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Underwater Wireless Communication Network

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Abstract

The research of Underwater Acoustic Networks (UANs) is attracting attention due to their important underwater applications for military and commercial purposes. Underwater wireless communication networks (UWCNs) consist of sensors and autonomous underwater vehicles (AUVs) that interact, coordinate and share information with each other to carry out sensing and monitoring functions. In last several years, underwater communication network (UWCN) has found an increasing use in a widespread range of applications, such as coastal surveillance systems, environmental research, autonomous underwater vehicle (AUV) operation, oil-rig maintenance, collection of data for water monitoring, linking submarines to land, to name a few.

Keywords: Autonomous underwater vehicle;sensor nodes;hybrid communication; underwater acoustic network.

1. Introduction

Acoustic communications is defined as communication methods from one point to another by using acoustic signals. Acoustic signal is the only physical feasible tool that works in underwater environment. Compared with it electromagnetic wave can only travel in water with short distance due to the high attenuation and absorption effect in underwater environment. It is found that the absorption of electromagnetic energy in sea water is about $45\times f$ dB per kilometer, where f is frequency in Hertz. In contrast, the absorption of acoustic signal over most frequencies of interest is about three orders of magnitude lower. There are some investigations about utilizing optical signal for underwater applications. However, they find out that optical signal can only pass through limited range in very clean water environment (deep water, for example). Thus, it is not a proper tool for long-distance transmission underwater, or in a not-so-clean water, e.g., shallow water, environment.

Underwater Acoustic Networks, including but not limited to, Underwater Acoustic Sensor Networks (UASNs)and Autonomous Underwater Vehicle Networks (AUVNs), are defined as networks composed of morethan two nodes, using acoustic signals to communicate, for the purpose of underwater applications.UASNs and AUVNs are two important kinds of UANs. The former is composed of many sensor nodes, mostly fora monitoring purpose. The nodes are usually without or with limited capacity to move. The latter is composed ofautonomous or unmanned vehicles with high mobility, deployed for applications that need mobility, e.g., exploration. An UAN can be an UASN, or an AUVN, or a combination of both.

2. Fundamentals of Waves

Understanding the first principles of each physical wave used in UWSN wireless communication is critically important. In this section we layout the fundamental physical properties and critical issues for each of the acoustic and optical wave propagations in underwater environments. We discuss each physical carrier's advantages and disadvantages towards efficient underwater wireless communication.

2.1 Acoustic Waves

Among the types of waves, acoustic waves are used as the primary carrier for underwater wirelesscommunication systems due to the relatively low absorption in underwater environments. We start the discussion with the physical fundamentals and the implications of using acoustic waves as the wireless communication carrier in underwater environments.

2.1.1. Physical Properties:

An acoustic wave has a number of propagation characteristics that are unique from other waves, two of which are highlighted below:

Propagation velocity: The extremely slow propagation speed of sound through water is an important factor that differentiates it from electromagnetic propagation. The speed of sound in water depends on the water properties of temperature, salinity and pressure (directly related to the depth). A typical speed of sound in water near the ocean surface is about 1520 m/s, which is more than 4 times faster than the speed of sound in air, but five orders of magnitude smaller than the speed of light. The speed of sound in water increases with increasing water temperature, increasing salinity and increasing depth. Most of the changes in sound speed in the surface ocean are due to the changes in temperature. This is because the effect of salinity on sound speed is small and salinity changes in the open ocean are small. Near shore and in estuaries, where the salinity varies greatly, salinity can have a more significant effect on the speed of sound in water. As depth increases, the pressure of water has the largest effect on the speed of sound.Under most conditions the speed of sound in water is simple to understand. Sound will travel faster in warmer water and slower in colder water. Approximately, the sound speed increases 4.0 m/s for water temperature .As the depth of water (therefore also the pressure) increases 1 km, the sound speed increases roughly 17 m/s. It is noteworthy to point out that the above assessments are only for rough quantitative or qualitative discussions, and the variations in sound speed for a given property are not linear in general.

Absorption: During propagation, wave energy may be converted to other forms and absorbed by the medium. The absorptive energy loss is directly controlled by the material imperfection for the type of physical wave propagating through it. For acoustic waves, this material imperfection is the inelasticity, which converts the wave energy into heat.

3.2 Optical Waves

Using optical waves for communication obviously has a big advantage in data rate. However, there are a couple of disadvantages for optical communication in water. Firstly, optical signals are rapidly absorbed in water. Secondly, optical scattering caused by suspending particles and planktons is significant. Thirdly, high level of ambient light in the upper part of the water column is another adverse effect forusing optical communication.

