Underwater Communication Systems: A Review

Harsh Vardhan Sharma, Neeraj Manglani

Abstract

There is a high demand for underwater communication systems due to the increase in current human underwater activities. Underwater communication systems employ either sonar or electromagnetic waves as a means of transferring signals. These waves are different physically and electrically, and thus the systems that employ them also differ in their design architecture, wave propagation and devices used for emission and reception. As a result, the two systems have varying advantages and limitations. This paper presents an in-depth review of underwater communication based on sonar and electromagnetic waves, a comparison of the two systems and a discussion of the environmental impacts of using these waves for underwater communication. In the tradeoff between preserving the underwater environment and the need for underwater communication, it appears that underwater electromagnetic wave communication has the most potential to be the environmentally-friendly system of the future.

Keywords—underwater communication system, routers, sonar

Introduction

Demands for inter-medium communication systems are increasing due to ongoing expansion of trans-medium human activities [1]. Communication crossing air-water boundaries in particular is attracting interest, as underwater communication itself continues to grow steadily [2]. There are only two types of waves that could be used to establish underwater communication systems, sonar waves and electromagnetic waves; in some cases both of these waves are used together. These two waves are different in nature; sonar waves are caused by a physical vibration of particles and electromagnetic waves are caused by interference in an electromagnetic field. Due to their physical nature, sonar waves perform very well when they are used in an underwater environment itself but impractical for underwater communication involving the air-water interface. However, it is possible to employ electromagnetic waves for underwater communication, as well as for the trans-boundary air-water and the underwater itself. Although all underwater communication systems are the same in terms of circuitry, they are different in terms of the device employed for emitting or transmitting and receiving these waves. A transducer called a hydrophone is used to emit and receive sonar waves, and electromagnetic waves are transmitted and received using antenna [3]. In term of system architectures, underwater sonar communication has two modes of architecture, the passive mode and active mode. Similarly underwater electromagnetic communication also has two categories; the buoyant system and the direct linkage system.

Underwater Sonar Communication System

For several years, sonar waves were used in various underwater communications activities and such underwater communication is commonly known as sonar communication. The general layout of a sonar communication system is shown in Figure 1. In this figure, the system consists of two sets of transducers connected to processing circuitry [4]. The processing circuitry is kept in a water proof body, but the transducers are kept into water environment. Commonly this underwater transducer is called hydrophone. The first set of hydrophone is the emitter hydrophone (Tdx) that changes an electrical signal into sonar waves, which enable propagation in almost half hemispherical direction into water. The second hydrophone is the receptor hydrophone (Rdx), which receives in-coming sonar waves and changes them back into electrical signals. The performance of hydrophone depends on the underwater vibration sensitivity and it is either a pressure sensor or a capacitive sensor. The emitter hydrophone (Tdx) and receptor hydrophone (Rdx) may have the same or different vibration sensitivity depending on particular application. The processing circuitry in a sonar communication system is...
cascaded electronic circuits such as an amplifier, comparator, signal generator and many other processing circuits. The main purpose of the circuitry is to process the differences (in time or in phase) between emitted and received sonar waves, and then to make decisions based on these differences. From Figure 1 itself sonar communications can be divided into two types: passive sonar and active sonar communication [5]. The passive sonar communication system is only able to receive sonar waves traveling in the water environment. On the other hand, the active sonar communication system emits into and as well as receive sonar waves in the underwater.

**Active Sonar Communication System**

A basic block diagram of an active sonar communication system is presented in Figure 2. In this figure, a complete active sonar communication system has two separate sub systems and each sub-system is fixed with two sets of hydrophones: the Tdx hydrophone and the Rdx hydrophone. The electronic signal processing conducted in each sub-system was as explained in the previous section. But in such active sonar communication system the sonar wave itself is relayed among these underwater hydrophones. The sonar wave emitted by a Tdx hydrophone of one sub-system is received by the Rdx hydrophone of other subsystem. This same flow of sonar wave is performed on the opposite way. However these two pairs of hydrophone are not allowed to receive any sonar wave emitted form its own sub-system Tdx hydrophone. This condition implies such active sonar communication system has two different frequencies of sonar wave. Such described an active sonar communication system with its block diagram in Figure 2 is called the full duplex active sonar communication system because the sonar wave is relayed just among those two pairs of hydrophone. The full duplex active sonar communication system as shown in Figure 2 can be simplified into an active sonar communication system which has only one sub-system with a pair of hydrophone as shown in Figure 3. Specifically such active sonar communication system is called the half duplex active sonar communication system. This half duplex active sonar communication system receives its own emitted sonar wave after reflection from a dummy target. Therefore such active sonar communication system operates with only a single frequency. Once again the electronic signal processing involves in this system is as same as explained before. Both active sonar systems use the audible frequency range (50 Hz » 20 kHz), but in certain applications, it is as high as 50 kHz [6].

