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Moving Toward Energy-Efficient Underwater Acoustic Networks

Underwater wireless communications have experienced major developments in recent years, especially in the last decade. While the first generation of applications involved just a single transmitter and receiver communicating at low bit rates, nowadays underwater communications are associated with complex systems requiring the networking of several devices exchanging information and reacting accordingly. These novel applications range from autonomous observatory systems to cooperative missions between autonomous underwater vehicles, bottom-mounted nodes and crafts.

The main challenges in underwater communications are posed by the power-hungry and bandwidth-limited underwater acoustic channel. Indeed, it is not possible to use electromagnetic waves in the marine environment because of the high absorption of seawater at frequencies above a few hertz. At the same time, despite advances in optical free-space communications, the use of wireless optical solutions for underwater communications is limited to a very short range and can only be seen as a complementary technique for very specific applications.

In underwater acoustic communications, the signal propagates as a pressure wave, which is absorbed and spread in the medium while traveling toward the destination or the receiving device. One of the unique properties of the underwater channel is that the total signal attenuation depends not only on the distance between the communicating entities, but also on the signal frequency. As a result, the available bandwidth (and, consequently, transmission bit rate) depends on the distance and increases as the distance shortens. This phenomenon encourages the use of relay networks, in which the information between a transmitter and receiver is transferred over multiple short-range hops before reaching the destination.

The development of multi-hop networks is not only motivated by the higher bandwidth availability, but also by a reduction in power consumption. Underwater network components cannot be easily replaced or recharged, and solutions involving energy harvesting mechanisms (e.g., the generation of energy from underwater flows) are still too futuristic to be taken into account. By reducing the transmission range of acoustic modems, we can reduce the transmission power of the nodes and hopefully their cost. Some recent results show the significant effect on energy savings in acoustic modems featuring variable transmission power. When it comes to power consumed during data reception or idle power consumption, the trend is to let the nodes sleep when they are not actively participating in an ongoing communication. All these different aspects require the development of novel networking protocols to coordinate the communication among different devices and to properly route the information through the network.

We would be underestimating the underwater acoustic channel if we were only accounting for energy and bandwidth constraints. Indeed, there are several additional challenges that require the use of advanced transmission techniques and modulations, including but not limited to multipath propagation and Doppler effects. Despite the fact that single-carrier modulations have been the de facto standard for a long time, multi-carrier modulations can efficiently exploit the highly frequency-selective acoustic channel and achieve considerably high transmission bit rates. Recently, several transmission techniques involving more than one transmitter and receiver integrated into the same device and able to transmit cooperatively have proven to be good for high-bit rate and energy-efficient communications.

In closing, underwater wireless communication is a fast-evolving field that requires novel solutions both in terms of hardware design and protocols development. In the next few years, I envision the deployment of high-density networks, possibly integrated by variable-power and low-cost nodes, and able to span increasing distances with higher bit rates. The combination of all these new concepts will definitely widen the range of applications for communications and networks in the underwater domain. ■