSUES IN UNDERWATER WIRELESS ELECTROMAGNETIC, OPTICAL AND ACOUSTIC COMMUNICATION

The three forms of underwater wireless communication which as electromagnetic, optical, and acoustic are affected by several factors as shown in figure 4 and will be discussed below. This is because it is uneasy to establish a definite reliability of signals transmission where a high data rate is required. Since the marine environment is sophisticated and complex. These issues are also summarized in Table 1.

2.1 Factors Affecting Underwater Wireless Electromagnetic Communication

Depending on the water channel properties or oceanic environment, electromagnetic communication is affected by various factors such as turbidity, multipath propagation, fixed limited bandwidth, several types of noise, power resources, harsh water channel conditions, and underwater ambient conditions as in figure 4. However, as the electromagnetic wave involves propagation from air to water, the multi-path effect alters the signal propagation performance (Singh and Kumar, 2020). A large antenna is also required for its propagation (Singh and Kumar, 2020). Hence, antenna design, transmitting power, bandwidth, and noise are major factors to be resolved in the area of underwater wireless electromagnetic communication.

2.2 Factors Affecting Underwater Wireless Optical Communication

Optical signal propagation is affected by different types of noise that occur during underwater wireless communication (Ali *et al.*, 2019). These noises include; the quantum noise (due to random variation of received photons on the optical receiver), optical excess noise (due to the inadequacy of the transmitter), optical background noise/photo-detector dark current noise (due to the optical environment and electrical current leakage from photodetector). The propagation of the optical signals in underwater wireless communication is also affected by scattering and absorption effects as shown in figure 4. The scattering and absorption effect can be attributed to the presence of suspended particles in the underwater (Spagnolo *et al*., 2020). Also, the physiochemical properties that alter optical propagation in water are temperature and pressure. As the techniques to enhance optical propagation and performance have been discussed by (Kaushal and Kaddoum, 2016; Uysal *et al.*, 2016; Saeed *et al*., 2019a).

2.3 Factors Affecting Underwater Wireless Acoustic Communication

Since absorption depends on signal frequency, the diminishing energy of acoustic waves by signal propagation in water directly affects frequency as it suffers from absorption (Hattab *et al*., 2013). Besides absorption, other factors that limit the efficiency and performance of the acoustic system is energy losses and scattering caused by suspended particles. Among the external interference is noise such as the ambient noise and man-made noise. According to Ali *et al*. (2019), underwater acoustic communication is influenced by noise, path losses, multi-path losses, Doppler spread, high and variable propagation delay. These determine the temporal and spatial variability of the acoustic channel and alters the range, frequency, and bandwidth. Meanwhile, acoustic nodes are power consuming, huge, and expensive (Partan *et al*., 2007). This has been managed in recent times by the application of underwater acoustic wireless sensor networks (UAWSNs) which are cost-effective but limited by inefficiency of power batteries replacement (Saeed *et al*., 2019a). Another factor that affects underwater acoustic communication is channel impulse response since the propagation speed of the acoustic wave in air is slow and the time coherence in the acoustic channel is limited. This results in a higher spread delay. These factors are illustrated in figure 4. The techniques to address issues related to underwater acoustic communication have been reported by (Zakharov and Li, 2016).

Table 1: Comparison of different underwater wireless communication technologies

Type of technology	Ranges	Latency	Transmission power	Affecting factors determine channel quality
Underwater wireless electromagnetic communication (UWRF)	Few meters (up to 10 m)	Moderate	mW–W	Conductivity and permittivity of channel
Underwater optical wireless communication (UWOC)	Up to 100 m	Low	mW–W	Absorption, scattering, turbidity, suspended and organic matter of channel link
Underwater wireless acoustic communication (UWAC)	Up to 20 km	High	> 10 W	Absorption, scattering, pressure, temperature, and salinity of water channel

Sources: (Gussen *et al.,* 2016; Saeed *et al*., 2019a)

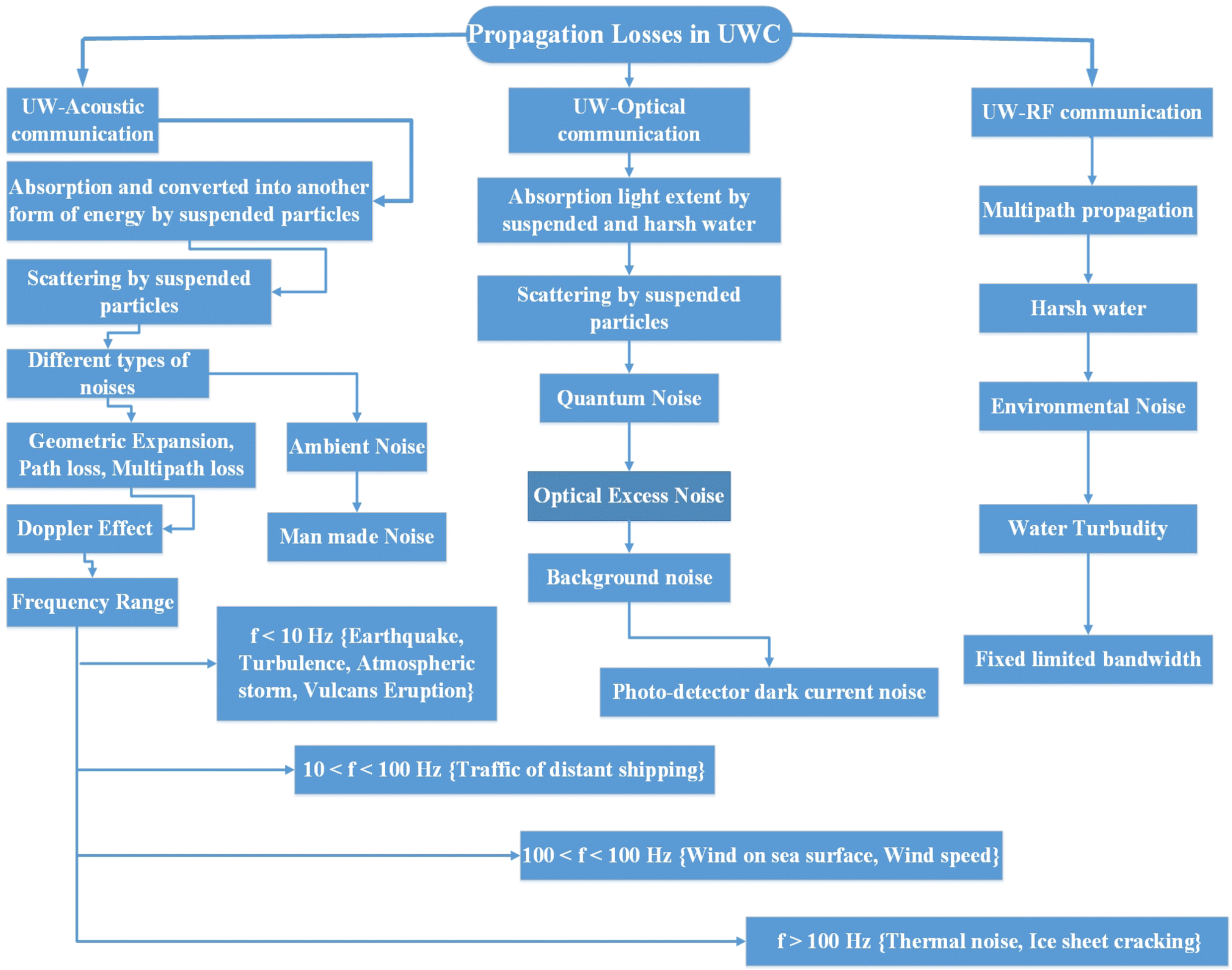

Figure 4: Affecting factors, signal fading and propagation losses in different underwater wireless communication techniques Source: (Ali *et al*., 2019)

