PAPER

A Literature Review on Data Transmission Using Electromagnetic Waves Under Different Aquatic Environments

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ABSTRACT

Because of the unpredictable range of propagation, knowledge of the wave transmission properties of the aquatic environment is needed for efficient underwater electromagnetic (EM) wave activity. Most publications concern low frequencies to achieve long contact distances, and data transmission is widely known to be captivated with one of the critical parameters, frequency. However, there are some new applications that need data in order to be implemented underwater over short distances. This survey provides a detailed overview of current underwater communication techniques, as well as their advantages and disadvantages. Potential future directions and recommendations for enabling next-generation underwater wireless networking systems are discussed. This paper also summarizes radio-frequency communication studies and, as a result, developments in radio-frequency identification technology for data transmission in a variety of aquatic environments, including freshwater and saltwater.

Keywords: electromagnetic waves, underwater communications, radio frequency, radio-frequency identification, path loss

Introduction

Safety and potency in service at offshore production sites are critical in the oil and gas industry, especially for pipelines. Adapting an efficient and cost-effective inspection technique is often a key factor in achieving this. This incorporates the examination of offshore facilities, primarily platforms, and subsea pipelines in the oil and gas industry (Al-Taie et al., 2015).

Offshore platforms and underwater pipelines are now the most common ways to access undersea petroleum resources, although this could change in the future (Al-Taie et al., 2015). Inspection and monitoring pipelines for maintenance and repair is a difficult job that necessitates the use of a wide range of resources, as pipelines can span hundreds of miles or thousands of kilometers in both shallow and deep waters (Al-Taie et al., 2015). For example, the Gulf of Mexico has 45,310 miles of underwater pipelines that transport oil and gas, and the majority of pipeline failures are caused by corrosion (Kaiser & Narra, 2018). Pipeline damage or leaks are responsible for a large portion of oil spills, posing various environmental threats such as oil contamination and potentially resulting in production loss (Patin, 2013). According to a recent study, the number of accidental spills in the transportation of oil through the marine environment is about 600 tonnes per year out of a total of 20,000 tonnes (Patin, 2013). Many systems are now being used to track and maintain pipelines underwater, both internally and externally. Pipeline inspection gauges (PIGs), mobile robots, autonomous underwater vehicles (AUVs), and remotely operated vehicles (ROVs) are examples of these technologies (Kaiser & Narra, 2018). The deployable technologies are specifically designed to detect and locate pipeline leakage (Patin, 2013), corrosion, and data analysis underwater. In current times, underwater wireless communication (UWC) is a novel approach to communication. It was chosen for collection and transmission of data in the underwater world (Patin, 2013). Wireless networking systems have now become an integral part of human life, and they have become a significant area of research in recent years (Furqan Ali et al., 2019). Sensor network architectures are currently one of the methods used to transfer data underwater. Electromagnetic (EM) (radio frequency [RF]) wireless carriers, optical wireless carriers, and acoustic wireless carriers are some of the most commonly used UWC techniques in underwater wireless signal transmission. EM waves (in the form of RFs) that adapt a function of high data rate over short ranges are the first and foremost technology to be listed (Furqan Ali et al., 2019; Che et al., 2010). Second, the optical signal transmission (OPT) technique underwater requires a line attenuating location during signal propagation over moderate distances in order to achieve higher bandwidth and data rate. Finally, acoustic waves, the third and most commonly used technology, are used for the longest range of contact distances (Furqan Ali et al., 2019). The below section covers sensor network architectures, possibilities and challenges in underwater communication, and advances in RF identification (RFID) technology.

Sensor Network Architectures for Monitoring Underwater Pipelines

Apart from the abovementioned methods, there are a variety of other sensor network architecture designs that can be used to send data underwater. They are a hybrid of wired/acoustic and wired/RF wireless sensor networks (WSNs). Mohamed et al. (2010) compare and contrast the reliability issues, features, benefits, and drawbacks as well as methods that could be tailored to these network architectures. The reliability assessment was carried out with certain things in mind, such as network compatibility, network power supply continuity, and, as a result, physical network security (Mohamed et al., 2010).

