Inside Out

Underwater Communications

by Hovannes Kulhandjian

The importance of underwater communications during World War I led to extensive research advancements during World War II. Though military application initially was the main driving force, underwater communications has gained considerable interest in commercial applications as well. The technology can potentially be used in addressing major problems in our times such as offshore exploration, pollution control and tracking, climate change monitoring, study of marine life, disaster prevention, tsunami detection, and tactical surveillance.

The main physical carriers for wireless underwater communications are radio frequency (RF) electromagnetic waves, optical waves, and acoustic waves. RF electromagnetic waves can only be used over very short ranges (up to 10 metres), as they are affected by high attenuation. Optical electromagnetic waves, on the other hand, do not suffer from such high attenuation, but are strongly influenced by scattering and require high precision in pointing light beams of transmitter and receiver. Accordingly, underwater optical communications have ranges of a few tens of metres only and are usually directional. Acoustic waves, instead, can provide long-range communications means, as they suffer from relatively low absorption. Still, due to the unique characteristics of the underwater channel, acoustic signals suffer from severe transmission loss, coloured ambient noise, time-varying multipath propagation, Doppler spread, limited and distance-dependent bandwidth, and high propagation delay. Therefore, it is very challenging to establish reliable underwater acoustic communications.

Underwater acoustic communications have evolved over the years. Initially, researchers were mainly focusing on non-coherent modulation techniques, such as frequency-shift keying, due to their simplicity, reliability, and robustness. However, non-coherent schemes are known to suffer from low bandwidth utilization, thus data rates of only about 1-2 kbit/s can be achieved over a few kilometre links in shallow and deep water channels. In oceanic literature *shallow water* is typically referred to a body of water with depth lower than 100 m, while *deep water* is used for deeper oceans. Furthermore, underwater acoustic communication links can be classified as very long, long, medium, short and very short. Typical bandwidths of underwater links for various ranges are presented in Table 1.

Underwater experiments at Lake LaSalle conducted by the Wireless Networks and Embedded Systems (WiNES) Laboratory, State University of New York at Buffalo.

Advancements in phase tracking algorithms paved way for phase-coherent modulation techniques, such as phase-shift keying and quadrature amplitude modulation, with the intention to increase the spectral efficiency and communication range. Interestingly, the data rates provided by coherent modulation scheme are one order of magnitude higher than those of existing non-coherent schemes for the same communication range.

One way to overcome the long delay-spread in underwater acoustic channels is to use multi-carrier modulation schemes such as orthogonal frequency-division multiplexing (OFDM). Recently, OFDM schemes have actively been investigated and studies suggest that OFDM modulation is a feasible and flexible means for underwater acoustic communications. Experiments conducted in a shallow water channel over a distance of 2.5 km using quadrature phase-shift keying (QPSK) modulation in 24 kHz acoustic bandwidth data rate of 30 kbit/s was recorded.

	Range [km]	Bandwidth [kHz]
Very Long	1000	< 1
Long	10 -100	2 - 5
Medium	1 - 10	≈10
Short	0.1 - 1	20 - 50
Very Short	< 0.1	> 100

Table 1: Available bandwidth for different ranges in underwater acoustic channels.

The success of special multiplexing techniques, known as multiple-input-multiple-output modulation schemes, in RF communication have lately inspired researchers to explore them in underwater communications to further enhance the data rate and spectral efficiency. By using multiple transmit and receive antennas, multiple independent streams of information through spatial channels, so-called multiplexing gain may be achieved, which may lead to increase in data rate. On the other hand, diversity gain may be explored by transmitting multiple copies of the same information through different independently fading channels, which may increase the probability of correct reception. Using QPSK modulation scheme with four transmit antennas, data rates of 48 kbit/s over 23 kHz bandwidth over a range of 2 km were reported.

In spite of all the research efforts, as of today the available underwater acoustic technology can support only low data-rate and delay-tolerant applications. Researchers are constantly striving to push the boundaries in underwater communications.

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