3.0 CURRENT EMERGING TECHNOLOGIES IN THE FIELD OF UNDERWATER WIRELESS COMMUNICATION

There are several emerging technologies in the field of underwater wireless communication as shown in figure 5. Due to the different limitations faced while exploring the previous or existing technologies. The ocean basins are less well mapped, explored, and understood when compared to the Moon and Mars. The emerging technologies include Energy Harvesting System for UWSNs (due to less possibility to change batteries and charged a capacitor of sensor nodes in the underwater environment), Massive Multiple-input-multiple-output (MIMO) System Aided Underwater Communication (to enhance the real-time activities, high quality of data transmission between floating buoy and a large array of hydrophones), Non-orthogonal Multiple Access (NOMA) Assisted Underwater Communication (due to its greater spectrum efficiency), millimeter(mm)-Waves Enabled in Underwater Communication (due to its efficient communication performance in underwater and extremely high frequency), Underwater Sensor Networks (UWSNs) (made up of a group of sensors that record and explore data from the deep marine environment, then enable communication among devices, aid data retrieval and exchange information with buoy or base stations. It consists of specific devices and network nodes such as connected devices ROV and AUVs., and Internet of Underwater Things (IoUTs).

The Internet of Underwater Things (IoUTs) will be well discussed in this report in terms of its application and implementation in underwater wireless communication.

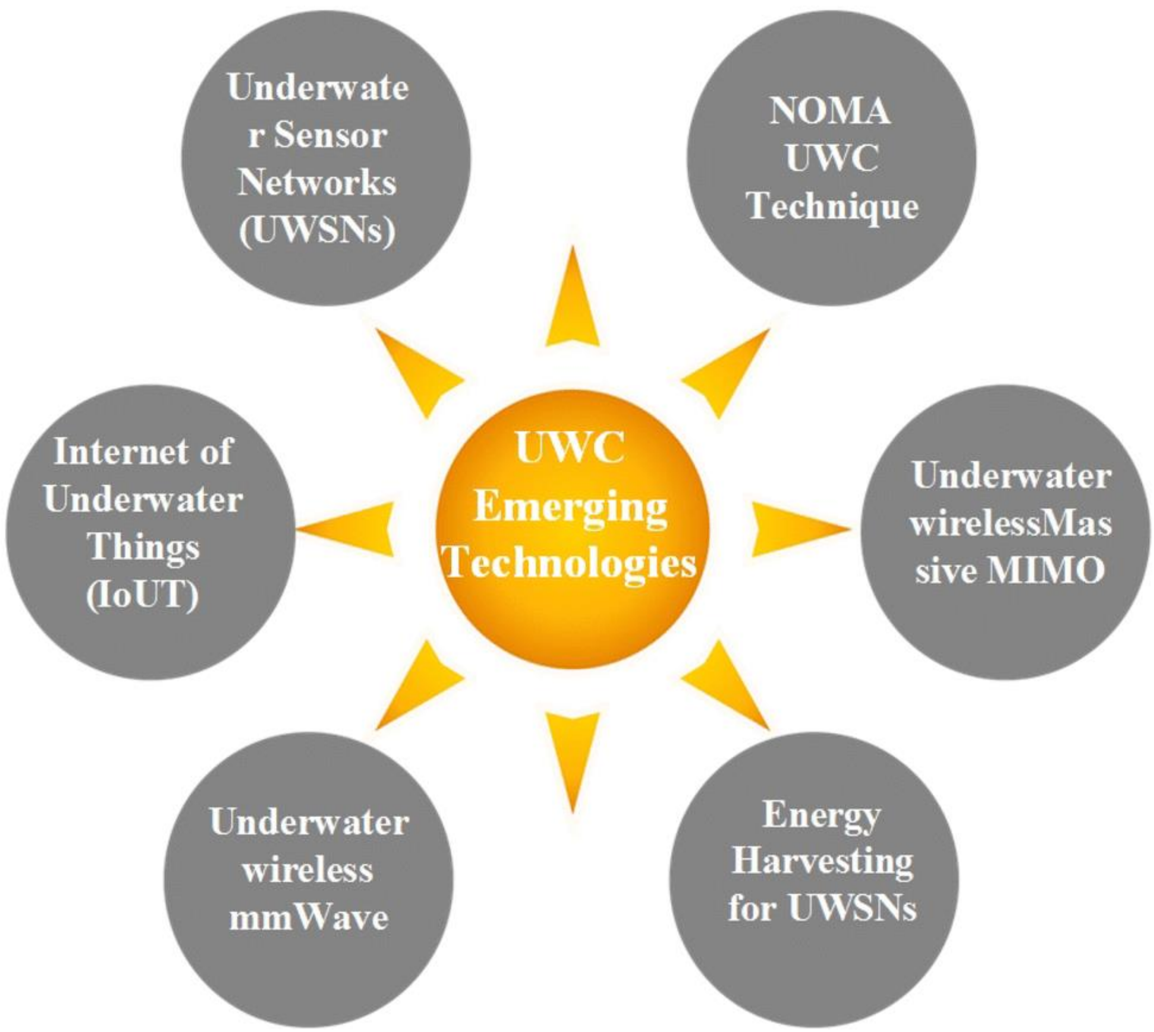

Figure 5: Emerging techniques in underwater wireless communication

Source: (Ali *et al*., 2019)

4.0 INTERNET OF UNDERWATER THINGS (IOUTS)

Internet of Underwater Things (IoUTs) is a technological revolution of computing and communication which provides a world-wide network of smart interconnected underwater objects with digital entities (Kao *et al*., 2017; Coutinho *et al*., 2020). It is used in underwater wireless communication to monitor the marine environment, observe marine life, secure information exchange of vast ocean volume, and understand the underwater habitats (Coutinho *et al*., 2020). Internet of Underwater Things (IoUTs) is a significant part of the Internet of things (IoT) which deals with interconnected underwater devices and underwater sensors to improve the quality of service (QoS) of the system (Ali *et al*., 2019).