The majority of sensor networks used to track underwater pipelines are linear. The sensed data will be forwarded by the sensors in one of three ways: left, right, or both directions (Mohamed et al., 2010). The salinity level of seawater, which is about 3.5% on average, is a significant consideration when considering marine environmental conditions. Still, in freshwater, this value drops to 0.05%, implying that a different salinity value corresponds to a different electrical conductivity value. Above all, freshwater has an electrical conductivity of around 0.01 S/m at room temperature, while seawater has an electrical conductivity of around 4 S/m at 25°C (Gussen et al., 2016).

The key results, as well as the end result of this fact, are that the depth of penetration is higher for freshwater and the attenuation, or reduction in amplitude, is lower; this is an important factor to consider.

This implies that the bulk of research on the possibility of communicating underwater using EM fields would be based on the marine environment (Mujtaba et al., 2016). EM fields can only be accustomed to transmitting radio signals underwater when their frequency is very low or extremely low, according to certain basic measurements that require measuring the depth of penetration. They have also created and tested a hierarchical sensor network architecture for tracking underwater pipelines. As opposed to underwater wired sensor networks, they have fewer security issues (physically) about communication in this architecture. This is because physical attacks on the network would not monitor or cause hindrance to the network's connectivity to any degree (Mohamed et al., 2010).

It is essential to create an analytical model that deals with data and is used to compare the reliability of various architectures for monitoring underwater pipelines (Mohamed et al., 2010).

Advantages of Wired Over WSNs

In general, wired sensor networks are preferred over WSNs. Multiple wires would be connected to the sensor nodes in a wired sensor network. In that case, power supply would not be a problem since it flows through the wires, and also if one wire gets disconnected, the remaining wires will handle data transmission. Its drawbacks include the long-term viability of underwater cables, as well as the power source, which is critical when dealing with seawater. RF waves lose energy steadily as they travel farther under the surface of the water. The Internet of Underwater Things makes use of the power of light in this situation. WSNs can address some of the existing wired sensor network's reliability problems in pipeline monitoring (Mohamed & Jawhar, 2008; Mohamed et al., 2010).

The different types of sensor network architectures are discussed hereinafter.

UWC Structure of Acoustic Communication

Acoustic devices have been used to incorporate UWC connections until recently and have overcome noise issues. Table 1 shows the details. A comparison of sensor networks is presented, as well as three commonly used underwater communication technologies. Among them, acoustic communication is one of the most

TABLE 1

Comparison of sensor networks.

Sensor Network architecture	Design	Properties	Advantages and Disadvantages	
RF communication	• Since each sensor node is connected to a surface buoy via a cable (Mohamed et al., 2010), the nodes can communicate via RF channels. • Radio transceiver and solar cell in surface buoy	• RF communication cannot be used underwater because the RF wave transmission speed is restricted, i.e., 5 and 20 kb/s (Che et al., 2010). • Due to high attenuation and salinity, radio signals have a restricted range of transmission through water. Although long radio waves can be used for short distances and attenuation is based on frequency and conductivity (3.5–5 dB/m), attenuation is based on frequency and conductivity (Che et al., 2010; Mohamed et al., 2010).	Better communication bandwidth, propagation delay, BER, and connectivity, as well as lower power consumption for signal processing (Palmeiro et al., 2011).	RF signals have the ability to pass along a variety of routes, including crossing the water-air boundary and propagating through the sea level (Mujtaba et al., 2016). In seawater, RF signal attenuation is higher than that in freshwater (Che et al., 2010).
Optical waves	• Higher bandwidth; however, absorption, scattering, line of sight, and temperature variations affect it underwater (Palmeiro et al., 2011). • Short distances (up to 100 m)	• Propagation range was restricted to a few tens of meters. In seawater, attenuation is 0.39 dB/m, whereas in turbid water, it is 11 dB/m (Palmeiro et al., 2011).	Deployment is more complex than underwater acoustic propagation (Che et al., 2010).	
Acoustic communication	• Can travel up to a long distance of 20 km (Palmeiro et al., 2011).	• Acoustic bandwidth is up to 20 kbps, and attenuation is dependent on distance and frequency (0.1–4 dB/m) (Gussen et al., 2016). • The permeability of seawater and freshwater is approximately the same. As a result, there is no difference in the magnetic field.	Propagation delay of acoustic signals underwater is very high and variable (Zhou & Wang, 2014). Battery power consumed	The bandwidth between nodes is very small. It is determined by the distance and frequency of acoustic channels (Zhou & Wang, 2014).