**Passive Sonar Communication System**

The passive sonar communication system has just one set of Rdx hydrophones [6] and its general layout is as shown in Figure 4. The passive sonar communication system only detect any sonar waves emitted by underwater entities, such as moving submarines, crowds of fish or even the rotating of a vessel’s propeller. The detected sonar wave is converted into equivalent electrical signals and is processed as explained before. In communication terminology, the passive sonar communication system is referred to as a simplex communication system because it only receives any emitted underwater sonar wave. The passive system usually uses the audible frequency range (50 Hz » 20 kHz) and may even use a higher range if needed.
Underwater Electromagnetic Communication System

Underwater communication is not restricted only to communication within an underwater environment itself but it may also include communication paths that cross the air-water boundary [7]. For such trans-air-to-water underwater communication, electromagnetic waves are the best choice, since these waves are not adversely affected by the air-water boundary, which could be either air-seawater or air-fresh water interfaces. Therefore, the underwater electromagnetic communication system could be classified according to its system design architecture, merely, the buoyant electro-magnetic communication system and the direct linkage electromagnetic communication system.

Bouyant Communication System

Figure 5 shows the general architecture of a buoyant communication system with the complete system has three main circuits: an underwater transceiver, an interface circuit, and an in-air transceiver. The underwater transceiver is connected through a very long cable to the interface circuitry encapsulated in the floating buoy. Electrical signals flow between the underwater transceiver in the submerged body to the interface circuitry in the floating buoy through the long wire cable. The buoy is employed not only for keeping the interface circuitry water-proof, but it also acts as a floating agent for holding and to erect the in-air antenna [7]. On the in-air side, the in-air antenna converts the electrical signal received from the interface circuit into electromagnetic waves. Then the transmitted electromagnetic wave is received by another in-air antenna attached to another part of an in-air transceiver. On the way back, an electrical signal generated by the in-air transceiver is converted into electromagnetic waves and then sent to the buoy’s antenna and back to the underwater transceiver through the same long wire cable. Obviously in both to-and-fro paths, the propagation of electromagnetic waves is simply relayed between a pair of in-air antenna without the need to cross the physical boundary of air-to-water. Therefore, the buoyant communication system is not a truly underwater system. Such communication is just like other common and well known air-to-air electromagnetic communication. In terms of frequency, the buoyant underwater electromagnetic communication system may use any allocated frequency range, usually in MHz, and may be as high as GHz.

Direct Underwater Communication System

In the direct underwater communication system, the propagation of electromagnetic waves is relayed between a pair of antenna in which both antennas can be in different mediums; one set of antenna can be submerged in water and the other set can be in the air. Another possible arrangement is both set of antenna are submerged in the underwater [8]. Figure 6 shows the concept of direct underwater communication systems, which demonstrate the use of both pairs of antenna. There is an in-water antenna attached to the underwater transceiver with its complement in-water antenna is attached to another underwater transceiver. This pair of in-water antenna is purposely for transmitting and receiving electromagnetic waves propagating within the underwater environment itself. The other antenna arrangement is an-in-air antenna attached to the underwater transceiver with its pair is an in-air antenna connected to the in-air transceiver. Therefore in the later arrangement, the propagation of electromagnetic waves passes to-and-fro directly over the physical boundaries of air-water. In terms of frequency, both sets of antennas operate at different frequency ranges. For over several years before, the frequency ranges of electromagnetic waves used for underwater communication systems have been either LF
(below 100 kHz), VLF (below 20 kHz), or even ELF (below 10 kHz) [9]. Consequently, the constructed antennas in this direct underwater communication system commonly are in the form of very long wire cables, which can be as long as 300m. Due to current demand such very low frequency is no longer practical and therefore higher frequency ranges in MHz is required.

Figure 6: The direct underwater communication system.