4.1 The characteristics of the Internet of Underwater Things (IoUTs)

It uses different communication technologies, requires different localization techniques, different network density, different energy harvesting technologies such as piezoelectric energy harvesting, microbial fuel energy, and ocean thermal energy used by Autonomous Underwater Vehicles (AUVs) developed by NASA/Scripps Institution of Oceanography. It uses a novel thermal recharging engine powered by the differences in temperature found at different ocean depths and also IoUTs have different tracking technologies as illustrated in Table 2 below**.**

Table 2: Comparison between tracking techniques.

Characteristics	**Types of tags**		
	Acoustic tags	**Radio tags**	**Passive Integrated tags**
Freshwater	Yes	Yes	Yes
Seawater	Yes	No	No
Detection range	Freshwater: 1km Seawater: 200m	Freshwater:10m	Freshwater: 20 cm
Size: Length	19–74mm	20–80mm	11–28mm
Diameter	6–16mm	9–30mm	2–3.5mm
Battery	Yes	Yes	No
Battery life duration	19 day–4years (depending on the tag ping rate and the battery size)	9 day–3years (depending on the time between bursts and the battery size)	–
3-D position estimation	Yes	No	No
Store information	No	No	Yes
Need recapture	No	No	Yes

4. 2. Internet of Underwater Things (IoUTs) Architecture

The IoUTs architecture is divided into three layers as shown in figure 6. The perception layer identifiers object and gather information. It is formed mainly by underwater sensors, underwater vehicles, surface stations (sinks), monitoring stations (such as tablet PC, smartphones, etc), data storage tags (acoustic/ radio/ passive integrated tags), and hydrophones/receivers/tags readers (Xu *et al*., 2019). The network layer comprises a converged network made up of wired/ wireless privately-owned networks, internet, network administration systems, cloud computing platforms, etc. It processes and transmits the information gotten from the perception layer (Xu *et al*., 2019). However, the application layer is a set of intelligent solutions that apply the Internet of Underwater Things (IoUTs) technology to satisfy the needs of users. Some IoUT application servers that can be used are acoustic server, radio and radio frequency identification servers, and monitoring server (Xu *et al*., 2019).

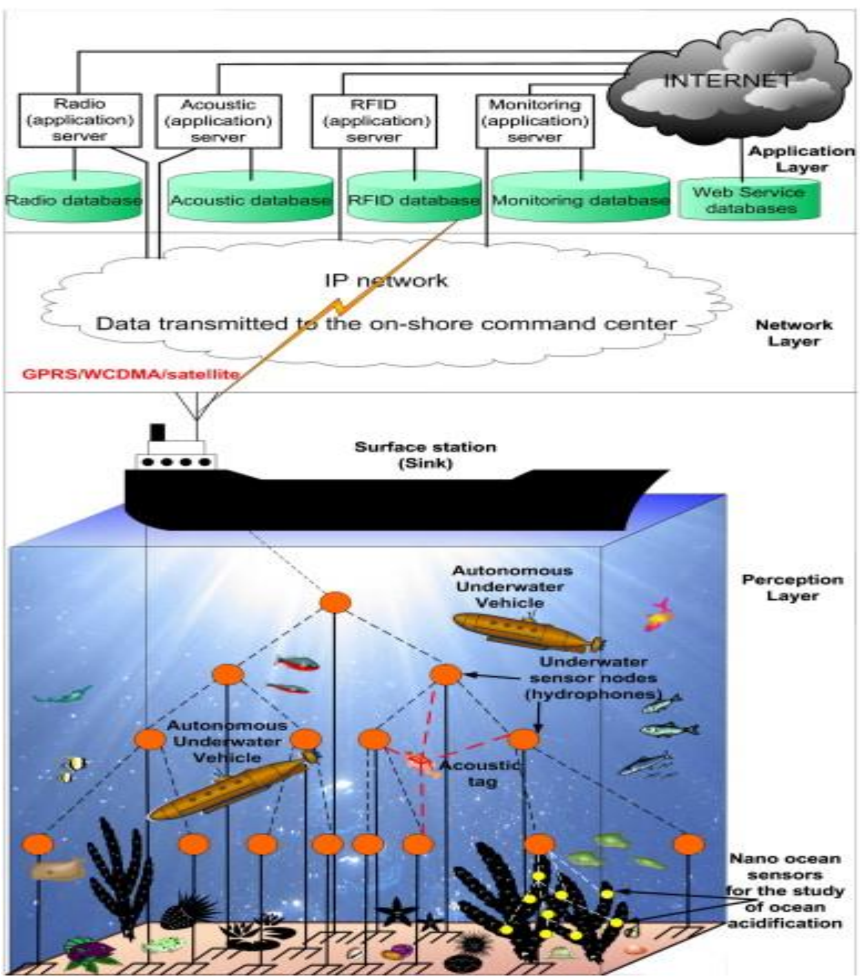

Figure 6: IoUT architecture Source: (Domingo, 2012).

4.3 Application of Internet of Underwater Things (IoUTs)

According to Heidemann *et al*. (2012), the underwater application of the (IoUTs) can be divided into sectors such as scientific, industrial, and military applications. The scientific applications deal with the observation of the environment, that is, the monitoring of geological processes on the ocean floor, water characteristics, and marine life. The industrial applications focus on the monitor and control commercial activities. Meanwhile, the military applications involve securing port facilities or ships, communicating with submarines and divers. Other IoUT applications are illustrated in figure 11.

4.3.1 Scientific Application: Aquarium Scenario

Figure 7 illustrates that the unique identifier (ID) of tagged fishes are detected with the aid of a reader embedded in a monitoring station such as a smartphone, video, and webcam over the internet in real-time. This has been implemented in Singapore using a radio frequency identifier (RFID) system for a sea exhibition in 2007 (Domingo, 2012).