continued

TABLE 1

Continued

Sensor Network architecture	Design	Properties	Advantages and Disadvantages	
Integrated wired/ acoustic WSN	• Each node is connected to a device that includes a transceiver, memory, and a storage unit, as well as a wired network interface that has the same configuration as the above (Mohamed et al., 2010). • The nodes are linked through wireless acoustic and wired links.	• Each node regularly tracks the network's status on both sides by sending echo messages to its neighbors (Mohamed et al., 2010).	One of the major drawbacks of this architecture is that if a single wire is broken, the network's average bandwidth (data rate) drops to the bandwidth of the replacement acoustic communication path (Mohamed et al., 2010).	
Integrated Wired/ RF WSNs	• The buoy is connected to the nodes and floats on the surface as the transceiver inside the floating buoy is activated to provide communication and connectivity between them, effectively replacing the underwater link (Mohamed et al., 2010).	• When there is a cut or fault in the wire connecting two nodes, a buoy fitted with a radio transceiver is released (Mohamed et al., 2010).	Since the buoy will not appear unless there is a problem with the wired link, this design will provide greater physical security protection for the network than an RF WSN (Che et al., 2010; Mohamed et al., 2010).	

widely used underwater communication methods.

Acoustic sensor nodes can be installed underwater over the pipeline, with the nodes being placed in a specific target area to collect data. These nodes include a system that includes an acoustic transceiver, a processor for operations, a battery for power supply, memory, and small storage, as well as one or more sensor devices (Mohamed et al., 2010).

Drawbacks

Restricted communication bandwidth, very high propagation latency, high bit error rate (BER), high power consumption due to advanced signal processing techniques, and limited battery life are some of the major disadvantages of underwater acoustic WSNs. In most long-distance applications, acoustic transmissions outperform other data transmission techniques such as electromagnetics in terms of vertical range and represent the best engineering solution (Lucas et al., 2004). However, refraction in deep water, which is affected by angle, thermal effects, and reflections in shallow water, imposes operational constraints, necessitating the development of alternative solutions (Gussen et al., 2016). Unlike acoustic signaling, EM signaling uses a particular transmission mechanism.

Structure of RF Communication

An alternative solution for tracking underwater pipelines is an RF WSN. The device in this form of WSN consists of radio transceivers mounted on surface buoys that are linked to sensor nodes submerged. When compared to acoustic WSNs, RF WSNs offer greater bandwidth, transmission delay, BER, and low power consumption (Mohamed et al., 2010).

Factors Considered

When attenuation is a consideration underwater, RF works well with extremely low frequencies, and unlike other data transmission methods, air-to-water and water-to-air transitions are not an issue with RF. Integrated wired/acoustic WSNs and integrated wired/RF WSNs have the advantage of gathering data more easily, as proposed in this paper (Mohamed et al., 2010).

Structure of Optical Communication

Optical wave technology is another method for UWC. The action of the medium, where the water is used as a conductor for RF and as a dielectric for optical wave propagation, is the key difference between RF and optical communication in seawater (Furqan Ali et al., 2019).