**Proposed Work**

Sonar waves and electromagnetic waves are totally different in their physical appearance and they have their own unique characteristics that distinguish them. Due to these differences; both of them have their own advantages and limitations in their employment in underwater communication. Regarding path propagation, sonar waves can only propagate through any medium in which physical vibration can be performed with its propagation speed varies according to the physical characteristics of the propagation medium. There is no doubt that sonar waves are a good means for the underwater communication itself but for communication that involves crossing the air-water boundary, sonar waves are not practical. Its amplitude is seriously attenuated over the crossing boundaries of the air-water. On the other hand, electromagnetic waves, which are simply an interference of the electromagnetic fields that surround everything, can propagate through any physical substance; even into free space with its speed of propagation remains almost constant in any medium of propagation.

The passive system can only pick up sonar waves, whereas the active system can not only pick up these waves but can also emit them. These modes show a practical application within underwater itself. Conversely, the electromagnetic underwater communication system design using electromagnetic waves is quite effective, whether using the buoyant mode or direct linkage mode design architecture. In the buoyant system architecture, electromagnetic waves propagate just between the in-air antennas. However, in the direct linkage design architecture, the waves propagate across the air-water boundaries. Commonly sonar communication systems employ sonar wave with audible frequency range (50 Hz » 20 kHz) but it may goes to MHz in particular application. Conversely, electromagnetic underwater communication systems employ an electromagnetic wave with frequency as low as ELF to GHz. The buoyant communication system may use MHz to GHz frequency but the direct underwater communication systems normally use ELF and LF frequencies. The deeper under water the lower the frequency is used, maybe even as low as 5 Hz.

Concerning about environmental issues, the passive sonar communication system and both modes of electromagnetic underwater communication system do no imposes any disturbances to underwater species because these systems do not emit any harmful waves into underwater environment. Similarly the active sonar communication system is also not endangering to underwater inhabitants if it emit non-disturbance, low power and over limited period sonar wave into the underwater. The active sonar communication system will disturb and destroy the underwater life if it emits ELF and very powerful sonar wave, in some case as high as 240 dB, into the underwater.

**Result**

The above explained methodology has been implemented using the MATLAB tool box and has generated the results under the two different environments.
The figure shows the network simulation inside the water and the code demonstrates the packet transfer process between the routers.

Figure 9: Router network partially underwater

The figure 9 shows the router network simulation of the same model over the surface of the water and clearly the over the surface network range is better than the underwater network range due the low density of the air.

Conclusion

Construction of underwater communication systems may use either sonar wave or electromagnetic wave. The passive sonar communication system simply picks up any sonar waves propagating in the underwater but the active sonar communication system receives as well as emits sonar wave in the underwater. Both passive and active mode use a hydrophone as the device for emitting or receiving sonar waves in the underwater itself. These sonar communication modes are not practical for air-water trans-boundary communication due to the greatly amplitude attenuation as they cross the air-water interface. Alternatively electromagnetic wave communication systems are practical for cross-boundary air-water underwater communication with almost without any limitation of speed and amplitude attenuation. These systems employ just a pair of antenna for both transmit and receiving any electromagnetic wave. Generally, underwater electromagnetic communication systems are divided into two types of architecture: the buoyant system and the direct linkage system. In the buoyant system, the waves travel just between a pair of antenna in the air but in the direct linkage system, the electromagnetic waves relies between a set of in-air antenna and underwater antenna over directly crossing the air-water boundary, or they simply travel between a pair of antenna that are entirely in the underwater. Concerning the environmental effects the passive and electromagnetic underwater communication systems have been used for decades without any apparent harmful side effects to the underwater environment or inhabitants. For the active underwater sonar systems, however, there are two conditions; the low power active sonar communication system is considered relatively safe for the underwater environment. The only harmful system that endangers to the underwater environment and species is the high-power low-frequency active sonar communication system.

References


[3] 2. Nagothu, K., M. Joordens, and M. Jamshidi, «Communications for underwater robotics re-

[4] search platforms," 2nd Annual IEEE Conference on Signals, Circuits and Systems, 1(6, Mon-


[15] tromagnetic wave propagation in seawater," Proceeding of the 36th European Microwave Con-


Author’s details

1Computer Science Dept. Jagannath University, Jaipur, India, Email: 4uharshvardhan@gmail.com

2Computer Science Dept. Jagannath University, Jaipur, India, Email: neeraj.maglani@jagannathuniversity.org