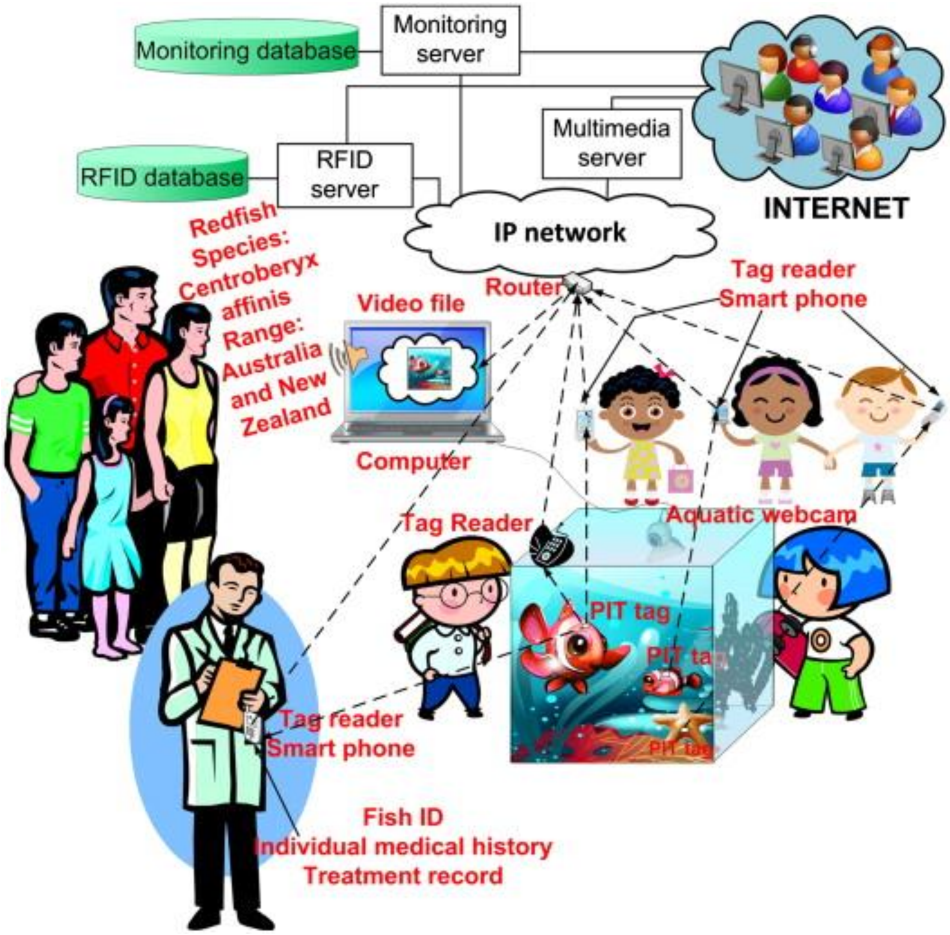

Figure 7: Illustration of Aquarium scenario Source: (Domingo, 2012).

4.3.2 Industrial Application: Fish Farm Scenario

Fish farming is an industrial application which involves the raising of fishes in an enclosed area usually for food. A unique code identifier is used to detect the radio tag placed on each fish and the monitoring station (smartphone) scans the radio tags as shown in figure 8. Besides, receivers set in the tanks/ponds, can be used to obtain the tag ID string and forward it towards the monitoring station using Bluetooth or ZigBee (Domingo, 2012). Then, sent from the monitoring station to the radio server. Cost-effective PIT tags can be used instead of the radio tag, but PIT tags have a more limited detection range. Since the water is prone to contamination, its quality can be studied using an underwater sensor that detects indicators such as water temperature, dissolved oxygen concentration, pH value, and electrical conductivity (salinity). Then the sensed data are sent through the surface sink, monitoring server, and then the monitoring station. In China, Zhu *et al*. (2010) reported the use of a remote wireless monitoring system that uses wireless communication technology to provide water-quality information for intensive aquaculture.

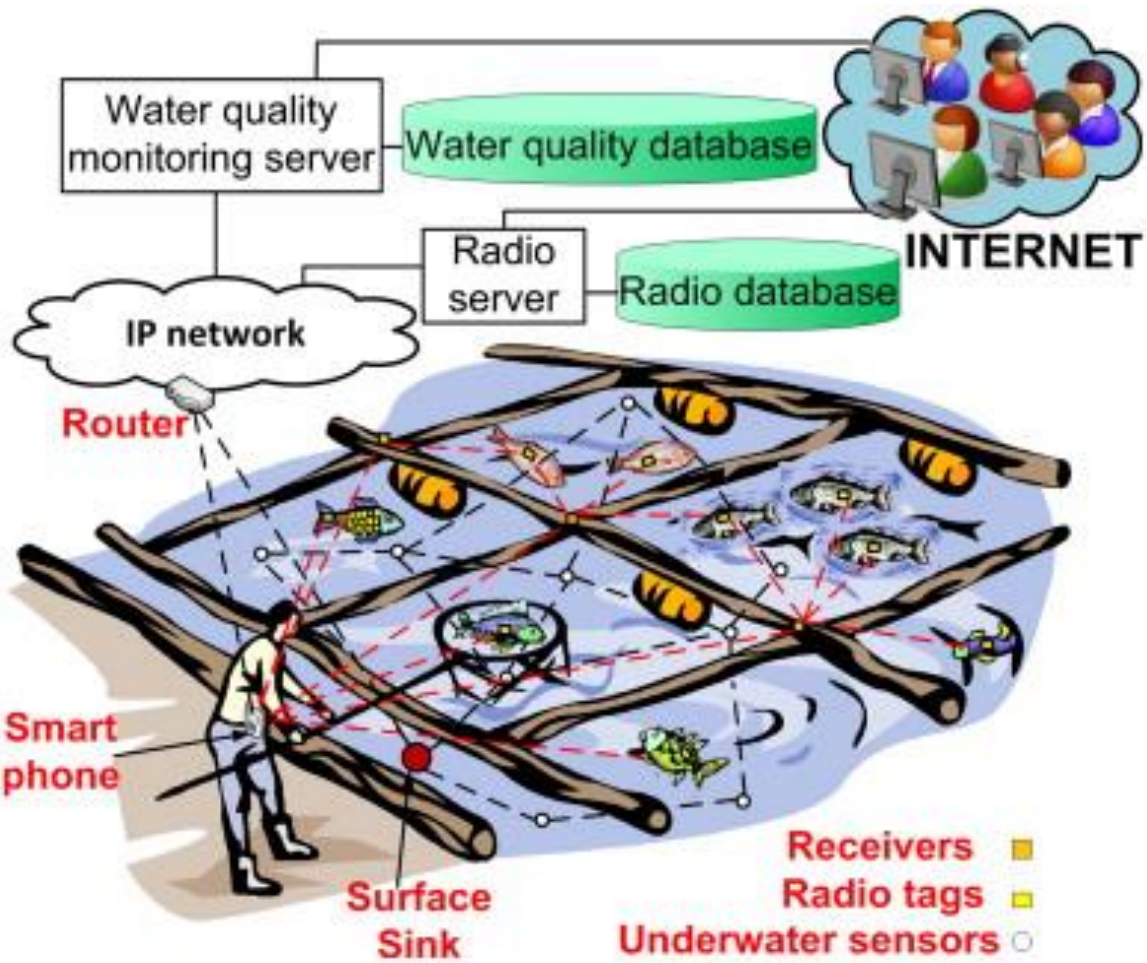

Figure 8: Illustration of Fish Farm Scenario Source: (Domingo, 2012).