A phenomenon known as plasma frequency emerges, the value of which defines the frequency spectrum for which the medium acts as a conductor or a dielectric (Furqan Ali et al., 2019; Palmeiro et al., 2011). As a consequence, when a higher frequency EM wave travels through the plasma, the conductor is in place. Furthermore, since no particle has enough time to allow feedback, the incident wave does not change significantly, and the seawater transitions from conductor to dielectric at frequencies of about 250 GHz (Furqan Ali et al., 2019). The EM wave has a lower attenuation in a dielectric medium than in a conductor medium (Che et al., 2010; Mohamed et al., 2010).

Advantages of Optical Communication Over RF

As compared to RF, optical communication technology can provide higher data rates (bandwidth) for a narrow transmission range of tens of meters (Palmeiro et al., 2011). Physical features such as the Doppler principle and its implications are almost nonexistent in optical wireless communications since the speed of light is about higher order of magnitude faster than the speed of propagation of acoustic waves in fluids (Palmeiro et al., 2011).

Emergence of RF Communication Underwater

Despite the fact that underwater radio links were tested in the early days of radio, they were unable to meet the requirements of the time (Butler, 1987). It is time to re-evaluate the role of EM signals in the underwater world, given the evolving future of modern operational requirements and immediate availability of digital communications technologies. As compared to acoustic and optical wave technologies, RF EM technology has a lot of potential for underwater sensor communications (Butler, 1987).

Liu et al. (2013) discuss the advent and future of engineering implementations for efficient data transmission and information exchange in the form of signals. This is achieved by wireless communication between nodes in an underwater sensor network using physical waves as the carrier (Liu et al., 2013). The advantages and disadvantages of implementing various communication technologies (acoustic, radio, and optical) are contrasted, as well as potential aspects

(Liu et al., 2013). The potential gap will be dealing with densely and widely distributed nodes, as well as, most likely, improving connectivity efficiency in such underwater environments (Liu et al., 2013).

Chakraborty et al. (2009) provided a detailed overview of the relationship between several EM wave propagation parameters.

For different values of distance and conductivity of the medium, certain characteristics such as skin depth, propagation velocity, total path loss, wavelength, and frequency were studied for underwater communication (Chakraborty et al., 2009).

Permeability, permittivity, conductivity, and volume charge density are the four main characteristics of EM wave propagation (Chakraborty et al., 2009). In RF communications, a lot of work has gone into very low frequency (VLF), which is based on the idea that decreasing the frequency to get a wider range of contact yields better performance. Researchers from Swansea Metropolitan University in the United Kingdom ran simulations at a low-frequency range of 3 kHz, with nodes located between some contact distance limits of about 40 m (Chakraborty et al., 2009).

Gara Quintana-Diaz et al. (2017) investigated underwater WSNs using EM waves in shallow water, where the use of acoustic and optical technology has significant drawbacks, including a lack of line of sight in the latter and noise in the former.

A test bed for underwater communications in a real-time environment is planned and assembled, which includes a measuring device (transmitter and receiver chamber; Gara Quintana-Diaz et al., 2017). Several measurements were made with dipole and loop antennas in an underwater environment, yielding enough data to establish some basic device parameters. Several measurements were made in an underwater environment with dipole and loop antennas, providing enough data to determine some basic communication device parameters.

Loop antennas were found to be the most useful for shallow waters with an acceptable size and lower losses based on the measurements (Gara Quintana-Diaz et al., 2017). The sensor nodes in use have specific carrier frequencies, maximum distances that can be covered, and maximum distances that can be reached by the nodes, all of which can be simulated (Gara Quintana-Diaz et al., 2017).

Feedback was obtained for a variety of frequency ranges between 10 kHz and 1 MHz for various distances, making these findings a valuable tool for further field research (Gara Quintana-Diaz et al., 2017). Future experiments with ferrite antennas can be carried out to evaluate their output, and there is potential for a node prototype to be built for use in an underwater environment (Gara Quintana-Diaz et al., 2017). Jiang and Georgakopoulos (2011) investigated the propagation of EM waves in freshwater at frequencies ranging from 23 kHz to 1 GHz. Two potential EM wave analyses are presented in this work. The authors measured the transmission loss obtained from reflection at the air-water transmission interface on the one side and evaluated the propagation loss within the water based on its physical properties on the other hand (Jiang & Georgakopoulos, 2011).