3. Optical Communication

The present technology of acoustic underwater communication is a legacy technology that provides low-data-rate transmissions for medium-range communication. Data rates of acoustic communication are restricted to around tens of thousands of kilobits per second for ranges of a kilometer, and less than a thousand kilobits per second for ranges up to 100 km, due to severe, frequency-dependent attenuation and surface-induced pulse spread. In addition, the speed of acoustic waves in the ocean is approximately 1500 m/s, so that long-range communication involves high latency, which poses a problem for real-time response, synchronization, and multiple-access protocols. In addition, acoustic waves could distress marine mammals such as dolphins and whales. As a result, acoustic technology cannot satisfy emerging applications that require around the clock, high-data-rate communication networks in real time. Examples of such applications are networks of sensors for the investigation of climate change; monitoring biological, biogeochemical, evolutionary, and ecological processes in sea, ocean, and lake environments; and unmanned underwater vehicles used to control and maintain oil production facilities and harbors.

An alternative means of underwater communication is based on optics, wherein high data rates are possible. However, the distance between the transmitter and the receiver must be short, due to the extremely challenging underwater environment, which is characterized by high multiscattering and absorption. Multiscattering causes the optical pulse to widen in the spatial, temporal, angular, and polarization domains.

Optical signal gets scattered badly underwater, and the absorption is also high. Beside of these, optical wavetransmission requires high precision in pointing the narrow laser beams. In very clean water, e.g., deep sea,blue-green wavelengths may be used for short-range connection. The advantage of optical signal lies in itshigh data rate up to 100 m. Up to today, the only practical solution for underwater communication with acceptable range is utilizing acoustic signal, which travels underwater withlonger distance, less attenuation, and higher reliability. However, available bandwidth is extremely limitedfor acoustic signal.For a very long distance at theorder of 1000 km, the available bandwidth falls below a kHz; while only at very short ranges below about 100 m,more than a hundred kHz of bandwidth may be available. Lack of available bandwidth is the biggest issuefor underwater acoustic communication /network. High bit error rate is common in underwater channels, due to the multi path interference and time-varying nature of underwater acoustic channels.

4. Engineering counter measures

In this section, we describe the engineering countermeasures that have been developed to address the physical challenges for each wave used as the communication carrier in underwater sensor networks. These are physical layer techniques to achieve point-to-point communication among sensor nodes.

4.1Acoustic Communication

Multicarrier modulation: The idea of multicarrier modulation is to divide the available bandwidth into a large number of overlapping sub bands, so that the waveform duration for the symbol at each sub band is long compared to the multipath spread of the channel Consequently, inter-symbol interference may be neglected in each sub band, greatly simplifying the receiver complexity of channel equalization. Precisely due to this advantage, multicarrier modulation in the form of orthogonal frequency division multiplexing (OFDM) has prevailed in recent broadband wireless radio applications.

Multi-input multi-output techniques: A wireless system that employs multiple transmitters and multiple receivers is referred to as a multiple-input multiple-output (MIMO) system Hence, MIMO modulation is a promising technology to offer yet another fundamental advance on high data rate underwater acoustic communication. MIMO has been applied in both single carrier transmission and multicarrier transmission.

4.2Optical Communication

As pointed out water quality plays a key role in deciding whether optical waves can be used for underwater communication. As a result, the applicability of optical communication heavily depends on environments. Using the same analogy for acoustic and electromagnetic waves, we say that optical communication works in the environment-limited region. So far, there are not many commercial activities on underwater optical communication, and no commercial optical modems are available specifically for underwater. Recent interests in underwater sensor networks and sea floor observatories have greatly stimulated the interest in short-range high-rate optical communication in water.

5. Conclusion

The results presented indicate that networks based on underwateroptical wireless links are feasible at high datarates for medium distances, up to a hundred meters. Suchnetworks could serve subsea wireless mobile users. In addition,by placing multiple relay nodes between the chiefnetwork nodes, messages could traverse very long distancesdespite severe medium-induced limitations on the transmissionranges of individual links. Additional improvements tothe availability of the network could be achieved by a hybridcommunication system that would include an optical transceiver and an acoustical transceiver. A hybrid communicationsystem can provide high-data-rate transmission by using the optical transceiver. When the water turbidity ishigh or the distance between the terminals is large, the system can switch to a low data rate using the acoustic transceiver, thereby increasing the average data rate and availability. However, the complexity and cost of the system are increased. In this kind of system, smart buffering and prioritization could help to mitigate short-term data rate reduction. Many aspects of the proposed system remain to be investigated .Extensive studies should be made of the nature of multiple scattering in different oceanic channels.

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