4.3.3 Industrial Application: Pipeline Monitoring Scenario

The efficient inspection of underwater marine infrastructures such as the control and detection of an oil spill at pipelines can be achieved by the use of both underwater sensors and AUVs as shown in figure 9. When the sensors are placed, their positions are detected using localization techniques (Su *et al*., 2020). Then, the data collected by sensors is transmitted through the sensor network towards the sink, which forwards it to the onshore monitoring center, as the AUVs move through the monitoring zone. Hence, the AUVs communicate with underwater sensors through acoustic links to also gather all necessary data. Hydrophones (acoustic sensors) can be used to track the 3-D position of AUVs (carrying acoustic tags); it is computed by the acoustic server at the monitoring center. However, AUVs can also carry tag readers, since PIT tags can be attached to the underwater pipeline to pinpoint more accurately where to do repairs. The underwater multimedia acoustic sensor networks serve as support information during inspection and repair tasks while it also enables picture and video acquisition and classification.

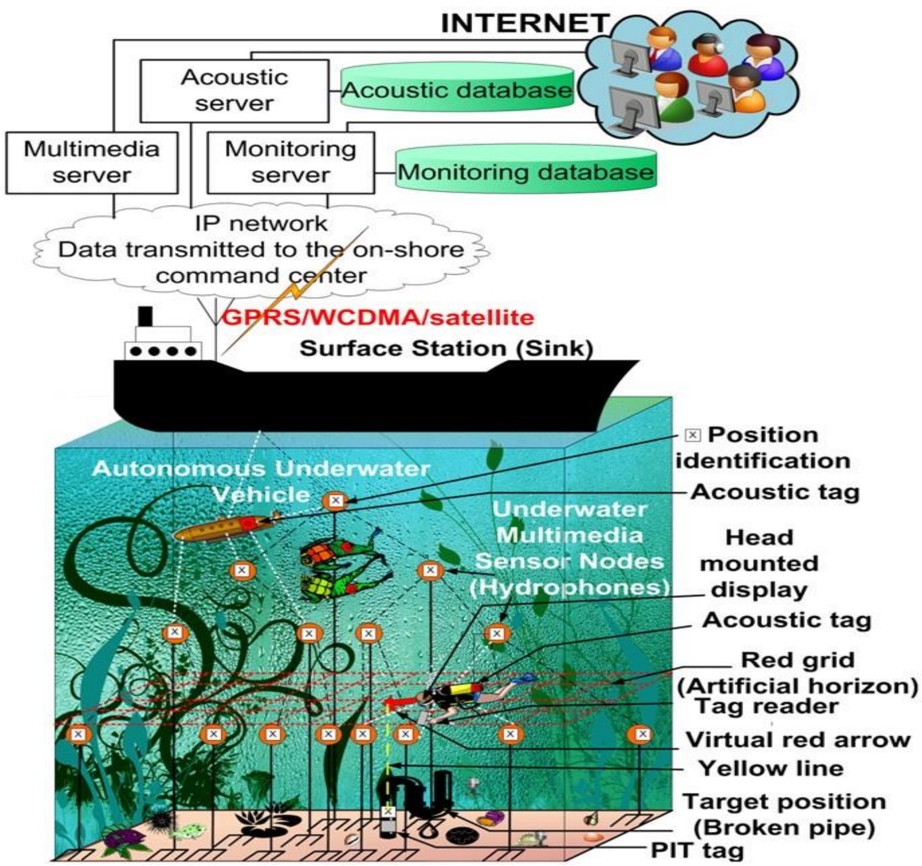

Figure 9: Industrial Application in Pipeline Monitoring (the red grid represents the visualization of an artificial horizon, the virtual red arrow sign pointing to the task location, a yellow line links the arrow with the target position (worksite), then the divers' position is tracked).

Source: (Domingo, 2012).

4.3.4 Military Applications: Harbor Security Scenario

Harbor security is a type of military applications. This can be achieved with the use of underwater sensor networks together with underwater and surface vehicles as shown in figure 10. The network consists of ASVs, AUVs, airplanes, and satellites which make up the mobile security network and buoys and sea mounted equipment that makes up the stationary platforms. Several sensors can be mounted on the vehicles. The sensed data is sent to the surface station (sink), which floats on the water surface and uses long-distance radio communication to send this data to an onshore station directly or through airplanes for further analysis. Barr *et al*. (2011) described an energy-conserving approach to detect intruding submarines using this approach. To measure the distance to and other properties of the target, an optical remote sensing technology called Light Detection and Ranging (LIDAR) is used (Hu *et al*., 2020). It illuminates the target with light by using pulses from a laser. The detected videos and images by the underwater robots and multimedia acoustic sensor networks are sent to the multimedia server.

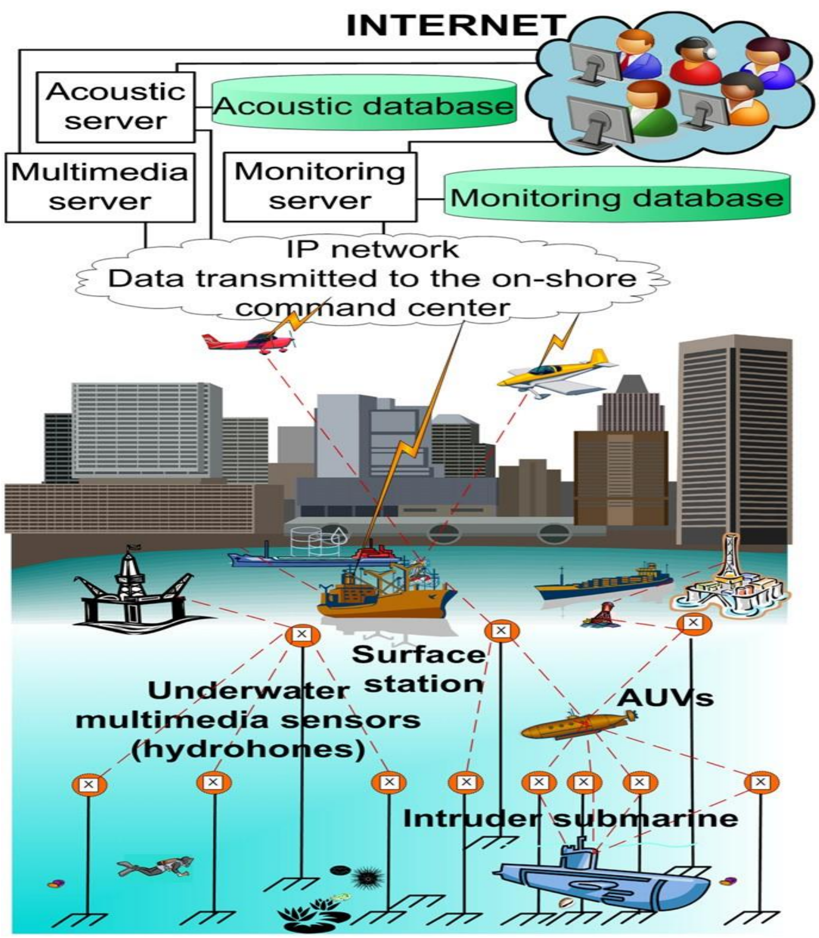

Figure 10: Military Applications in Harbor Security Scenario

Source: (Domingo, 2012).