Furthermore, the total loss in the frequency range is a maximum of 100 MHz, for a depth of 1 m, and sound decibels range from 10 to 45 dB, which is smaller than the loss in lower and higher frequencies (Jiang & Georgakopoulos, 2011). Finally, a half-wavelength loop antenna operating at 100 MHz within freshwater is evaluated, and the antenna needs just 5.3 cm of total diameter to operate (Jiang & Georgakopoulos, 2011).

Novelty Using FPGA Modem

Since attenuation is much greater than other communication methods, Anguita et al. (2009) dismissed the use of RF technology for underwater communication. As a result, the 2.4-GHz frequency was deemed unsuitable for RF communication. EM signals, on the other hand, produce outputs that are up to an order of magnitude higher than acoustic signals (Anguita et al., 2009). For example, Nowsheen et al. (2010a, 2010b) developed an FPGA-based modem that used frequencies ranging from 100 kHz to 1 MHz and binary phase-shift keying (BPSK) modulation. This method of modulation is used for phase shift with data packet transmissions that have a time span of 1 ms and a hold time of 20 ms, and it has been reported that this is an acceptable time interval to avoid the effects of reflections in the tank (Anguita et al., 2009).

Research on RF communication in the 2.4-GHz Industrial Scientific Medical frequency band was conducted by Lloret et al. (2009). The number of lost packets (data) and roundtrip time (cycle) for 1, 2, 5.5, and 11 Mbps at various frequencies and modulations for various distances between underwater wireless sensors were calculated at different frequencies and modulations (Lloret et al., 2009). The range the frequency band can obtain was determined in the findings. The above frequency band has not been subjected to any additional research.

Palmeiro et al. (2011) provided an overview of the various forms of data telemetry used in the aquatic world. Data telemetry is a method of collecting data (measurements) from different remote locations and transmitting it to a receiver.

The effects of EM propagation in an aquatic environment, the impact of wavelength on increasing frequency, and the degree to which wavelength is shortened in different aquatic environments are all explored in this paper. This includes the atmosphere, such as free space, freshwater, and saltwater (Palmeiro et al., 2011), as well as the effects of increasing frequency on distance propagation for both freshwater and saltwater (Palmeiro et al., 2011).

Novel System for Acoustic RF Communication

Massachusetts Institute of Technology (MIT) researchers (Matheson, 2018) have developed and engineered a one-of-a-kind system to address the long-standing disadvantage of direct data transmission between underwater and airborne devices. TARF (translational acoustic-RF communication) is a modulation scheme that transforms a coded message into various data. Almost 500 tests were carried out with the TARF communication technique in a water tank in two separate swimming pools, and signal processing algorithms were designed to focus on the fast-moving waves while ignoring the slower ones. Additional study will be to carry out the task under various climatic conditions.

This article by Butler (1987) focuses on the characteristics of underwater radio wave transmission, as well as the range and extent to which the radio waves can make use of those characteristics. It also includes an in-depth examination of the transmission options available for the lowest range of RF (1.8 MHz) at the time the article was written (Butler, 1987).

Radio communication under the sea is not an appealing choice for a radio amateur experiment because it necessitates the use of extremely low frequencies, massive antenna systems, and extremely high forces (Butler, 1987). One choice will be to perform experiments with lower frequency bands over longer distances in order to evaluate the transmission range.

Characteristics of 2.4-GHz ISM Channel

Mujtaba et al. (2016) discussed the characteristics of the 2.4-GHz ISM frequency band channel, as well as potential effects on EM frequencies. Real-time experiments were carried out at 2.4 GHz in both terrestrial and freshwater environments, allowing researchers to learn about the underwater environment's various physical characteristics (such as EM wave properties, propagation speed, and absorption loss; Mujtaba et al., 2016).