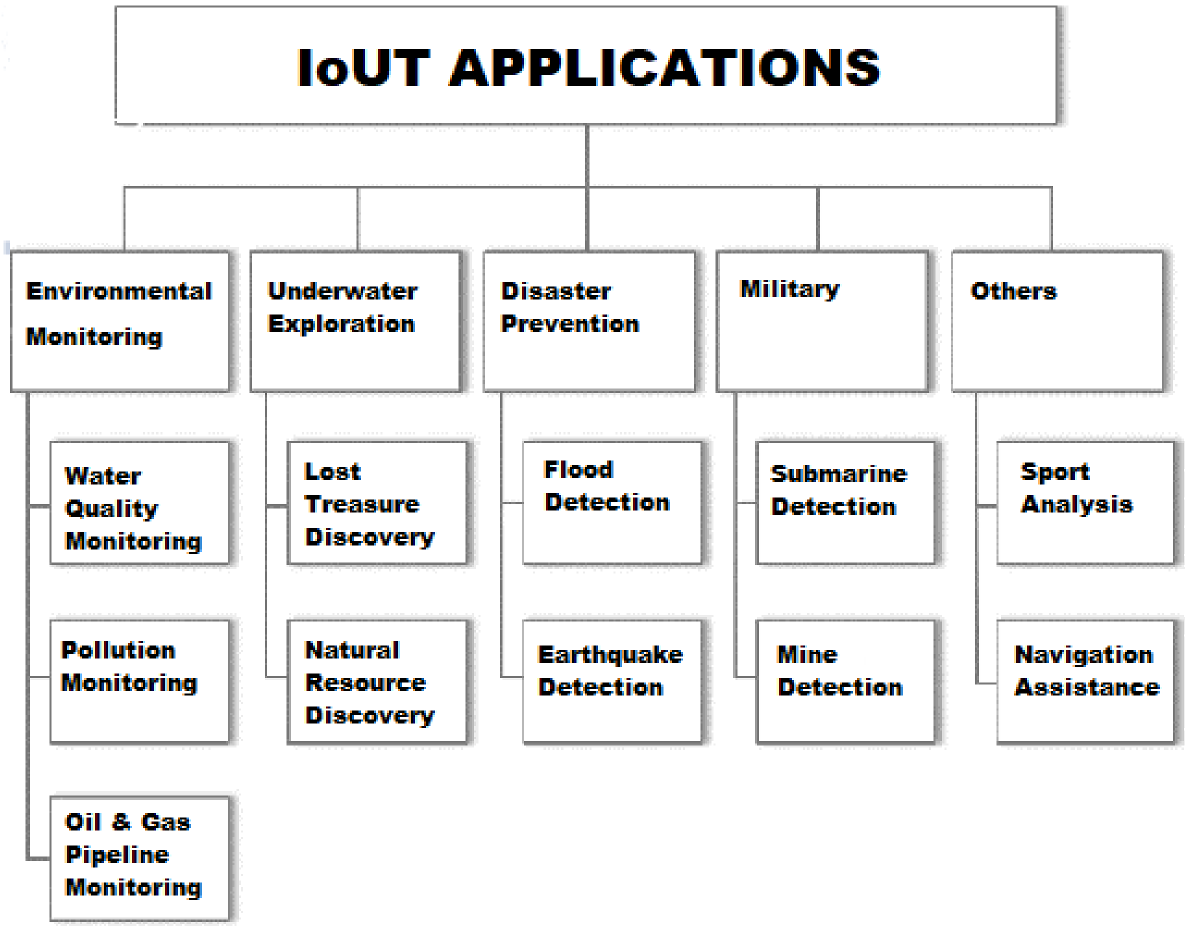

Figure 11: IoUT Application Source: (Kao *et al.*, 2017).

Driven by an increase in time-sensitive IoUT applications as described and illustrated above, a high-speed underwater wireless communication is most preferable. Traditional underwater wireless communication systems have utilized acoustic waves due to their low loss in underwater environments. However, it only supports a fairly low bit rate because of its narrow bandwidth (Schmidt, 2020). To ensure a higher transmission rate, an underwater optical wireless communication (UOWC) is suitable (Diamant *et al.*, 2017). However, underwater optical wireless communication faces several challenges due to the severe underwater channel conditions, such as absorption, scattering, and turbulence (Saeed *et al*., 2019a). Recently, researchers have discussed and tackled some of the challenging and technical issues.

5.0 SOME RECENT WORKS IN UNDERWATER WIRELESS COMMUNICATION USING INTERNET OF UNDERWATER THINGS (IOUTS).

5.1 Underwater optical wireless communication-based IoUT networks: Medium Access Control (MAC) performance analysis and improvement

The concept of IoUT is well supported by underwater wireless communication mainly through acoustic and optical waves. High-speed underwater wireless communication is more preferred for time-sensitive IoUT applications, such as environmental monitoring, underwater exploration, and scientific data collection which have gained more attention in recent research (Al-Halafi and Shihada, 2018; Cossu *et al.*, 2018).

In previous times, the acoustic wave has been employed for most underwater wireless communication systems because of its low loss in underwater environments. However, acoustic communication can only support a relatively low bit rate due to its narrow bandwidth (Stojanovic, and Preisig, 2009). Therefore, underwater optical wireless communication (UOWC) have been deployed in recent projects to obtain a higher transmission rate (Diamant *et al.,* 2017). Meanwhile, underwater optical wireless communication faces severe channel conditions such as absorption, scattering, and turbulence, which pose significant challenges. To solve these challenges most recent research has focused on the Physical (PHY) layer. Nevertheless, for IoUT networks connecting multiple devices, the study of PHY/MAC cross-layer analysis for UOWC-based IoUT networks is important.

In the research by Nguyen *et al*. (2020), an underwater optical wireless communication-based IoUT network which consists of different optical access points (OAPs) was used. As illustrated in figure 12, the OAP gathered information from multiple nodes that can appear at different locations and different depths around the OAP. This can be underwater sensors, autonomous underwater vehicles, or divers. Thus, the transmission between a node and the OAP is based on optical wireless communication. In this study, an OAP and several nodes were used as shown in figure 13. So, the effect of different Underwater Optical Wireless Communication PHY factors on MAC performance was detected in terms of delay, success rate, and throughput. Then, the performance improvement was achieved by using frame retransmission which was confirmed and validated using Monte- Carlo simulations

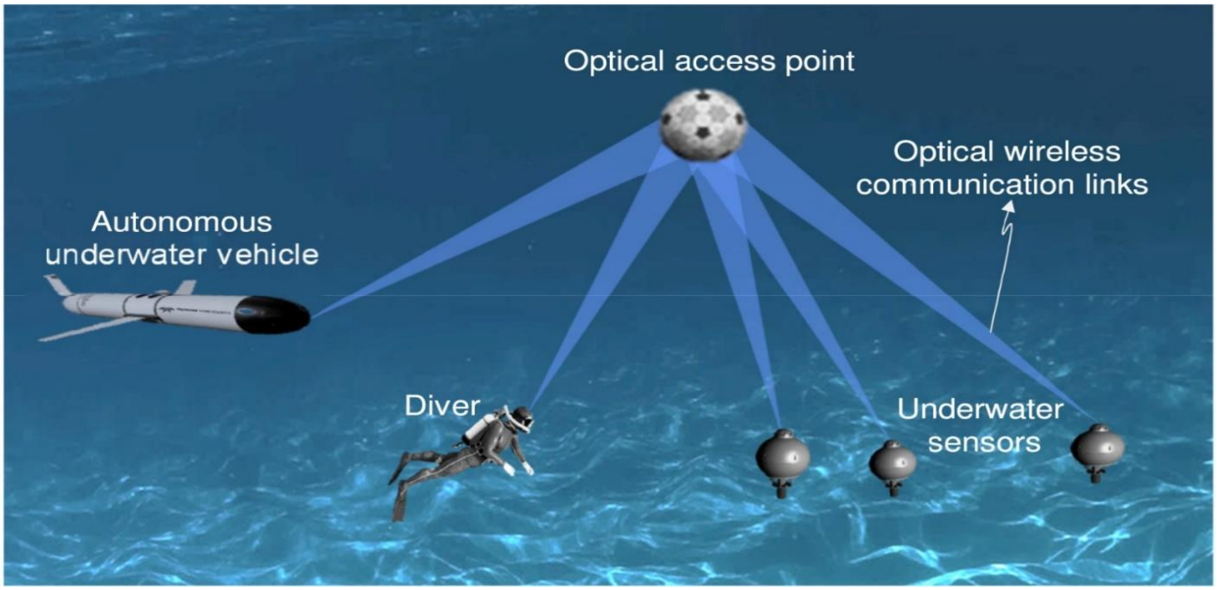

Figure 12: A scenario of UOWC-based IoUT network Source: (Nguyen *et al*., 2020)

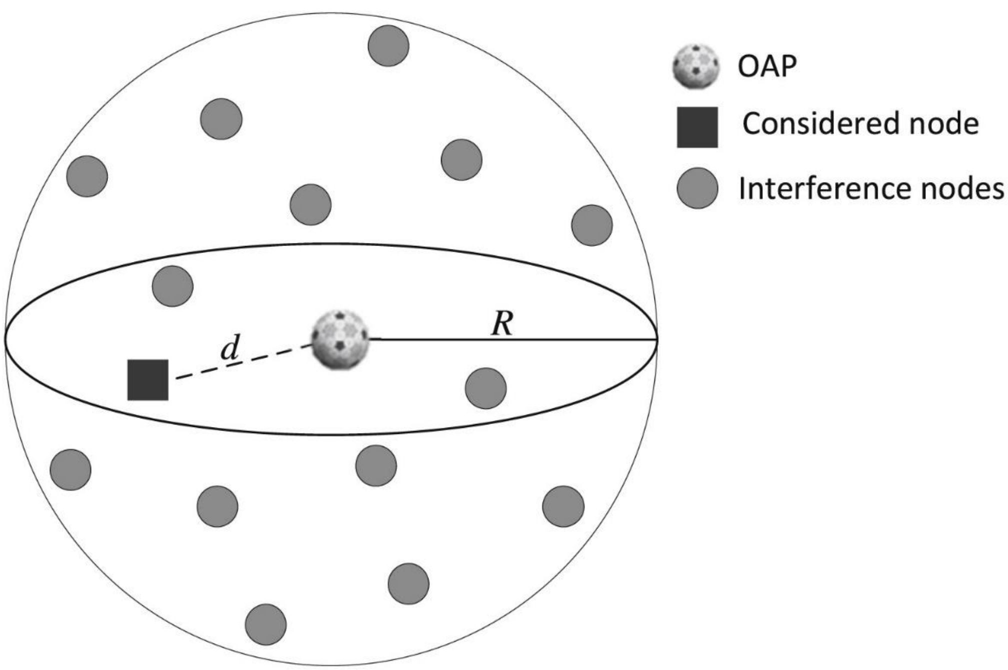

Figure 13: Node distribution in the network Source: (Nguyen *et al*., 2020)

5.2 Underwater Wireless Optical Communication: High-speed and reliable system using Multiple-Input Multiple-Output and channel coding techniques for IoUT applications

Recent research on Underwater Wireless Optical Communication (UWOC) systems is mainly due to its promising high transmission speeds and reliable communication over short ranges (∼ tens of meters) in the ocean/seawater channels. This technology has several underwater applications like ocean monitoring, safe navigation, and disaster prevention, etc. In solving some of the challenges related to the UWOC system such as beam absorption, scattering, and underwater turbulence, that results in optical beam attenuation and fluctuation that degrades the system performance (Ramavath *et al.*, 2018). Jamali *et al.* (2016), reported further improvement in the performance of the UWOC system by employing multiple transmit sources along with the multiple detectors at the receiver.

Then, Ramavath *et al.* (2020) studied the Bit Error Rate (BER) performance of an On-Off Keying (OOK) modulation based UWOC system in weak turbulence and propagation loss due to beam attenuation regimes for Single-Input to Single-Output (SISO), Single-Input to Multiple-Output (SIMO), Multiple-Input to Single- Output (MISO) and Multiple-Input to Multiple-Output (MIMO) schemes. Here, the RS-code was chosen because of its moderate complexity and ability to correct burst errors (Simpson *et al*., 2010). Figure 16 shows the UWOC system schematic diagram, where $T1$, $T2$, to TN are N number of LASER sources, and $D1$, $D2$, to DM are M PDs. Figure 17 a and b shows the link geometry and structure of the MIMO UWOC transmitter and receiver array. The improvement in performance due to transmit power gain by the use of MIMO and RS channel code in a UWOC system was confirmed and quantified by analysis and simulations. It was concluded that the use of MIMO and diversity schemes along with suitable channel codes can be a suitable and efficient technique to realize high-speed and reliable UWOC systems (Ramavath *et al.*, 2020). Some suggested application of these techniques includes inter submarine communication submarine to jetty communication, communication between sensors collecting oceanic parameters and aggregating devices, etc.

Therefore, the emerging technologies like the Internet of Underwater Things (IoUT) will have a great impact on UWOC as these systems require a high degree of information integrity, high data rates, and energy efficiency when used in conjunction with data transfer between underwater vehicles and objects. The RS-coded MIMO UWOC system offers high reliability and power efficiency when employed in IoUT applications.