Since EM waves are in general faster than acoustics, even underwater, path loss within fresh water at 2.4 GHz is approximately 1.6 times greater than path loss in an indoor environment using the same frequency; EM waves can be considered for real-time applications as well (Mujtaba et al., 2016). Furthermore, the results of absorption losses for 2.4 GHz when simulated underwater at various medium conductivities show that absorption losses increase with increasing water conductivity (Mujtaba et al., 2016). Furthermore, critical characteristics such as path loss, propagation velocity, absorption loss, and signal loss rate in various underwater environments must be measured and presented in order to comprehend why EM signals cannot spread in seawater and other aquatic environments (Mujtaba et al., 2016). The next step will be to perform experiments at various depths under freshwater and seawater to see how far EM waves would travel.

Multihop Static Topology in an Underwater Environment

Multihop is a wireless network with a vast network coverage area and no need for a common centralized node. Xianhui et al. (2009) focused on the many advantages that electromagnetics can have in a unique underwater environment. The benefit of using multihop static technology in an underwater environment is that the network coverage area is typically greater than that of single nodes. They used a small-scale WSN based on EM waves with a multihop static topology in shallow water where there is a lot of sediment and a lot of aeration (Xianhui et al., 2009). The Ad-hoc On-Demand Distance Vector (AODV) routing protocol was chosen due to the network's unique characteristics (Xianhui et al., 2009). Modeling and simulations are used to assess network efficiency in terms of constrained variables such as failure tolerance, congestion handling, and optimum grid configurations, all of which have a significant effect on the outcomes (Xianhui et al., 2009). The findings support the selected network's potential effects in this type of situation and under these conditions.

Possibilities, Applications, and Challenges of Underwater Sensor Networks:

Heidemann et al. (2006) investigated the possibilities, and thus the applications and challenges, that underwater sensor networks face, as well as the potential applications to offshore oilfields for monitoring applications such as seismic, equipment monitoring, and underwater robotics, and they have developed a basic design on short-range acoustic communication hardware (Heidemann et al., 2006).

Their study focuses on the advantages and disadvantages of underwater acoustics and RF communications, concluding that RF is not ideal for underwater use due to limited propagation (current mote radios transmit 50–100 cm; Heidemann et al., 2006). Acoustic telemetry is a form of underwater communication used when industrial acoustic modems are not suitable for underwater sensor networks with hundreds of nodes due to a number of factors, including the need for a power supply for long-range, expensive systems rather than small, less-expensive sensor networks (Heidemann et al., 2006). Although propagation delay can be a concern for short-range RF, it is a critical factor for underwater wireless networks (Heidemann et al., 2006). While RF communication underwater is less efficient than other forms of communication, research is underway to develop RF communication with varying propagation distances for potential applications.

An Underwater WSN for Near-Shore Applications

Using EM waves, Ghaith et al. (2013) proposed an underwater WSN (UWSN) for near-shore applications (EM). They also introduced a practical path loss model for predicting EM wave attenuation in an underwater environment (Ghaith et al., 2013).

The proposed path loss model takes into account the frequency spectrum variance in relative permittivity (a significant factor) of seawater. In comparison to previous research, which treated permittivity as a fixed parameter that could not be altered, this study treats it as a variable that can be altered (Ghaith et al., 2013). Furthermore, the proposed model takes into account the difference in impedance at the seawater-air boundary interface, resulting in a more practical and valued signal attenuation approximation (Ghaith et al., 2013). Simulation is used to determine the predicted signal levels underwater for various considerations and conditions (Ghaith et al., 2013). The path loss is also measured using a sample implementation (Ghaith et al., 2013). Under slow fading channel conditions, the proposed schemes are simulated, and both path loss and BER output are presented (Ghaith et al., 2013).

With a graphical relationship, Zhang and Meng (2012) addressed the relationship between skin depth, that is, depth of penetration and frequency underwater. In addition, a series of experiments with loop antennas operating at a maximum frequency of 7 MHz underwater using RF communication in both freshwater and seawater have been carried out (Zhang & Meng, 2012). Experiments revealed that, due to the skin effect, radio waves attenuated rapidly at first, and then gradually, as predicted by theory, and the results revealed that radio waves propagate much more slowly in seawater than in freshwater (Zhang & Meng, 2012).

The reliability of an architecture designed for detecting faults based on an integrated wired and wireless sensor network for monitoring above-ground pipeline infrastructures is improved (Zhang & Meng, 2012), but it cannot be used in underground pipelines.

Advances in RFID Technology Underwater

A nondestructive approach capable of detecting flooding of the annulus region of flexible pipes becomes desirable in this scenario. RFID is a well-known technology that allows for the wireless reading of low-profile tags. Furthermore, when constructed properly, these tags can sense changes in the surrounding environment and may theoretically be used to detect seawater infiltration in the annular space of flexible pipes (e.g., Kuhn et al., 2019). A prototype was employed for validation and testing, and a preliminary version of an RFID sensor was designed in order to evaluate this concept using finite-element modeling. The frequency-response relationship between dry and wet circumstances differs significantly. The RFID sensor was also able to distinguish between water and oil flooding in the environment, and it demonstrated that it was capable of doing so. RFID technology is a recent advancement in RF that allows almost any entity to be wirelessly identified using data transmitted through radio waves (Bandyopadhyay et al., 2010). RFID can monitor several objects at the same time without having a clear line of sight (Qing & Chen, 2007), and it has different uses.

RFID utilizes RFs to transfer power and data between a reader and a tag. Though RFID technology is now widely used in a variety of industries for a variety of applications ranging from item tracking to personal identification, few studies have explored and explained the possibilities and risks of using RFID systems in marine or other aquatic environments for underwater monitoring operations (Benelli & Pozzebon, 2013).

Water is not a natural conductor, but the presence of dissolved salts or other substances transforms it into a partial conductor, making RFID one of the most modern technologies that is unsuitable for use in the presence of water (Benelli & Pozzebon, 2013). According to studies, the percentage of radio signals transmitted underwater is primarily determined by two factors: the conductivity of the medium (water) and the frequency spectrum of the radio waves (Allan et al., 2006). The electrical conductivity of water, which is an important parameter to consider, is a factor that cannot be improved or adjusted, but it does increase the likelihood of using radio waves underwater, and the only factor that can be modified to improve underwater efficiency is the RF spectrum (Benelli & Pozzebon, 2013). In general, these frequency ranges have significant technological limitations. To begin with, their incredibly long wavelengths necessitate antennas of immense dimensions with frequencies lower than 100 Hz and wavelengths of thousands of kilometers, necessitating the use of antennas that cover wider and broader regions. Second, these frequencies can only transmit text signals at slower data rates due to their short bandwidth (Qing & Chen, 2007).

Applications of RFID Technology Underwater

When it comes to applications, RFID technology has been used to monitor and trace pebbles underwater, with displacement being a key factor (Benelli & Pozzebon, 2013; Bertoni et al., 2010). Three types of transponders were used to read the range of the pebbles in the device (Benelli & Pozzebon, 2013; Bertoni et al., 2010). To determine the reading range, tests were performed under various conditions, and passive transponders were inserted into pebbles, with a core-125 reader selected to transmit EM waves to the transponder (Benelli & Pozzebon, 2013; Bertoni et al., 2010). An acoustic signal is produced that functions in such a way that, whenever a pebble is identified, the pebble's identification code is shown on the screen of a laptop connected to the reader right away (Benelli & Pozzebon, 2013; Bertoni et al., 2010). The location of the pebbles was measured using a complete station, and the best results were obtained using a 125-kHz system rather than a 13.56-MHz system because the latter had more attenuation (Benelli & Pozzebon, 2013; Bertoni et al., 2010). The disadvantage of this method is that the underwater transponder range is usually restricted.