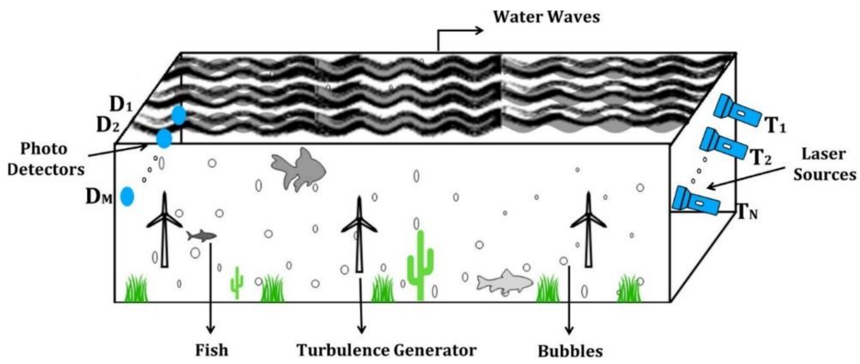

Figure 16: Schematic Diagram of the UWOC System   Source: (Ramavath *et al.*, 2020).

a

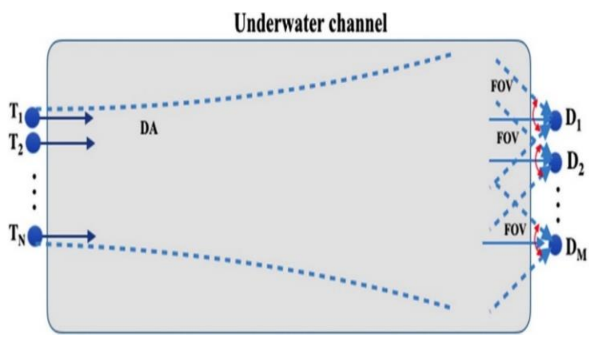

Figure 17a: shows the Link geometry of the MIMO UWOC system.

Source: (Ramavath *et al.*, 2020).

b

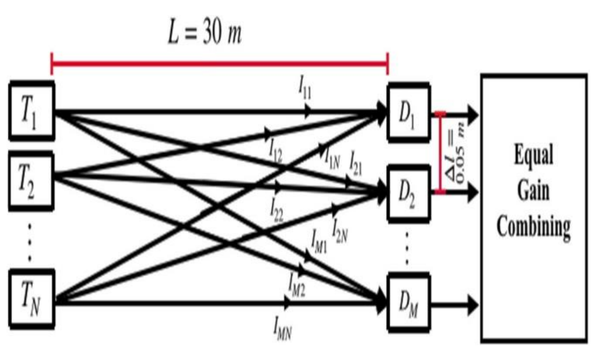

Figure 17b: Shows the Structure of transmitting and receive array.   Source: (Ramavath *et al.*, 2020).

Since the recent works discussed are on underwater optical communication, figure 16 shows the architecture of optical wireless communication-based IoUT.

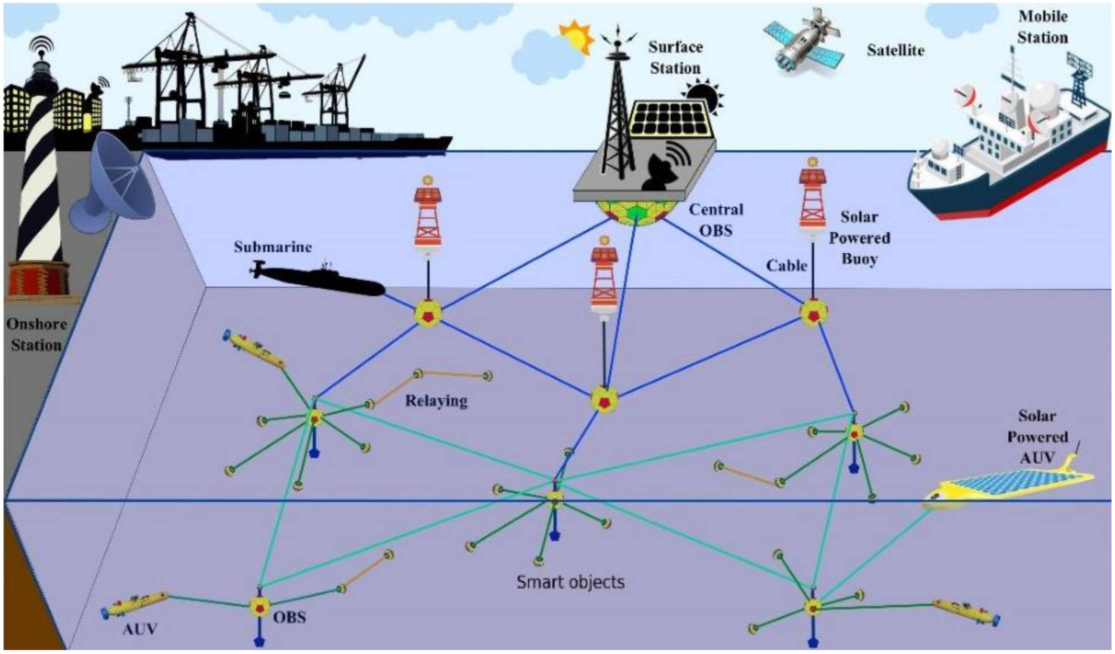

Figure 16: Architecture of Optical Wireless Communication-Based IoUT.

Source: (Saeed *et al*., 2019b)

6.0 DISCUSSION AND CONTRIBUTION

Over time, there has been an increase in the demand and use of underwater wireless communication mainly due to limitations by the terrestrial environmental weather conditions. Underwater wireless communication enables the exploration of the underwater environment over high bandwidth and data rates using distinct or hybrid wireless techniques. Individually, all of these underwater wireless communication techniques have their limitations. Therefore, a combined emergency of novel and advanced underwater wireless communication technique will trigger a major evolution in the future. This report gave a highlight on the current emerging technologies in underwater wireless communication but focused more on the Internet of Underwater Things (IoUTs) in terms of its characteristics, applications, and recent findings.

Recent projects on the implementation of the Internet of Underwater Things (IoUTs) in underwater wireless communications were discussed to encourage the development of an underwater communication framework along with future perspectives. This is to achieve improved quality, the efficiency of the system, and reliable underwater communication. Underwater networks and the Internet of Underwater Things (IoUTs) are a cost-effective solution for increasing maritime awareness through the large-scale and real-time monitoring of marine environments.

CONCLUSION

The future of humanity is dependent on adequate monitoring control and sustainable exploitation of marine environments. Internet of Underwater Things (IoUTs) as one of the current emerging underwater wireless communication, is suitable for a wide range of submarine tasks, repair pipeline, seismic detection, and under-ice ecological monitoring and applications. The future perspective of IoUTs is becoming a critical frontier of exploration for transport, oxygenate and food production, hydrocarbon exploitation, aquaculture, biofuel production, mineral exploitation, climate, and global water circulation. Hence, the potentials of the Internet of Underwater Things (IoUTs) cannot be overemphasized.

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