Limitations of RFID Technology

Owing to the reduced reading range, high-frequency systems operating at 13.56 MHz have several limitations. The range reduction is up to an 80% maximum for widely used, fixed antennas, which brings the transponder in contact and within range of the reader antenna, and for low-frequency systems operating in the 125- to 134-kHz band, the reduction is smaller (around 30%). A 50-cm reading range is still

TABLE 2

Challenges and opportunities of new technologies.

Challenges	Opportunities
• Range is a major challenge when considering underwater environment. • Since sensor nodes are deployed in harsh environmental environments, the chances of node failure are higher than in ground-based networks (Lloret, 2013).	• To avoid the loss of collected data and to improve the network's reliability, one choice is to provide a backup node, which can avoid data loss and makes them more energy efficient in terms of energy usage and recovery latency (Lloret, 2013; Wang et al., 2001).
• To improve the data transmission (output) ratio, thereby lowering the energy consumption of underwater sensor nodes (Fattah et al., 2020).	• AUVs can get closer to other underwater acoustic sensor nodes, creating a short-range, high–data-rate underwater channel for massive data transmissions (Palmeiro et al., 2011).
• Since power supply is a major concern, the use of node batteries aids in supplying power to the nodes, and nodes have a greater chance of storing power supply even if the wires are faulty.	• An integrated wired/wireless sensor network can provide reliable sensing and communication (Mohamed et al., 2010).

possible with longer range antennas (Qing & Chen, 2007). Application of writable and rewritable RFID tags is a future development in RFID. Data can be stored on rewritable RFID tags depending on the range and limit of the RFID reader.

The other advantages of RFID are its cost-effectiveness and off-the-shelf or industrial usability of hardware, and thus, the downside of RFID-based sensing is that, when tested with metal in a marine environment, the reading distance between the tag and the reader is significantly reduced (Benelli & Pozzebon, 2013; Qing & Chen, 2007). Furthermore, the region that can be sensed with RFID is primarily determined by the coil size of the tag.

Challenges and Future Opportunities in Underwater Communication

Almost all of the research papers have emphasized the significance and requirements of cutting-edge technology for underwater communications, as a result of the rapidly expanding spectrum of applications in the underwater world.

The difficulties and disadvantages of designing new technologies in this area of research are presented in Table 2.

Taking the facts into account, in underwater sensor networks:

1. The problems that should be considered in sensing systems vary depending on the range and distance of the region to be monitored. It can be used with one or a few independent sensors to track a small region or with a sensor network to monitor a wide zone in detail.
2. The impact of ROVs and AUVs, and hence the rise in the number of sensors installed in the water, has highlighted the need for higher bandwidth data rates to send more data over wireless networks.
3. Despite the fact that underwater sensor nodes and networks have been a hot topic for many years, it appears that this field will remain a hot topic for several years to come due to the need for more advances in the technology.

Summary and Conclusion

Because of recent developments in sensor, electronics, and wireless communication technologies, WSNs have become the technology of choice for a wide range of pipeline monitoring applications. It is difficult to keep track of long-distance pipelines for faults like corrosion, leakage, and other issues. Underwater communication is regarded as even more essential. Various communication mechanisms have been addressed, showing both the advantages and disadvantages of data transmission under freshwater and saltwater. Attenuation and depth of penetration in relation to frequency are relevant factors to consider.

To address these issues, many researchers have proposed interesting solutions and ideas based on a WSN. The majority of these analyses are summarized in this paper, which also includes a summary of the research and development work performed in the field of pipeline monitoring using WSN technology in various aquatic environments. In comparison to other communication systems, recent developments in RF communication, especially RFID technology, provide more rapid and substantial progress for data transmission and storage in various aquatic environments, according to the above literature review.

RFID rewritable tags can be added to the pipe in a variety of locations within the RFID reader's range, and data can be stored as needed. Overall, EM waves have a small advantage over acoustic communication in terms of path loss, and there has not been much research on RF communication in terms of depths in various aquatic settings, which may be a potential gap for RFID technology.

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